UPM contribution on sensitivity analysis for LWR SMR: NuScale

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Meeting of the OECD/NEA WPEC-SG46
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2. Computational tools
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1. Introduction

- A gap was identified at previous WPEC/SG46 meetings concerning sensitivity analyses for advanced LWR/SMRs.
- An LWR/SMR NuScale model has been developed based on open specifications.
- We are ready to provide sensitivities for this model so that it can be included on the subsequent TAR assessment.

2. Computational tools

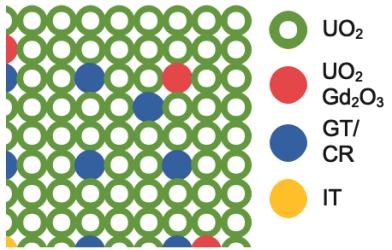
- **SCALE 6.2.3**
  - **TSUNAMI-3D continuous energy (CE) as reference module**
    - Linear perturbation theory
    - Transport solver KENO-VI
    - Eigenvalue sensitivities: CLUTCH
    - AMPX-formatted CE JEFF-3.3 cross section data
    - Sensitivities provided into the SCALE 252g structure (.sdf file)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

3. Models: NuScale SMR core

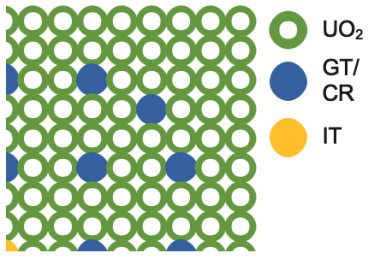
NuScale SMR core: loading pattern

- **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



UO_2 + Gd_2O_3 FA



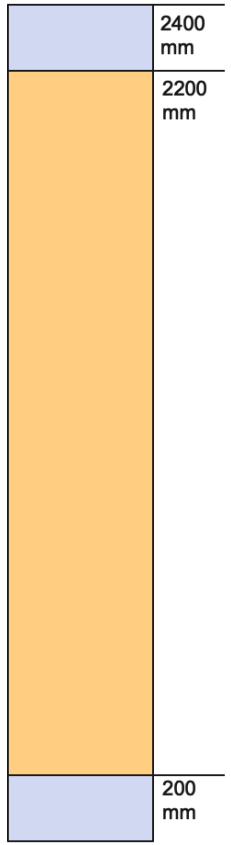
UO_2 FA

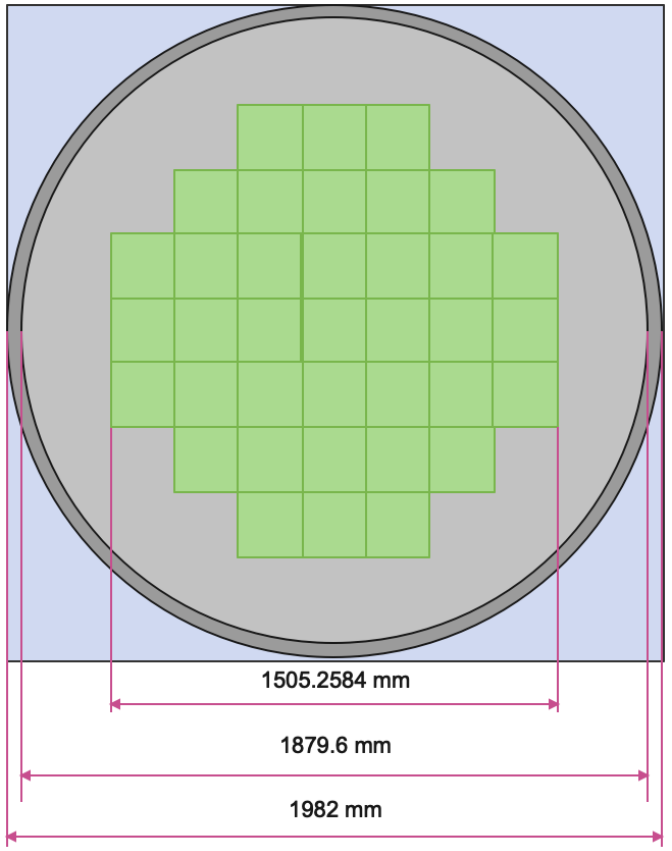
Suk, P., et al., (2021). **Simulation of a NuScale core design with the CASL VERA code.** Nuclear Engineering and Design, 371, 110956.

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

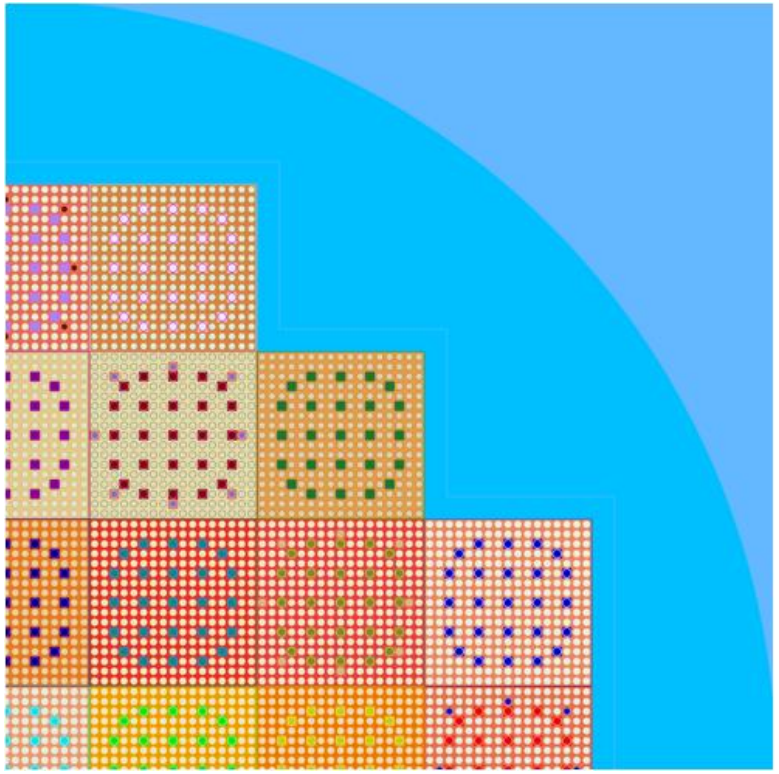




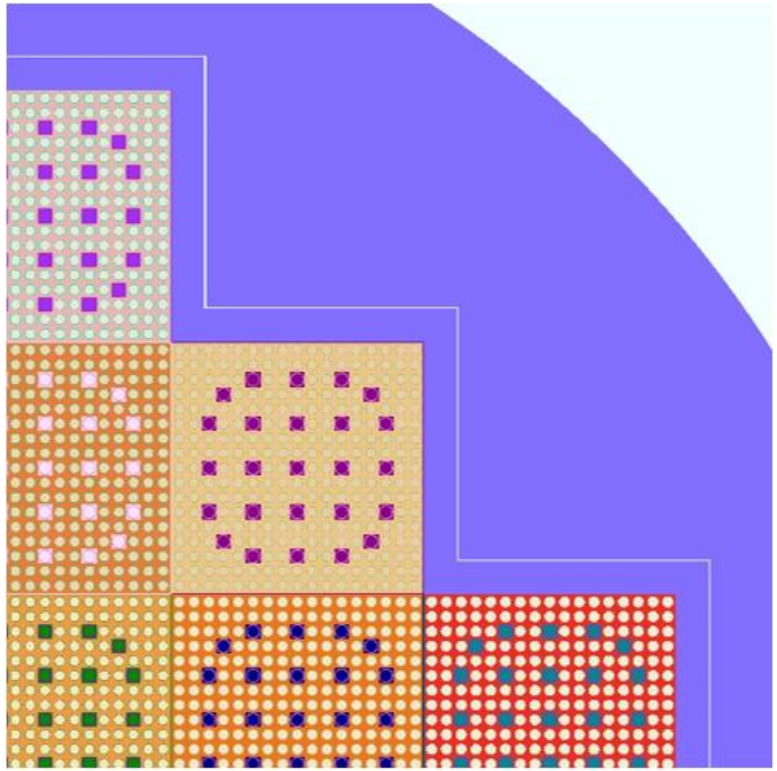
Burrell, M., et al., (2019). **Equilibrium Core Design of a NuScale Designed Small Modular Reactor Using CASL's Virtual Environment for Reactor Applications (VERA).** Transactions of the American Nuclear Society - Volume 121, 127-129.

3. Models: NuScale SMR core

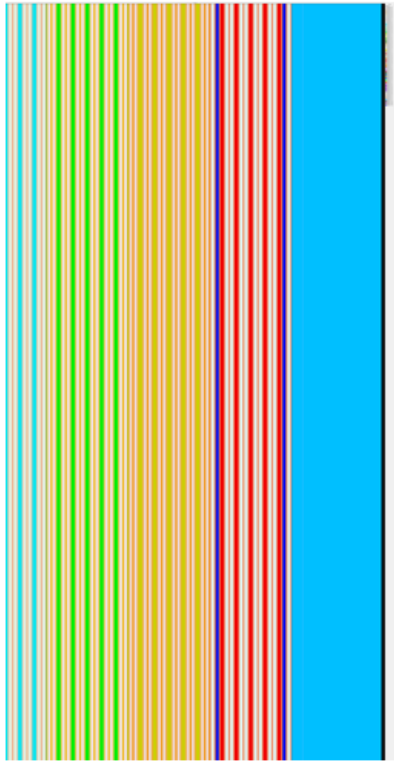
NuScale SMR core: KENO-VI model – 3D heterogeneous model



Quarter symmetry



Water-gap zoom

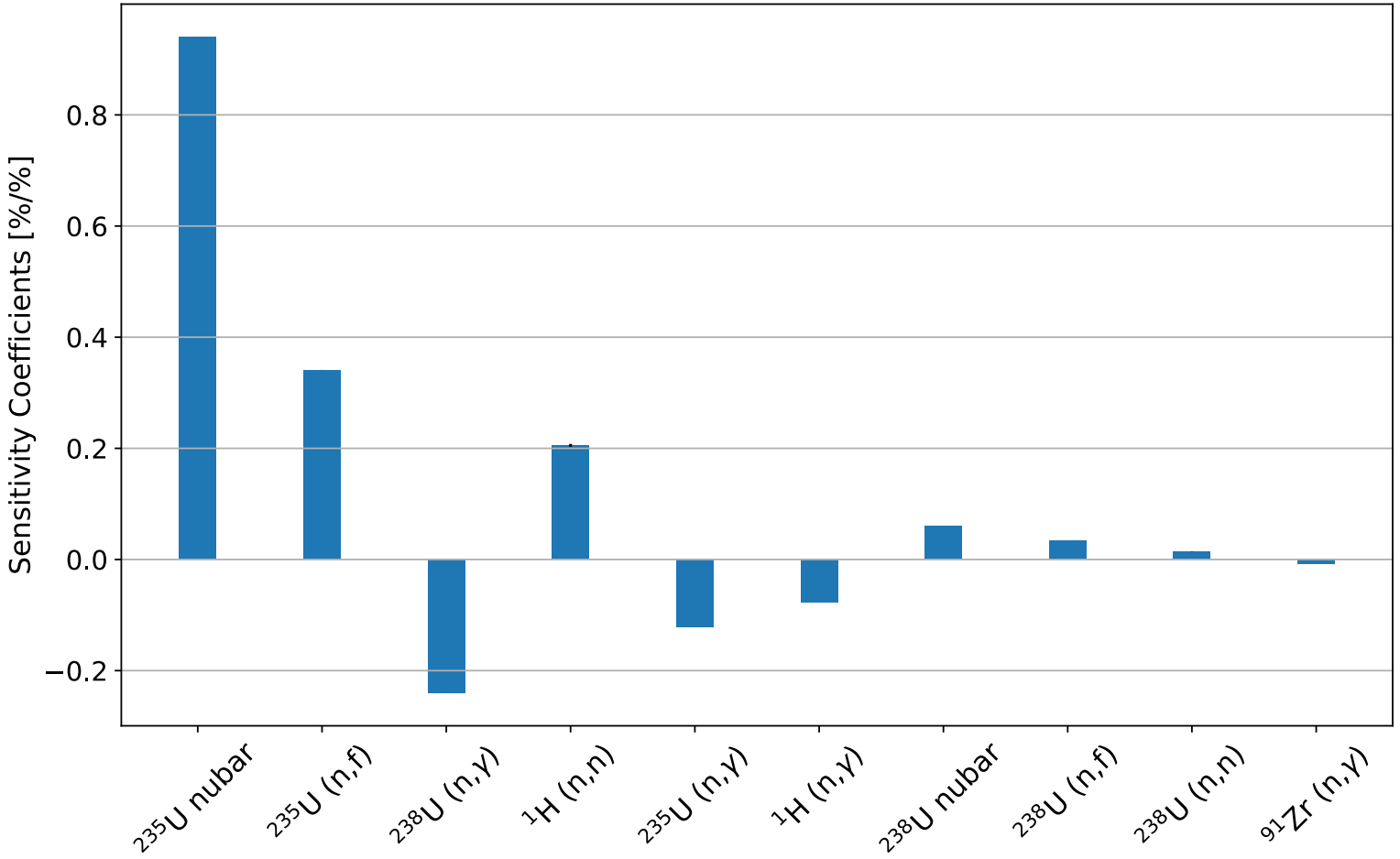


Axial model

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. Sensitivity results

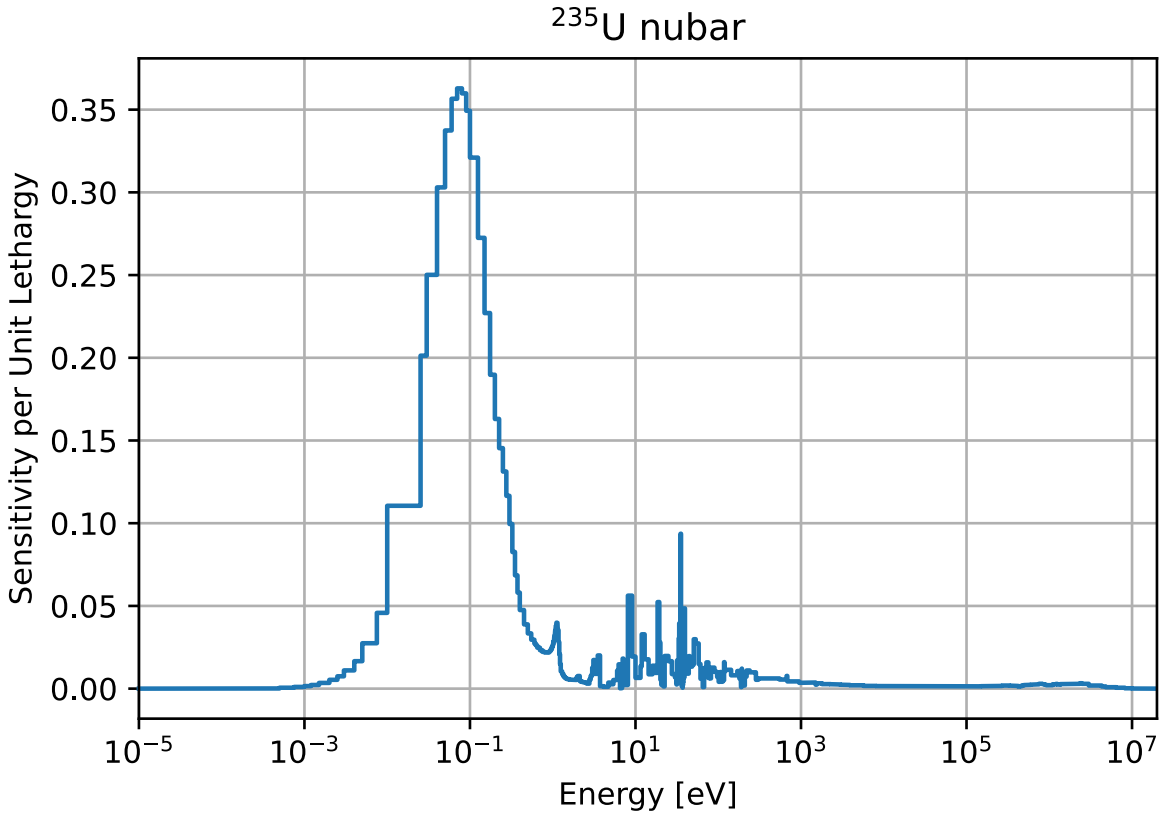
Sensitivity results for multiplication factor



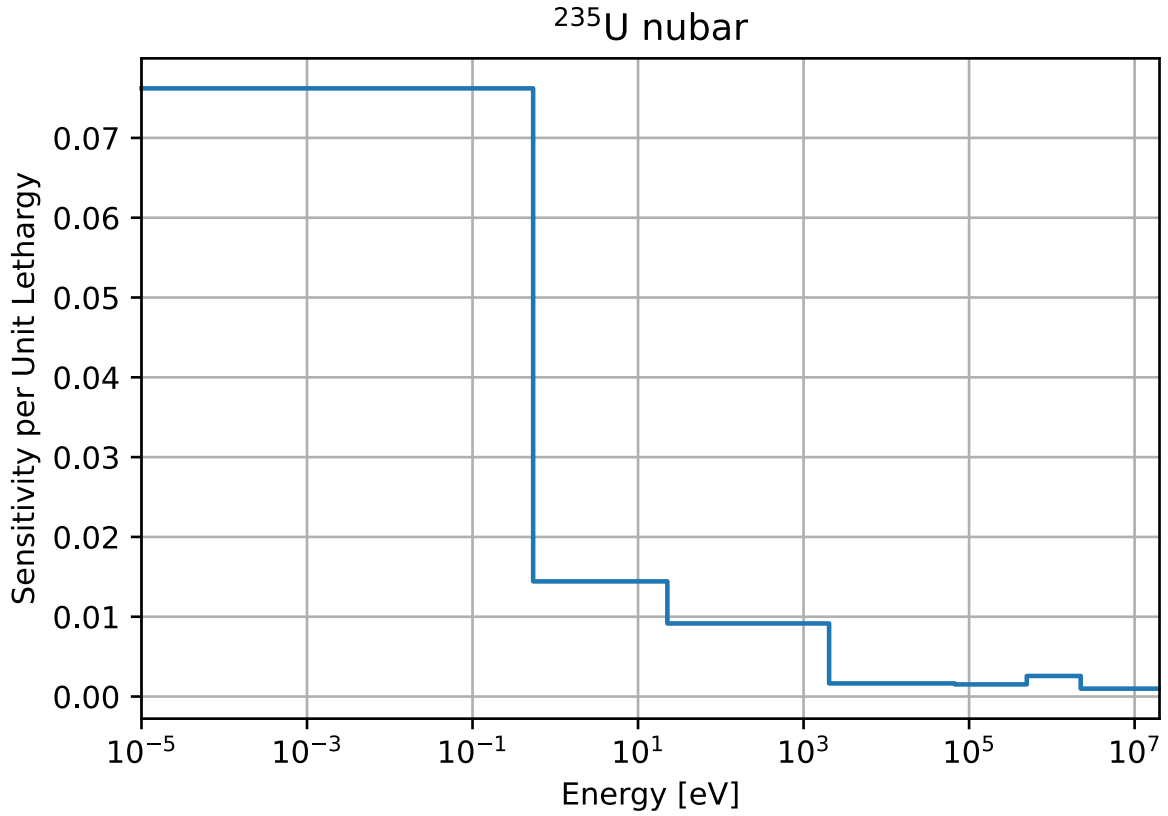
Top-10 energy, region and mixture – integrated sensitivity coefficients for multiplication factor ranking

4. Sensitivity results

Energy-dependent sensitivities collapsed into the SCALE 252-group structure

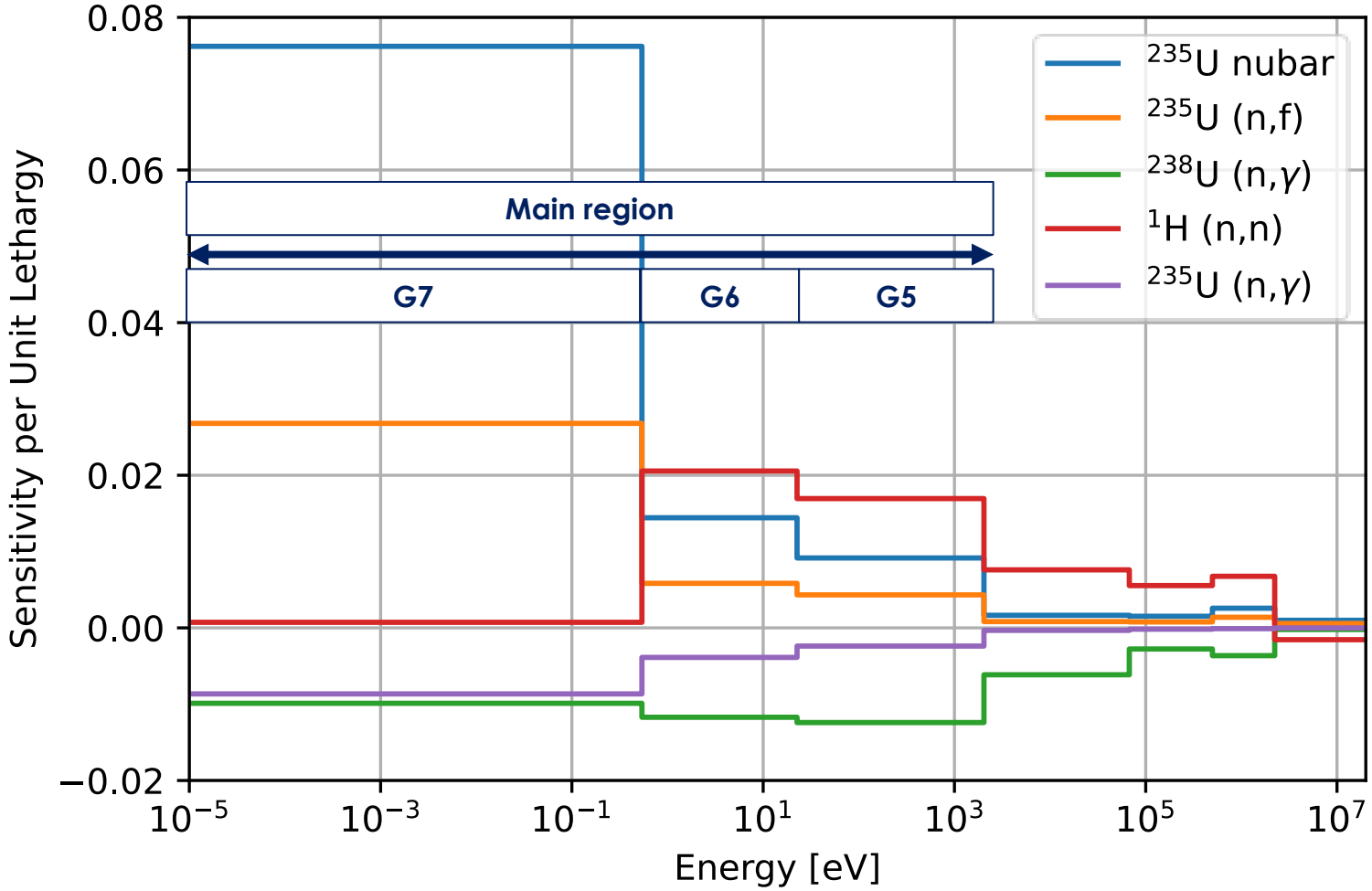


Energy-dependent sensitivities collapsed into the 7-group structure suitable for the TAR exercise



4. Sensitivity results

Sensitivity results for multiplication factor (7g)

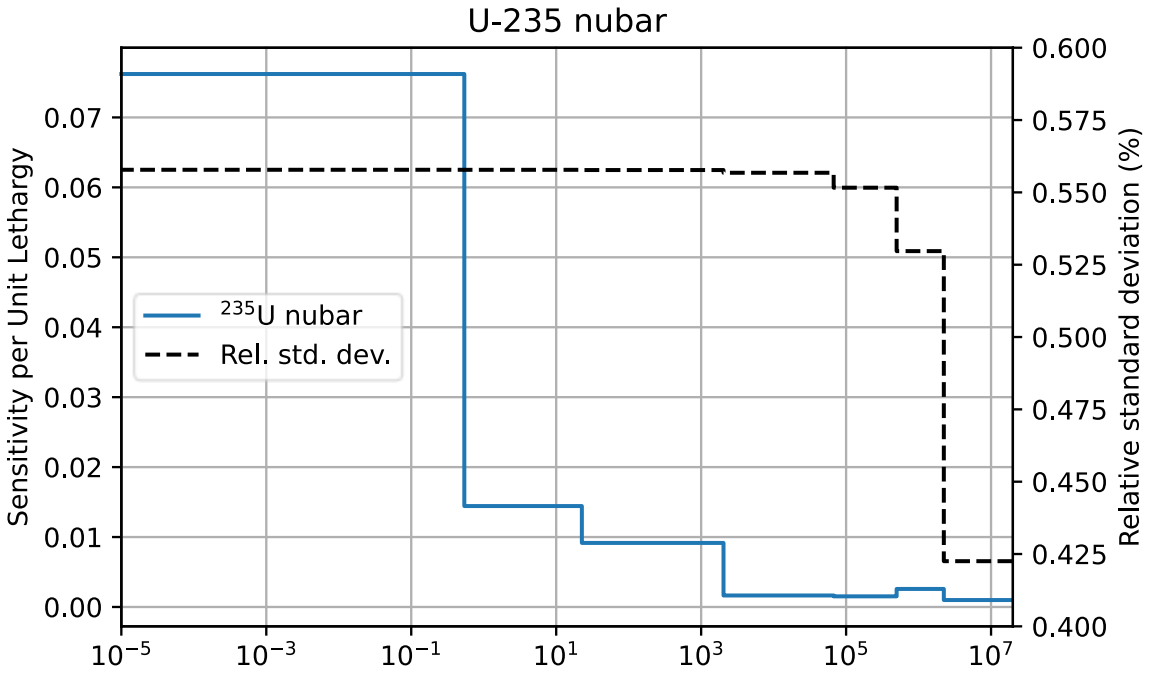


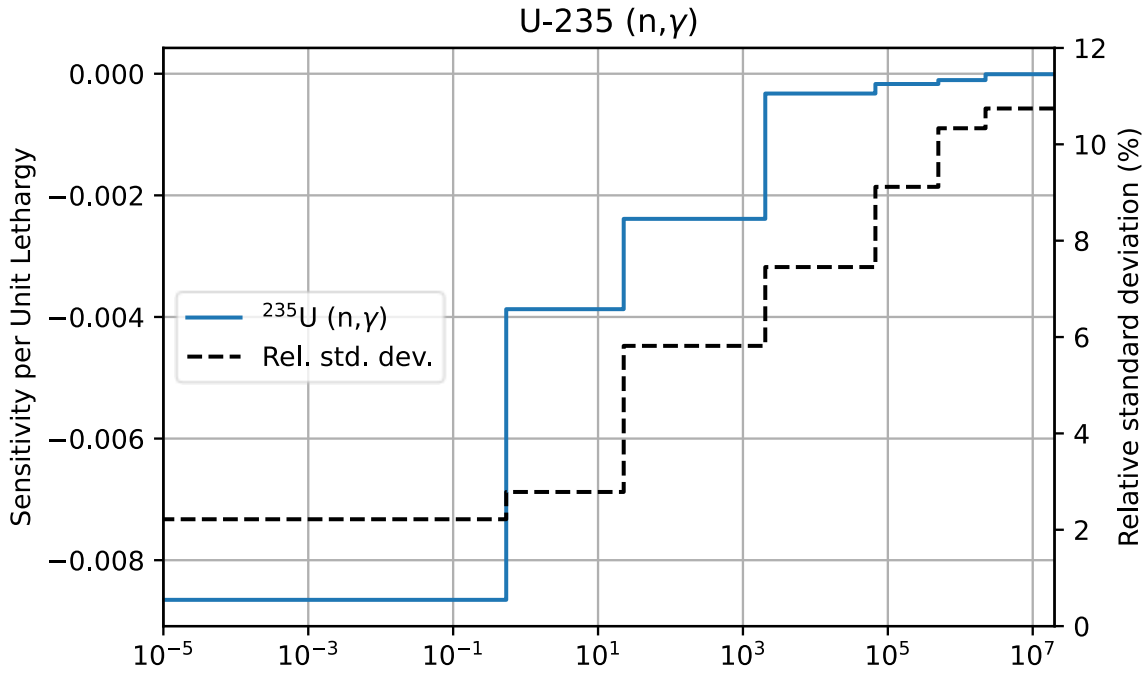
4. Sensitivity results: uncertainty quantification

Reactor	Response	TAR WPEC/SG46 [%]	Uncertainty [%] 7g JEFF-3.3	Uncertainty [%] 56g SCALE6.3 ENDF/B-VIII.0
NuScale	k-eff	0.3	0.698 ± 1.1E-04	0.567 ± 3.5E-05

Target accuracy exceeded!

JEFF-3.3				SCALE6.3 (ENDF/B-VIII.0)			
Reaction	Δk/k (%)		Std. Dev.	Reaction	Δk/k (%)		Std. Dev.
^{235}U nubar	0.52	±	4E-05	^{235}U nubar	0.43	±	1E-05
^{235}U (n,γ)	0.23	±	3E-06	^{238}U (n,γ)	0.20	±	1E-06
^{235}U (n,f)	0.22	±	2E-05	^{235}U (n,f)	0.17	±	8E-06
^{238}U (n,γ)	0.21	±	4E-06	^{1}H (n,n)	0.16	±	3E-05



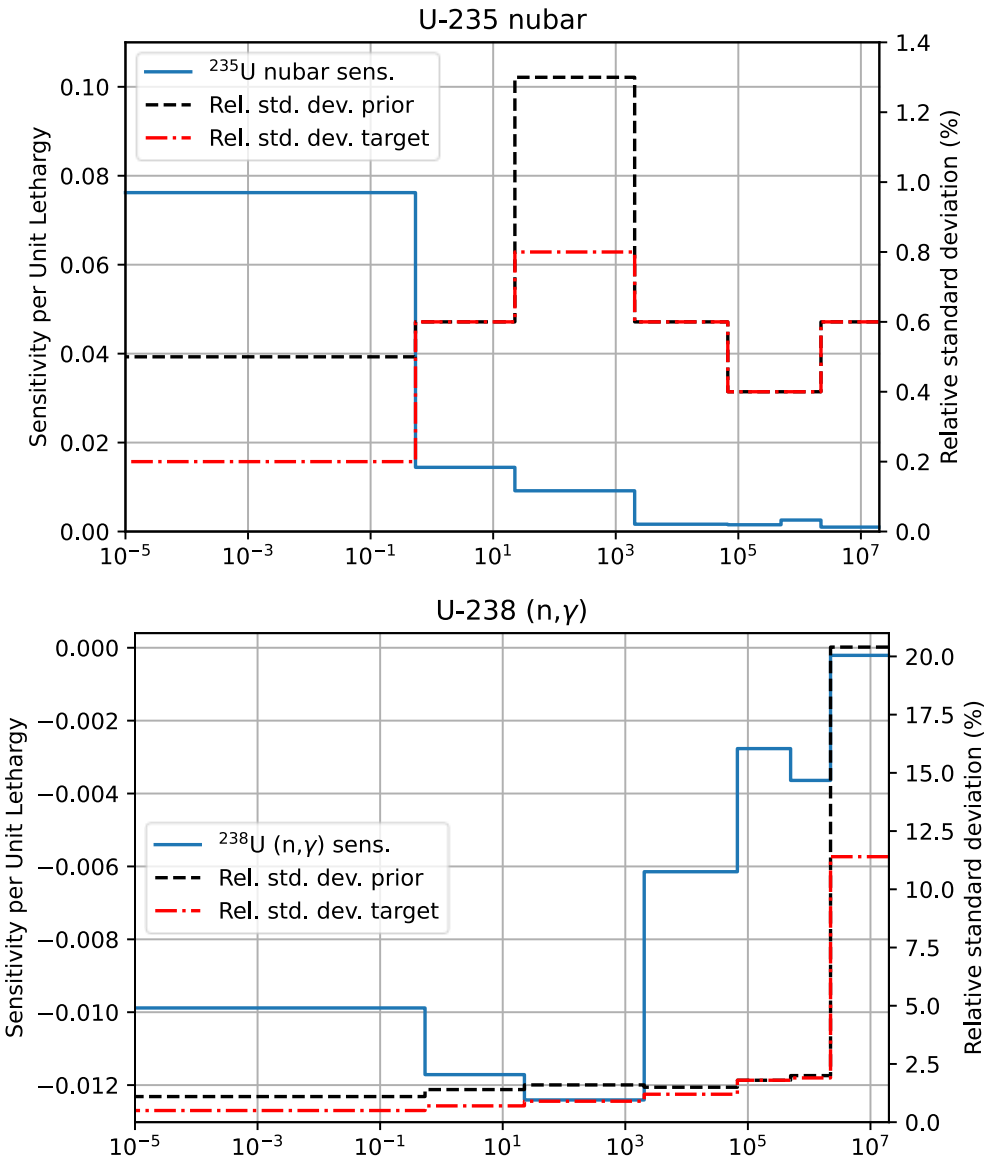


4. Sensitivity results: preliminary TAR assessment

TAR 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

- A gap was identified at previous WPEC/SG46 meetings concerning sensitivity analyses for advanced LWR/SMRs. We are working on closing this gap.
- An LWR/SMR NuScale model has been developed based on open specifications.
- For that model, we are ready to provide:
  - 7g sensitivity profiles for the TAR assessment, for which more comprehensive conclusions may be extracted.
  - 252g sensitivity profiles for Uncertainty Quantification analyses.
- **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:
  - Safety-related reactivity coefficients.
  - Power distribution.
  - Reaction rates.
  - Control rod worth.
  - Boron concentration.

Acknowledgments

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Thank you! Questions?

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