Oak Ridge National Laboratory

February 13, 2025

Impact of Nuclear Data on Advanced Nuclear Energy Systems Safety and Operation

Germina Procop

WANDA 2025, Arlington, VA, Feb. 10-13, 2025

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

What we achieved in the first year

Our Team

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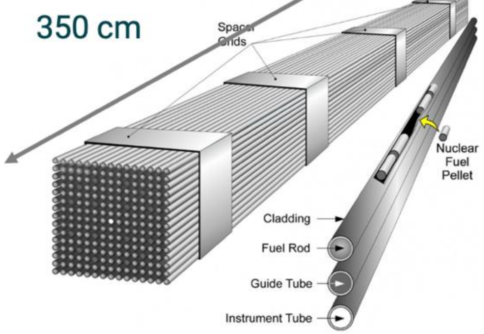
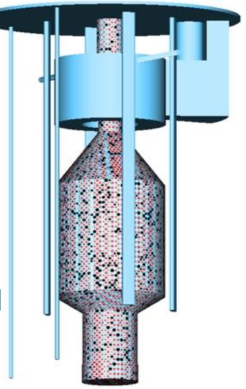
Advanced reactor technologies are significantly different than LWRs

Different geometries

LWR fuel assembly

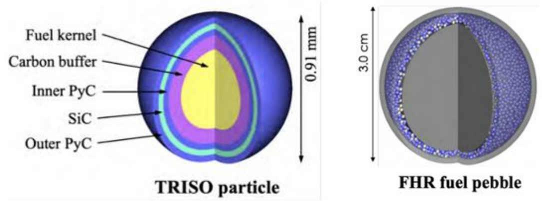


Different concepts

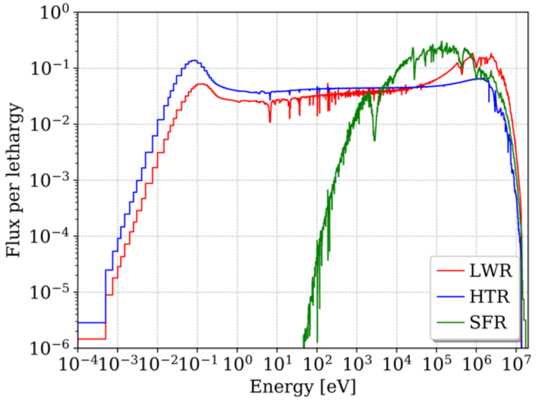


SCALE model of Hermes

Different fuels



Different physics behavior



Different needs and requirements for computational tools and nuclear data

Ref: https://www.ornl.gov/scale/learning

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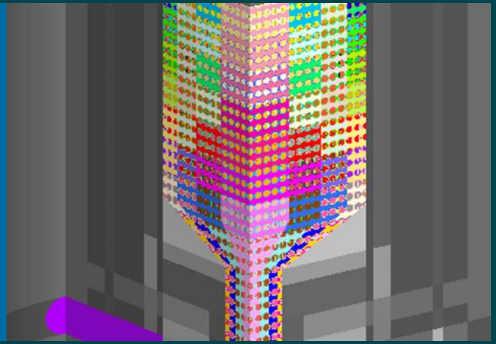
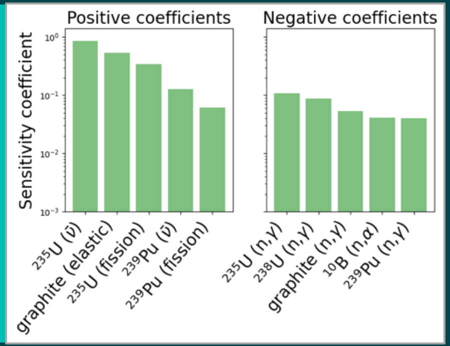
We are developing resources for enabling end-user-driven, application-driven improvements in the nuclear data pipeline to address these needs

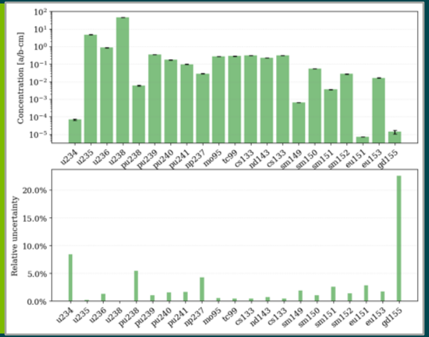
Benchmark models to assess nuclear data impacts beyond k_{eff} and fresh fuel, as function of fuel burnup



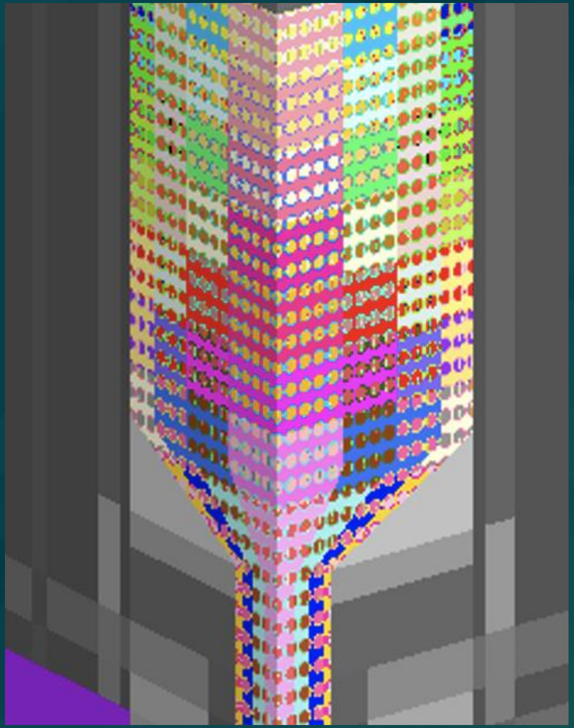
Sensitivity coefficients of key nuclides and nuclear data with impact on advanced reactor performance and safety metrics

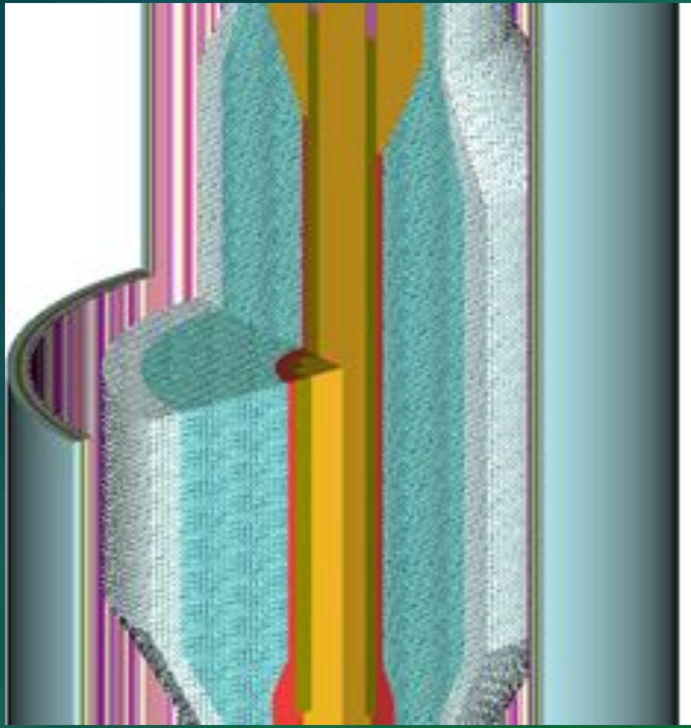


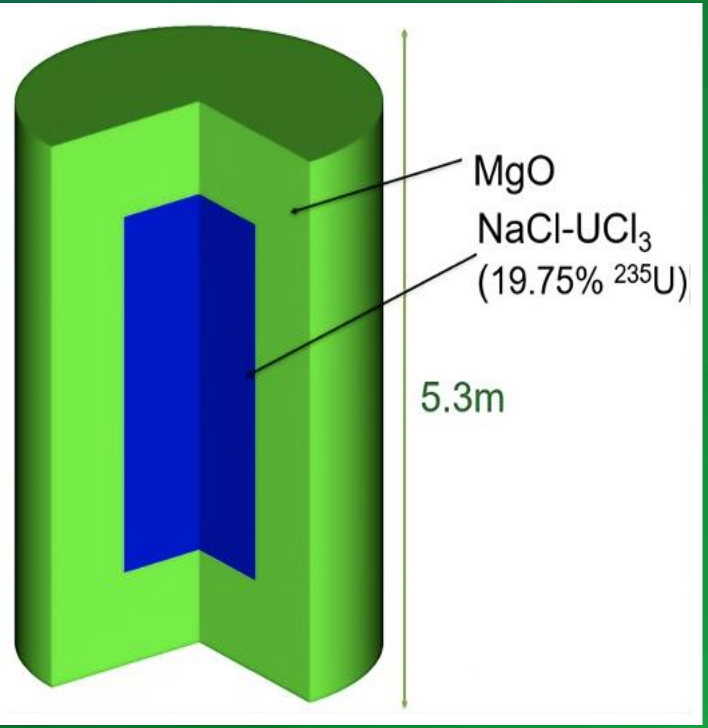
Uncertainties of key advanced reactor and fuel metrics due to nuclear data uncertainties



Benchmark models were developed that are representative of three high priority advanced reactor technologies : HTGR, FHR, MCFR







HTGR: created a full-core power model for HTR-10 pebble bed reactor, based on existing IRPhE benchmark for initial (fresh fuel, room temperature)criticality

FHR: created an improved equilibrium fuel composition model for a fluoride salt cooled high temperature reactor, by leveraging a model developed under another project

MCFR: created a computationally effective fuel burnup model that is representative of molten chloride fast reactor MCFR-D, as basis for studying nuclear data impacts

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Sensitivity coefficients and uncertainties resulting from nuclear data were calculated for the benchmark models using capabilities in the SCALE code system

TSUNAMI toolset
(perturbation theory, with CE or MG data)

k_{eff} sensitivities

k_{eff} uncertainties

reactivity coefficients sensitivities

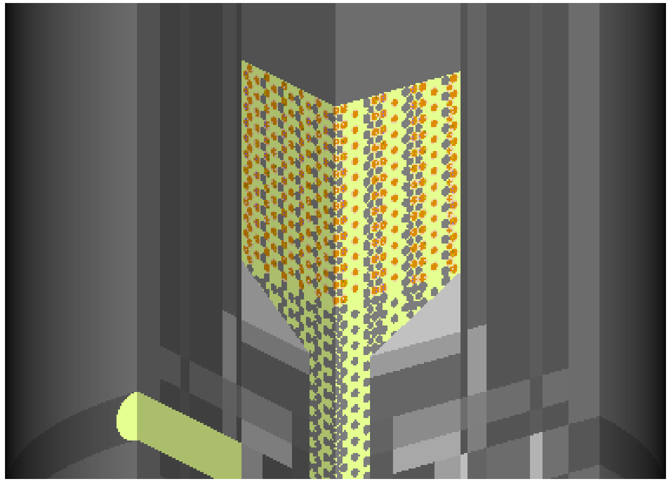
SAMPLER
(random sampling, with MG data)

Uncertainties in responses (e.g., actinides content) due to uncertainties in (cross sections, fission yields, decay data)

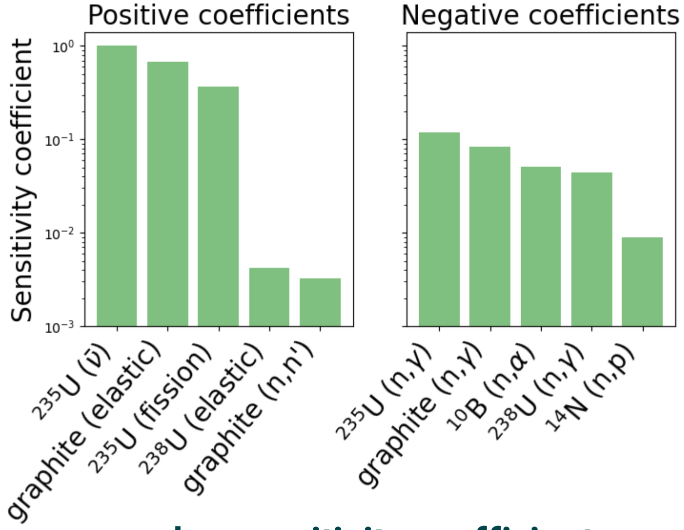
HTR-10: top k_{eff} sensitivities for fresh fuel core and full-power core show similarities, and ^{239}Pu as relevant player for non-fresh fuel

$$\frac{dk_{eff}}{k_{eff}} = 0.6767 \pm 0.0026\,\%$$

k_{eff} uncertainty resulting from nuclear data uncertainties

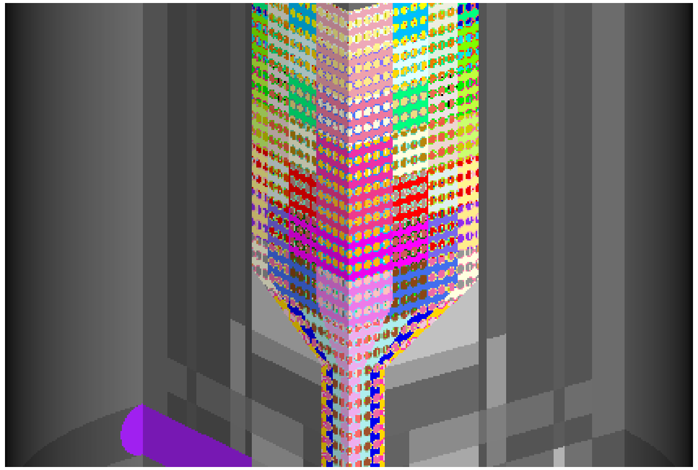


initial, fresh fuel, core model

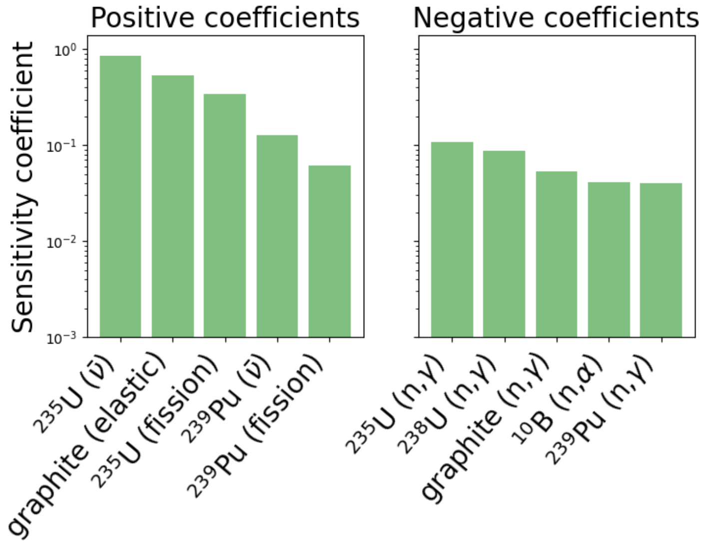


k_{eff} sensitivity coefficients

$$\frac{dk_{eff}}{k_{eff}} = 0.5539 \pm 0.0037\,\%$$

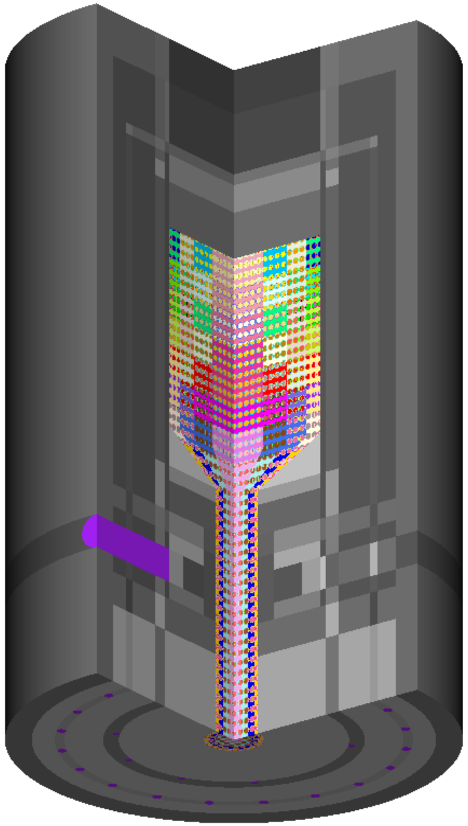


full-power core model

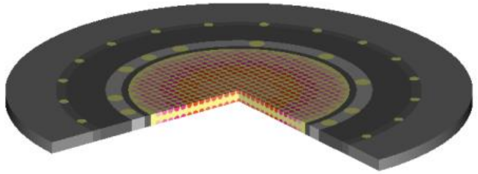


Ref: R. Elzohery et. al, "Nuclear data impact on HTR-10 pebble bed reactor metrics", M&C 2025 (accepted)

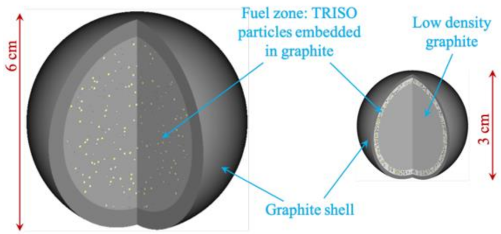
HTR-10: uncertainties resulting from nuclear data in selected actinides and fission products in fuel at 81 GWd/t discharge burnup are generally less than 5%



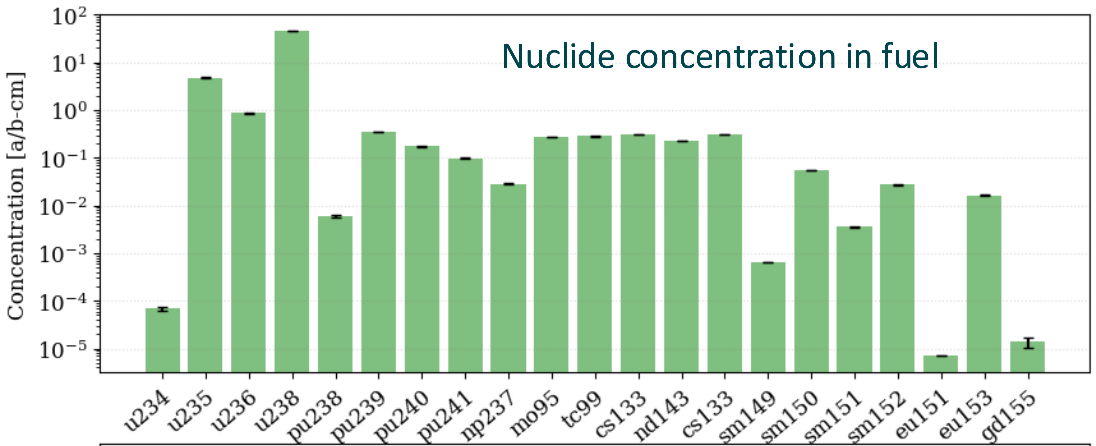
HTR-10 full core SCALE model

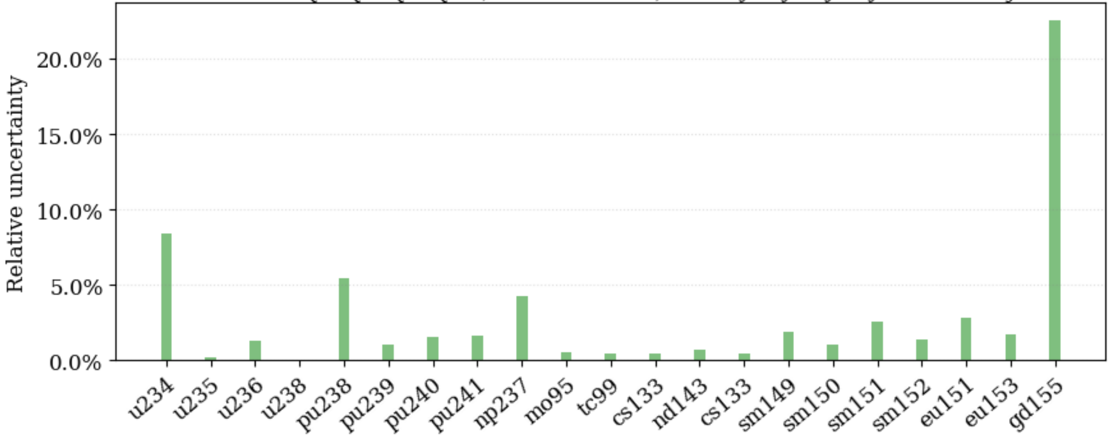


Core slice model



HTR-10 vs FHR fuel pebble

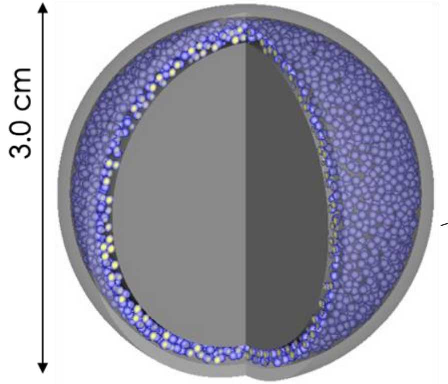




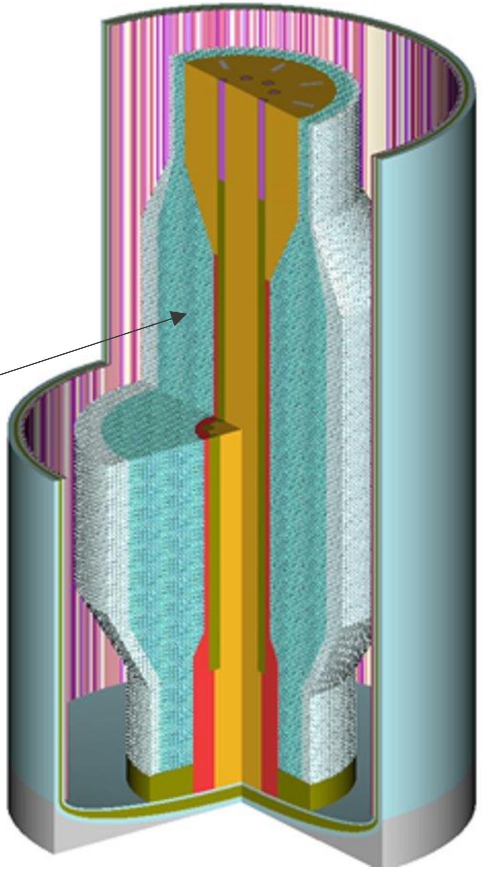
Relative uncertainties in predicted nuclide mass as result of cross sections and fission yields and FY uncertainties

Ref: R. Elzohery et. al, “Nuclear data impact on HTR-10 pebble bed reactor metrics”, M&C 2025 (accepted)

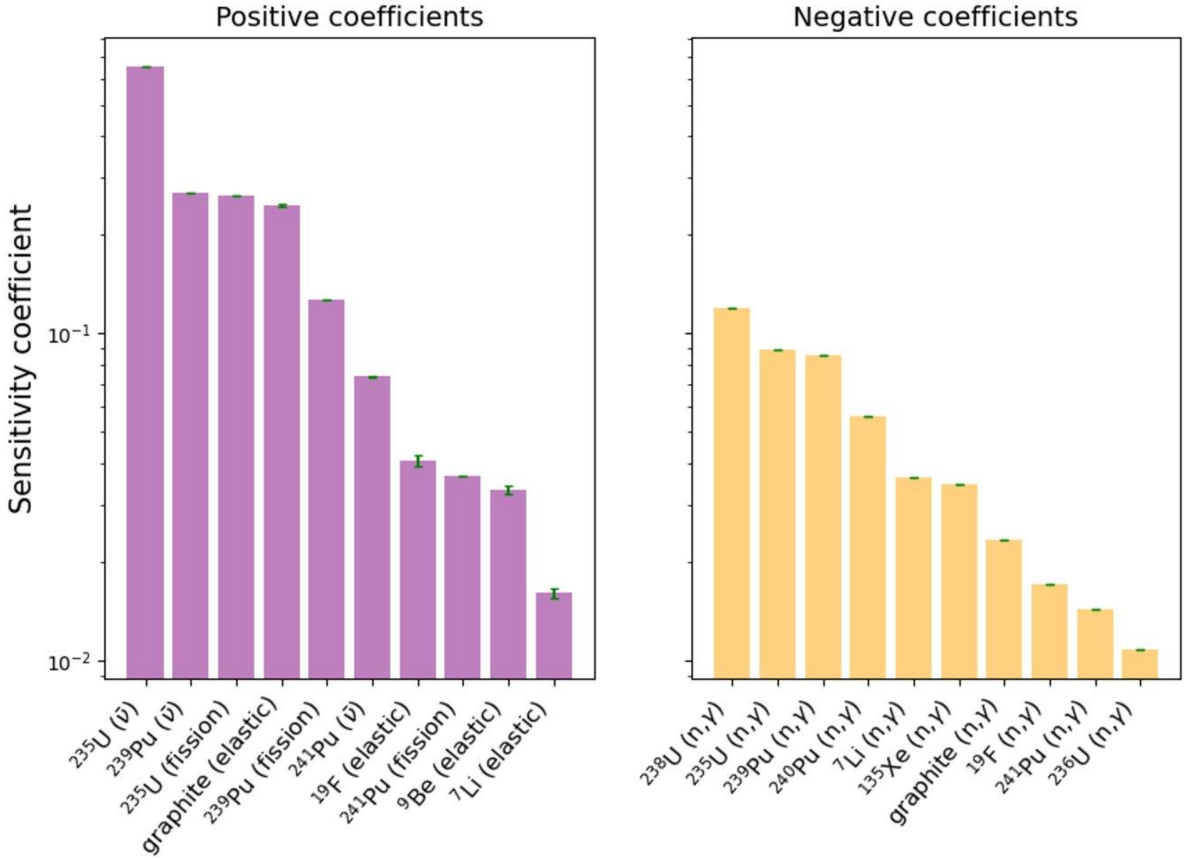
FHR: top k_{eff} sensitivities show similarities to HTR-10 full-power core, except for relevant nuclides in the coolant salt ^{7}Li, ^{9}Be, and ^{19}F



FHR fuel pebble model



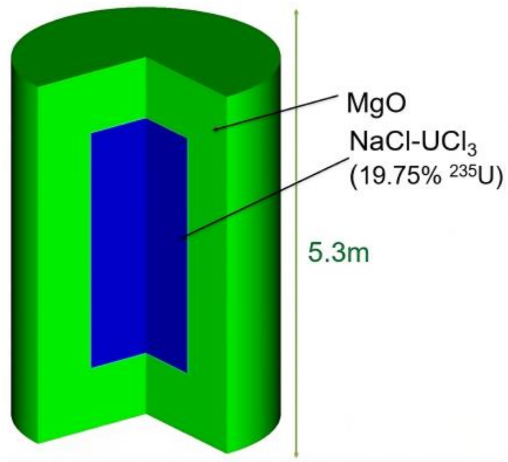
FHR SCALE model



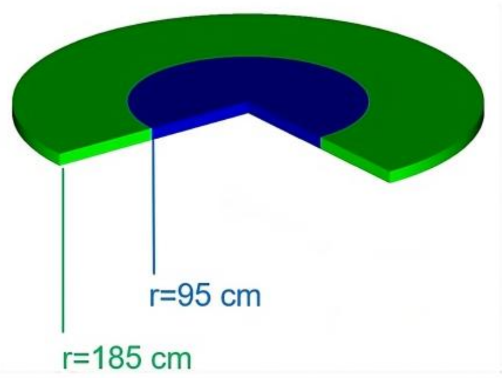
k_{eff} top positive and negative sensitivity coefficients

Ref: F. Bostelmann et. al, “Impact of cross section and fission yield uncertainties on the fuel inventory in a high temperature FHR”, ND2025 (accepted)

MCFR-D: top contributors to k_{eff} uncertainty for fresh fuel core and core at 5-yr operation are reactions in ^{25}Mg and U isotopes



3D core model



Axial slice model

fresh fuel core

Nuclide	Reaction	Contribution (% Δk/k)
^{235}U	n,γ	$1.655 \times 10^{+00} \pm 2.616 \times 10^{-04}$
^{238}U	n, n′	$4.282 \times 10^{-01} \pm 8.768 \times 10^{-04}$
^{238}U	n,γ	$2.657 \times 10^{-01} \pm 1.394 \times 10^{-05}$
^{235}U	χ	$2.643 \times 10^{-01} \pm 3.641 \times 10^{-03}$
^{235}U	fission	$2.141 \times 10^{-01} \pm 1.903 \times 10^{-05}$
^{238}U	nubar	$1.357 \times 10^{-01} \pm 9.356 \times 10^{-06}$
^{24}Mg	elastic	$1.173 \times 10^{-01} \pm 1.227 \times 10^{-04}$
^{235}U	nubar	$9.917 \times 10^{-02} \pm 1.934 \times 10^{-06}$
^{24}Mg	n,γ	$9.022 \times 10^{-02} \pm 8.332 \times 10^{-07}$
^{238}U	χ	$8.226 \times 10^{-02} \pm 3.886 \times 10^{-04}$

Uncertainty (% Δk/k)

1.790 ± 0.004

core at 5-yr operation

Nuclide	Reaction	Contribution (% Δk/k)
^{235}U	n,γ	$1.408 \times 10^{+00} \pm 2.152 \times 10^{-04}$
^{238}U	n, n′	$4.786 \times 10^{-01} \pm 1.065 \times 10^{-03}$
^{238}U	n,γ	$2.656 \times 10^{-01} \pm 1.596 \times 10^{-05}$
^{235}U	χ	$2.543 \times 10^{-01} \pm 3.454 \times 10^{-03}$
^{235}U	fission	$2.005 \times 10^{-01} \pm 2.004 \times 10^{-05}$
^{238}U	nubar	$1.396 \times 10^{-01} \pm 1.088 \times 10^{-05}$
^{24}Mg	elastic	$1.072 \times 10^{-01} \pm 1.231 \times 10^{-04}$
^{238}U	χ	$8.665 \times 10^{-02} \pm 4.718 \times 10^{-04}$
^{235}U	nubar	$8.452 \times 10^{-02} \pm 1.877 \times 10^{-06}$
^{235}U	elastic / n,γ	$8.189 \times 10^{-02} \pm 4.040 \times 10^{-04}$

Uncertainty (% Δk/k)

1.576 ± 0.004

Ref: R. Hirji et. al, “Development of a representative molten chloride fast reactor model to assess the impact of nuclear data”, M&C 2025 (accepted)

Two conference full-papers were accepted for M&C 2025 and two accepted for oral presentation at the ND2025 conference

Nuclear Data Impact on HTR-10 Pebble Bed Reactor Metrics

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[leave space for DOI, which will be inserted by ANS]

ABSTRACT

This study investigates the impact of nuclear data on selected key core metrics for the HTR-10 pebble-bed reactor, as part of a broader project that aims to facilitate the identification of nuclear data deficiencies and needs in the US Nuclear Data Program databases that impact the safety of advanced reactors. This study's focus extends from analyzing a fresh fuel core configuration to examining an equilibrium core, in which additional nuclides significantly influence the reactor's behavior compared to the fresh fuel configuration. Sensitivities to and uncertainties due to nuclear data were determined for the effective multiplication factor (k_{eff}) and the temperature of fuel and temperature of pebble graphite reactivity responses of two full-core models of the HTR-10: an initial core with fresh fuel and an equilibrium core. The underlying simulations were performed using the SCALE code system with the ENDF/B-VII.1 nuclear data library. With respect to sensitivities, the results indicate that $\bar{\nu}$, fission, and (n,γ) reactions of ^{235}U, elastic scattering and (n,γ) of graphite, and (n,α) of ^{10}B are significant nuclides and reactions for both fresh fuel and equilibrium cores. For the equilibrium core, additional nuclides and reactions come into play, including $\bar{\nu}$, fission, (n,γ) of ^{239}Pu and ^{241}Pu, as well as (n,γ) reactions of fission products such as ^{143}Nd, ^{149}Sm, and ^{135}Xe. With respect to uncertainties, $\bar{\nu}$ of ^{235}U and elastic scattering and (n,γ) in graphite are among the top contributors to the nuclear data–induced uncertainty of quantities considered for both core configurations. Specific nuclide–reaction pairs for the equilibrium core are (n,γ) of ^{135}Xe, elastic scattering of ^{144}Nd, and fission and (n,γ) of ^{239}Pu.

Keywords: nuclear data, advanced reactors, pebble bed reactor, sensitivity coefficients, uncertainty analysis

1. INTRODUCTION

With the growing global interest in advanced reactors, it has become essential to develop an understanding of these systems using modeling and simulation tools to ensure safety during normal operation and accident conditions. Modeling and simulation tools used to compute quantities of interest and predict the system's behavior during operation require input parameters that include geometry specifications, material descriptions, operational data, and nuclear data (i.e., cross sections, fission yields, and decay data). Among these parameters, nuclear data are known to be a major source of uncertainty induced in simulation predictions. They directly impact reaction rates, such as fission, absorption, and scattering, which play a significant role in the derivation of all key quantities of interest in reactor physics.

Development of a Representative Molten Chloride Fast Reactor Model to Assess the Impact of Nuclear Data

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[1]Georgia Institute of Technology, Atlanta, GA; [2]Oak Ridge National Laboratory, Oak Ridge, TN

[leave space for DOI, which will be inserted by ANS]

ABSTRACT

The SCALE code system was employed to conduct a preliminary investigation of the impact of nuclear data eigenvalue calculations of a ^{235}U enriched fast spectrum molten chloride salt–fueled reactor. A computationally effective depletion model that is representative of the reactor system was successfully developed and used to conduct fuel depletion simulations. Eigenvalue uncertainty calculations using the ENDF/B-VII.1 library resulted in uncertainties above 1.5% for both the reactor at beginning of life and after 5 years of operation. The primary driver of this uncertainty was found as the uncertainty in the ^{235}U (n,γ) cross section. Uncertainty calculation results from this study were compared to results available for a ^{235}U enriched sodium-cooled fast reactor to confirm similarities and identify differences with respect to nuclear data impacts between the two advanced fast spectrum reactors.

Keywords: Nuclear data, MCFR, SCALE, Uncertainty analysis

1. INTRODUCTION

The need to meet growing domestic demands for clean energy and energy security has become critical in the United States. By leveraging support from the US Department of Energy (DOE), private industry is actively engaged in developing and deploying advanced nuclear energy systems. Accurate and efficient modeling and simulation (M&S) is integral to the successful deployment of these systems, and one of the most important components of M&S is nuclear data. Nuclear data relevant to traditional light-water reactors (LWRs) is very well studied as a result of 60 years of operational experience. Because advanced reactors differ from LWRs in materials, geometries, and physics behavior, relevant nuclear data for these reactors include other nuclides and energy ranges compared to LWRs that may have larger uncertainties or may be less well studied and tested [1]. Thus it is important to perform nuclear data assessments for each new type of advanced reactor under development. This paper presents a preliminary investigation for a fast-spectrum molten chloride salt–fueled reactor (MCFR).

The work presented here is preliminary and is part of an extensive study being conducted at Oak Ridge National Laboratory (ORNL) to identify the nuclear data that have the greatest impact on advanced nuclear

International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&C 2025)
Denver, CO, April 27-30, 2025

Impact of cross section and fission yield uncertainties on the fuel inventory in a high temperature fluoride salt-cooled reactor

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Abstract

The significant impact of uncertainties in nuclear data on the simulation of key metrics relevant for reactor physics has been studied for decades. One of the main subjects of these studies is the impact of cross section uncertainties on quantities such as reactivity or power. However, fewer studies propagate uncertainties in cross sections—and potentially additional nuclear data uncertainties such as those related to fission yields—through depletion calculations to spent fuel compositions. Additionally, most studies have focused on light-water reactors (LWRs), and advanced reactors have only recently attracted more attention due to their improved safety characteristics and economics compared to those of traditional LWRs.

Accurate computational prediction of fuel inventory during operation and the prediction of spent fuel compositions, even without uncertainty propagation, can be challenging for some advanced reactors under consideration for deployment because of these reactors' continuous operation with online refueling. One such advanced reactor is the high-temperature fluoride salt–cooled pebble-bed reactor (pebble-bed FHR), which operates for most of its lifetime at a state of equilibrium during which fuel pebbles that have achieved their target discharge burnup are continuously removed and replaced with fresh fuel pebbles.

Over the past few years, Oak Ridge National Laboratory (ORNL) has developed an approach, the **S**CALE **L**eap-**In** method for **C**ores at **E**quilibrium (SLICE), for the prediction of pebble-bed reactor fuel compositions using various modules of the ORNL-developed SCALE code system. Based on this approach, this study propagates cross section and fission yield uncertainties to the fuel inventory of a pebble-bed FHR. The approach to generate pebble-bed reactor fuel inventory and the propagation of nuclear data uncertainties will be briefly described. Then, uncertainties in the fuel inventory will be discussed by presenting relative uncertainties of relevant nuclide densities for both the equilibrium core as well as the spent fuel pebble inventory.

Impact of nuclear data on advanced reactors key metrics

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Abstract

Research funded by the US Department of Energy, Nuclear Data Program, is ongoing at Oak Ridge National Laboratory (ORNL) to facilitate identifying nuclear data deficiencies and needs in the US Nuclear Data Program databases that have the most impact on advanced nuclear energy systems' safety and operation. As part of this effort, resources to enable end-user-driven, application-driven improvements in the nuclear data pipeline will be developed. Under the first year of this three-year research project, the main target was to formulate extended advanced reactor benchmark models with irradiated fuel and to use these models to generate sensitivity and uncertainty data for key nuclides and nuclear data that are relevant for key reactor physics metrics. The models developed to date are a representative high-temperature gas cooled reactor (HTGR), molten chloride salt-fueled fast reactor (MCFR), and fluoride salt-cooled high-temperature reactor (FHR). The overall project goal and plan, as well as the achievements up to date, will be discussed. Highlights will be presented on the determined preliminary sensitivity and uncertainty data for eigenvalue and reactivity coefficients, for the three mentioned representative reactors, both with fresh and irradiated fuel.

16th Nuclear Data for Science and Technology Conference (ND2025)
Madrid, Spain, June 22-27, 2025

We are helping bridging the gap between nuclear data developers and end-users that are engaged in developing and deploying advanced nuclear energy systems

By the end of this year, we will have an initial repository with comprehensive models and S/UQ result files to share for review by and feedback from our BNL colleagues

Acknowledgments

Funding of this effort is provided by Department of Energy, Office of Science, Nuclear Data Program