The status of the nuclear data uncertainty libraries

and the problem of too small uncertainties on differential data and too large uncertainties on integral data

Vladimir Sobes

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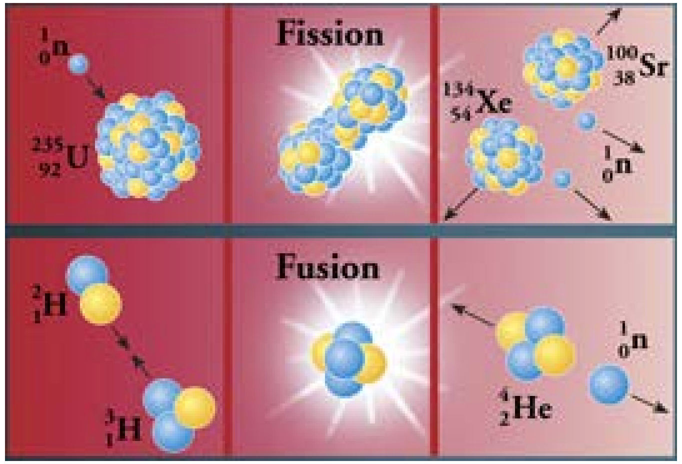
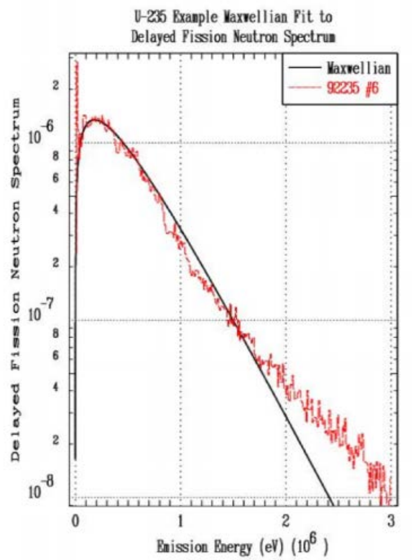
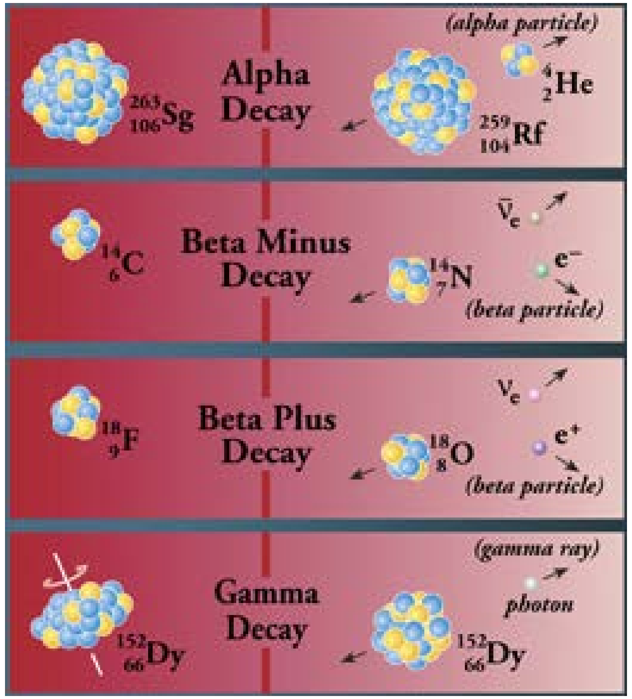
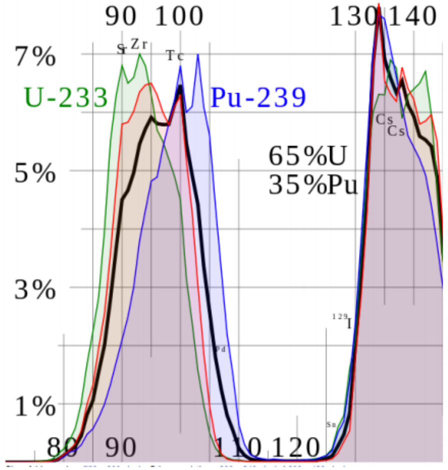
Nuclear data is of fundamental importance in nuclear science and engineering

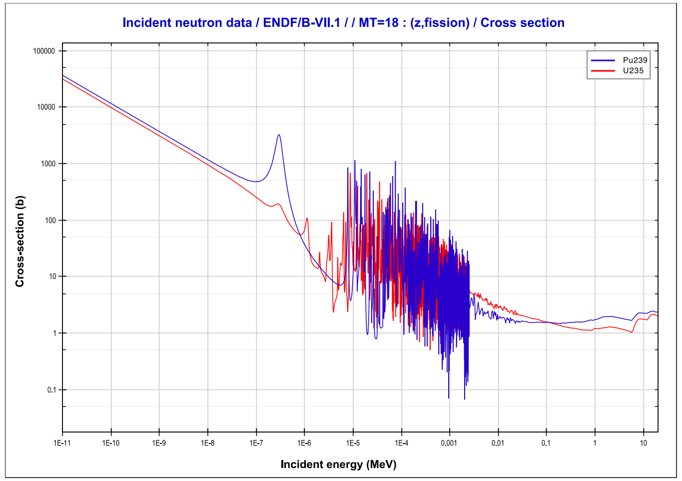
Nuclear data includes all of the nuclear interaction information required for computational modeling











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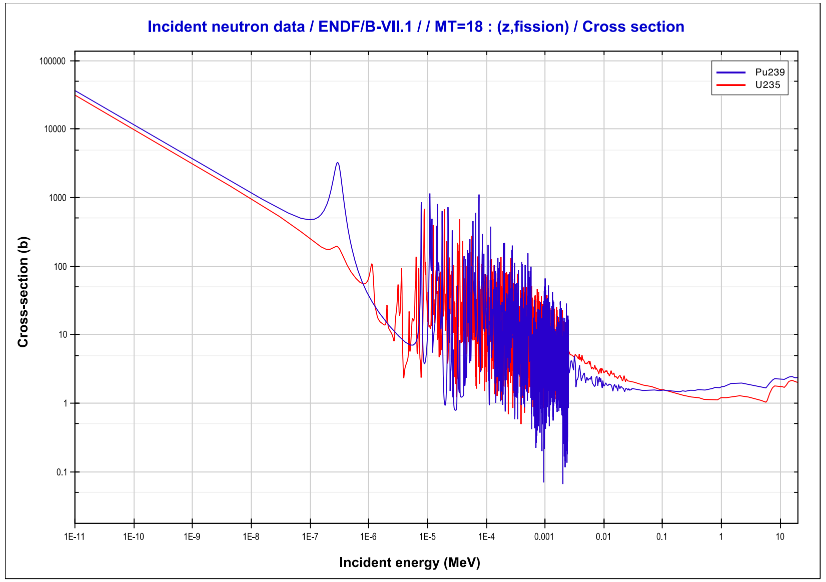
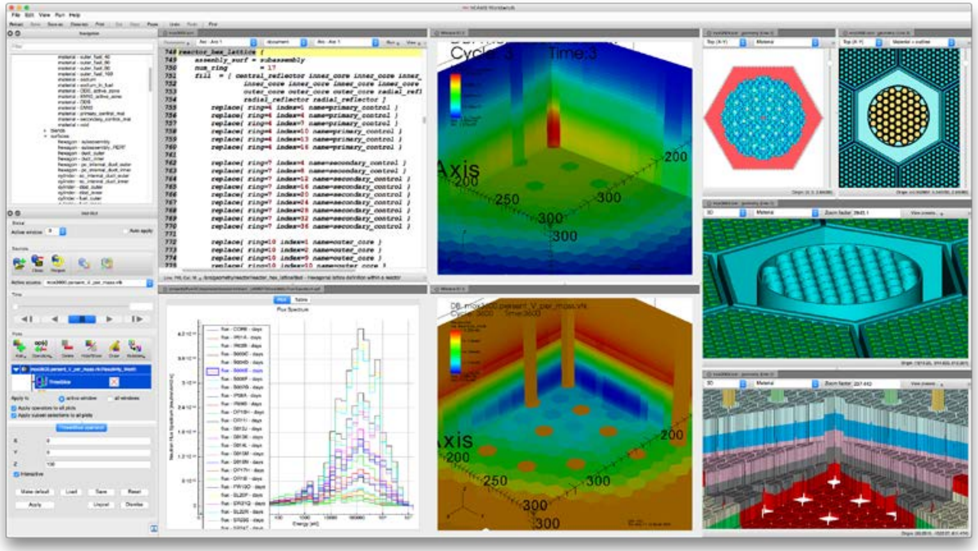
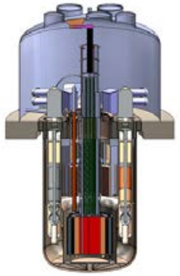
2. Uncertainty in differential nuclear data
3. Propagated uncertainty to integral applications
4. Have your cake and eat it too: nuclear data correlations

Nuclear data is necessary for reliable modeling and simulation of the next generation of nuclear reactors

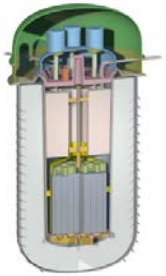




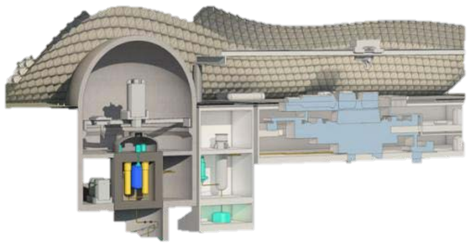
TerraPower



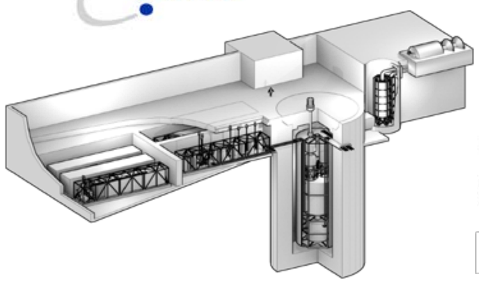
TERRESTRIAL ENERGY



TRANSATOMIC

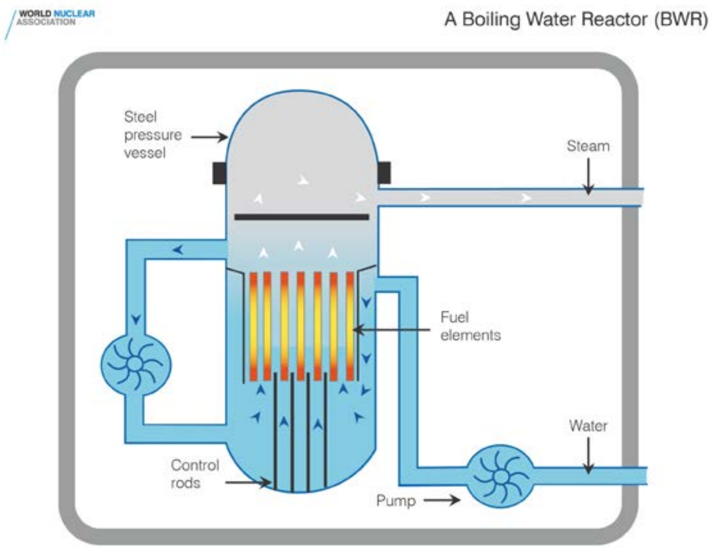


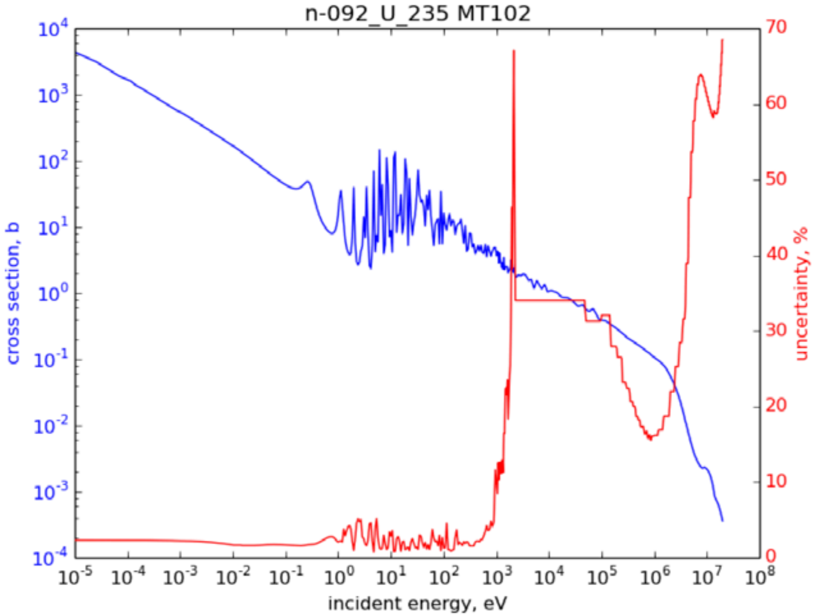
Flibe ENERGY

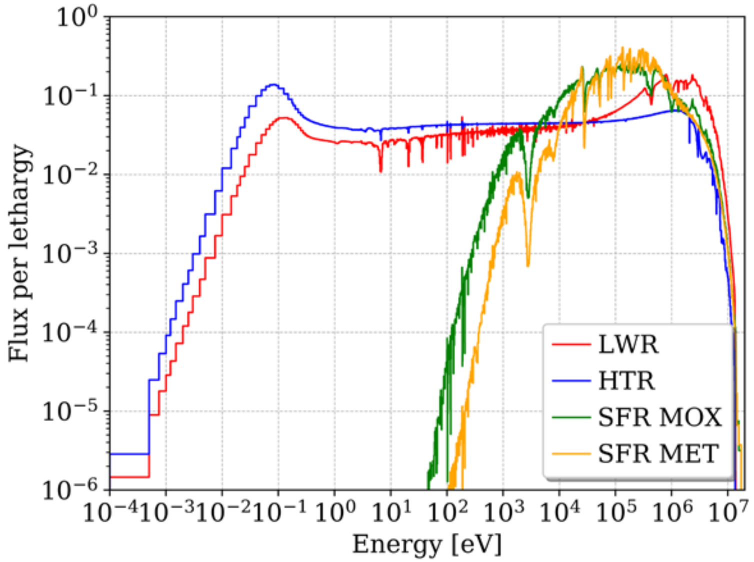


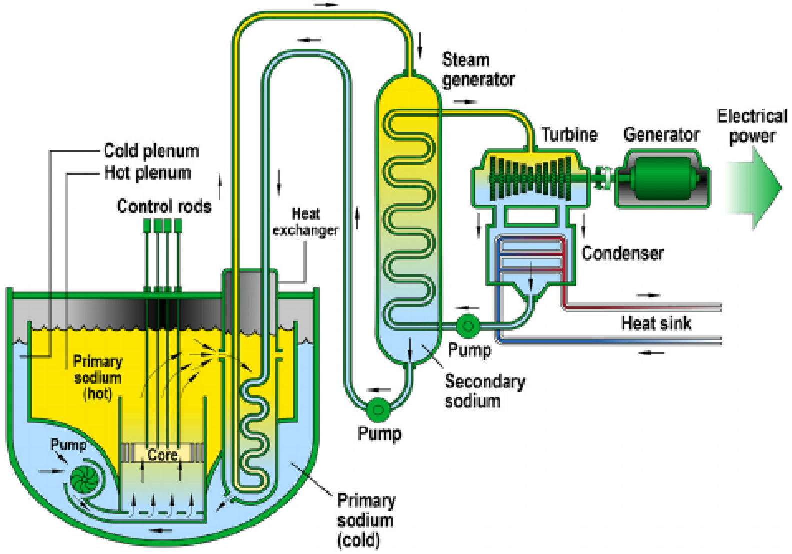
X energy

The problem of extrapolating nuclear data to new designs





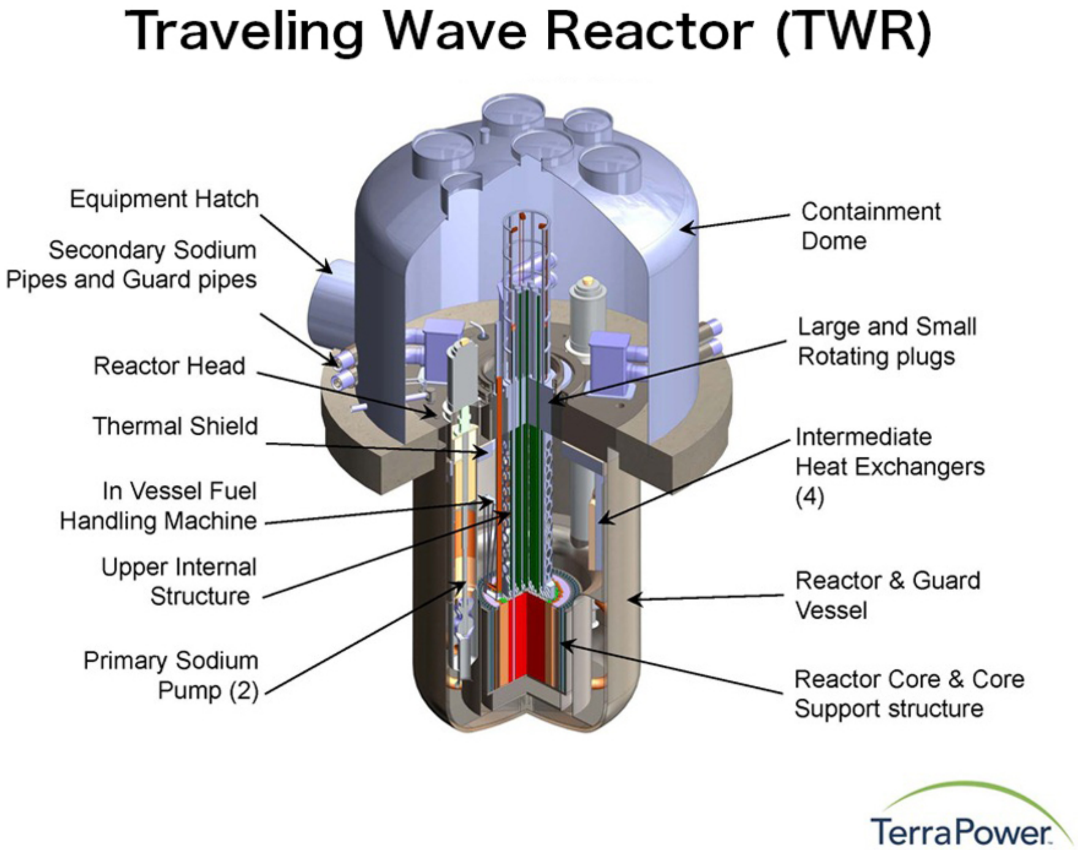




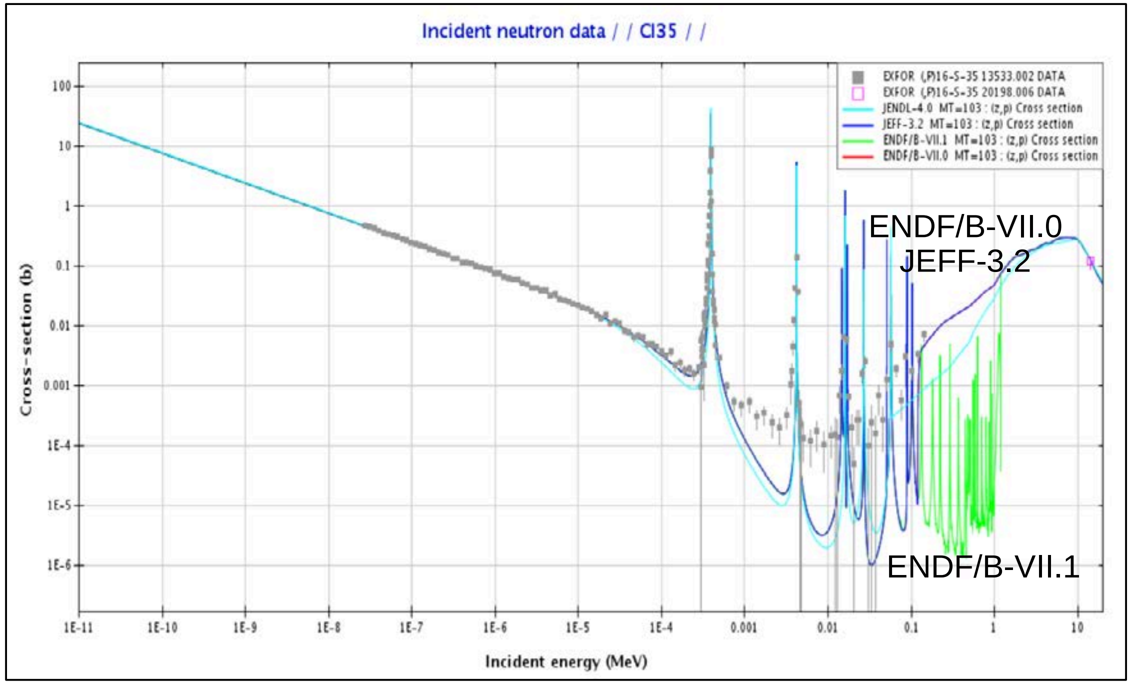
Nuclear data effecting reactor design (1/2)
Traveling Wave Reactor

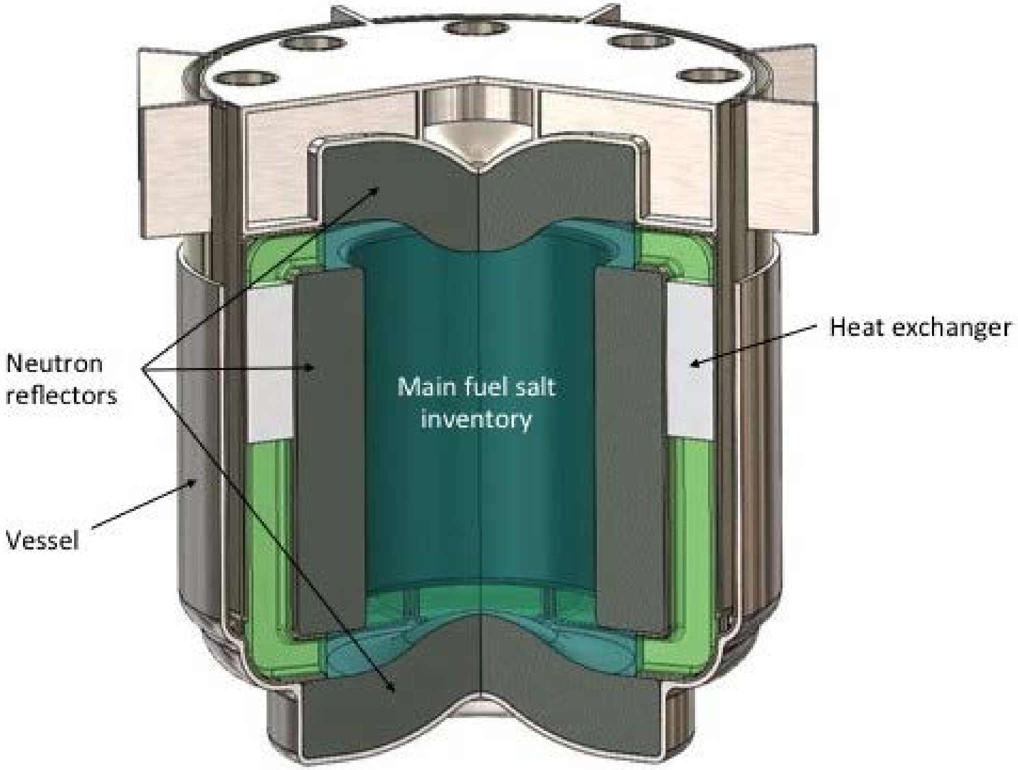
Nuclear data uncertainty dominates:

- Beginning-of-Life (BOL) k_{eff}
- Coolant temp. feedback
- Doppler feedback
- Control rod worth
- Void worth



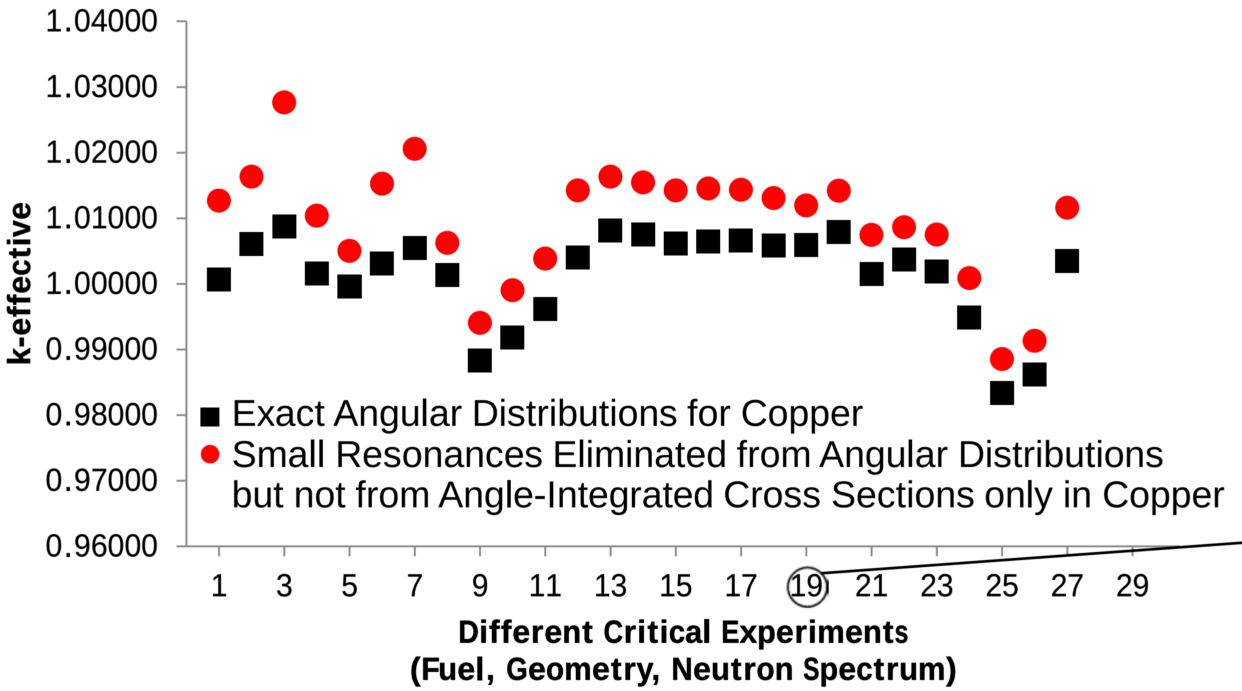
Nuclear data effecting reactor design (2/2)
Molten Chloride Fast Reactor

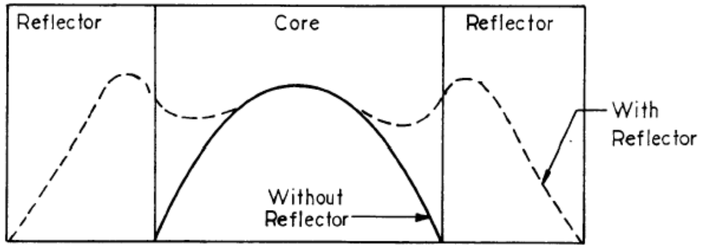


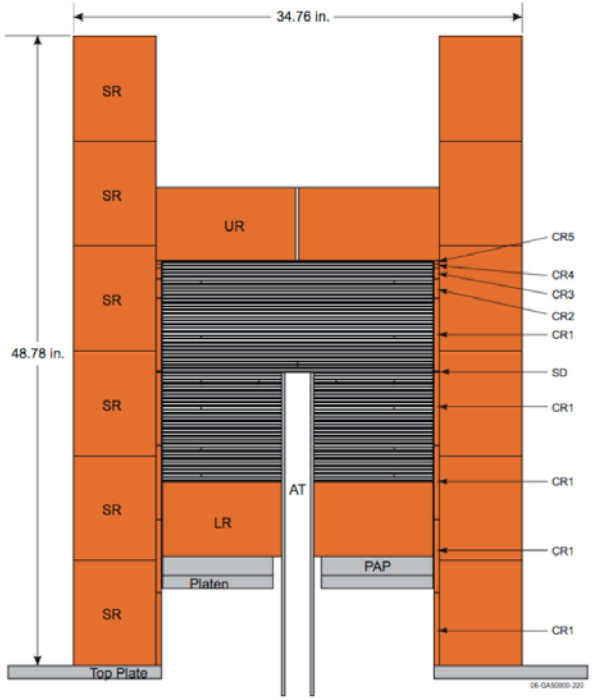


A change in absorption cross section of ^{35}Cl resulted in 2000 pcm change in BOL k_{eff}

Importance of angular distribution nuclear data







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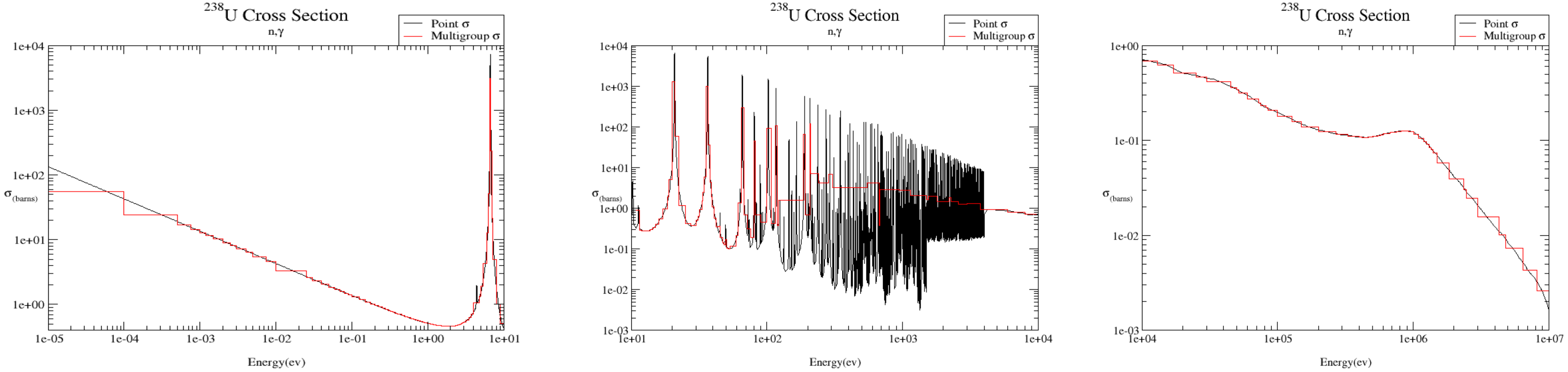
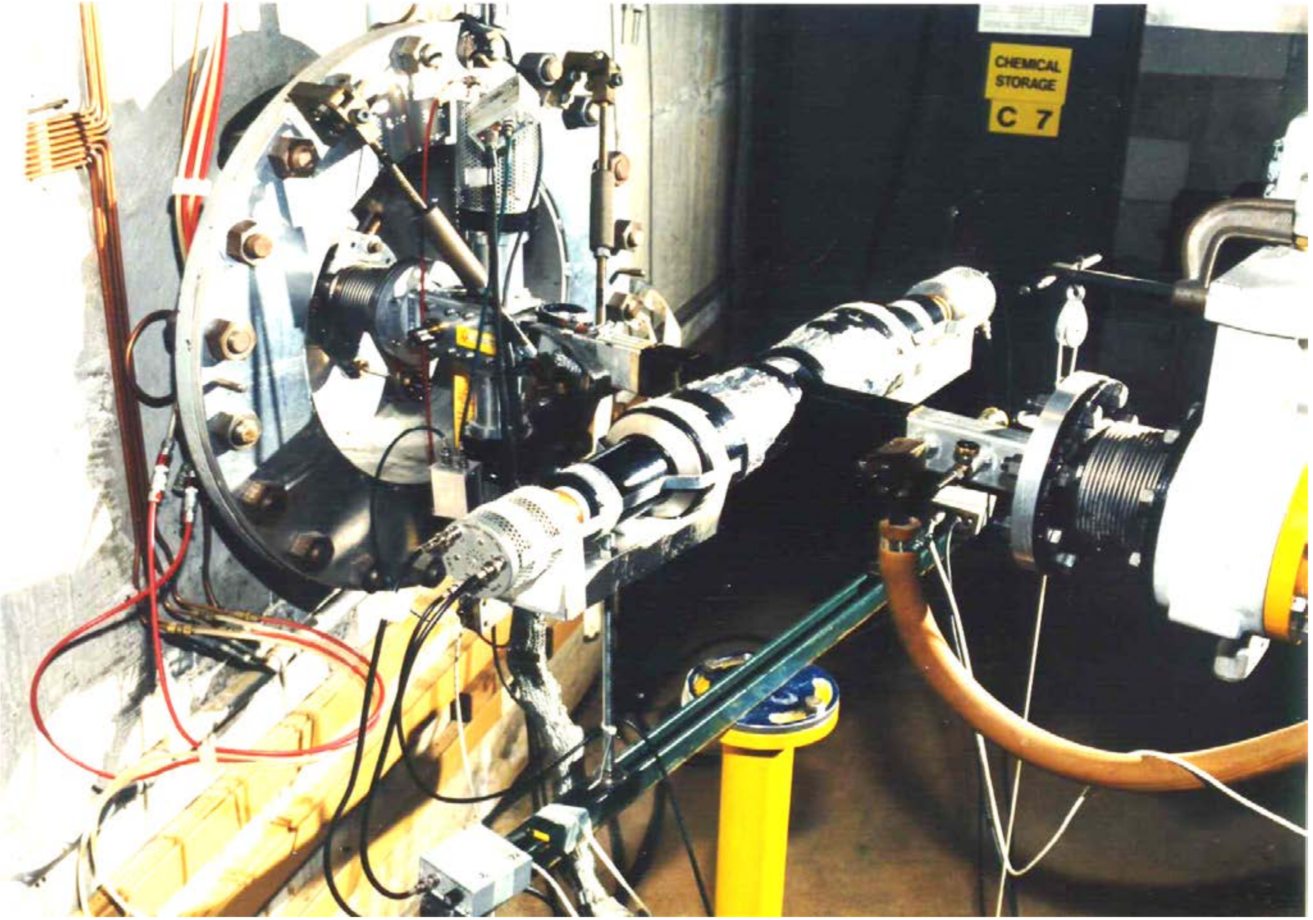
We cannot solve the cross sections from first principles because the nuclear potential, $V(\boldsymbol{r})$, is not well understood!

$$\left[-\frac{\hbar^2}{2m}\nabla^2 + V(\boldsymbol{r})\right]\psi(\boldsymbol{r}) = E\psi(\boldsymbol{r})$$



Thermal | Resonance range | Fast

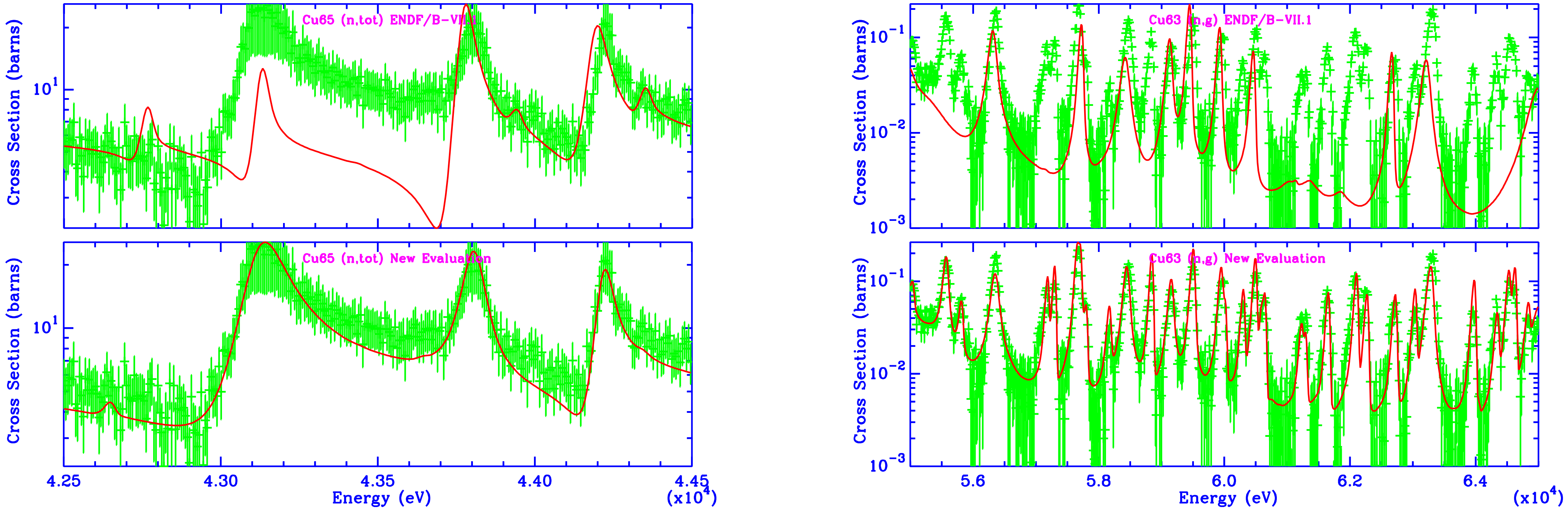
Experiments to measure cross sections are complex



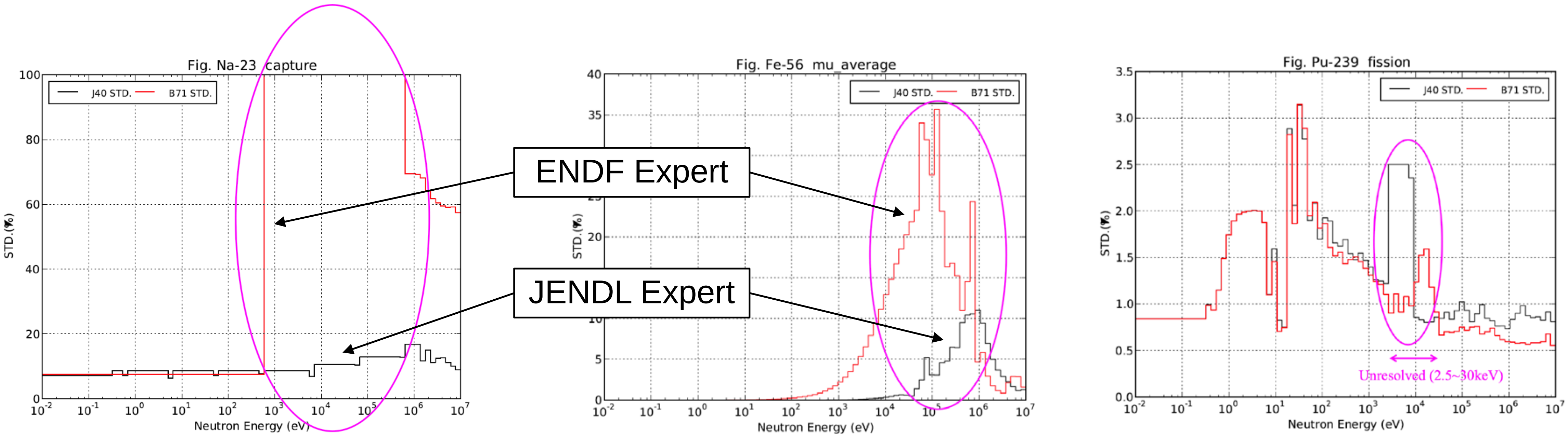
Capture measurement set up

Scattering measurement set up

Nuclear data measurements come with uncertainties
Nuclear data evaluation come with more uncertainties



Nuclear data uncertainties are not certain



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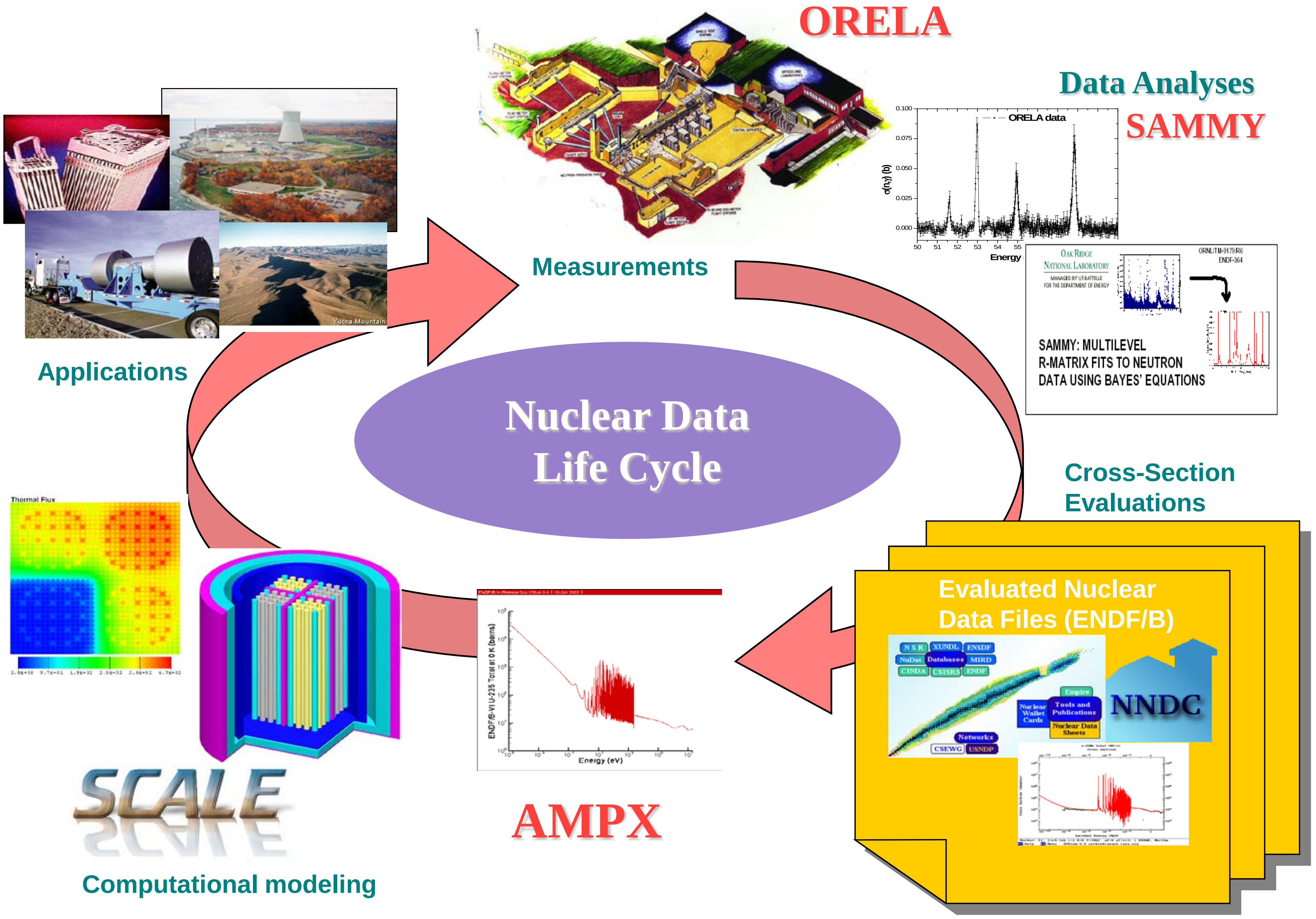
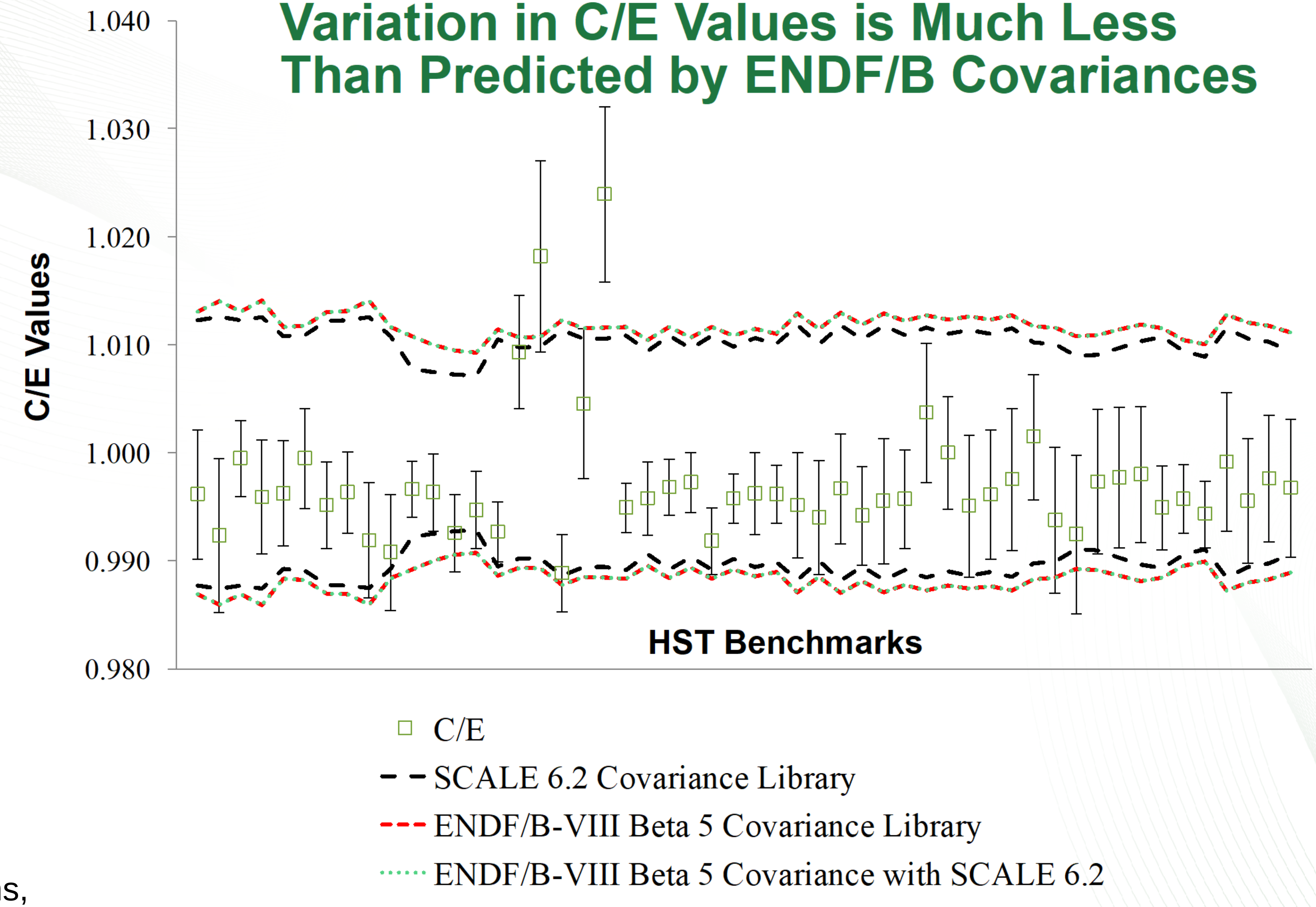


ORELA
Data Analyses
SAMMY
Measurements
Applications
Nuclear Data
Life Cycle
Cross-Section
Evaluations
Evaluated Nuclear
Data Files (ENDF/B)
NNDC
AMPX
SCALE
Computational modeling
SAMMY: MULTILEVEL
R-MATRIX FITS TO NEUTRON
DATA USING BAYES' EQUATIONS
ORELA data
Energy
Yucca Mountain
Thermal Flux
Energy (eV)

Variation in C/E Values is Much Less Than Predicted by ENDF/B Covariances



Slide from
M. Williams,
CSEWG 2017

The response from the European nuclear data community to large propagated uncertainties

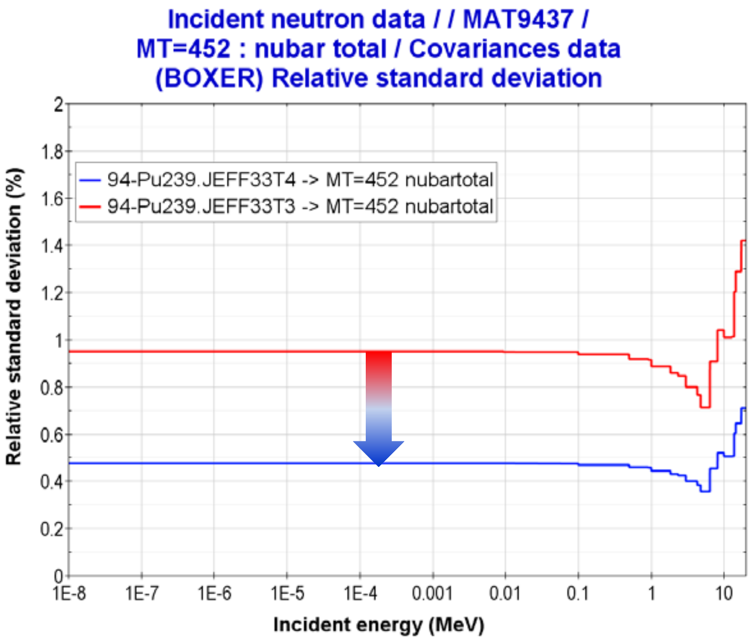
OECD
BETTER POLICIES FOR BETTER LIVES

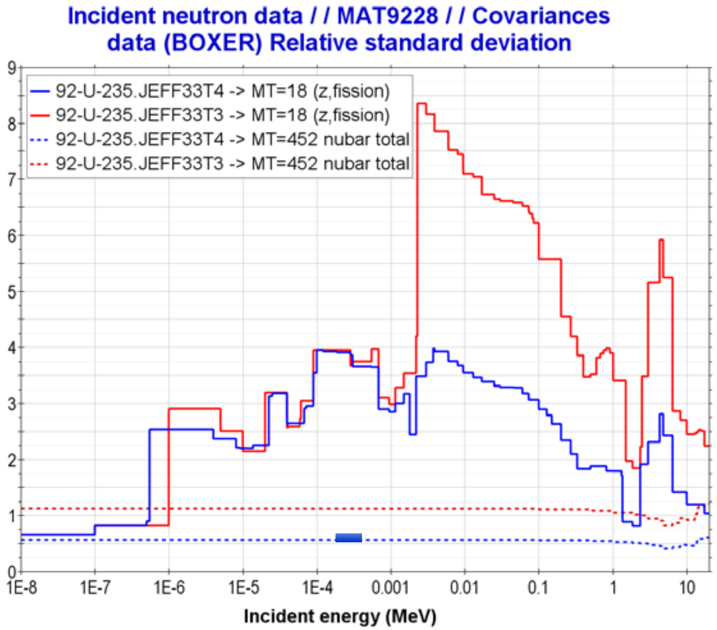
Nuclear Energy Agency

NEA
NUCLEAR ENERGY AGENCY

❑ Differences between JEFF-3.3T4 and JEFF-3.3T3

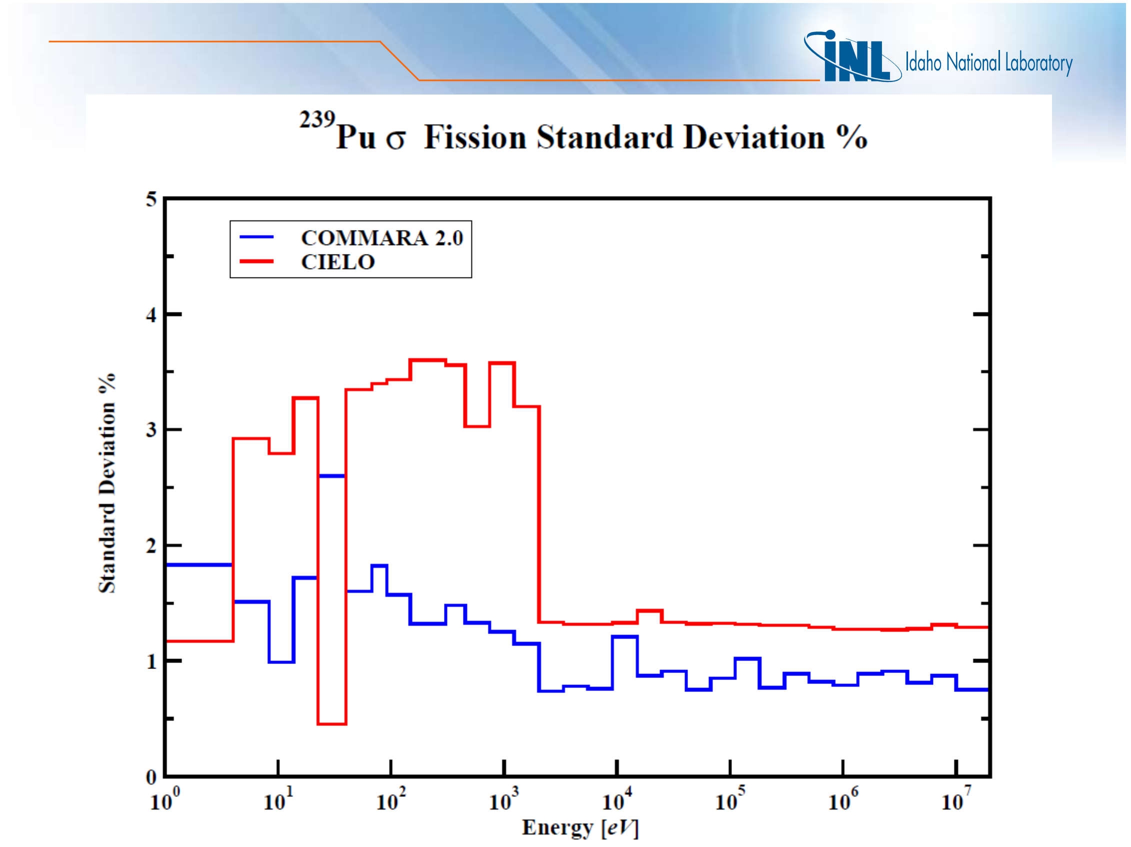
- **JEFF-3.3T3:** uncertainty in the fast range was based on microscopic experiment only.
  See files at: http://www.oecd-nea.org/dbdata/jeff-beta/JEFF33T3/neutrons/
- **JEFF-3.3T4:** reduced uncertainties to reflect adjustment (e.g. fast range to JEZEBEL).
  See files at: http://www.oecd-nea.org/dbdata/jeff-beta/JEFF33T4/neutrons/

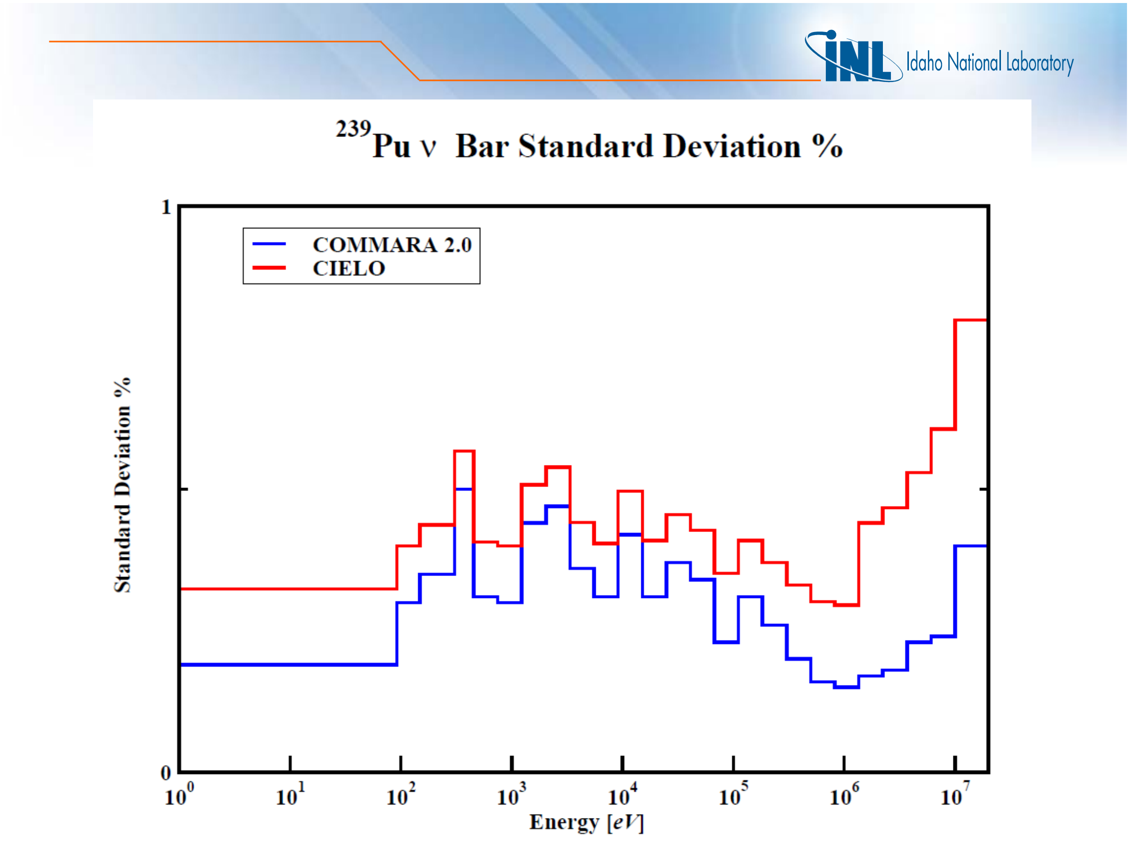




Slide from O. Cabellos, CW2017

The US nuclear data community has (generally) increased uncertainties in the new library (red)





Slides from P. Palmiotti, WPEC 2018

The current official guidance from the US nuclear data center

Comments about the covariance in current ENDF evaluations

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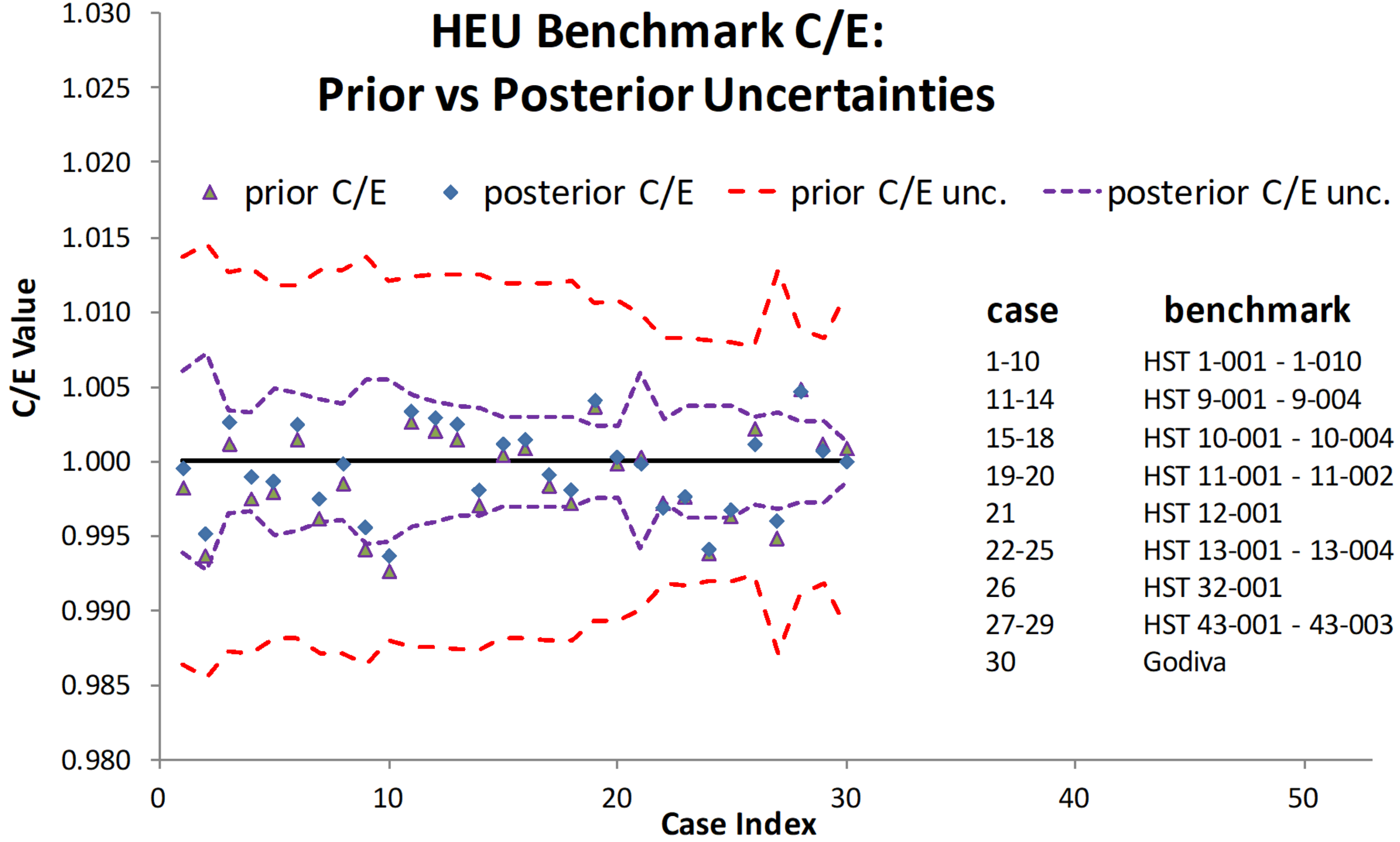
1. The covariance data in the ENDF evaluations represents uncertainties and correlations in differential data.

2. The use of this covariance to calculate uncertainties for integral quantities such as Keff will usually result in an overestimate of the uncertainty. That said, comparisons to integral data are essential during the evaluation process and users should not be surprised if the *mean value* nuclear data allow for the accurate prediction of Keff, even if the covariances to not reflect this consideration.

3. The recommended methodology to overcome this problem is to adjust the covariance to add information from set of integral data that represents the physics of the system for which the adjusted covariance will be used.

4. More information on this topic: https://www.oecd-nea.org/science/wpec/sg33/

5. CSEWG is currently studying the best covariance representation for future releases.

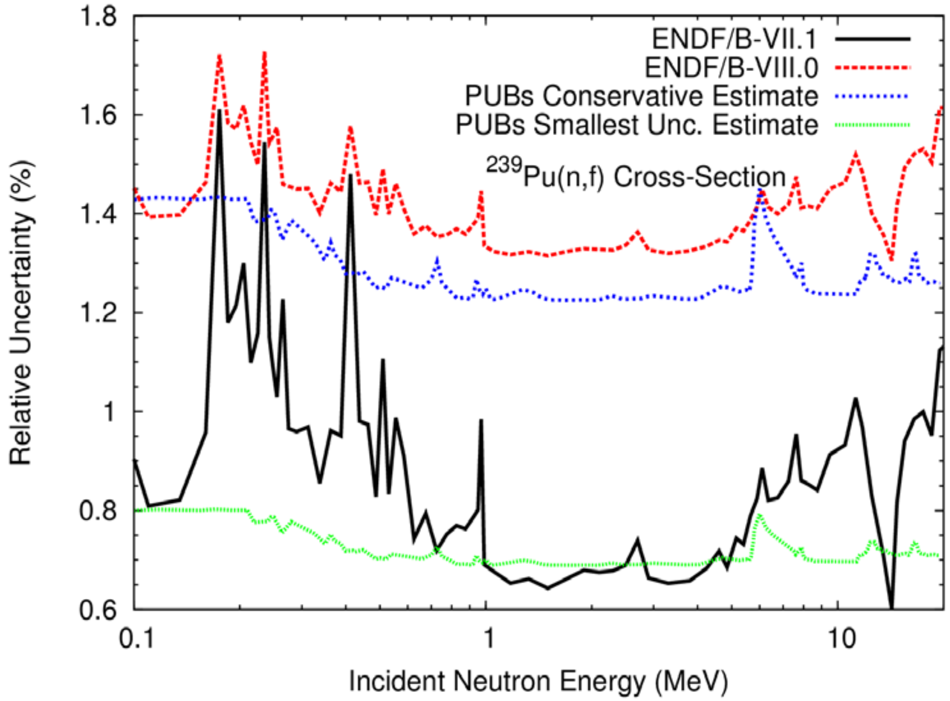


case	benchmark
1-10	HST 1-001 - 1-010
11-14	HST 9-001 - 9-004
15-18	HST 10-001 - 10-004
19-20	HST 11-001 - 11-002
21	HST 12-001
22-25	HST 13-001 - 13-004
26	HST 32-001
27-29	HST 43-001 - 43-003
30	Godiva

Slide from
M. Williams,
CSEWG 2017

There are minimum bounds on realistic uncertainty estimates and adjustment methodologies often violate these

(5) The conservative bound of PUBs is close to the ENDF/B-VIII.0 evaluated uncertainties.

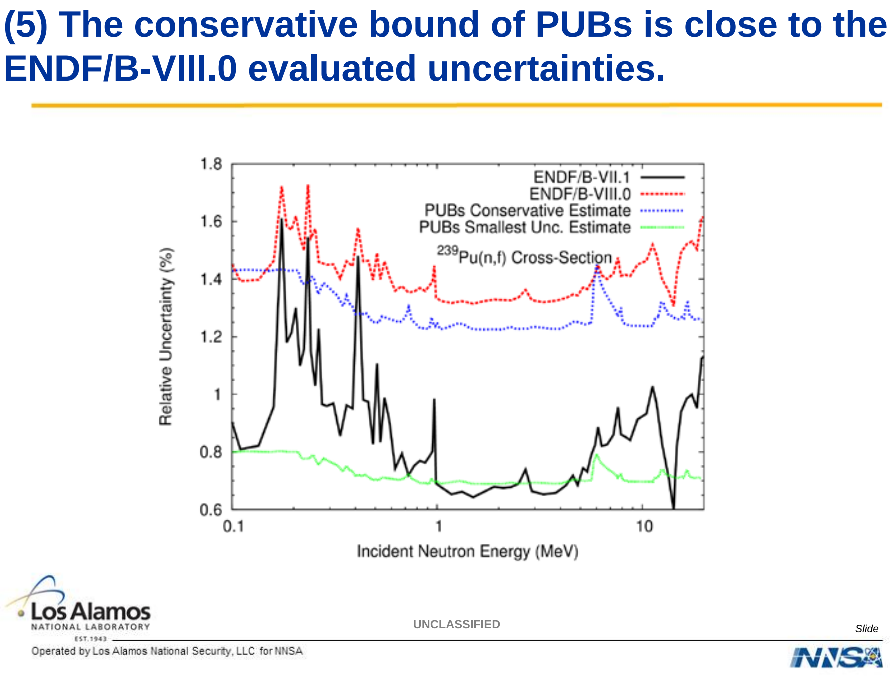


PUBs: Physical Uncertainty Boundaries

Slide from D. Neudecker, WPEC 2018

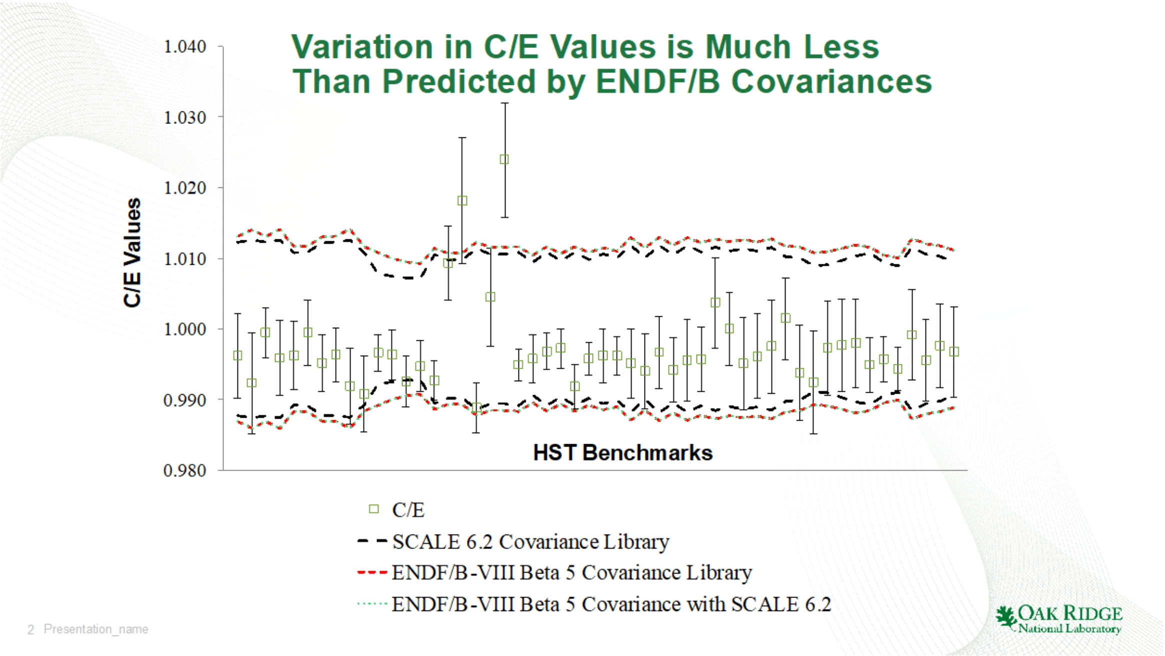
The problem of too small uncertainties on differential data and too large uncertainties on integral data

Nuclear data uncertainties are in danger of being smaller than what can be measured experimentally



Slide from of D. Neudecker, WPEC 2018

Nuclear data uncertainties are too large to reflect how well we actually know critical systems



Slide from of M. Williams, CSEWG 2017

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Have your cake and eat it too: solving the discrepancy with nuclear data correlations

We cannot experimentally measure nuclear data to precision below 1%,

$$\delta\bar{\nu} > 1\%, \qquad \delta\sigma_f > 1\%$$

But, only 1% uncertainty in $\bar{\nu}$ results in 1% uncertainty in k_{eff} (more than $1 of reactivity),

$$k_\infty = \frac{(\bar{\nu} \pm 1\%)\,\Sigma_f}{\Sigma_a} \rightarrow 1\% \text{ uncertainty in } k_\infty$$

However, the ability to predict k_{eff} with better accuracy than 1% **does not imply** the knowledge of the cross sections to better than 1%.

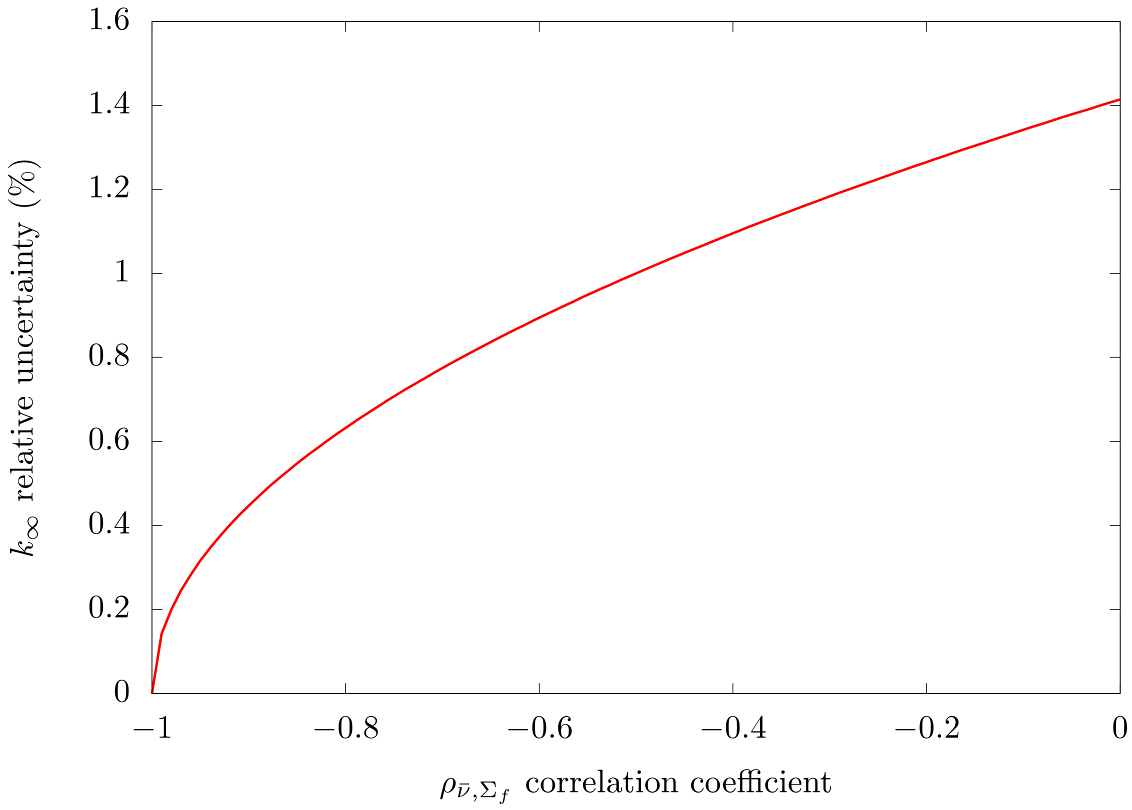
It only says that we know the integral of the cross sections (in the appropriate spectra) to better than 1%.

Have your cake and eat it too: solving the discrepancy with nuclear data correlations

- A negative correlation coefficient between multiplicative terms allows you to keep realistic uncertainties for differential nuclear data which will propagate to realistic uncertainties on integral applications.

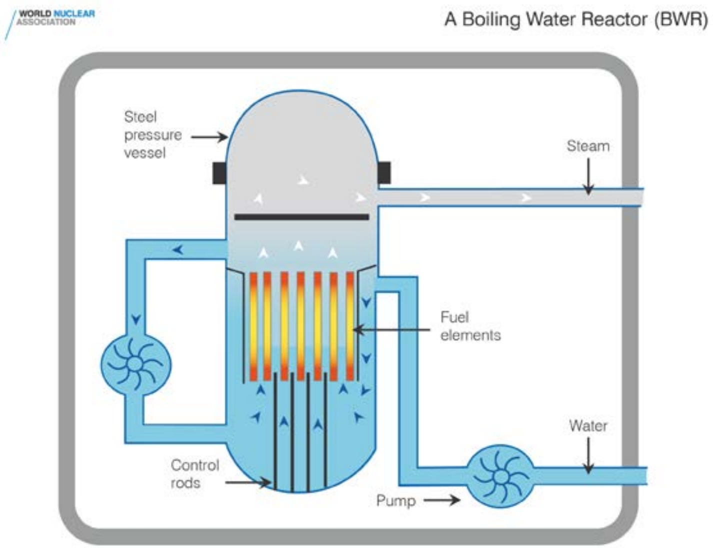
- Example:

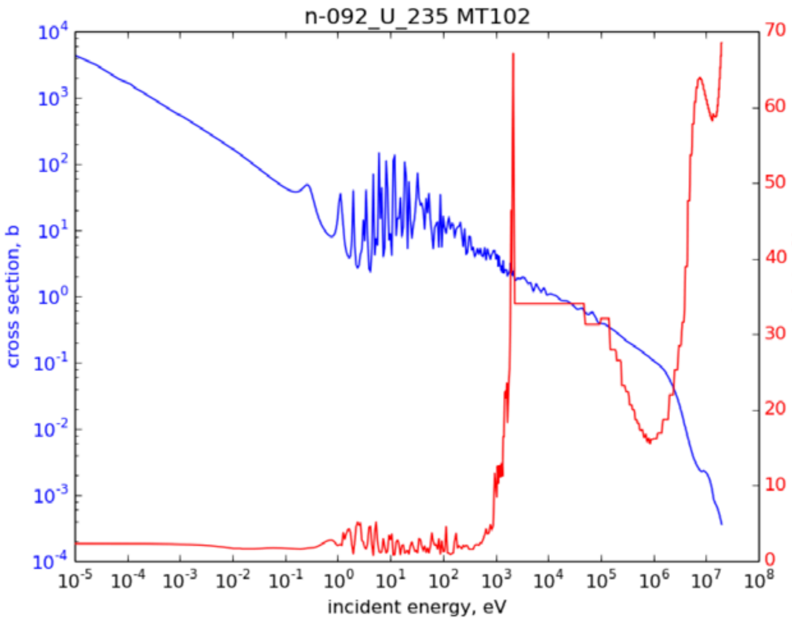
$$k_\infty = \frac{\bar{\nu}\,\Sigma_f}{\Sigma_a}, \qquad \frac{\delta\bar{\nu}}{\bar{\nu}} = 1\%, \qquad \frac{\delta\Sigma_f}{\Sigma_f} = 1\%$$

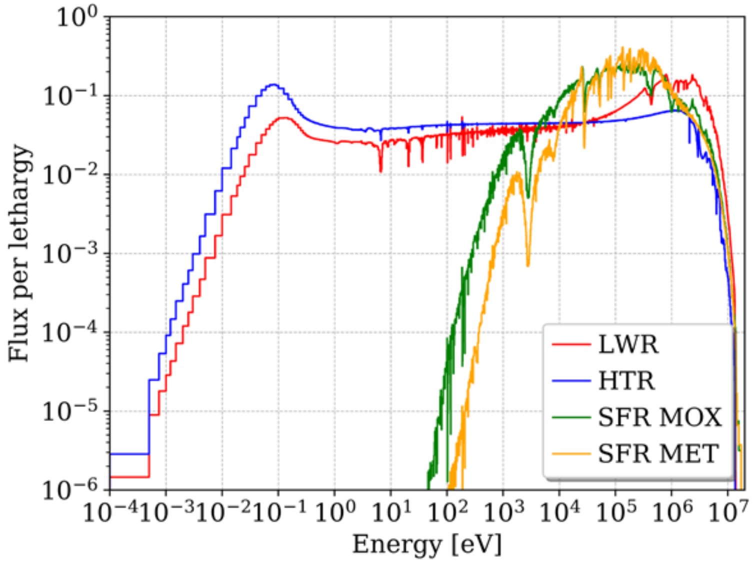


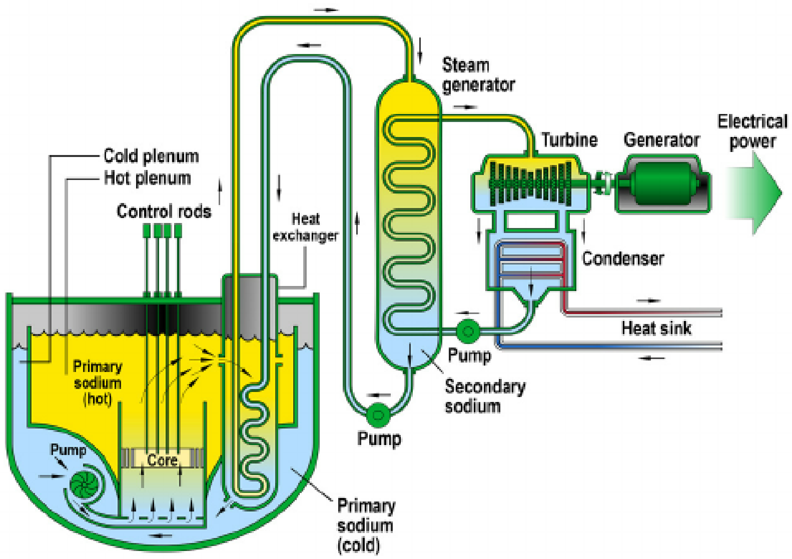
$$\frac{\delta k_\infty}{k_\infty} = \sqrt{\left(\frac{\delta\bar{\nu}}{\bar{\nu}}\right)^2 + \left(\frac{\delta\Sigma_f}{\Sigma_f}\right)^2 - 2\rho_{\bar{\nu},\Sigma_f}\left(\frac{\delta\bar{\nu}}{\bar{\nu}}\right)\left(\frac{\delta\Sigma_f}{\Sigma_f}\right)}$$

Through a careful examination of nuclear data correlations (energy, reaction, isotope), propagated uncertainties on well known systems can be small and large for systems without vast validation data









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