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National Laboratory

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Impact of Nuclear Data on Advanced Nuclear Energy Systems Safety and Operation: Project Status Update

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U.S. DEPARTMENT OF ENERGY

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Our goal: help bridging the gap between nuclear data developers and end-users that are engaged in developing and deploying advanced nuclear energy systems

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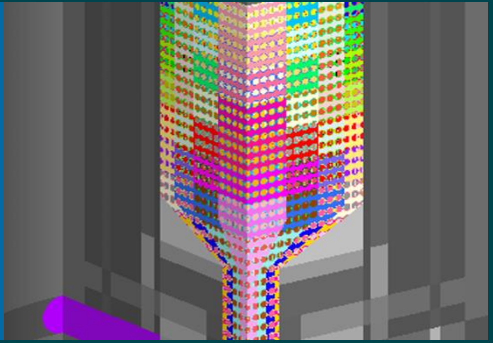
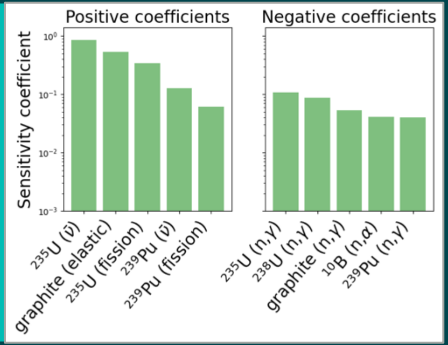
We are developing resources for enabling end-user-driven, application-driven improvements in the nuclear data pipeline to address user needs

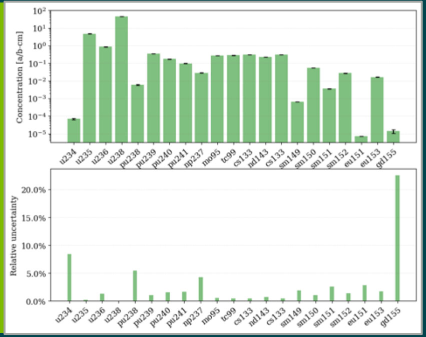
Benchmark models to assess nuclear data impacts beyond k_{eff} and fresh fuel, as function of fuel burnup



Sensitivity coefficients of key nuclides and nuclear data with impact on advanced reactor performance and safety metrics

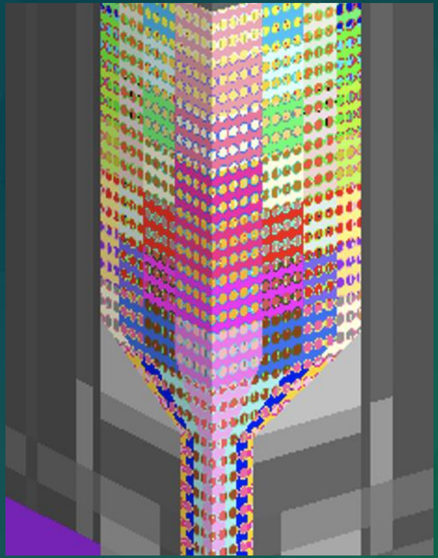


Uncertainties of key advanced reactor and fuel metrics that result from nuclear data uncertainties

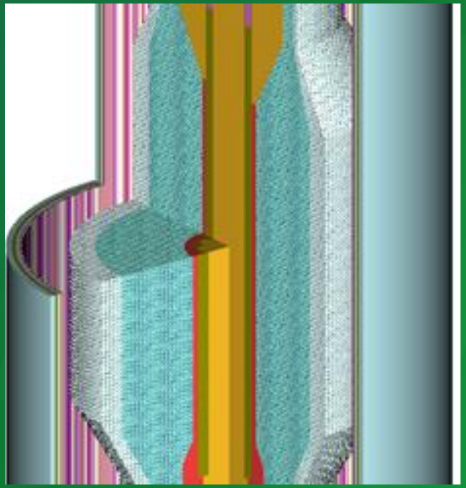


Benchmark models that are representative of four high priority advanced reactor technologies - HTGR, FHR, MCFR, SFR - were developed for assessing the nuclear data impacts as function of fuel burnup

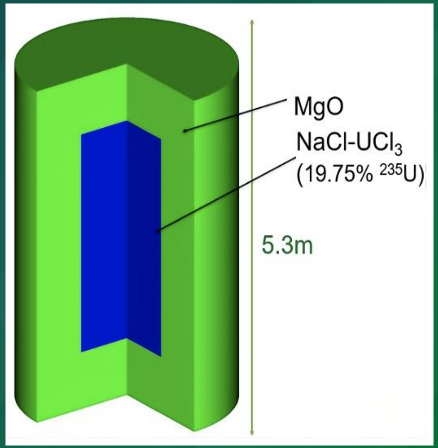
HTGR: created an equilibrium core model for HTR-10 pebble bed reactor, based on existing IRPhE benchmark for initial criticality (fresh fuel, room temperature), to examine the impact of nuclear data on fuel inventory and related metrics.



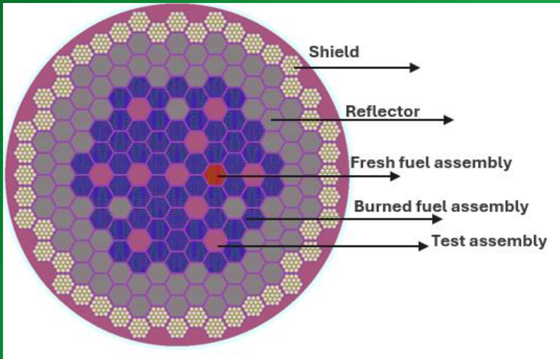
FHR: updated the equilibrium core fuel composition for a fluoride salt cooled high temperature reactor model – UCB Mark 1 – that was developed under an NRC-funded project.



MCFR: created a computationally effective fuel burnup model that is representative of the molten chloride fast reactor MCFR-D, as basis for examining the impact of nuclear data on fuel inventory and related metrics.



SFR/HALEU: created a representative fuel burnup model with HALEU fuel, based on the ABTR design, to examine the impact of nuclear data on fuel inventory and related metrics.



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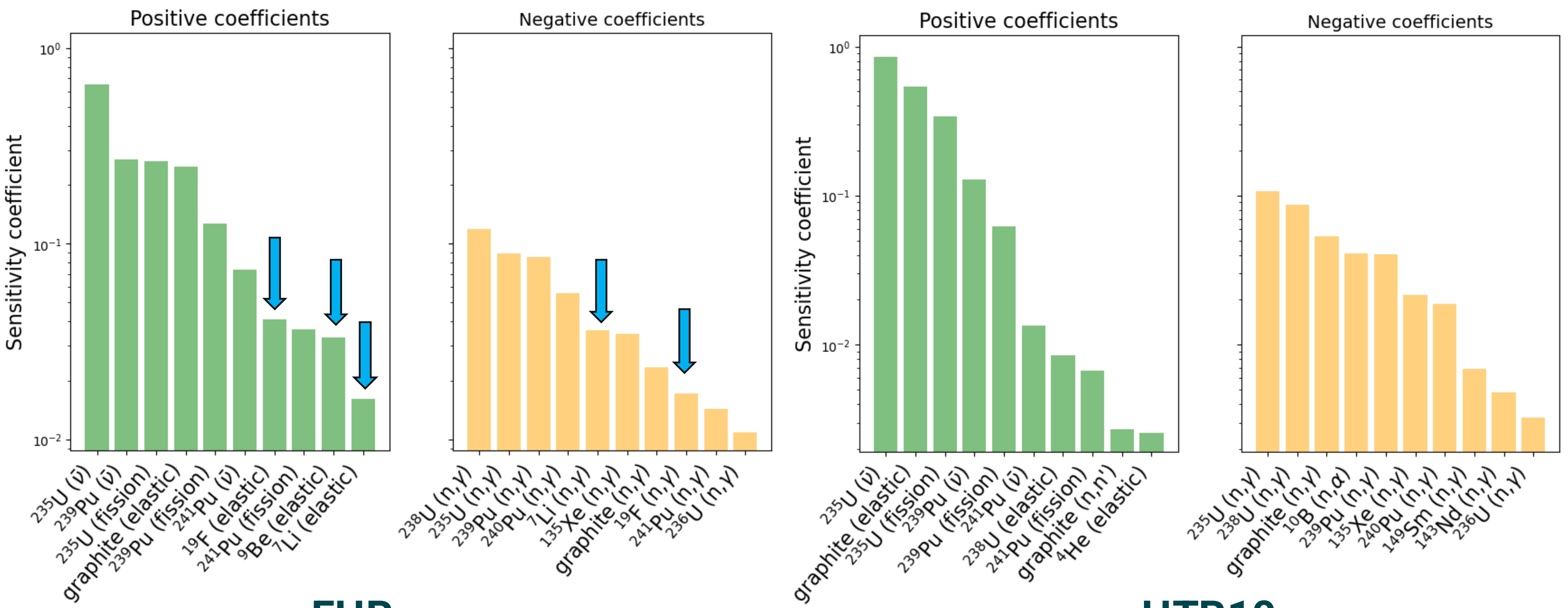
Sensitivity coefficients and uncertainties resulting from nuclear data were determined for the developed models using ORNL's SCALE code system

Neutron transport simulations **ENDF/B-VII.1** **CE or MG data***	**3D Monte Carlo** **Shift code**	**Fuel depletion & decay simulations**	**TRITON sequence** 3D Shift & ORIGEN 1D XSDRN & ORIGEN
TSUNAMI toolset **perturbation theory** **CE or MG data**	**k_{eff} sensitivities** **k_{eff} uncertainties** **reactivity differences sensitivities and uncertainties**	**SAMPLER** **random sampling** **MG data**	**Uncertainties in responses due to uncertainties in nuclear data: cross sections, fission yields, decay data**

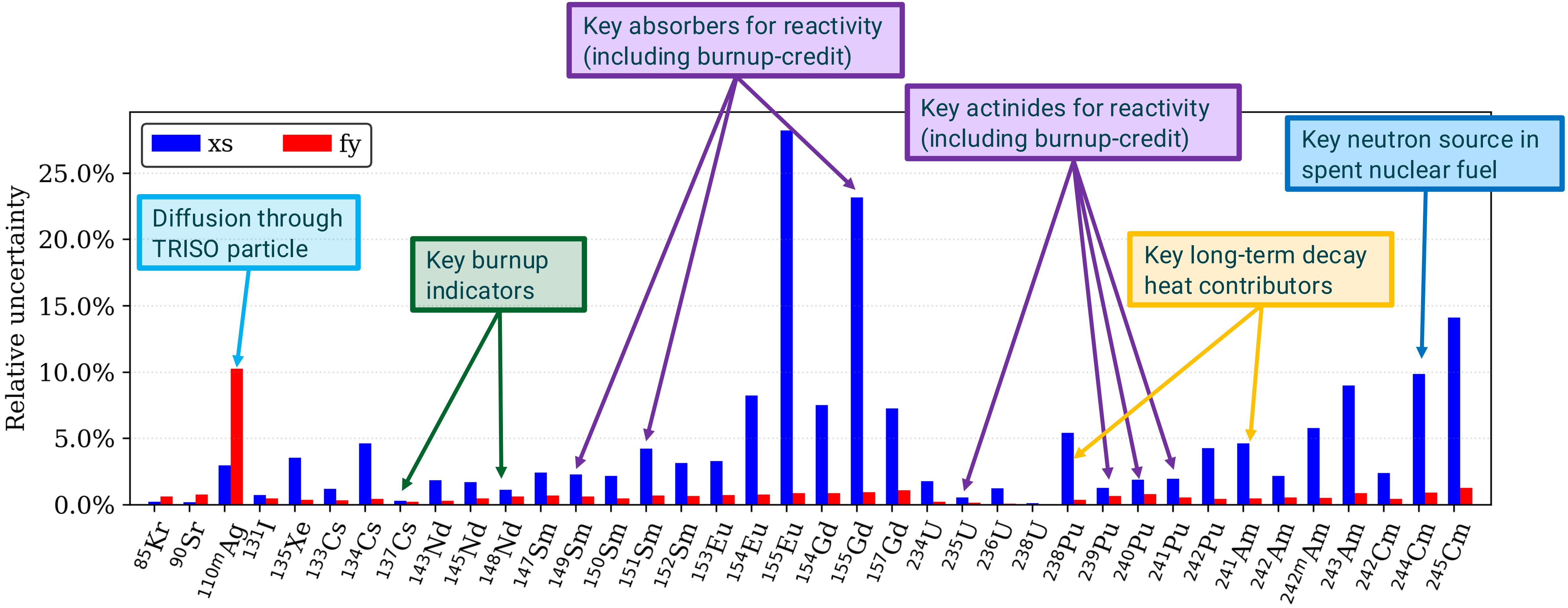
* Additional analyses using SCALE with ENDF/B-VIII.1data are currently being performed for selected FHR and MCFR-D metrics

FHR and HTR10 full-power core: top k_{eff} sensitivities show similarities except for FHR coolant salt relevant nuclides ^{7}Li, ^{9}Be, and ^{19}F



FHR **HTR10**

FHR: uncertainties in spent fuel inventory are generally driven by uncertainties in cross sections



Results correspond to inventory at discharge (no decay).

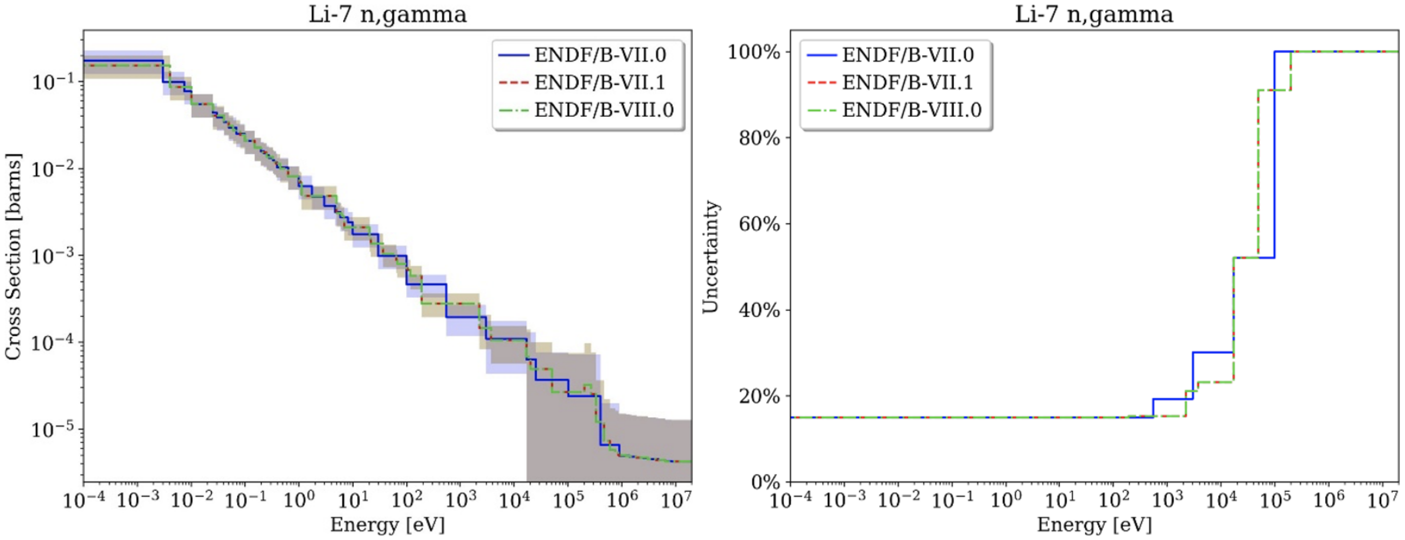
Selected key observations

Key observation: reducing uncertainty in ^{7}Li(n,γ) and ^{19}F (n,γ) and elastic will help improving uncertainties in k_{eff} and safety-relevant reactivity coefficients for FHR

^{7}Li(n,γ) is top contributor to k_{eff} uncertainty and 2nd most important contributor to uncertainty in fuel temperature reactivity response for FHR

$$\frac{\Delta\rho}{\rho} = 1.46 \pm 0.19\ \%$$

^{19}F(n,n') and ^{19}F(elastic) contribute to over 0.5% to uncertainty in fuel temperature reactivity response for FHR



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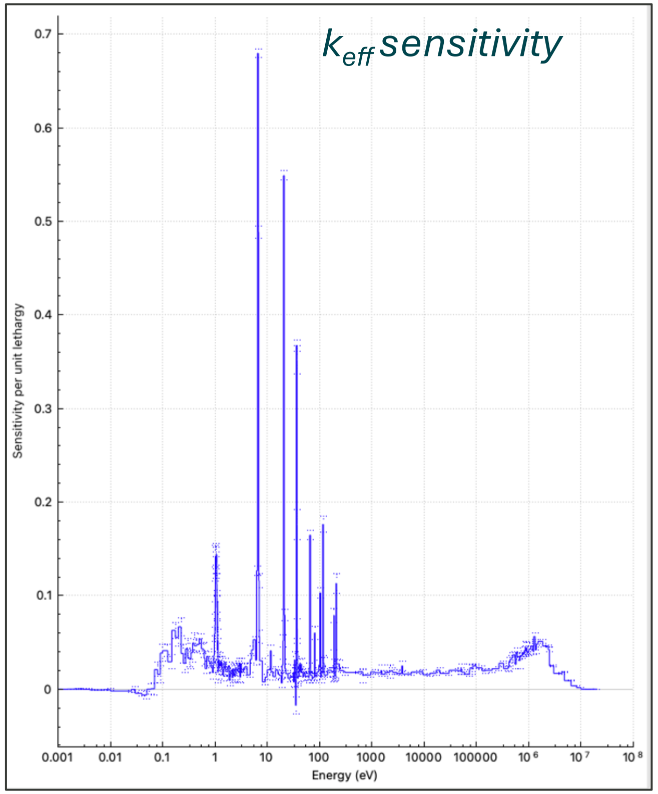
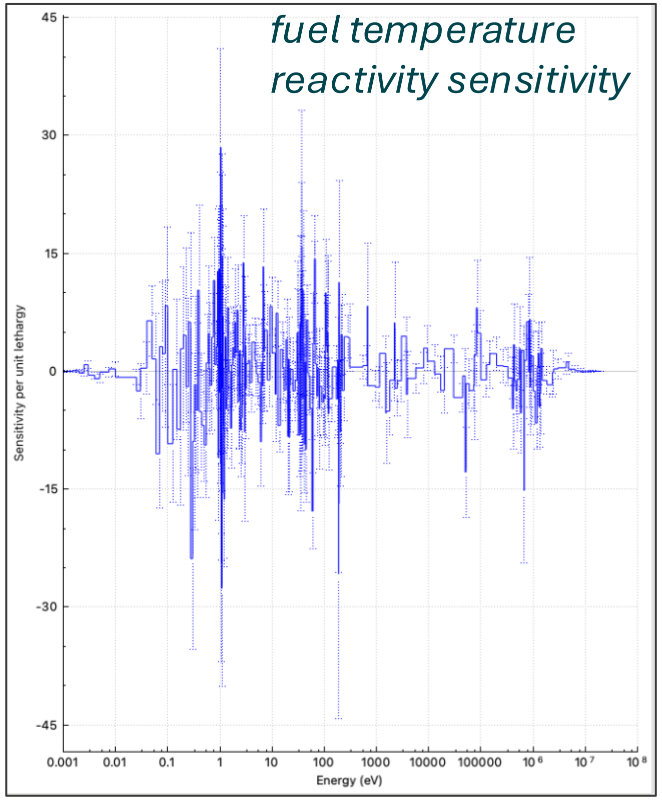
Key observation: we need improved methods and tools for scattering sensitivities determination in graphite-rich advanced reactor systems, to reliably estimate uncertainties

Uncertainty in fuel temperature reactivity difference for FHR: top 10 contributors to uncertainty include C-graphite, ^{9}Be and ^{19}F elastic

Uncertainty in fuel temperature reactivity difference for HTR10: top 10 contributors to uncertainty include C-graphite elastic and inelastic

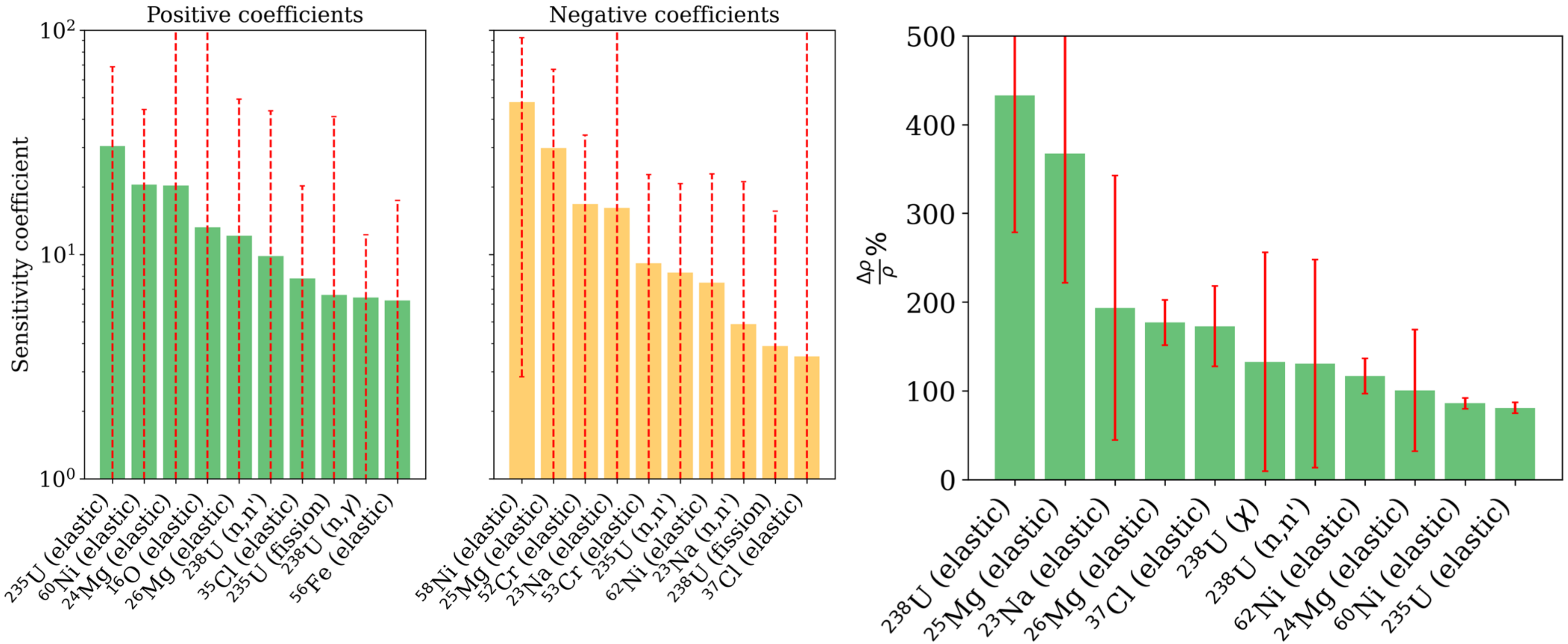




Graphite elastic XS: converged sensitivity for k_{eff} vs. unconverged fuel temperature reactivity sensitivity for HTR-10 equilibrium core

Poorly converged sensitivities may bias uncertainty quantification for metrics involving differences between two states of the system, such as for temperature reactivity feedback

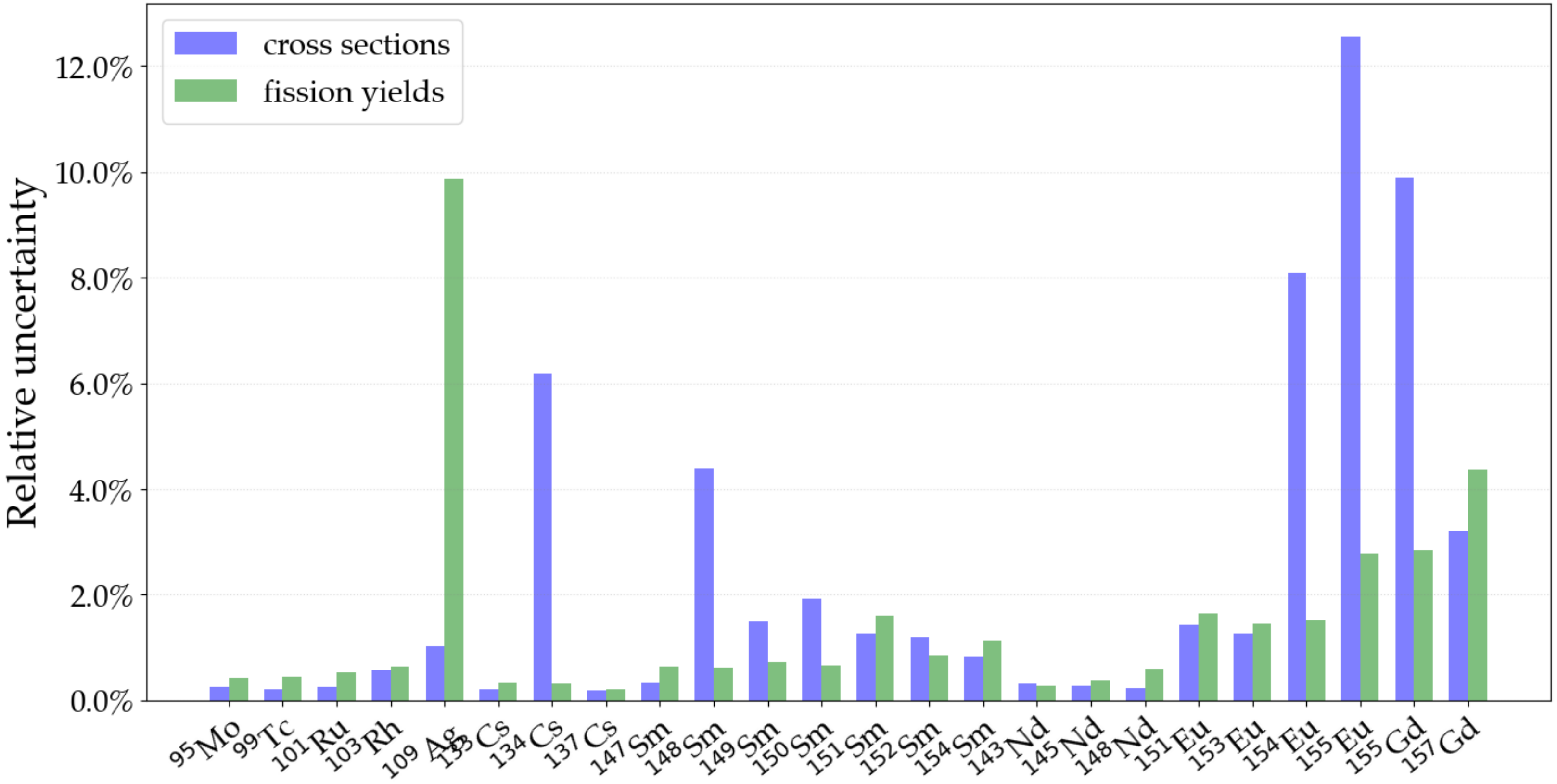
Key observation: large statistical uncertainties in elastic scattering sensitivities impact the reliable determination of metrics essential for reactor safety



$$\frac{\Delta\rho}{\rho} = 526 \pm 189\ \%$$

Cladding temperature reactivity difference - sensitivities and uncertainty top contributors for MCFR-D model with fresh fuel : large statistical uncertainties lead to unreliable estimate of reactivity response

Key observation: reliable estimation of ND-induced uncertainties in nuclide inventories and related key fuel metrics is essential for understanding and minimizing the overall uncertainties



Uncertainties in selected fission products inventories for MCFR-D fuel at 5-yr operation

Significant uncertainties for relevant fission products ^{155}Eu and ^{155}Gd were observed for MCFR-D, FHR, HTR10, and SFR/HALEU models

ND-induced uncertainties can be greater than those resulting from uncertainties in reactor fuel and operation and can vary, depending on the nuclide and the nuclide contribution to the burned fuel metric of interest (i.e., decay heat, dose rates, spent fuel reactivity)

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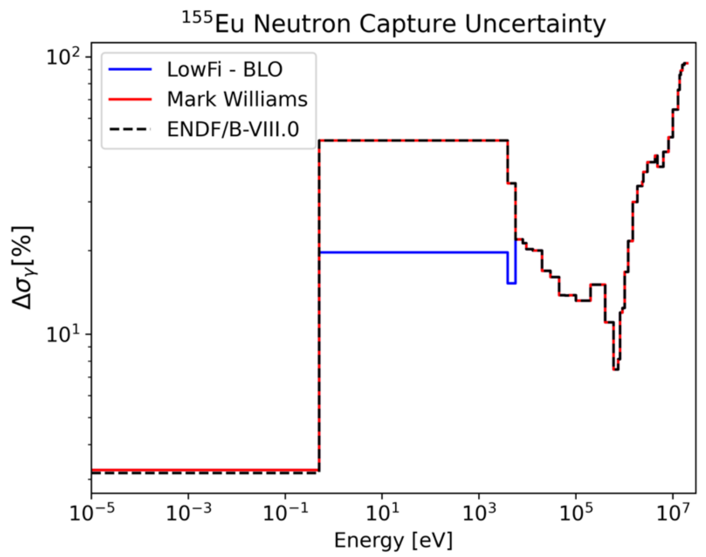
Key observation: large differences among ENDF/B libraries for uncertainty of ^{155}Eu (n, γ), which is the major contributor to uncertainty in ^{155}Gd, can impact end users



- ENDF/B-VII.1 library had covariance data from the LowFi project; *SCALE used Mark Williams's "special" E7.1 file instead*
- ENDF/B-VIII.0 data looks similar, though is not the same, with Mark Williams's evaluation
- ENDF/B-VIII.1 ***provides zero covariance***

^{155}Gd is one of the most effective neutron absorbers used to control reactivity during operation.

Gd use can be critical to both LWRs and advanced reactors operation: to enable passive and self-regulating reactivity control, longer fuel cycles, simplified operational strategies.

Effective use of Gd requires effective computational tools and associated nuclear data.

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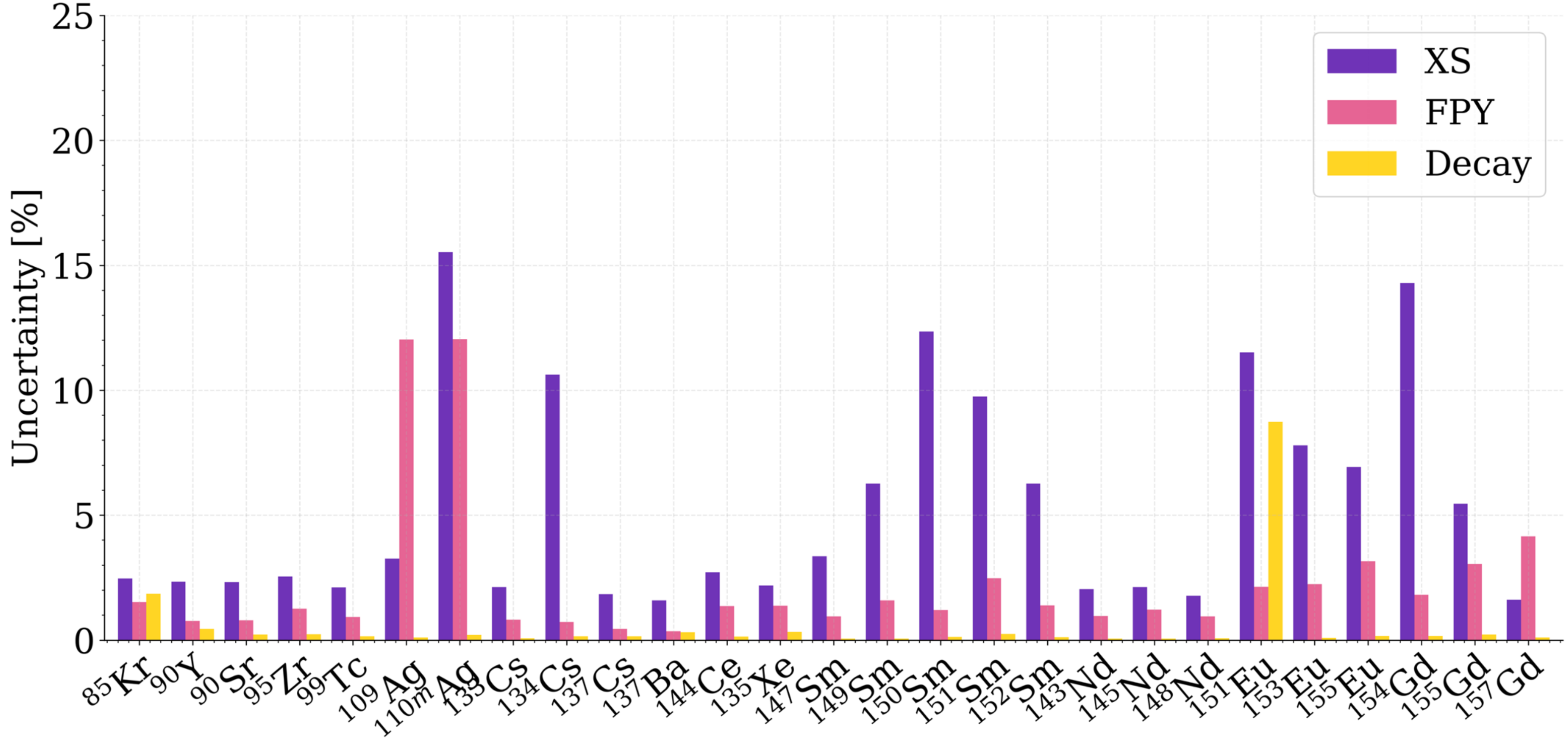
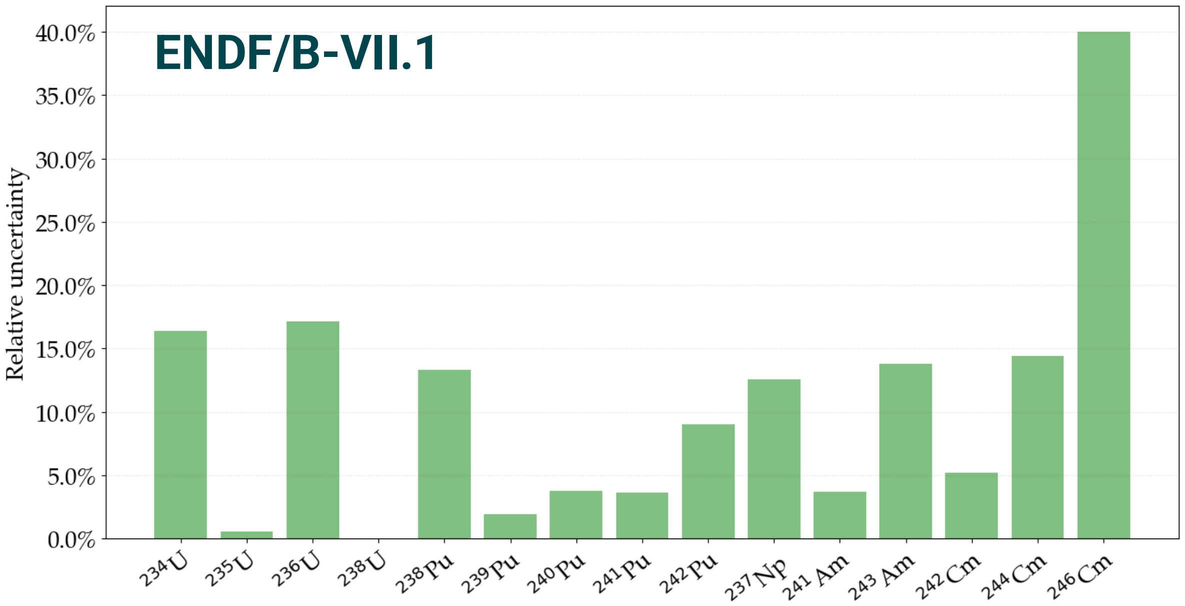
Key observation: uncertainties resulting from uncertainties in fission yields and decay data are not always negligible

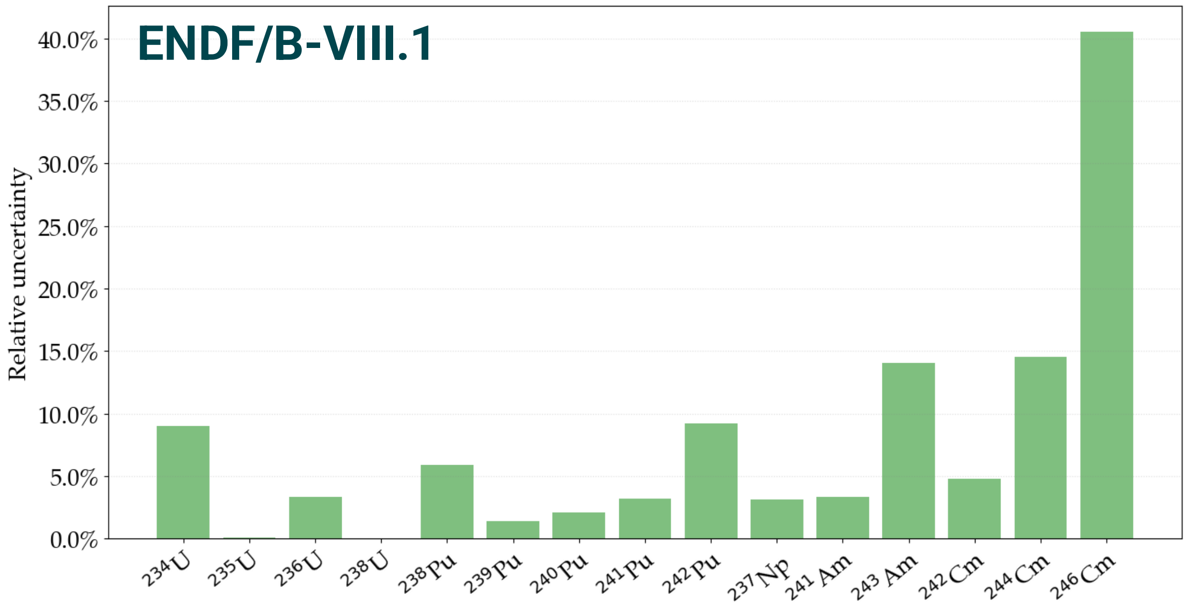


Ex: decay data induced uncertainty of ^{151}Eu is 9% resulting from uncertainty in beta-decay of its parent ^{151}Sm

Uncertainties in selected fission products inventories for SFR/HALEU fuel at discharge

Key observation: improvements in ENDF/B cross section uncertainty data can lead to reduction of inventory uncertainties for relevant nuclides





Significant reduction in uncertainty estimates for MCFR-D 5-yr irradiated fuel, primarily as result of updates for ^{235}U (n,γ) and ^{235}U (χ) in ENDF/B-VIII.1, were observed for:

^{236}U (-14%) , ^{234}U (-7%), ^{237}Np (-9%), ^{238}Pu (-8%)

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We aim to catalyze synergies between nuclear data scientists and end-users who are engaged in developing advanced nuclear reactors, by creating resources for enabling end-user-driven, application-driven improvements in the nuclear data pipeline to address user needs

During this last year of the project, we will focus on documentation of findings and conclusions

All developed resources – models, S/UQ result files, publications - are being archived on a GiLab repository

Going beyond criticality, fuel inventory analyses let us identify missing covariance data, assess the impact of uncertainty updates, identify data that are usually neglected or not considered important (fission product yields, decay data)

References

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6. F. Bostelmann et. al., **Impact of cross section and fission yield uncertainties on the fuel inventory in a high temperature fluoride salt-cooled reactor,** Proc. of 16th Nuclear Data For Science and Technology conference, Madrid, Spain, June 2025 (pending publication)

7. R. Elzohery et. al, **Nuclear data impact on HTR-10 pebble bed reactor metrics**", Proc. of Int. Conf. on Mathematics and Computational Methods Applied to Nuclear Science and Engineering, Denver, CO, April 2025. https://www.ans.org/pubs/proceedings/article-58173/

8. R. Hirji et. al, **Development of a representative molten chloride fast reactor model to assess the impact of nuclear data**, Proc. of Int. Conf. on Mathematics and Computational Methods Applied to Nuclear Science and Engineering, Denver, CO, April 2025. https://www.ans.org/pubs/proceedings/article-58173/

Acknowledgments

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