Nuclear data sensitivity and uncertainty analysis for LWR SMR: NuScale

A. Jiménez-Carrascosa, L. Durán-Vinuesa, O. Cabellos, N. García-Herranz

Department of Energy Engineering
Universidad Politécnica de Madrid (UPM), Spain

4th UPM/CEIDEN Workshop on "Neutronic Design of Small Modular Reactors"
May 19, 2022

Outline

1. Introduction
2. Computational tools
3. Models: NuScale SMR core
4. Results
5. Summary

1. Introduction

- With this study, we aim to extend our scope regarding the identification of main nuclear data needs and, specifically, targeting advanced fission systems.
- Since our previous work has been extensively focused on advanced fast reactor, a gap was identified concerning advanced LWR/SMRs.
- Thus, an LWR/SMR NuScale model has been developed based on open specifications.
- We propose a first set of parameters for which a sensitivity and uncertainty analysis has been carried out using different nuclear data libraries.
- Sensitivity profiles are now available to perform a comprehensive TAR assessment, which is the basis for identifying further nuclear data uncertainty reduction requirements.

2. Computational tools

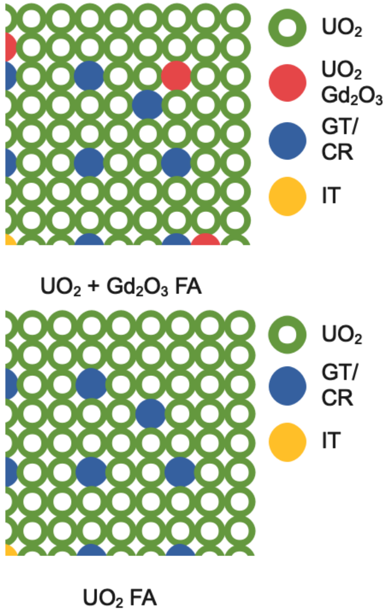
- **SCALE 6.2.3**
  - **TSUNAMI-3D continuous energy (CE) as reference module**
    - Linear perturbation theory
    - Transport solver KENO-VI
    - Eigenvalue sensitivities: CLUTCH
    - AMPX-formatted CE JEFF-3.3 cross section data
    - Sensitivities collapsed into the SCALE 252g structure (.sdf file)
      - Sensitivities to angular scattering distributions are not computed
    - TSAR module for reactivity responses sensitivity analysis
    - Covariance data: SCALE6.3-56g (ENDF/B-VIII.0 based) and 33g COVERX JEFF-3.3 and JEFF-4T1

3. Models: NuScale SMR core

NuScale SMR core: loading pattern

- **160 MWth light-water cooled small modular reactor**
- **UO_2 fueled core**
- **6 fuel assembly types** (Suk et al., 2021)
  - 4 poison-free FA (UXXX)
  - 2 FA with 8 Gd pins (GXX)
- **BOL HFP averaged conditions** ($k_{eff} \simeq 1.00000$)
  - $\rho = 0.796$ g/cm^3
  - $T_{mod} = 531.5$ K
  - $T_{fuel} = 700$ K
  - $C_{boron} = 1413$ ppm

Core loading pattern

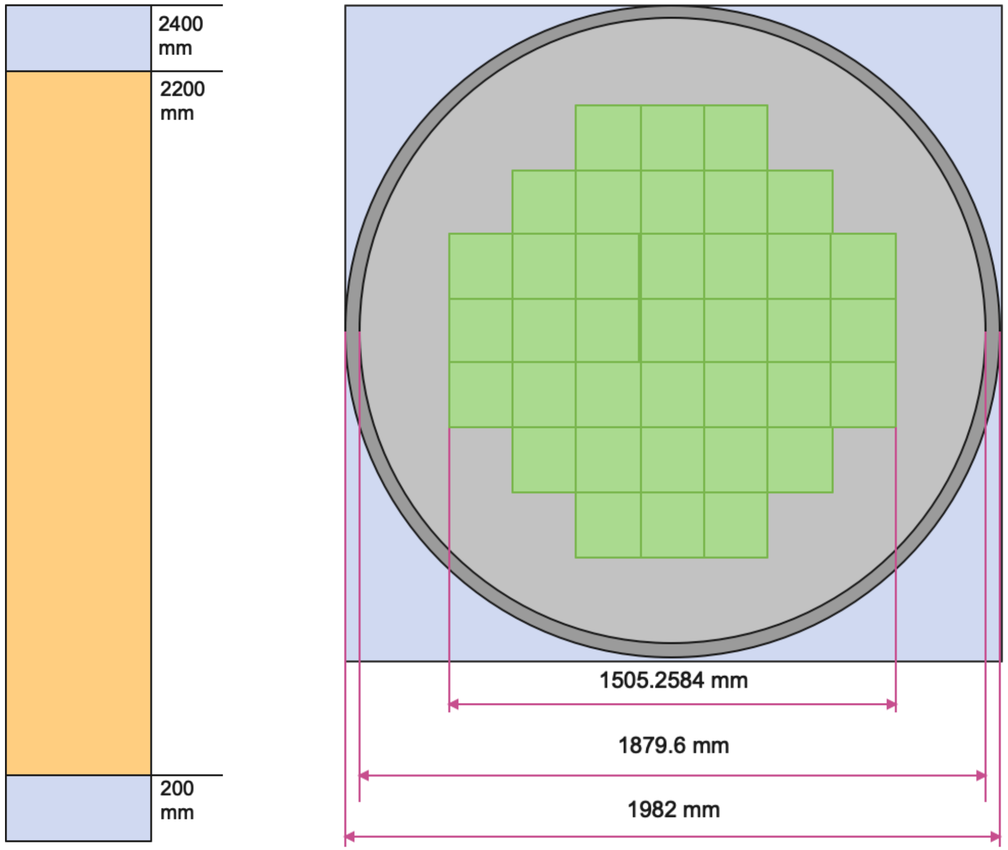


Suk, P., et al., (2021). **Simulation of a NuScale core design with the CASL VERA code.** Nuclear Engineering and Design, 371, 110956.

3. Models: NuScale SMR core

NuScale SMR core: reflector modelling

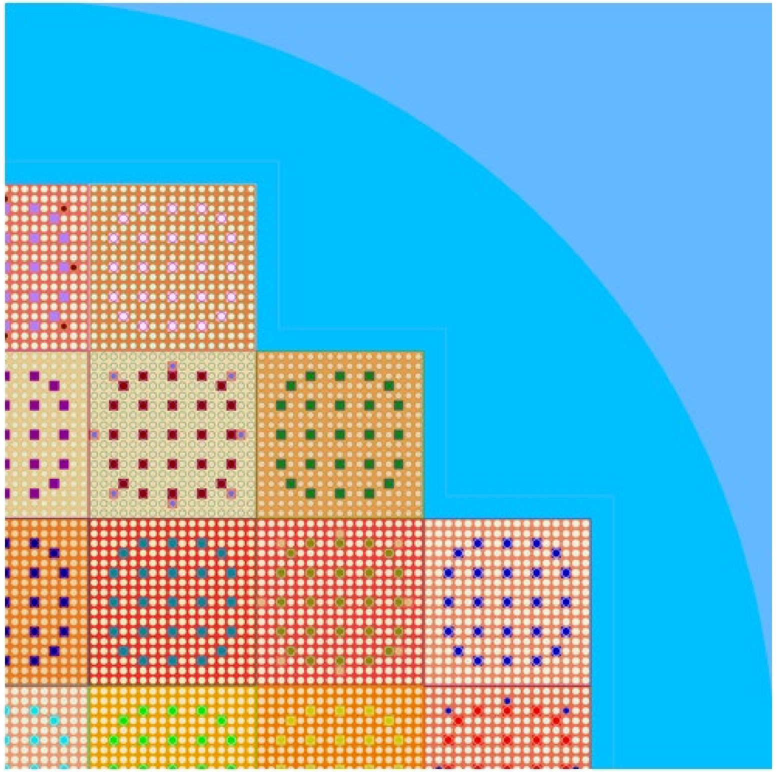
- **Active height:** 2 m
- **Simplified upper and lower reflector**
  - 20 cm height
  - Water (no fuel rod plenum)
- **Radial reflector layers** (Burrell et al., 2019)
  - Baffle (SS304): 2.8 cm thick
  - Water-gap: 0.1 mm thick
  - Heavy reflector (SS304): 93.98 cm radii
  - Core barrel (SS304): 5.12 cm thick
  - Water pool: cuboid



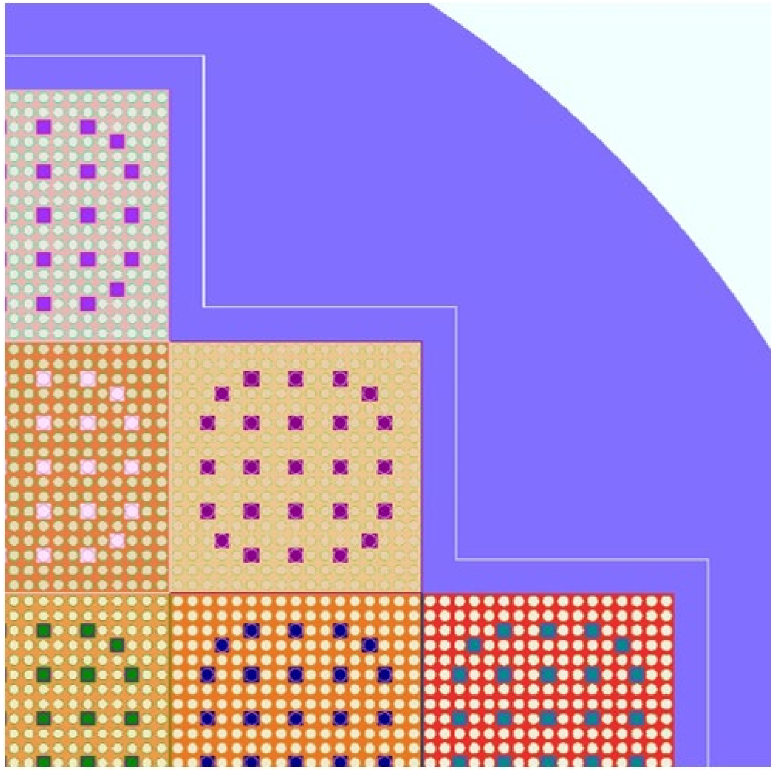
Burrell, M., et al., (2019). **Equilibrium Core Design of a NuScale Designed Small Modular Reactor Using CASL's Virtual Environment for Reactor Applications (VERA).** Transactions of the American Nuclear Society - Volume 121, 127-129.

3. Models: NuScale SMR core

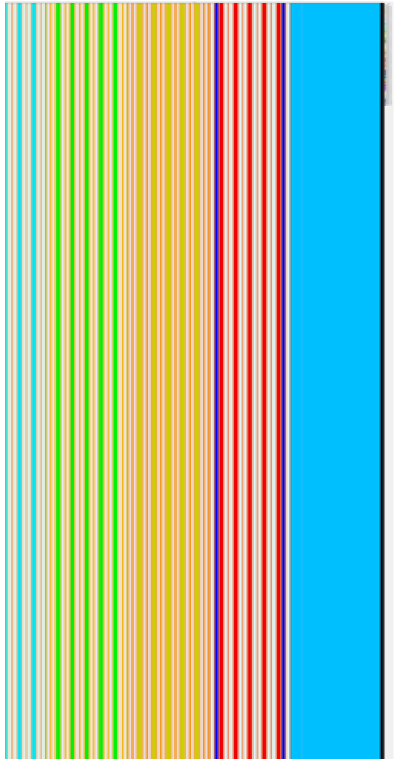
NuScale SMR core: KENO-VI model – 3D heterogeneous model



Quarter symmetry



Water-gap zoom



Axial model

Durán-Vinuesa, L.F., et al., (2022). **NuScale Spectrum of Rod Ejection Accidents at BOL Simulated using COBAYA4-CTF,** In Proceedings of 19th Int. Top. Meeting on Nuclear Reactor Thermal-hydraulics (NURETH-19), Brussels, Belgium, March 6-11, 2022.

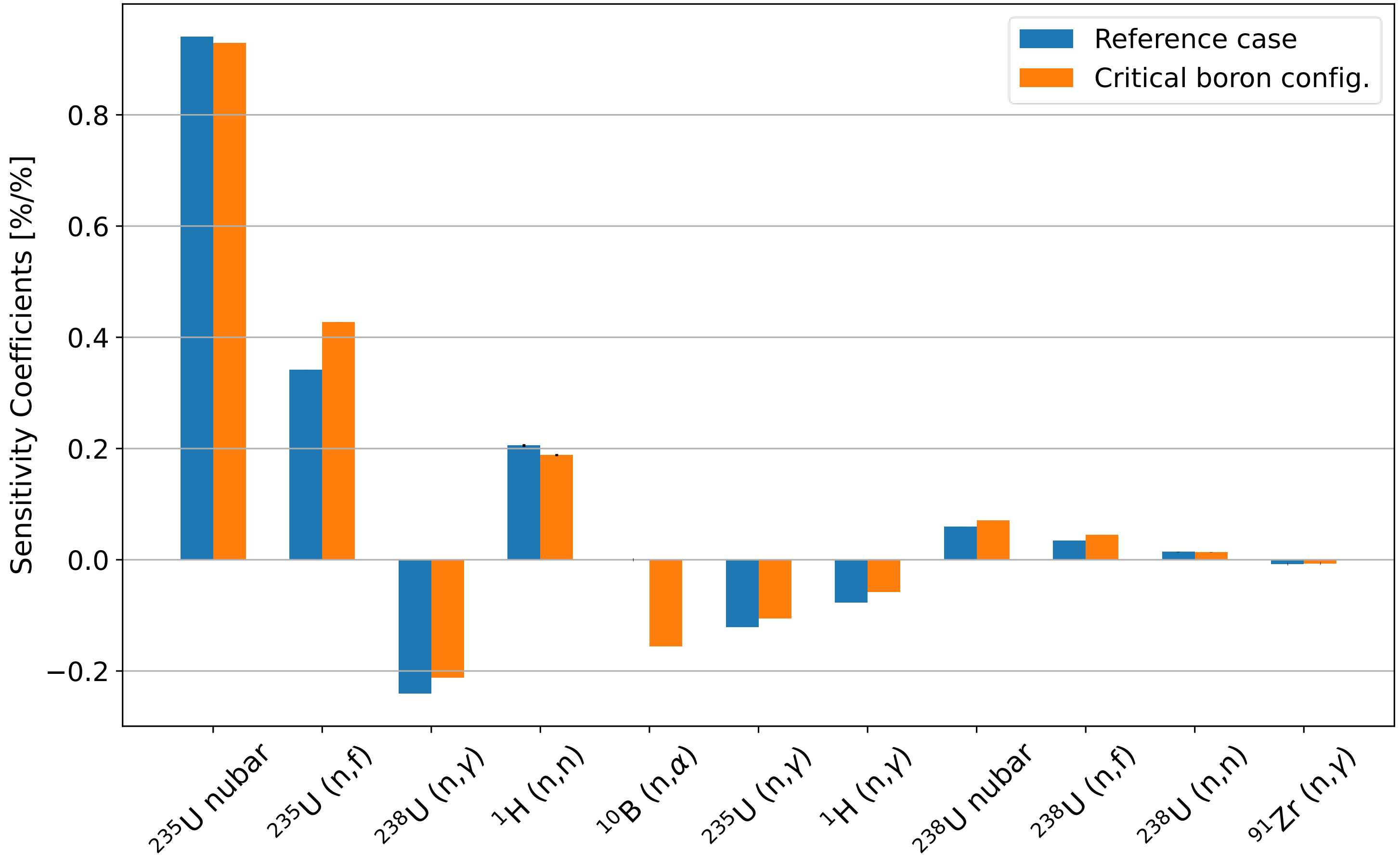
4. Results: evaluated parameters overview

NuScale SMR core: Set of evaluated parameters and uncertainty quantification results

Response	Value (1σ) JEFF-3.3	Uncertainty [%] 56g SCALE6.3 ENDF/B-VIII.0	Uncertainty [%] 33g JEFF-3.3	Uncertainty [%] 33g JEFF-4T1 (preliminary release)
k-eff (HFP)	1.20160(5)	0.562	0.707	0.707
k-eff (HFP critical boron concentration)	1.00433(5)	0.565	0.714	0.728
Total CR Worth (HZP)	-16 881(8) pcm	0.854 (144 pcm)	0.880 (149 pcm)	1.045 (176 pcm)

4. Results: sensitivity analysis

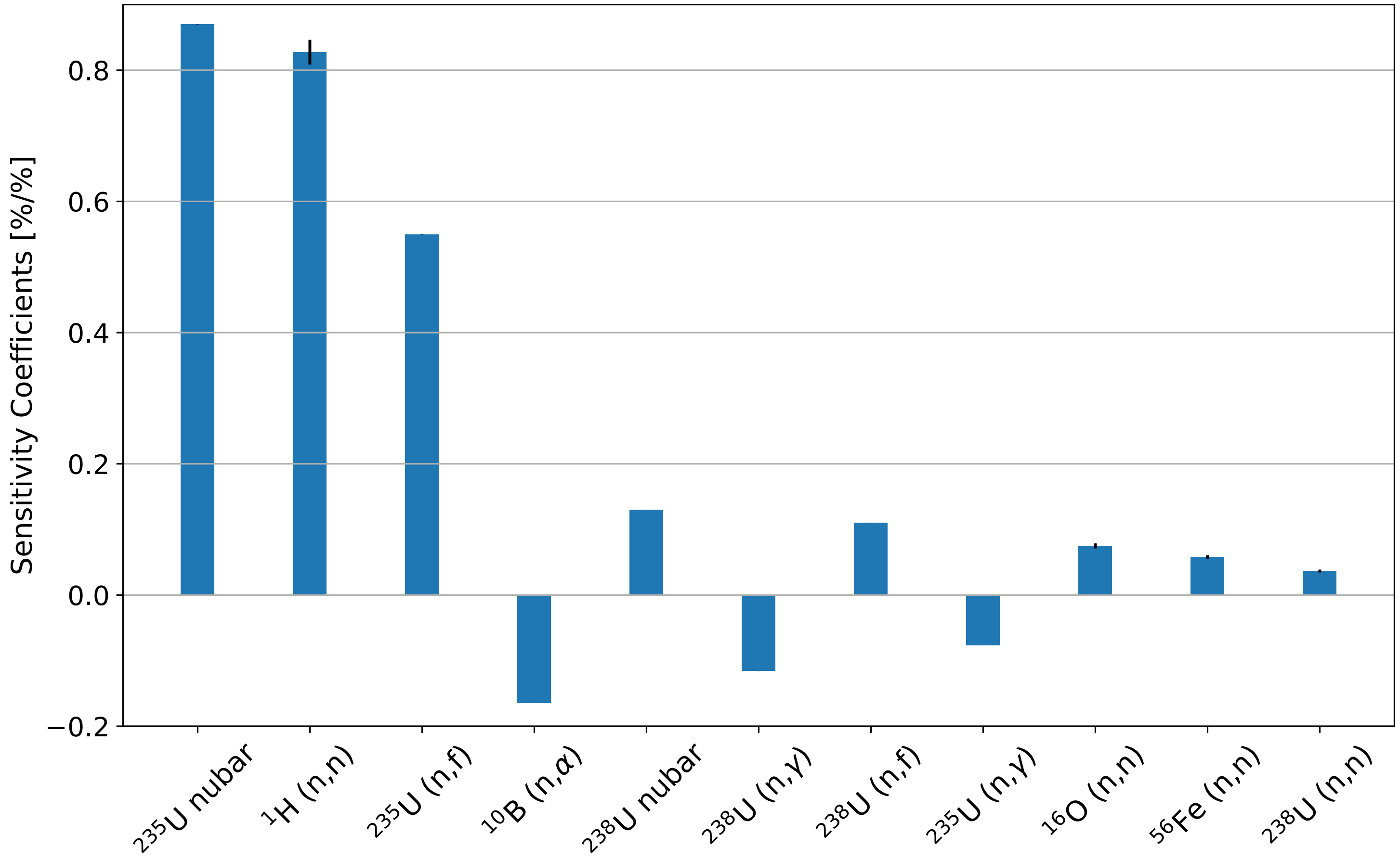
Sensitivity results for multiplication factor



Top energy, region and mixture – integrated sensitivity coefficients for multiplication factor ranking

4. Results: sensitivity analysis

Sensitivity results for Control Rod worth



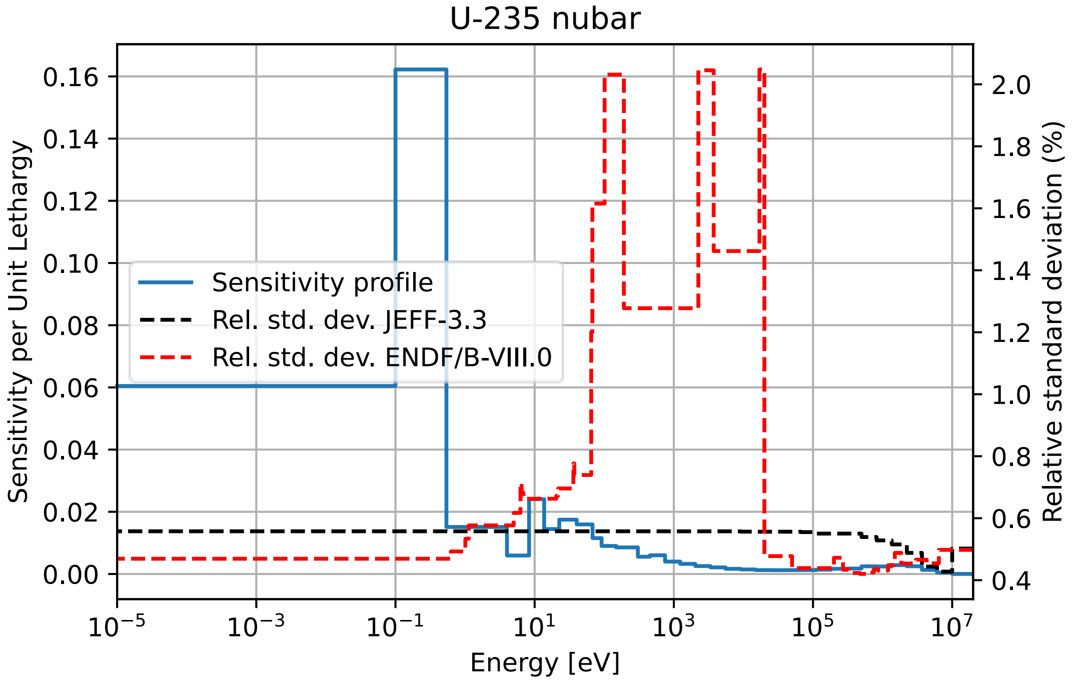
Top energy, region and mixture – integrated sensitivity coefficients for CR worth ranking

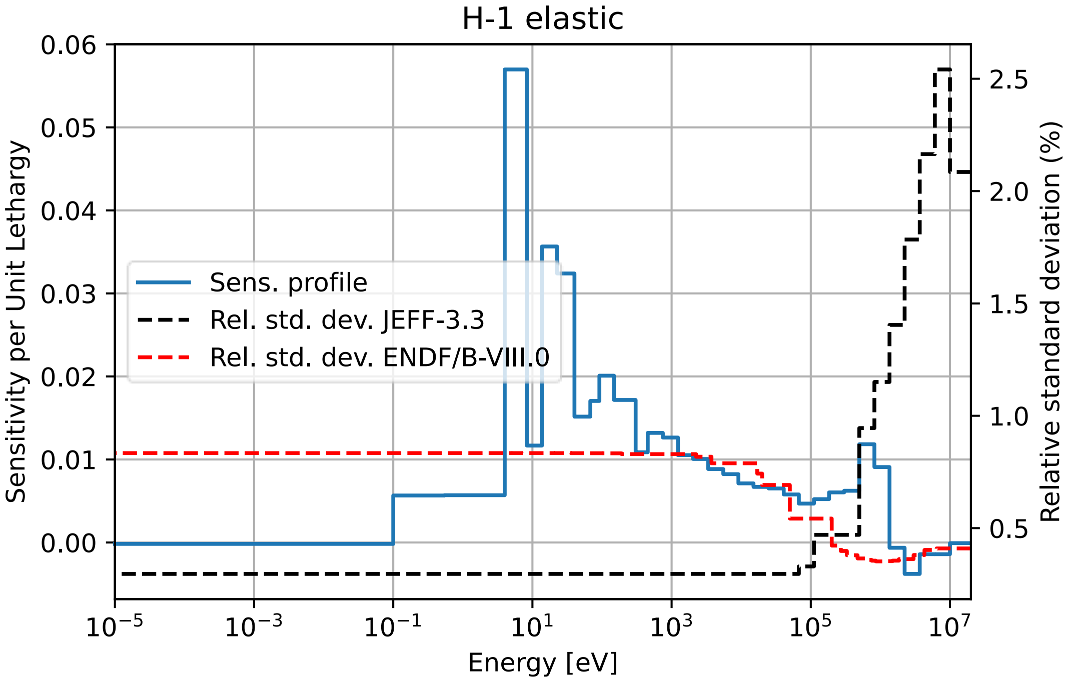
4. Results: uncertainty quantification

Global results		
Response	Uncertainty [%] 56g SCALE6.3 ENDF/B-VIII.0	Uncertainty [%] 33g JEFF-3.3
k-eff (HFP)	0.562	0.707

Major uncertainty contributors for each evaluation

SCALE6.3 (ENDF/B-VIII.0)		JEFF-3.3	
Reaction	Δk/k (%)	Reaction	Δk/k (%)
^{235}U nubar	0.43	^{235}U nubar	0.52
^{238}U (n,γ)	0.20	^{235}U (n,f)	0.22
^{1}H (n,n)	0.16	^{235}U (n,γ)	0.22
^{1}H (n, γ)	0.16	^{238}U (n,γ)	0.20





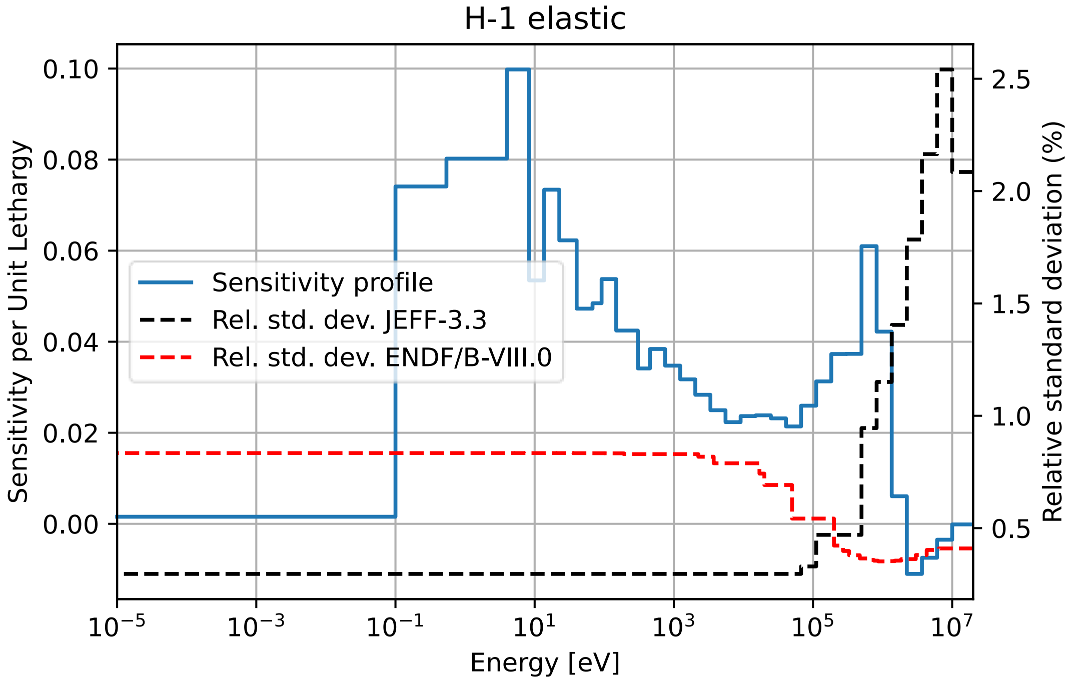
4. Results: uncertainty quantification

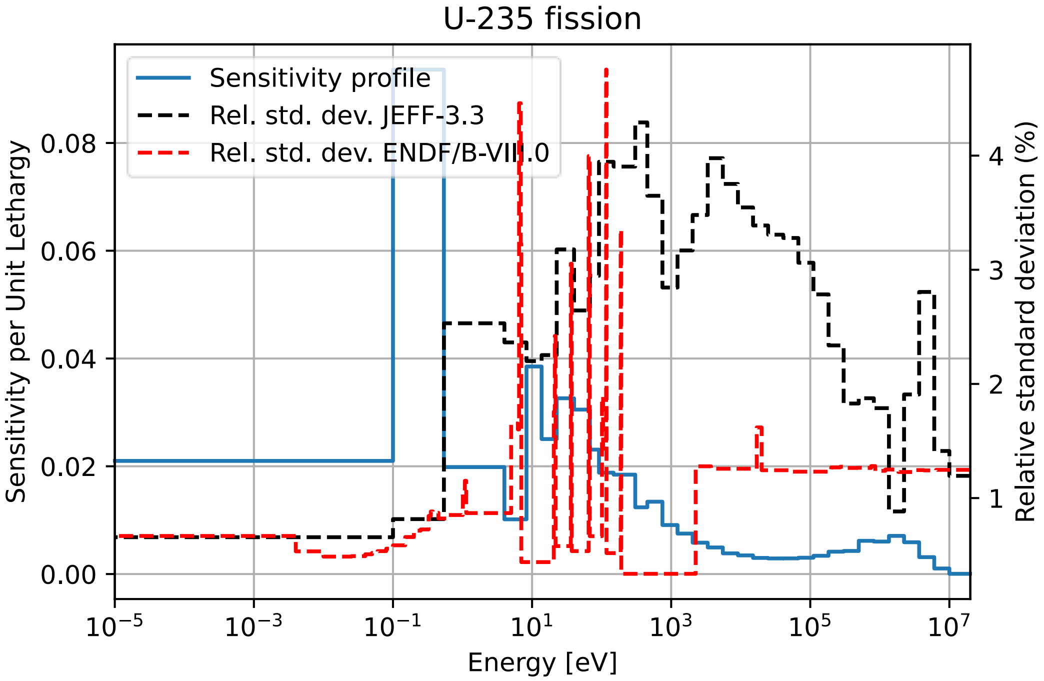
Global results

Response	Uncertainty [%] 56g SCALE6.3 ENDF/B-VIII.0	Uncertainty [%] 33g JEFF-3.3
Total CR Worth (HZP)	0.854	0.880

Major uncertainty contributors for each evaluation

SCALE6.3 (ENDF/B-VIII.0)		JEFF-3.3	
Reaction	**Δk/k (%)**	**Reaction**	**Δk/k (%)**
^{1}H (n,n)	0.43	^{235}U nubar	0.48
^{235}U nubar	0.39	^{235}U (n,f)	0.44
^{235}U (n,f)	0.21	^{238}U (n,f)	0.29
^{235}U (n,f) - ^{238}U (n,f)	0.17	^{1}H (n,n)	0.28



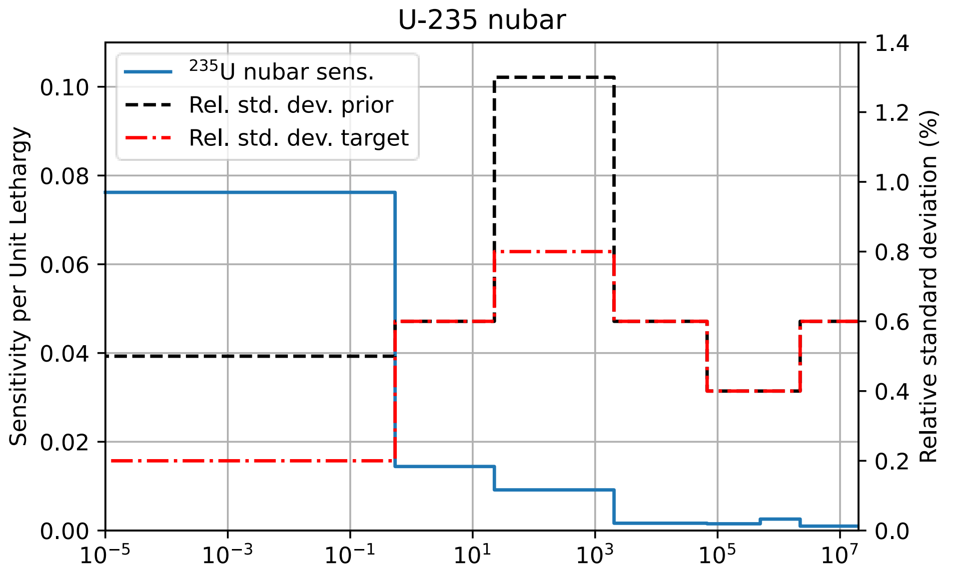


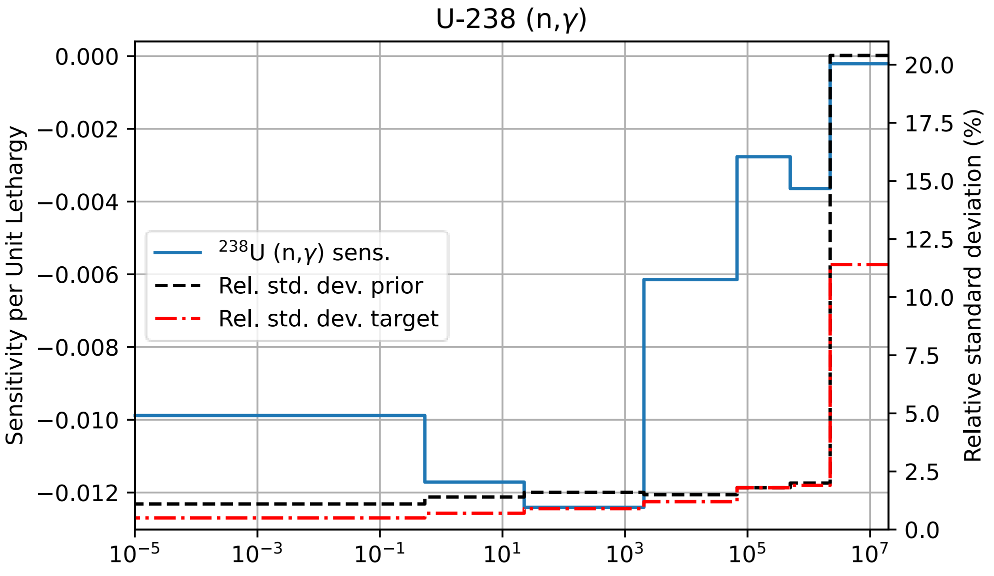
4. Results: preliminary TAR assessment

Target accuracy requirement on top-10 most important reactions: ENDF/B-VIII.0 (Correlations included)

Rank #	Reaction	Energy group	Current [%]	Target [%]	Rel. Unc. Reduction [%]
1	^{235}U nubar	7	0.5	0.2	69.2
2	^{238}U (n,γ)	7	1.1	0.5	7.9
3	^{235}U (n,f)	7	0.5	0.3	6.6
4	^{238}U (n,γ)	6	1.4	0.7	4.5
5	^{238}U (n,γ)	5	1.6	0.9	3.2
6	^{235}U nubar	5	1.3	0.8	3.1
7	^{16}O (n,n')	1	265.2	89.3	1.6
8	^{238}U (n,n)	5	3.9	1.2	0.7
9	^{238}U (n,f)	1	1.2	0.5	0.5
10	^{235}U (n,γ)	7	0.9	0.8	0.4

TAR NuScale k-eff value: 300 pcm





5. Summary

- This work is an extension concerning UPM activities on nuclear data needs complementing our studies for advanced fast reactors.
- An LWR/SMR NuScale model has been developed based on open specifications.
- For that model, we have performed a sensitivity and uncertainty study covering an initial set of parameters.
- **Uncertainty propagation results prove that LWR/SMRs nuclear data-related are still to be improved**.
- As future work, this study can be extended, if relevant, with sensitivities for the following parameters:
  - Safety-related reactivity coefficients.
  - Power distribution.
  - Reaction rates.
- **This is especially relevant in order to evaluate the impact of nuclear data uncertainties on transient sequences.**

Acknowledgments

This work is part of the SANDA project (Supplying Accurate Nuclear Data for energy and non-energy Applications) that has received funding from the European Union's H2020/Euratom under grant agreement No. 847552.

Thank you!

A. Jiménez-Carrascosa, L. Durán-Vinuesa, O. Cabellos, N. García-Herranz

Department of Energy Engineering
Universidad Politécnica de Madrid (UPM), Spain

4th UPM/CEIDEN Workshop on "Neutronic Design of Small Modular Reactors"
May 19, 2022