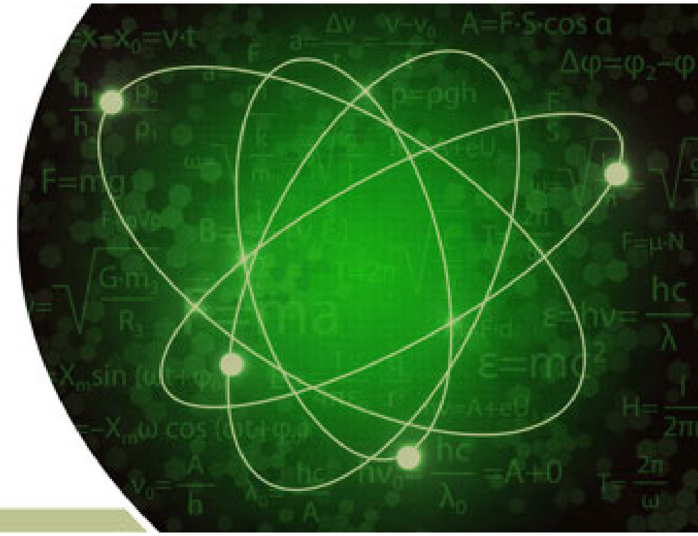
ANS Annual Meeting 2019

THE VALUE OF NUCLEAR



Initial Investigations of the Criticality Safety Validation Basis for HA-LEU Transportation

Bradley T. Rearden, Ph.D.
Leader, Modeling and Simulation Integration

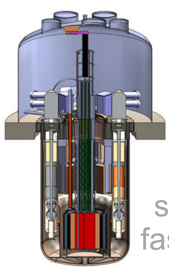
B. T. Rearden, W. J. Marshall, J. B. Clarity, A. M. Holcomb,
F. Bostelmann, and J. M. Scaglione

Oak Ridge National Laboratory

Industry is actively pursuing advanced reactor concepts

Intrinsically safe designs, lower costs, high burnup, minimal waste	Retain or increase electricity baseload in lieu of retiring LWR fleet	Achieve greenhouse gas reductions and clean air goals

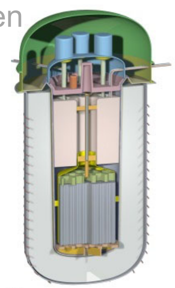
TerraPower



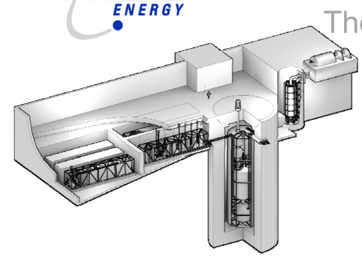
salt-fueled fast reactors

TERRESTRIAL ENERGY

Integral molten salt thermal reactor

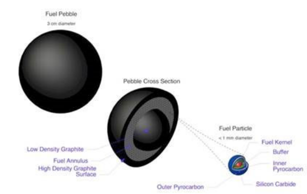


Flibe ENERGY



Liquid fluoride Thorium thermal reactor

Kairos Power



Liquid fluoride cooled thermal reactor (FHR)

- Work with the NRC, developers, and customers to develop common understanding and expectations (e.g. gap analysis report and PIRT processes).

Abbreviated reactor technology matrix (1/2)

Reactor Type	Companies	Licensing action expected	Fuel / Enrichment	Thermal spectrum	Fast Spectrum	Coolant	Radial core expansion	Flowing Fuel	Fuel Form
PWR	Westinghouse, AREVA, CE, CANDU	already	2-5%	✓		Water	minimal		Oxide
BWR	GE	already	2-5%	✓	✓	Water	minimal		Oxide
HPR	Oklo	2019	~20%		✓	Sodium heat pipes	✓		Metallic Casting
	Westinghouse (eVinci)	2019	19.75%	Thermal/ Epithermal		Sodium heat pipes			Oxide
SFR	TerraPower (TWR)		~20%		✓	Sodium	✓		Metallic Rods
	GE PRISM		~20%		✓	Sodium	✓		Metallic Rods
LFR	Westinghouse		15-20%		✓	Lead	✓		Oxide/ Nitride
HTGR	X-energy (Xe-100)	2020s	15.5%	✓		Helium		Pebbles	TRISO
	Areva (SC-HTGR)		~20%	✓		Helium			TRISO
FHR	Kairos	2020s	~17%	✓		FLiBe		Pebbles	TRISO

Abbreviated reactor technology matrix (1/2)

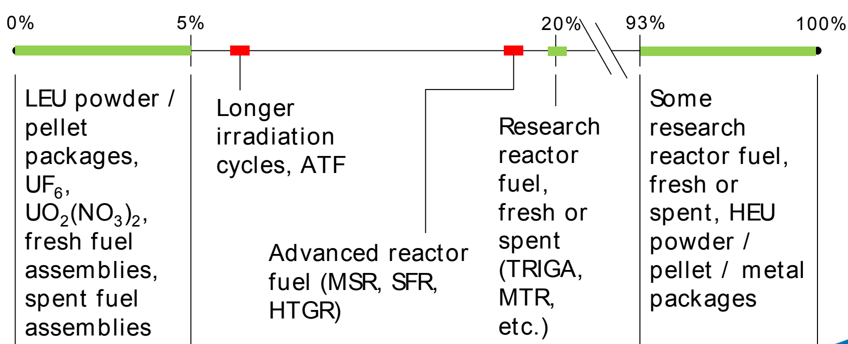
Reactor Type	Companies	Licensing action expected	Fuel / Enrichment	Thermal spectrum	Fast Spectrum	Coolant	Radial core expansion	Flowing Fuel	Fuel Form
MSR	Terrestrial Energy (IMSR)	2019	~5%	✓		Proprietary		Salt	Molten Salt
	Transatomic	2020s	~5%	Thermal/ Epithermal		FLiBe		Salt	Molten Salt
	TerraPower (MCFR)	2020s	~20%		✓	Chloride salt		Salt	Molten Salt
	Elysium		~20%		✓	Chloride salt		Salt	Molten Salt
	FLiBe Energy		Thorium	✓		FLiBe		Salt	Molten Salt

NRC perspectives on high assay fuel from Office of Nuclear Materials Safety and Safeguards

> 5.0 Weight Percent

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Code Validation:



NMSS

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

NRC Regulatory Perspective on Criticality Safety in Fissile Material Transportation and Spent Fuel Storage

Drew Barto
Criticality Shielding and Risk Assessment Branch
Division of Spent Fuel Management
US NRC

American Nuclear Society Winter Meeting
Washington, DC
October 30, 2017

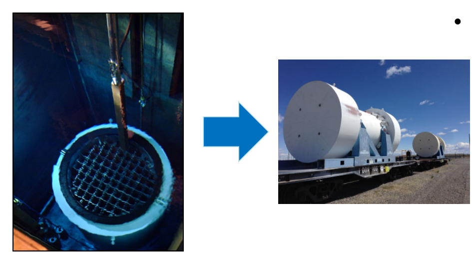
NMSS

Part 71/72 Interface

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

High-Capacity PWR Cask Criticality Safety Criteria:

Storage:
- < 5.0% Initial enrichment
- Minimum soluble boron during loading



Transportation:
- < 5.0% Initial enrichment
- > 45 GWd/MTU burnup
- Cooling time
- Limits on irradiation parameters:
  - Soluble boron
  - Specific power
  - Moderator temp.
  - Fuel temp.

NMSS

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Example criticality validation process using the ES-4100 package for 20% enriched UF_6

- Designed at the Y-12 National Security Complex
- The container is designed to ship fresh research reactor fuel and holds four separate containment vessels. Each vessel has a 5-inch (12.7 cm) inner diameter with an inside height of 58 inches (147.3 cm). The overall package is 34 inches (86.36 cm) in diameter and 71 inches (180.3 cm) tall. A cast ceramic absorber containing boron carbide is included for criticality control, and the Kaolite insulation is also included in the package model.
- This package was selected as a potentially representative container for shipping HA-LEU UF_6, though no plans exist at this time for certifying it for this application.
- The model includes 20 wt% enriched UF_6 homogenously mixed with water and polyethylene in the containment vessel. The UF_6 was modeled in a homogenous mixture with water and polyethylene because this approach was used in the calculations to demonstrate criticality safety for the package's certificate. An individual package is modeled with the maximum ^{235}U mass allowed in each containment vessel per the ES-4100 certificate, which is 1 kg per cylinder or 4 kg per package.

Photos Courtesy of Jeff Arbital
Y-12 National Security Complex

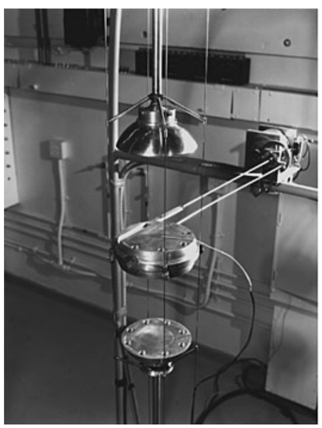
Impact of nuclear data tuning on criticality safety analysis increases importance of validation and safety margin determination

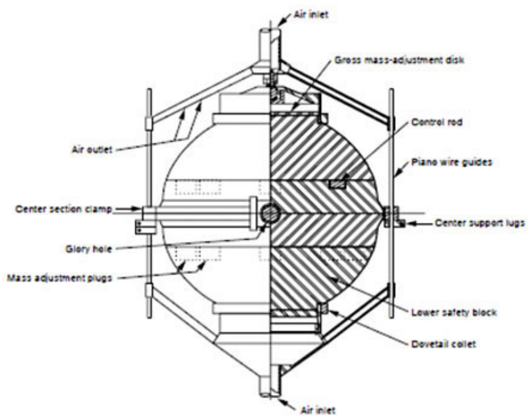
- A specific program (DOE-SC, NNSA/NCSP, NNSA/NA-22, DOD, international participant) funds an update in a nuclear data evaluation
  - New differential physics experiments
  - Data processing
  - Comparison to and **optimization with applications in their interest**
- National Nuclear Data Center - Cross Section Evaluation Working Group (CSEWG)
  - Updates are exchanged through a beta repository for ENDF and reviewed by a global team
  - Meets twice annually, with participation from IAEA, OECD/NEA, and others to review proposed updates
  - If changes benefit, or do not disrupt, applications of interest to these teams, the new evaluation is approved
- Only intermittent representation for Nuclear Energy applications

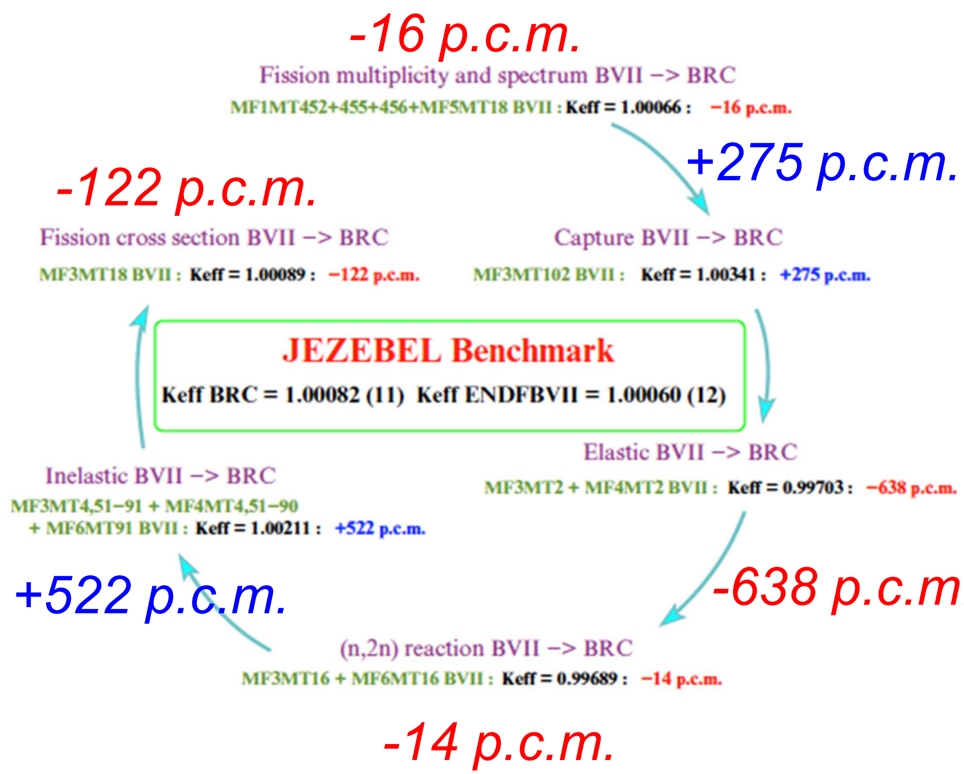
Compensating Errors in the Jezebel experiment k_{eff}

^{239}Pu metallic sphere at Los Alamos

- Eric Bauge* reported on an analysis where components of the Bruyères-le-Châtel (BRC) ^{239}Pu evaluation were replaced with those from ENDF/B-VII.1.
- *We do not know if either evaluation is "correct" but both get the "correct" answer.*

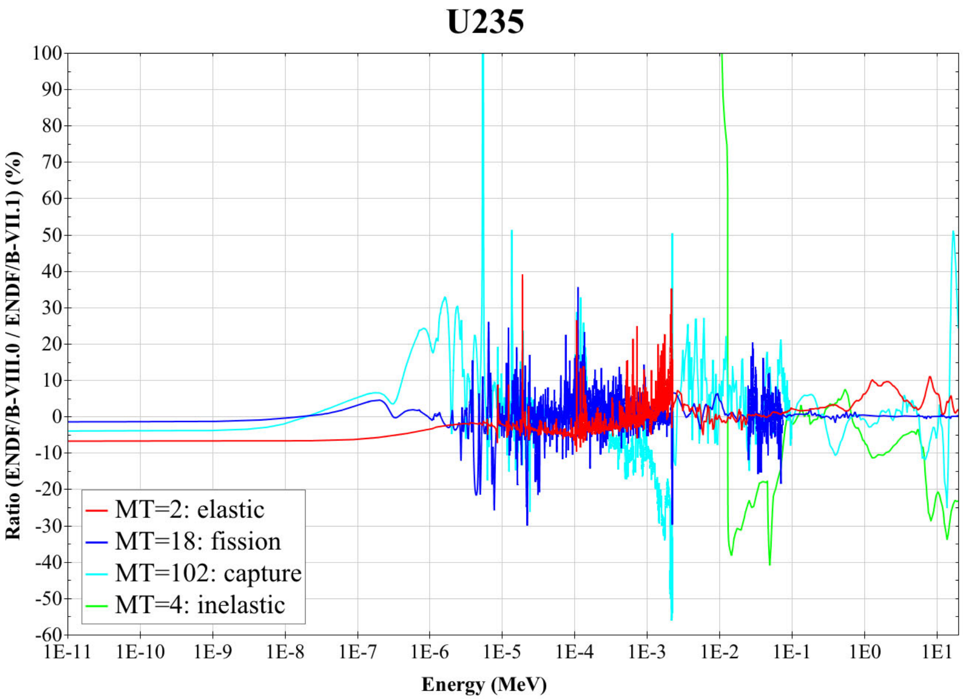


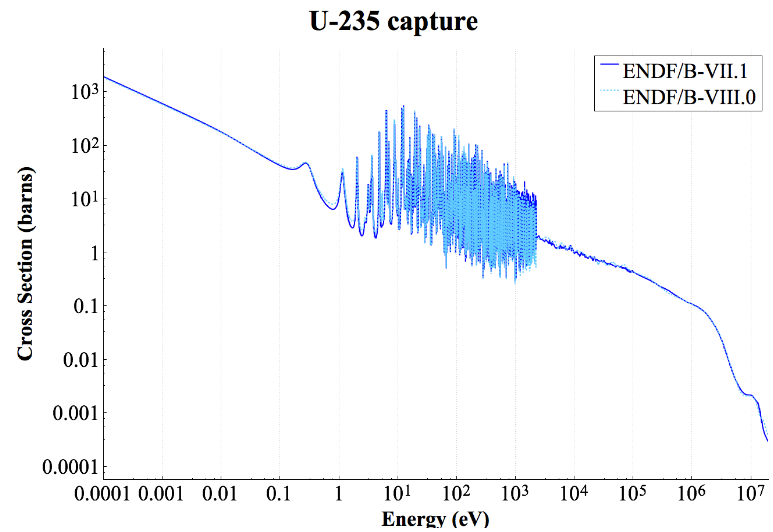


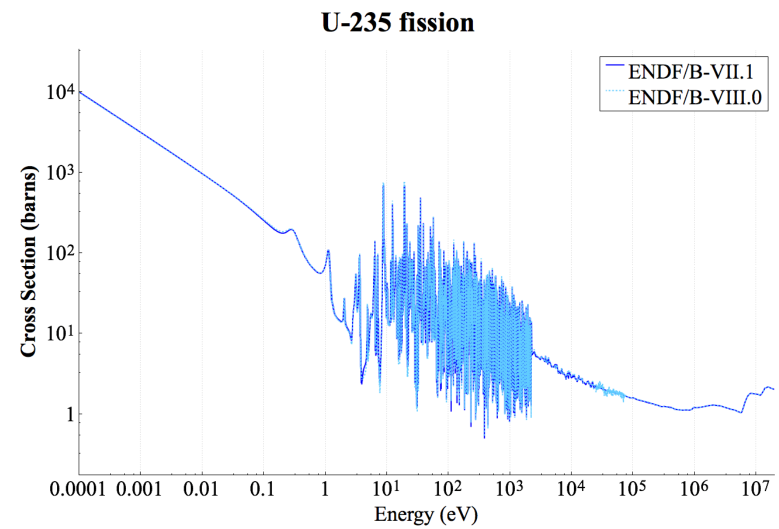


*E. Bauge *et al.*, Eur. Phys. J. A (2012) 48: 113

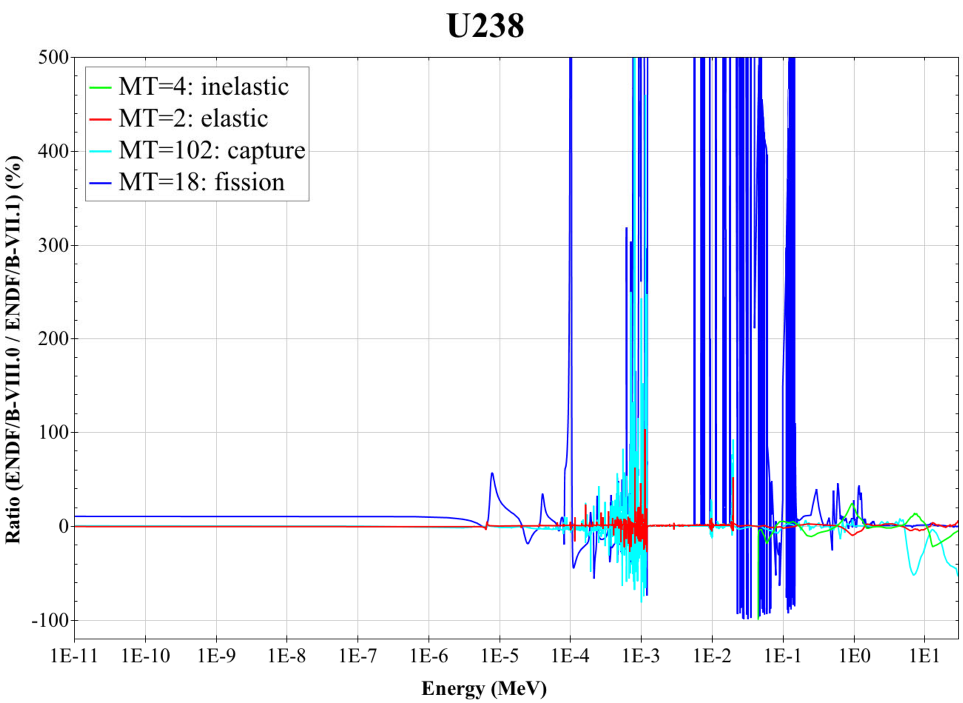
Cross section changes ENDF/B-VII.1 to ENDF/B-VIII.0

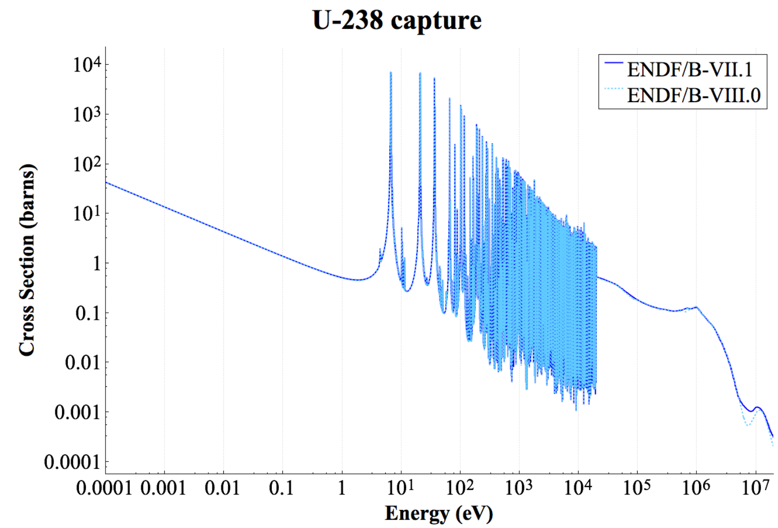


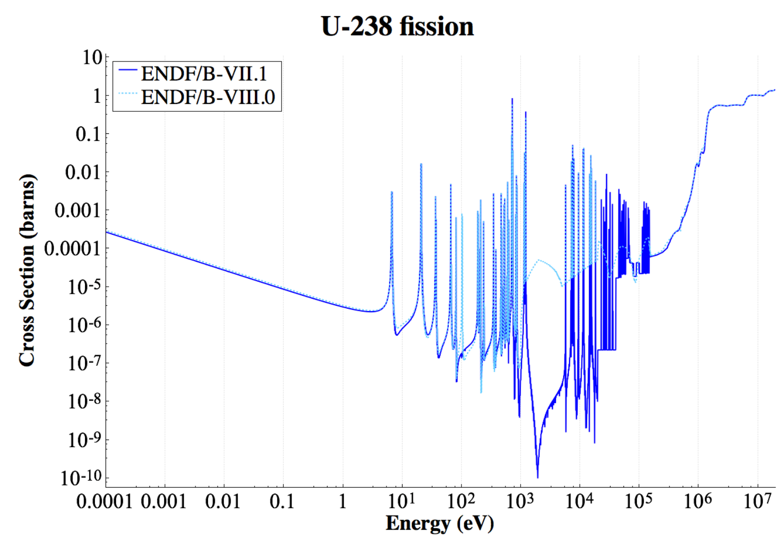




Cross section changes ENDF/B-VII.1 to ENDF/B-VIII.0







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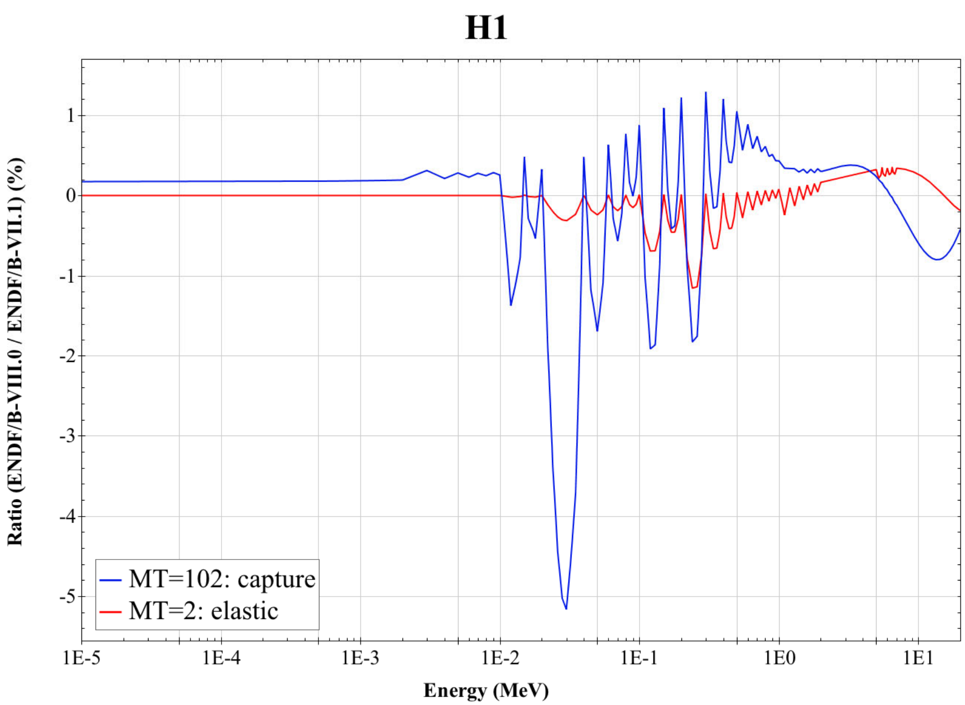
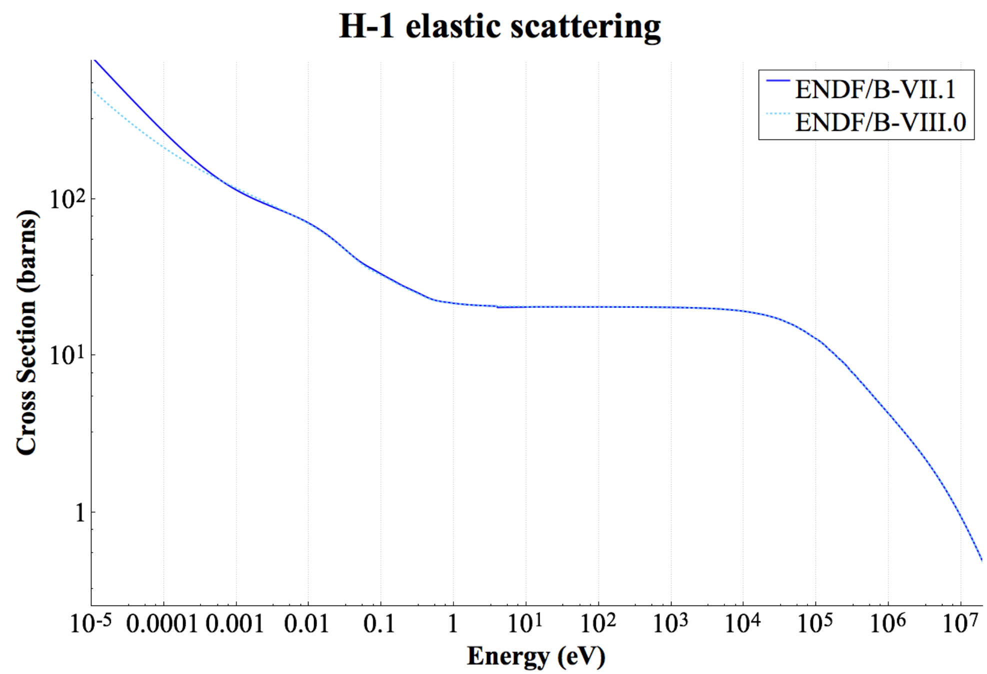
Cross section changes ENDF/B-VII.1 to ENDF/B-VIII.0





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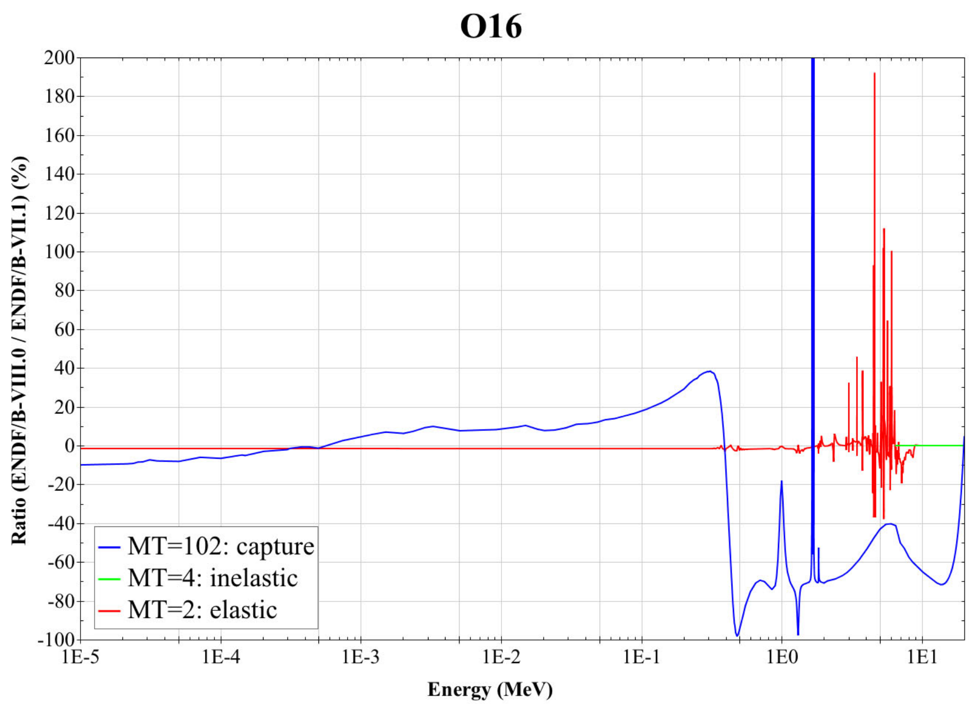
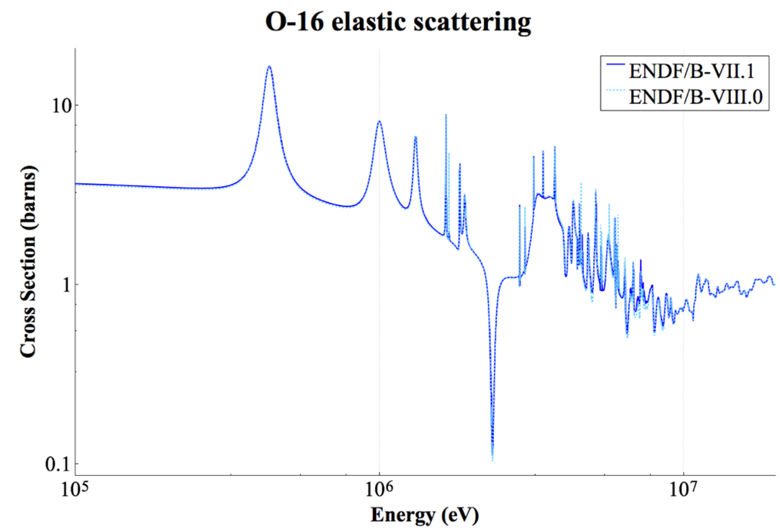
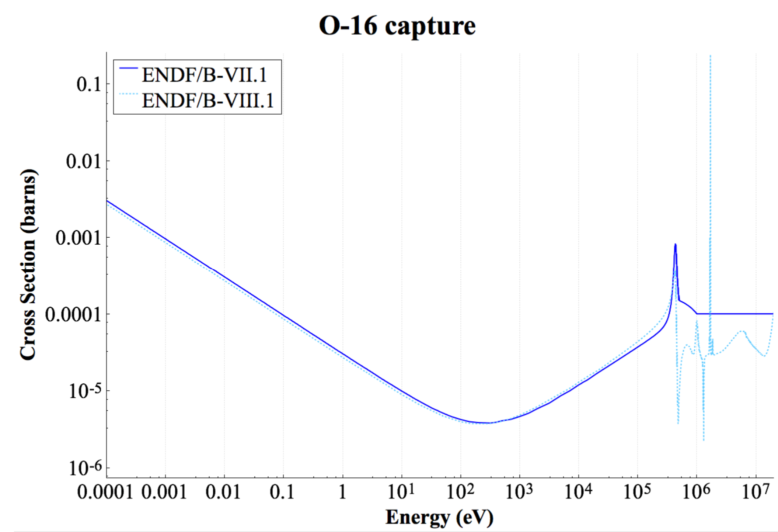
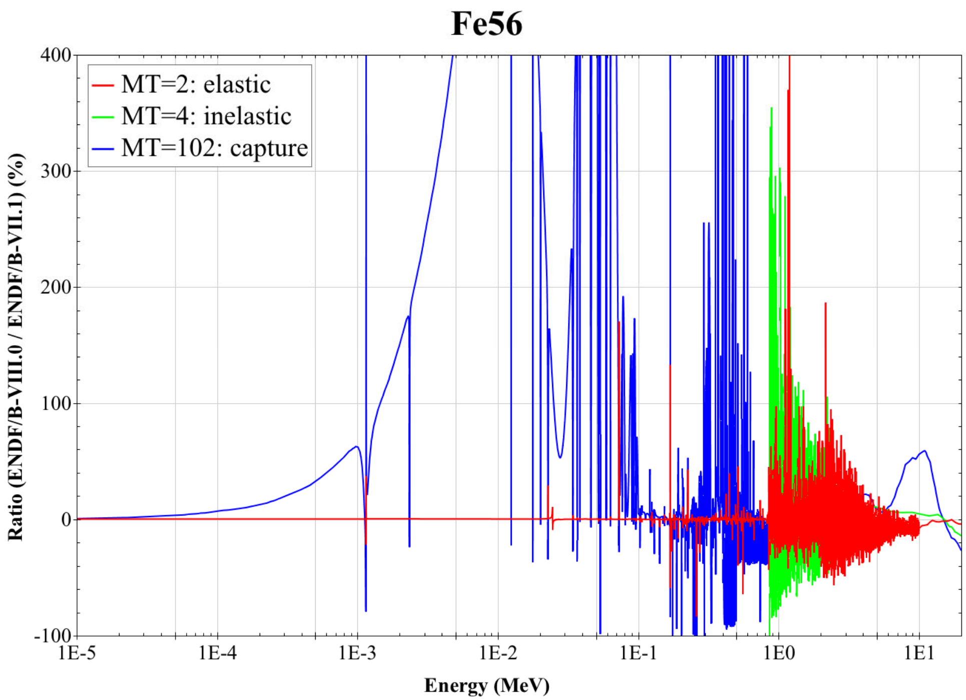
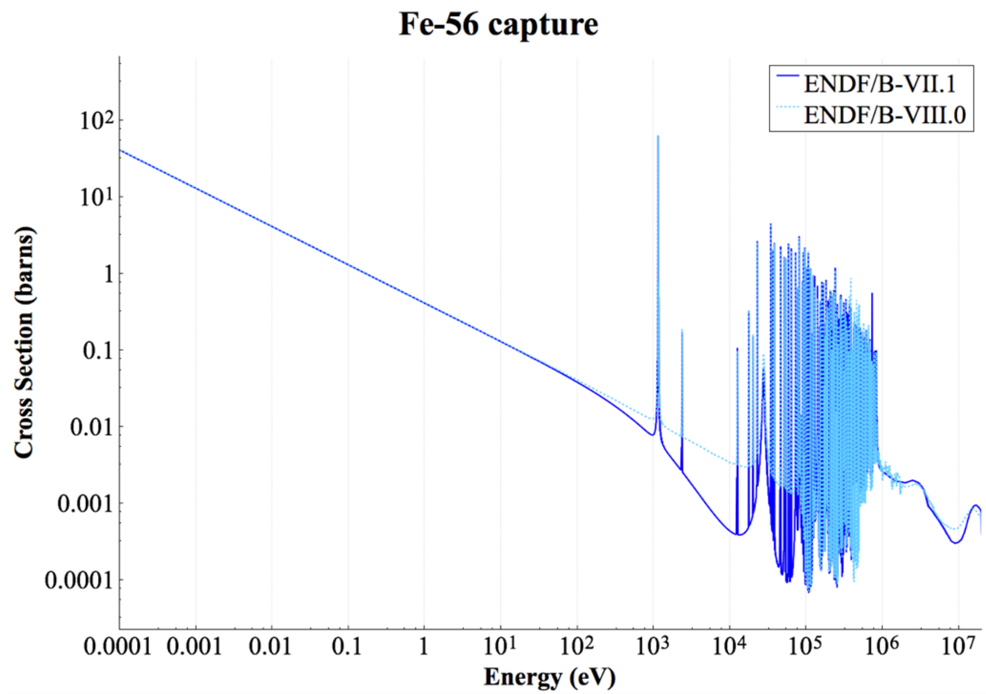




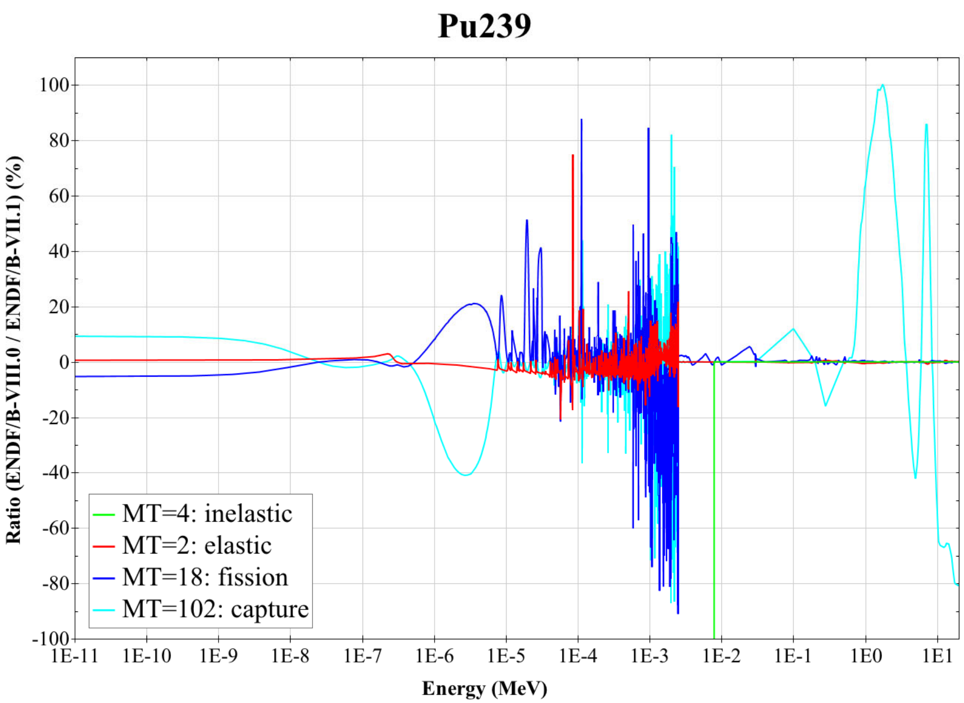


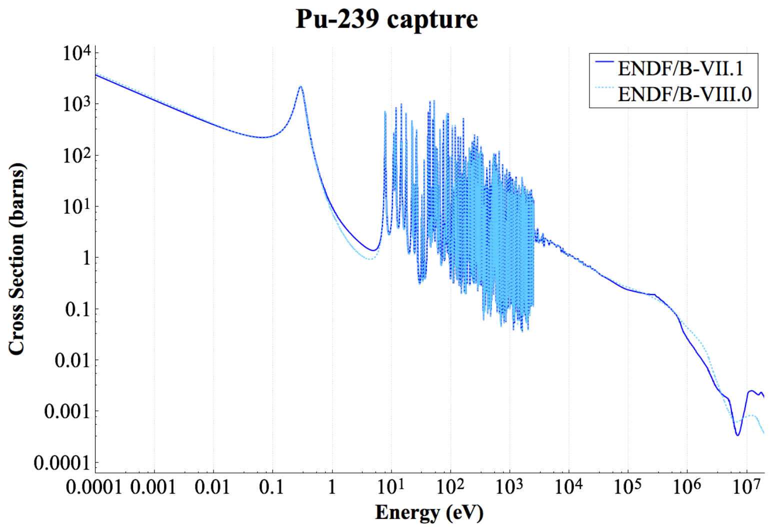
Cross section changes ENDF/B-VII.1 to ENDF/B-VIII.0

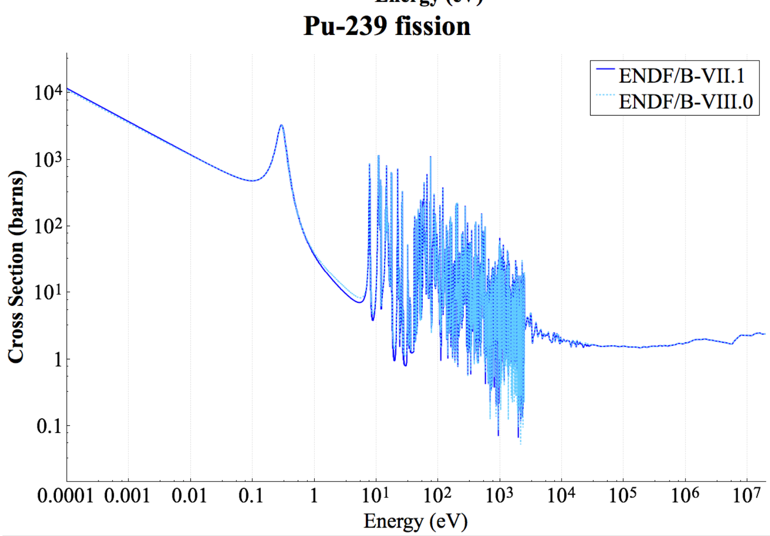




Cross section changes ENDF/B-VII.1 to ENDF/B-VIII.0







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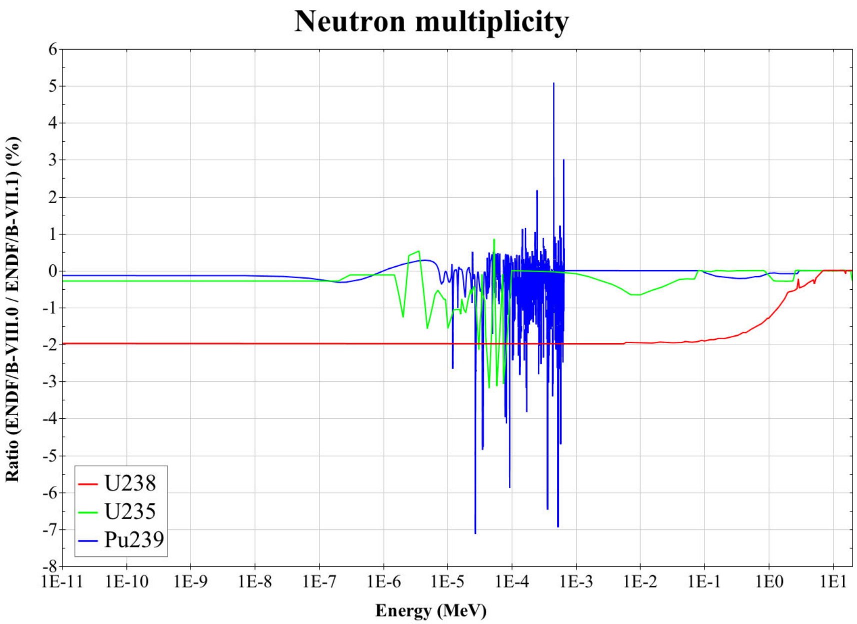
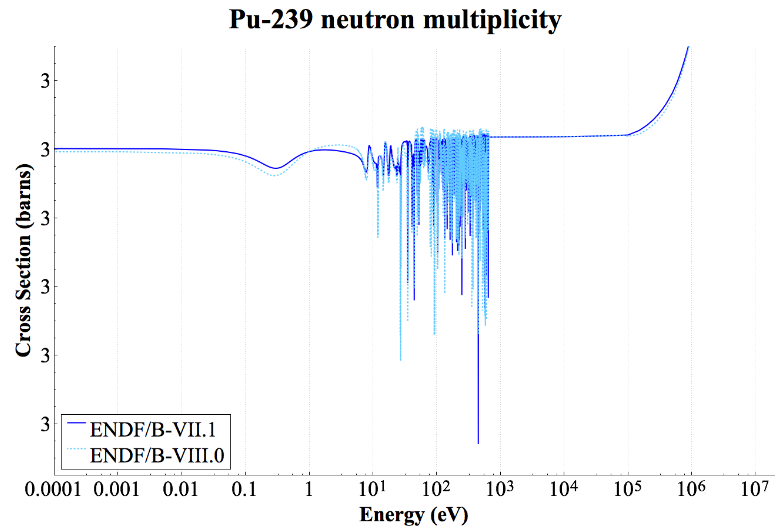
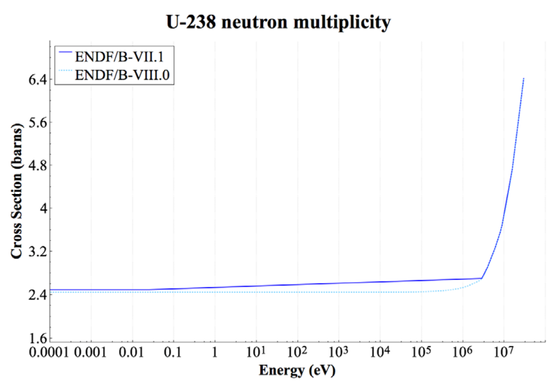
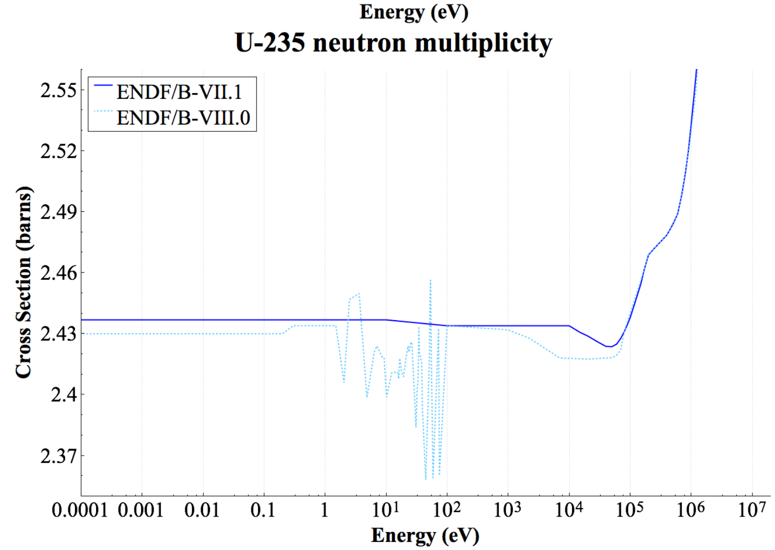
Cross section changes ENDF/B-VII.1 to ENDF/B-VIII.0









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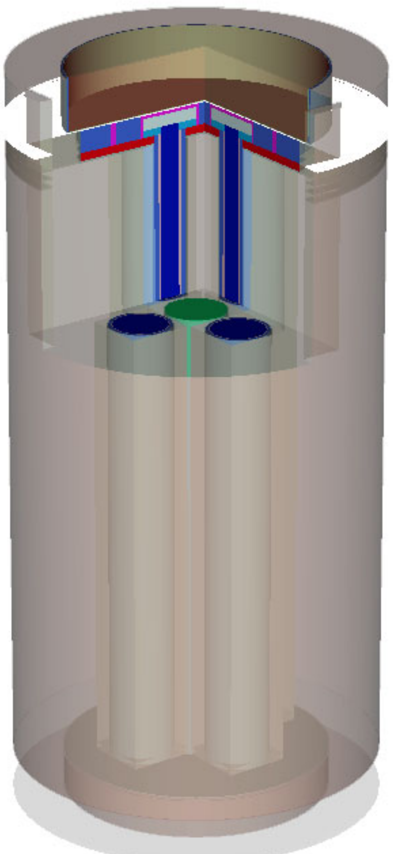
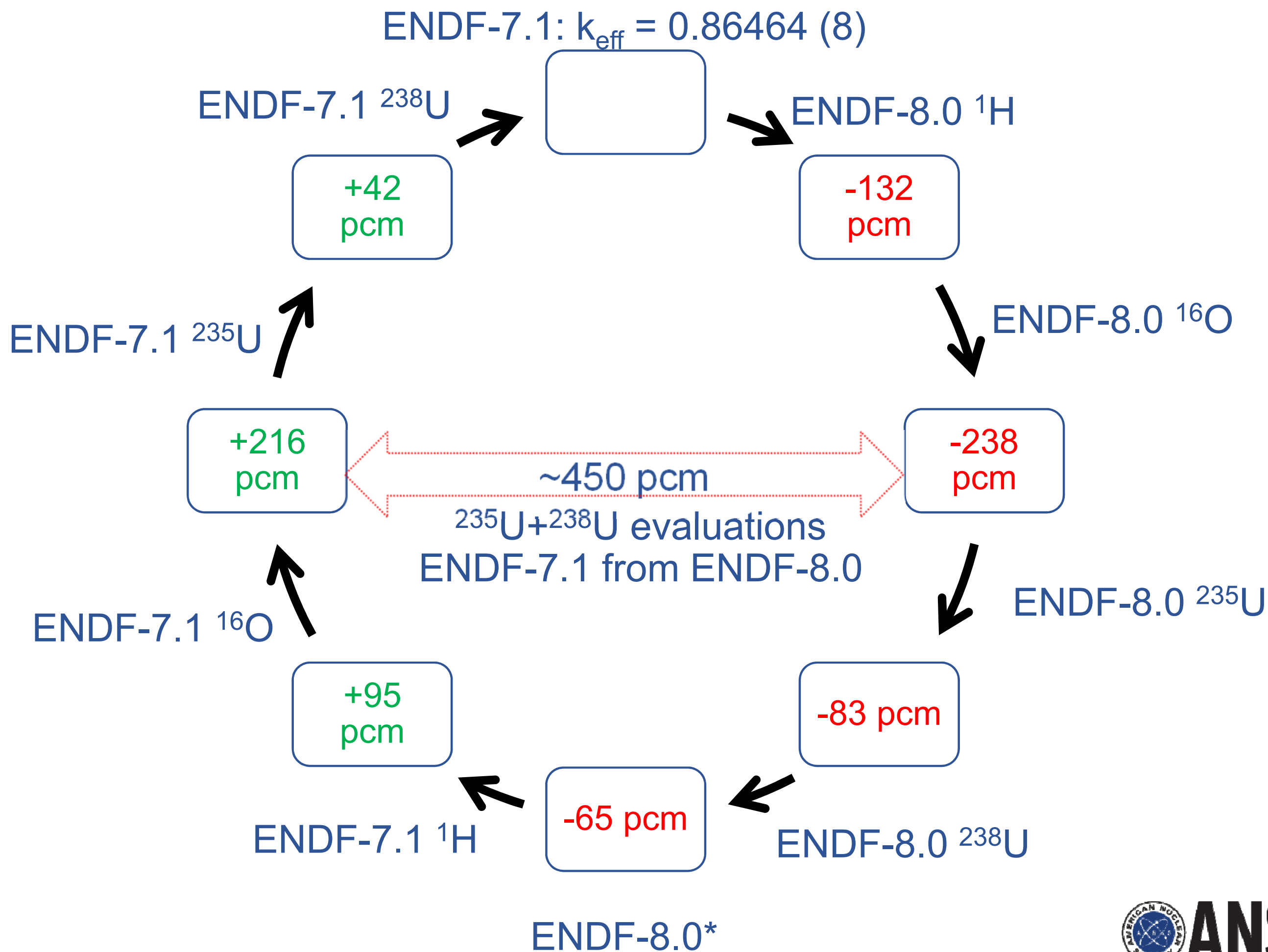
ES-4100 w/ 20 w/o UF_6 study on counteracting errors in ENDF/B-VII.1 – ENDF/B-VIII.0





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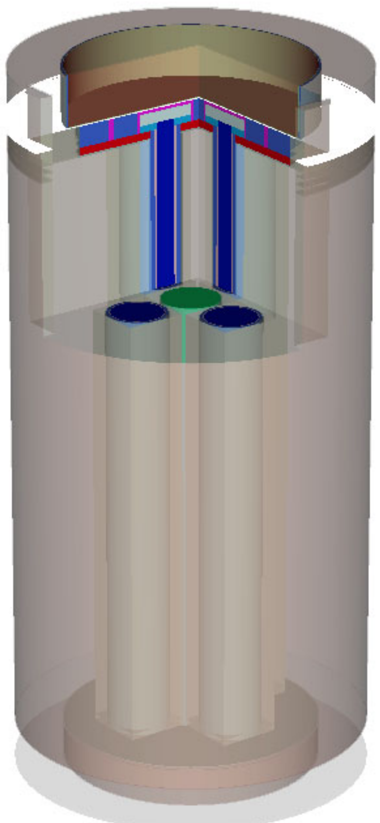
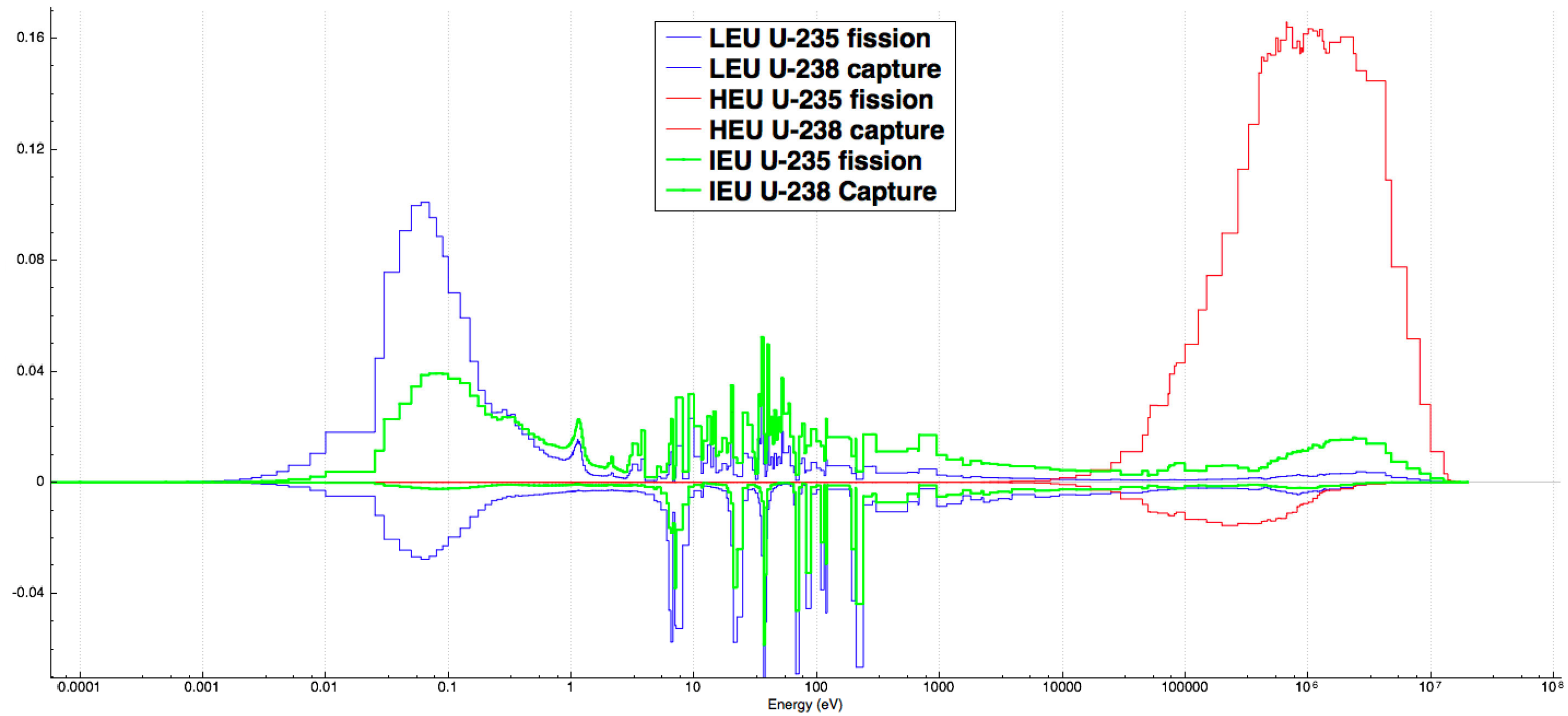
Sensitivity of k_{eff} to nuclear data quantifies how important each cross section is for application of interest





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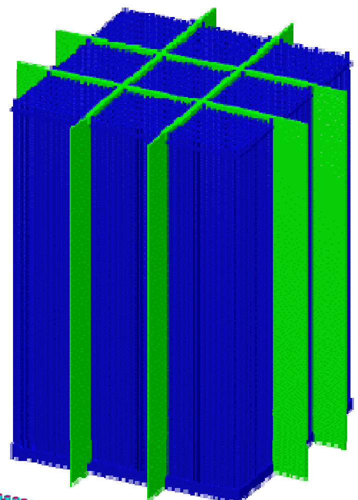
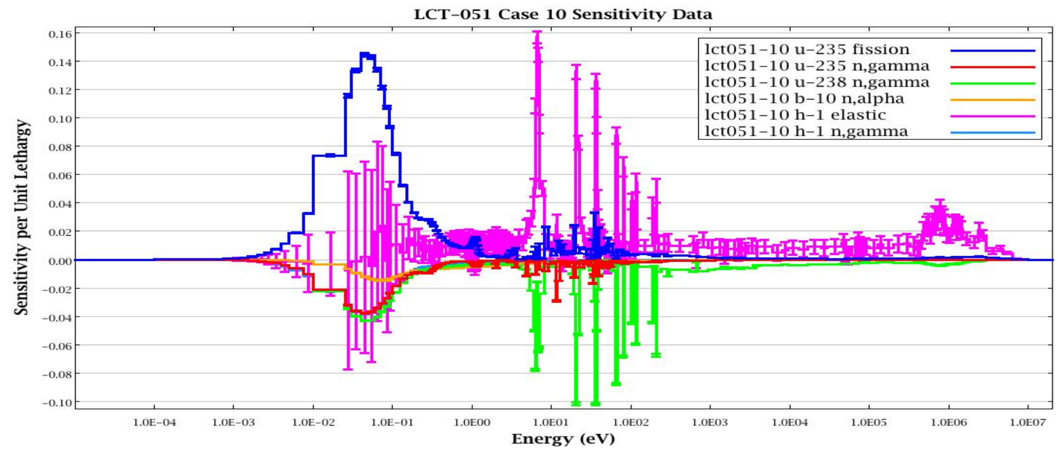
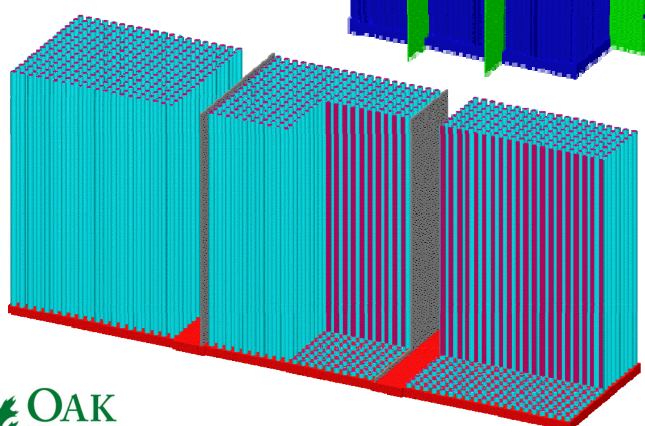
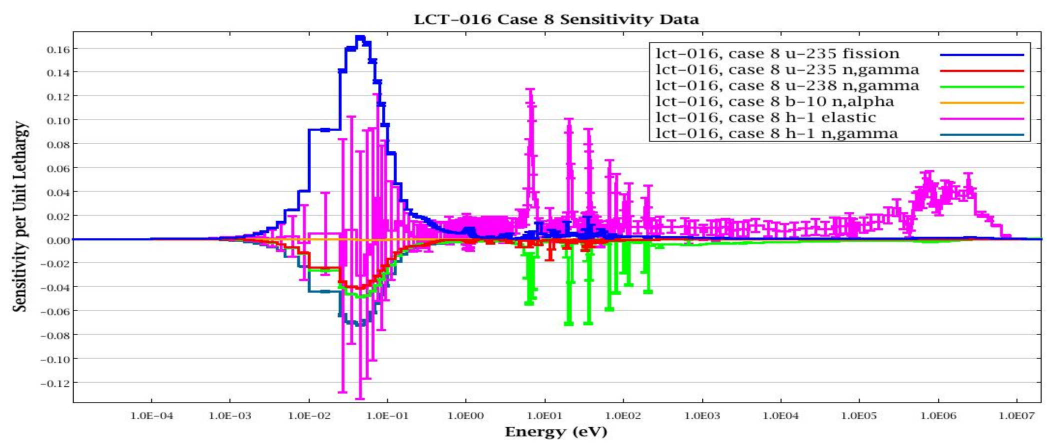
TSUNAMI approach to validation: identify and analyze benchmark experiments to quantify bias in application









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Correlation coefficient (c_k)

(a.k.a. representativity factor)

- Quantifies overall similarity potential sources of bias in k_{eff} between design application and benchmark experiment.

$$c_k = \frac{\sigma_{ae}^2}{\sigma_a \sigma_e}$$

Covariance between Experiment (e) and Application (a) due to all nuclides and reactions

Standard deviations for Application (a) and Experiment (e) due to all nuclides and reactions

Regulatory basis for validation applicability

FCSS ISG-10, Rev. 0 - 1 -

Justification for Minimum Margin of Subcriticality for Safety

ISG-10
$c_k \geq 0.95$
recommended

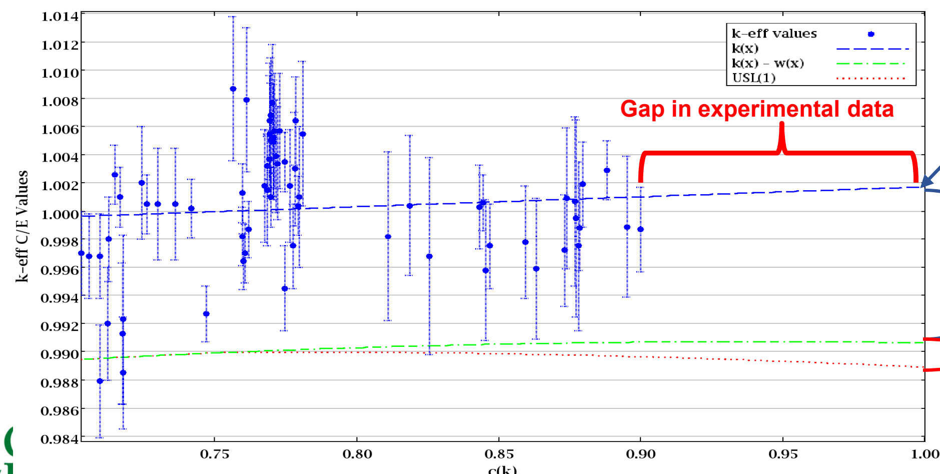
Prepared by

Division of Fuel Cycle Safety and Safeguards

Office of Nuclear Material Safety and Safeguards

Issue

Technical justification for the selection of the minimum margin of subcriticality for safety for fuel

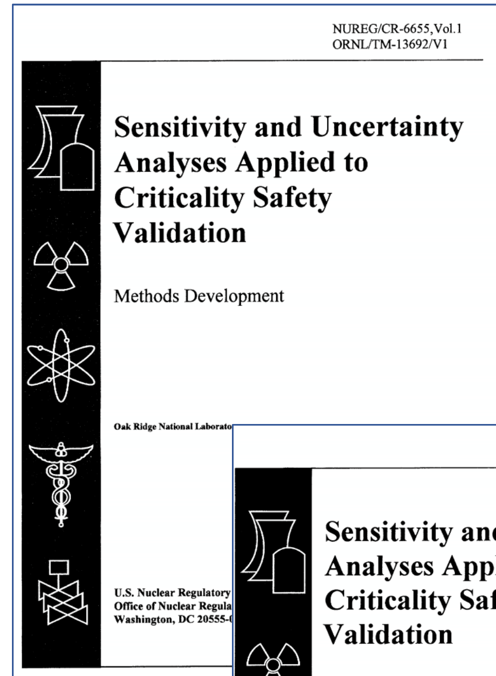


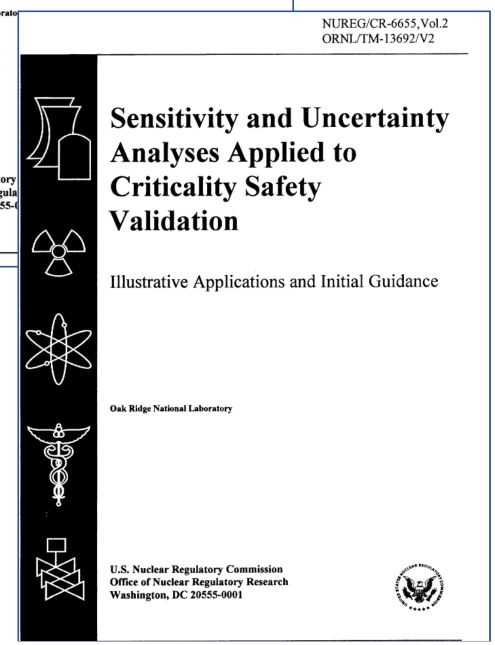
Gap in experimental data

Biased k_{eff} for Application
(bias is this intercept - 1.0)

Confidence band
(uncertainty in bias)

Positive Bias Adjustment





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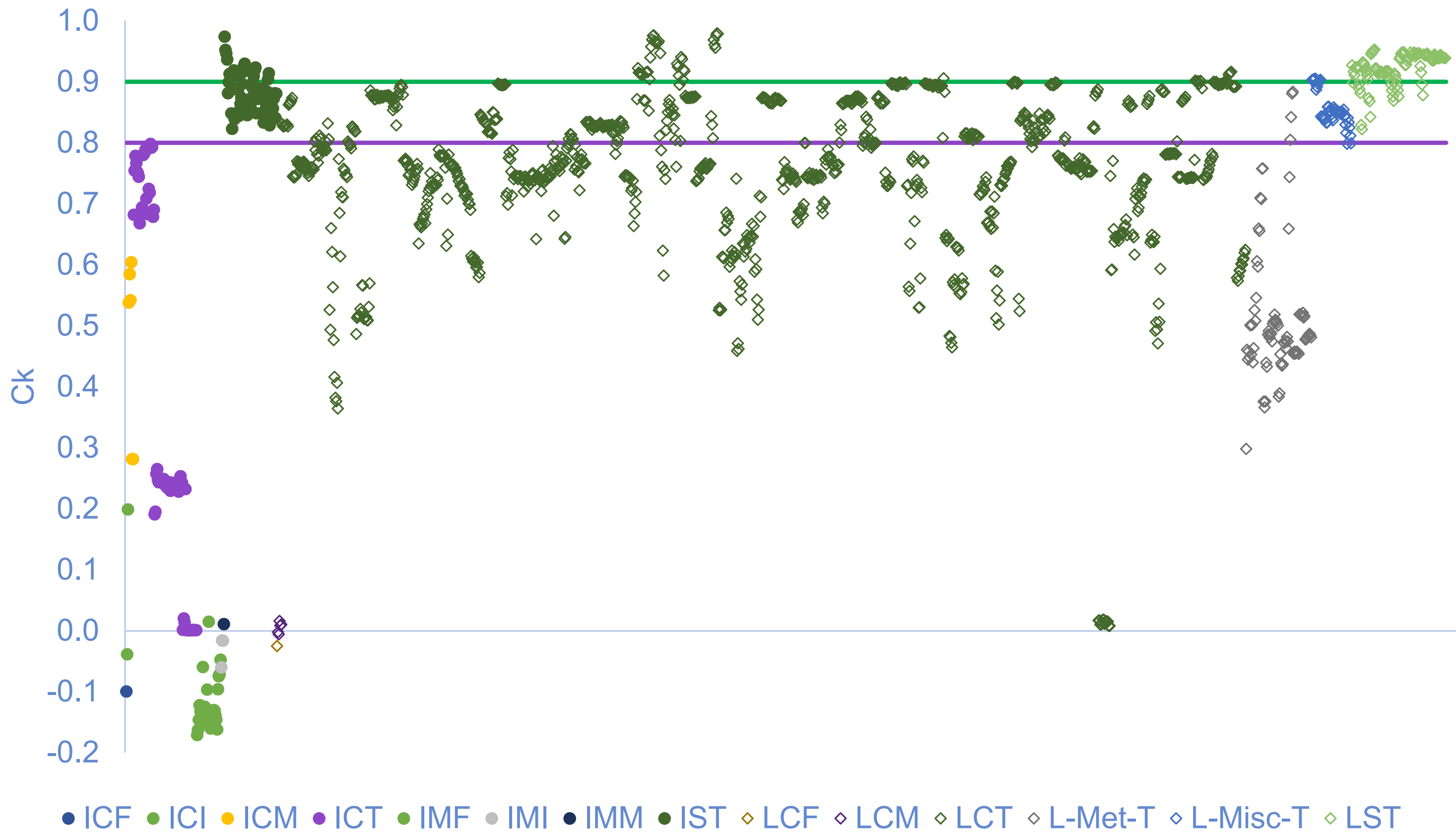
Selection of applicable critical experiments using SCALE/TSUNAMI similarity assessment

- 1,584 experiments considered
- ORNL VALID library
- NEA sensitivity data provided with ICSBEP
- Plot of c_k by criticality experiment type
- c_k is a correlation coefficient indicating how similar an experiment is to an application model with regard to physics and nuclear data
- A c_k of 1.0 indicates that the experiment and application use the same physics in the same way, so they should have the same computational bias



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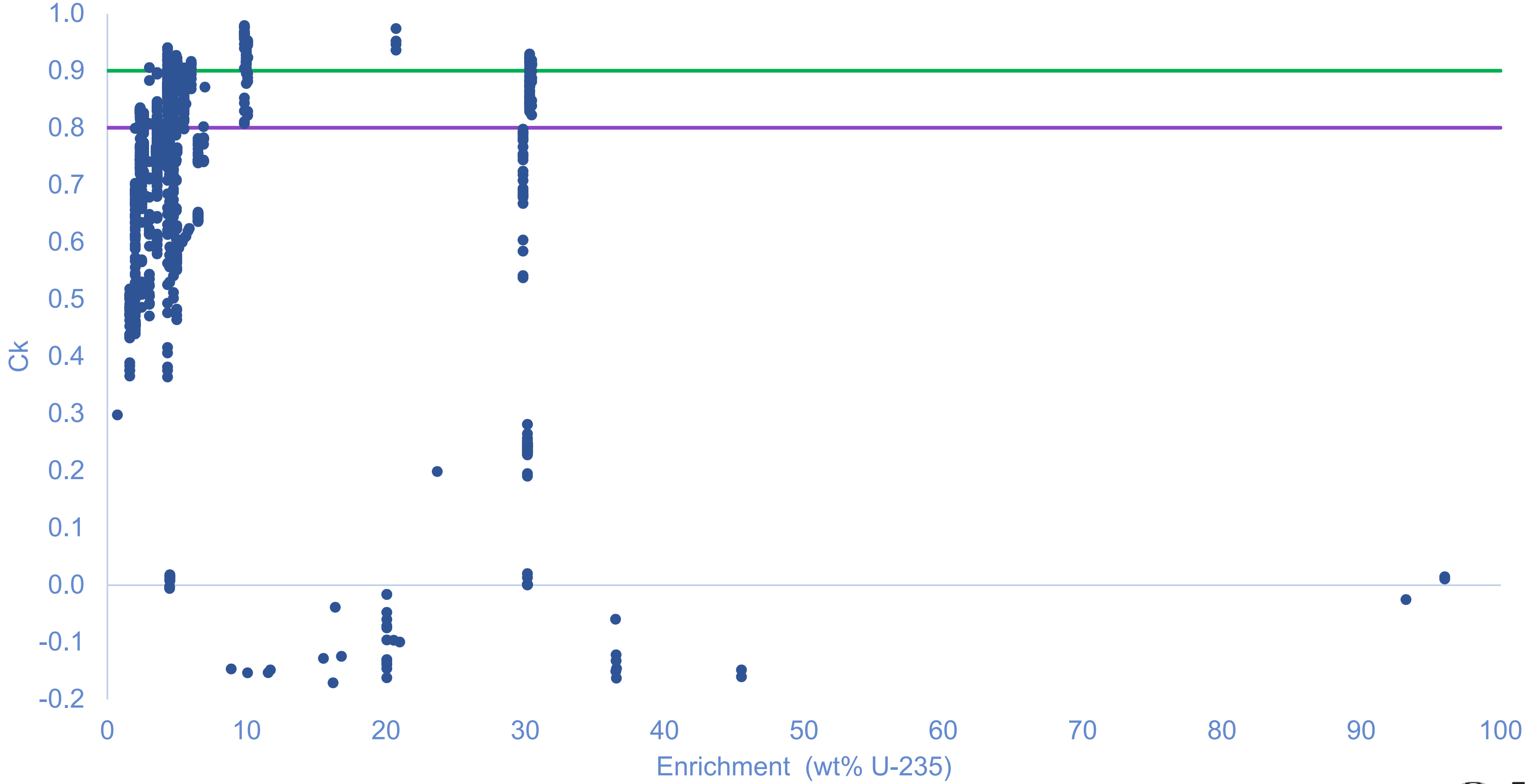
c_k sorted by enrichment for 20 wt% application



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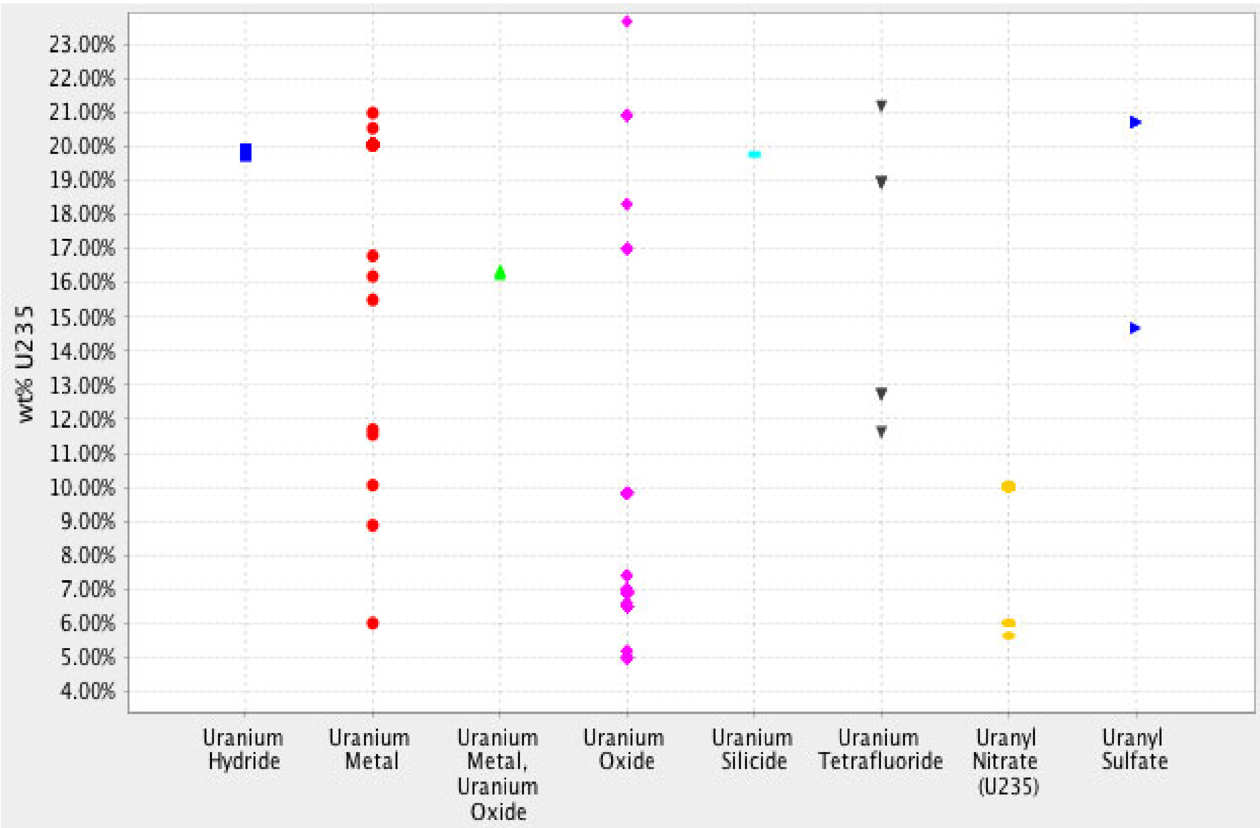
376 ICSBEP experiments with 5% < ^{235}U wt% < 25%



- Many legacy experiments for metallic cores
- IRPhEP has a few experiments for HTGR (HTR-10, HTTR)
- No experiments for molten salt (limited new measurements in Czech republic for non-fueled FLiBe)
- No data for FHR

Conclusions

- This paper describes the impact of recent nuclear data changes on HA-LEU and provides a preliminary sensitivity/uncertainty–based assessment of the applicability of available of criticality experiments for validation of licensing calculations for transportation of small quantities of 20 wt% UF_6.
- This study showed that while recent dramatic changes in the ENDF data due to nuclear data tuning may cause unpredictable behavior in new systems, existing criticality experiments available in the ICSBEP Handbook could provide a sufficient basis for validation, especially where the sensitivity/uncertainty approaches to validation are applied.

Ongoing activities

- New funding opportunities for nuclear data improvements:
  - Nuclear Data Working Group FOA
  - DOE-NE NEUP
- DOE-NE HA-LEU campaign teams at INL, ORNL, and PNNL are sourcing material and examining criticality safety issues for transportation
- Centrus will begin HA-LEU enrichment pilot program
- ORNL is continuing nuclear data reviews, validation assessments, and training to support NRC readiness for licensing actions

Office of Science

Funding: Department of Energy to Provide $7.5 Million for Nuclear Data Research

APRIL 22, 2019

Home » Funding: Department of Energy to Provide $7.5 Million for Nuclear Data Research

WASHINGTON, D.C.—Today, the **U.S. Department of Energy (DOE)** announced a plan to provide $7.5 million for new research on nuclear data. The aim is to expand and improve the quality of data needed for a wide range of nuclear-related activities from basic research in nuclear science, to isotope production, nonproliferation efforts, and nuclear power generation.

"Nuclear data is vital to a host of activities ranging fro
national defense," said Timothy Hallman, DOE Associa
"These data require upkeep and constant improvemen
availability of nuclear data for U.S. science, governmen

Four DOE programs have teamed up for the effort as p
Data Interagency Working Group. They include the Offi
Program within the Department's Office of Science, DO
Nuclear Security Administration's (DOE/NNSA) Office o

DOE Selects Centrus Energy Subsidiary for $115M Uranium Fuel Production Contract

Brenda Marie Rivers · June 2, 2019 · Contract Awards, News

A subsidiary of global nuclear fuel provider Centrus Energy received a $115M contract to demonstrate a method of producing high-assay low-enriched uranium to support the Department of Energy's research and development work on advanced nuclear reactors.

DOE asked American Centrifuge Operating to deploy a HALEU fabrication system by June 2022 and establish approaches to utilize U.S.-made technology in production efforts, according to a FedBizOpps notice posted Friday.

The contractor will also provide HALEU technology to support nuclear energy, national security and related R&D initiatives within three years as part of the sole-source award.

HALEU manufacturing process involves uranium enrichments of 5 percent to 19.75 percent and is intended for advanced reactors that do not require constant refueling.

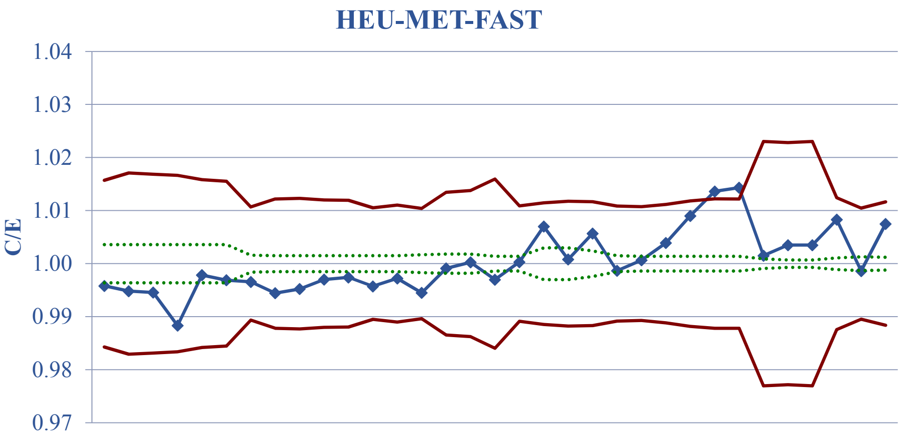
NUCLEAR DATA NEEDS FOR NUCLEAR ENERGY APPLICATIONS (MS-NE-2)
(FEDERAL POC: DAVE HENDERSON & TECHNICAL POC: BRAD REARDEN)
(UP TO 3 YEARS AND $400,000)

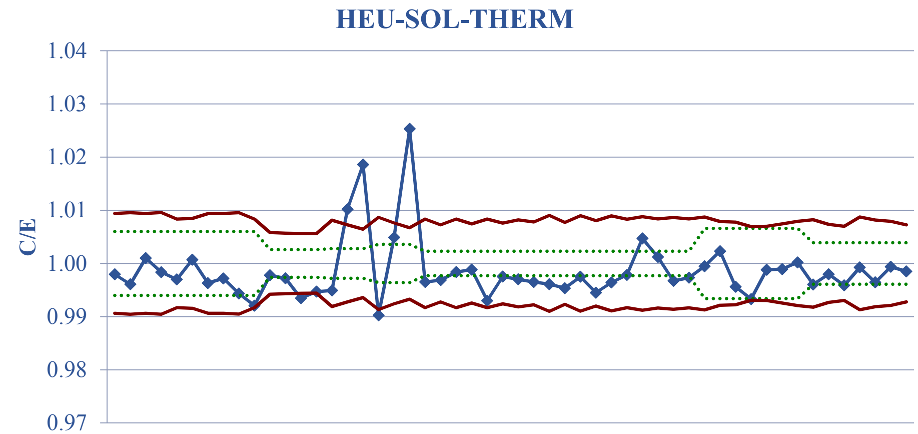
The Evaluated Nuclear Data File (ENDF) maintained by the National Nuclear Data Program (NNDC) at Brookhaven National Laboratory (BNL) provides the most reliable and commonly used nuclear data for nuclear energy applications. However, a close and critical examination of the existing nuclear data often finds that it is

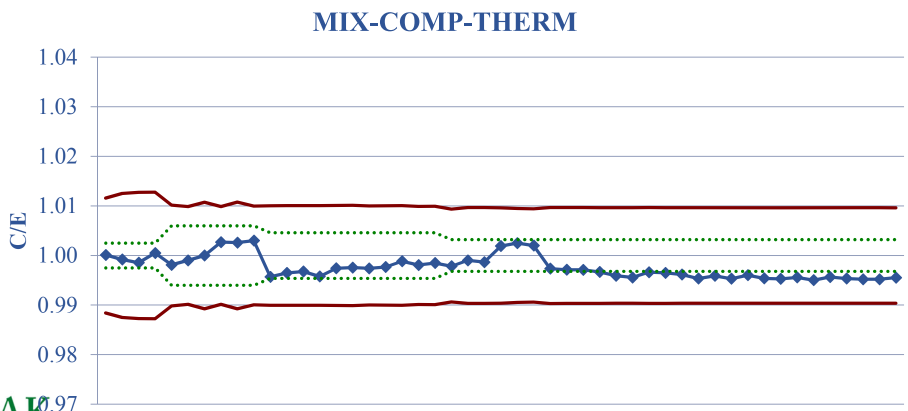
Backup slides

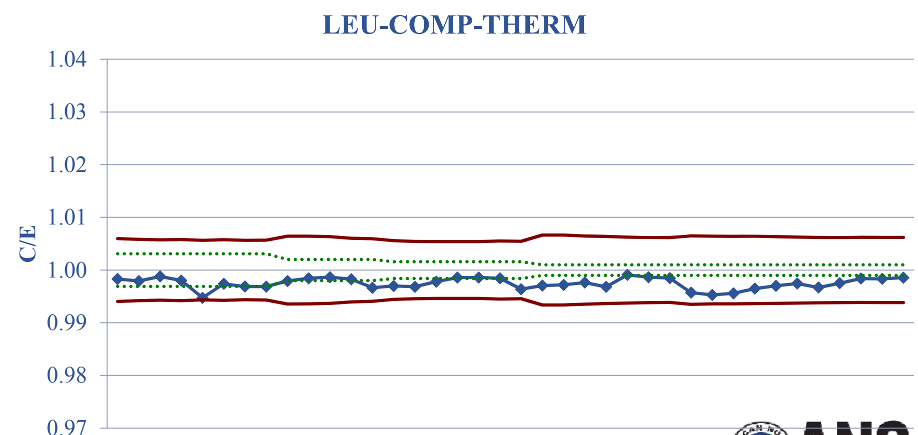
Computational bias for critical benchmarks

Computational Bias
Experimental Uncertainty
Cross-section Uncertainty









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Generation of Cu evaluation for ENDF/B-VIII.0

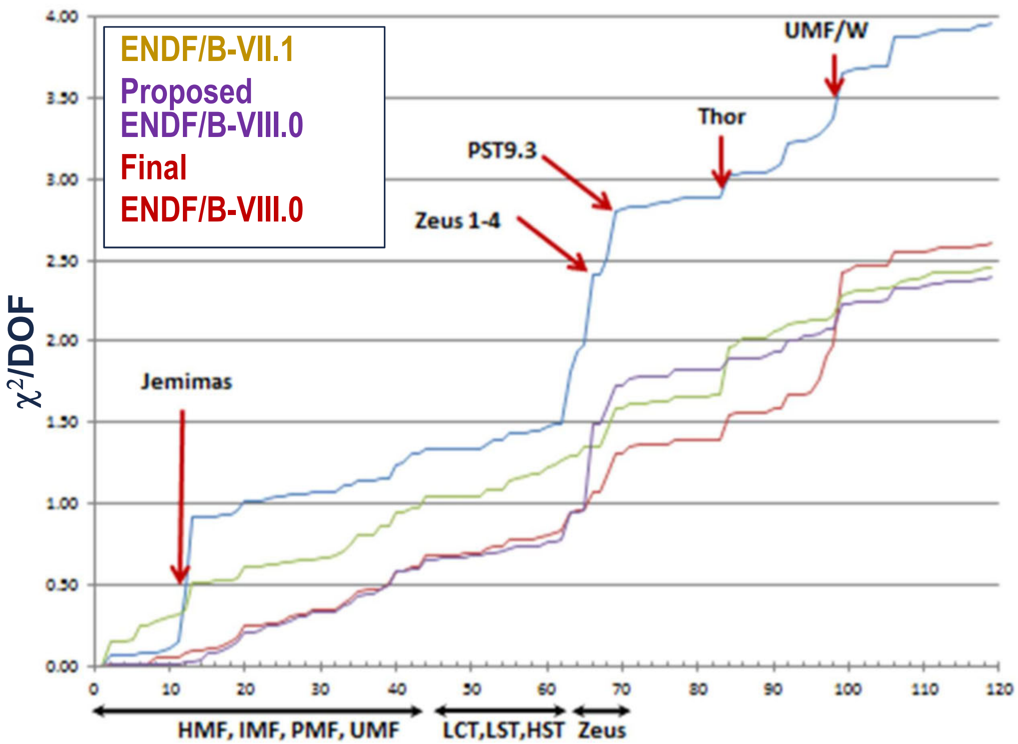
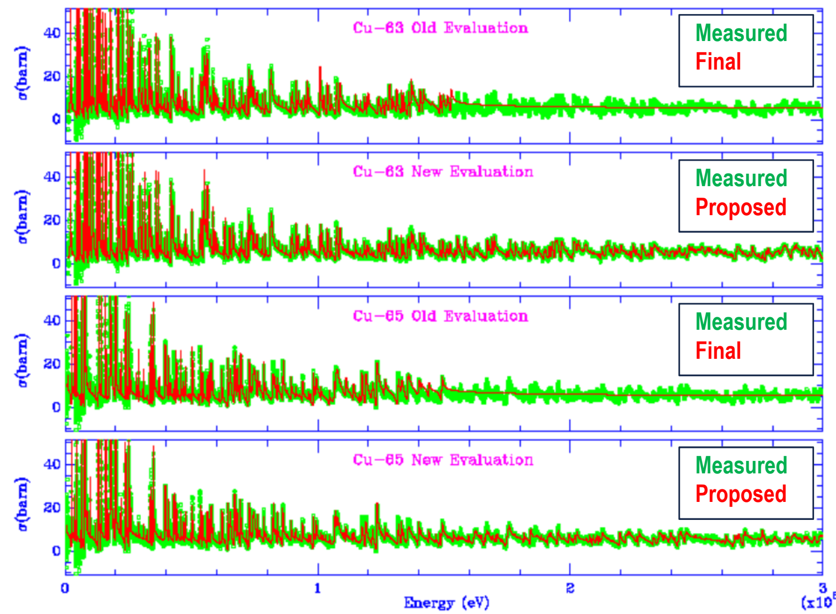
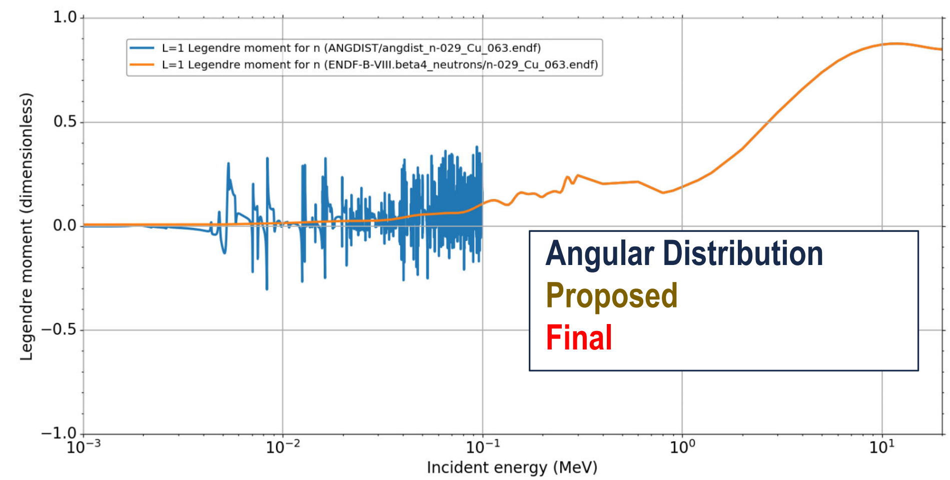


Figure 1: Cumulative Chi^2/DoF for the LANL suite of 119 benchmarks with different libraries.





Courtesy of V. Sobes