Sensitivity analyses of advanced reactors under the EC projects ESNII+ and ESFR-SMART

N. García-Herranz, A. Jiménez-Carrascosa
and former UPM students P. Romojaro, A. Martínez-Campo

Universidad Politécnica de Madrid (UPM)

Meeting of the WPEC Subgroup 46, 15 March 2022

1. EC ESNII+ and ESFR-SMART projects

Project information

ESNII PLUS

Grant agreement ID: 605172

Status
Closed project

Start date: **1 September 2013**
End date: **31 August 2017**

Funded under:
FP7-EURATOM-FISSION

Overall budget:
€ 10 362 135,40

EU contribution
€ 6 455 000

Coordinated by:
COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
France

FP7 ESNII+ project: Preparing ESNII for HORIZON 2020

Budget: 10 MEUR

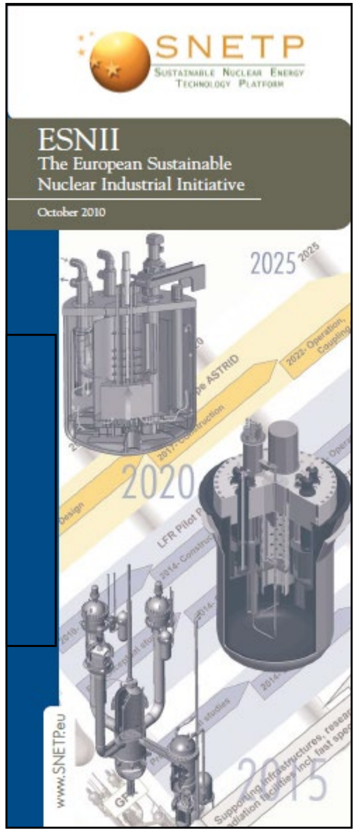
Timeframe: 1 Sep 2013 – 1 Sep 2017

Goals:

Establish the roadmap for the development of advanced fission systems in Europe

WP6 (Core Safety): Identification of R&D activities necessary for improving the present SFR, LFR and GFR designs: ASTRID, ALFRED, ALLEGRO

ESNII
European Sustainable Nuclear Industrial Initiative



1. EC ESNII+ and ESFR-SMART projects: reactors in ESNII+

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Grant agreement ID: 605172

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Closed project

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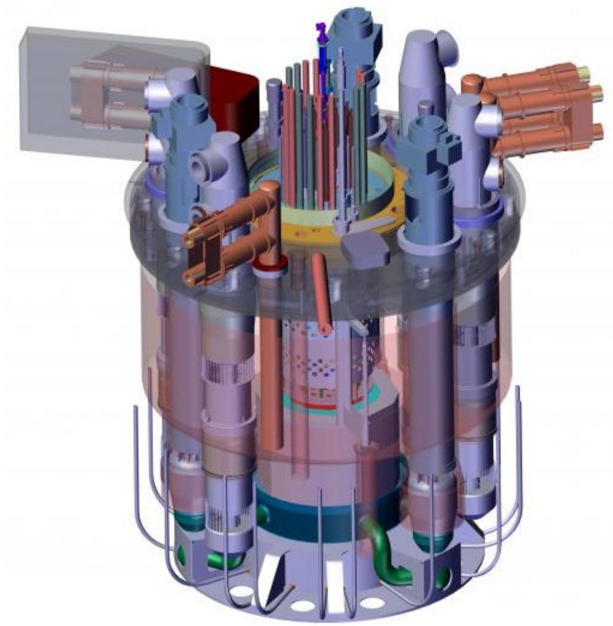
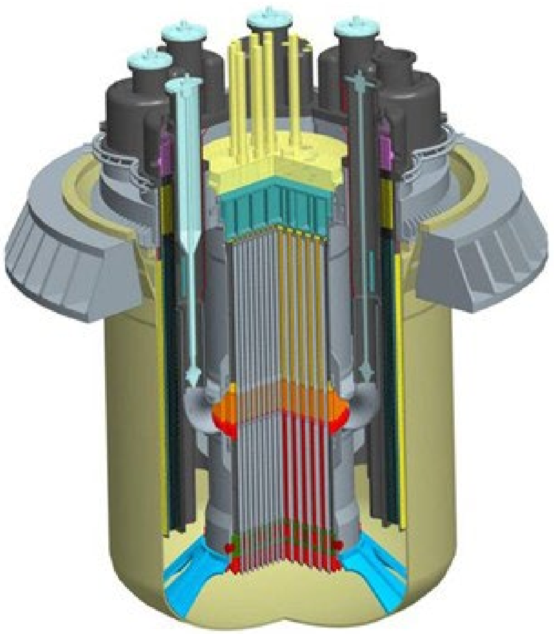


ASTRID-like
Advanced **S**odium **T**echnological **R**eactor for **I**ndustrial **D**emonstration
(Medium-size 1500 MWth core)



ALFRED
Advanced **L**ead **F**ast **R**eactor **E**uropean **D**emostrator
(300 MWth core)

1. EC ESNII+ and ESFR-SMART projects

Project information

ESFR-SMART

Grant agreement ID: 754501

Status
Ongoing project

Start date	End date
1 September 2017	**31 August 2021**

Funded under:
H2020-Euratom-1.1.

Overall budget:
€ 9 911 150

EU contribution
€ 5 000 000

Coordinated by:
PAUL SCHERRER INSTITUT
Switzerland

HORIZO2020 ESFR-SMART project: European Sodium Fast Reactor Safety Measures Assessment and Research Tools

Euratom Budget: 5 MEUR

Timeframe: 1 Sep 2017 – 31 August 2022

Goals:

Select and assess safety measures for the European SFR

WP1.2 & WP2.1: Calibration and validation of the computational tools to support safety assessments of Generation-IV SFRs, using the data produced in the project and selected legacy data

1. EC ESNII+ and ESFR-SMART projects: reactors in ESFR-SMART

Project information

ESFR-SMART

Grant agreement ID: 754501

Status
Ongoing project

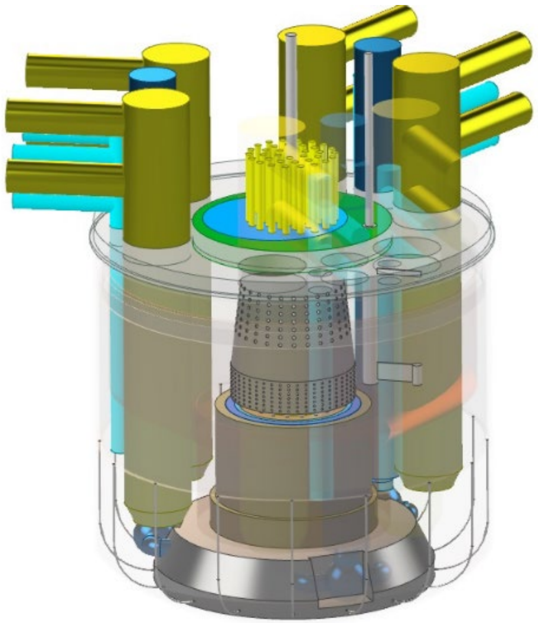
Start date	End date
1 September 2017	**31 August 2021**

Funded under:
H2020-Euratom-1.1.

Overall budget:
€ 9 911 150

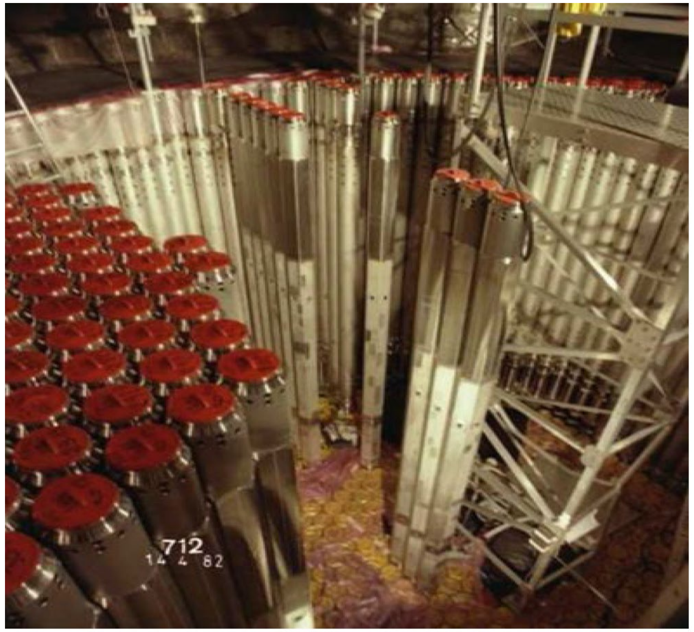
EU contribution
€ 5 000 000

Coordinated by:
PAUL SCHERRER INSTITUT
Switzerland



ESFR
European **S**odium **F**ast **R**eactor
(Commercial-size 3600 MWth core)

Guidez, J. and Prêle, G., 2017. *Superphénix: Technical and Scientific Achievements*. 2017.



SUPERPHÉNIX
French Sodium Cooled Fast Reactor
operated from 1986-1997
(Large-size 3000 MWth core)

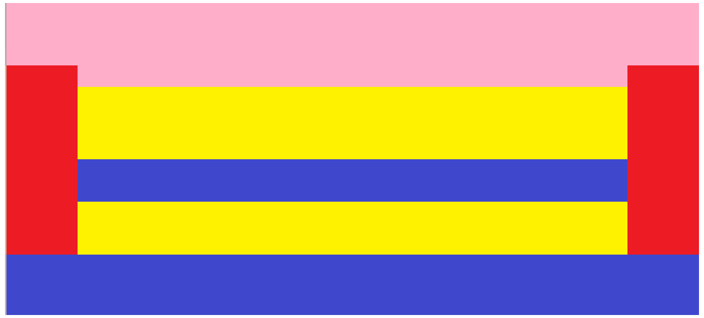
Main global parameters of the analyzed fast reactors

	ALFRED	ASTRID	ESFR	SPX
Thermal power (MWt)	300	1500	3600	3000
Coolant	Lead	Sodium	Sodium	Sodium
Core inlet/outlet temperature (°C)	400/480	400/550	395/545	395/545
Average core structure and coolant temperature (°C)	440	475	470	470
Average fuel temperature (°C)	900	1227	1227	1227
Average fertile temperature (°C)	-	627	627	627
Fuel type	MOX	MOX	MOX	MOX
Pu content at inner/outer zones (wt%)	21.8 / 27.9	24.3/20.7	17.99/17.99	15.1/18.7 *
Number of Subassemblies inner/outer core	57 / 114	177 / 114	216 / 288	190 / 168 *
Subassembly pitch (cm)	17.1	17.61	20.99	17.9
Fissile core equivalent diameter D (m)	2.6	3.8	5.5	3.7
Fissile core height H (m) inner/outer zone	0.6 / 0.6	0.60 / 0.90	0.75 / 0.95	1.0 / 1.0
EALF (MeV)	0.123	0.181	0.177	0.128

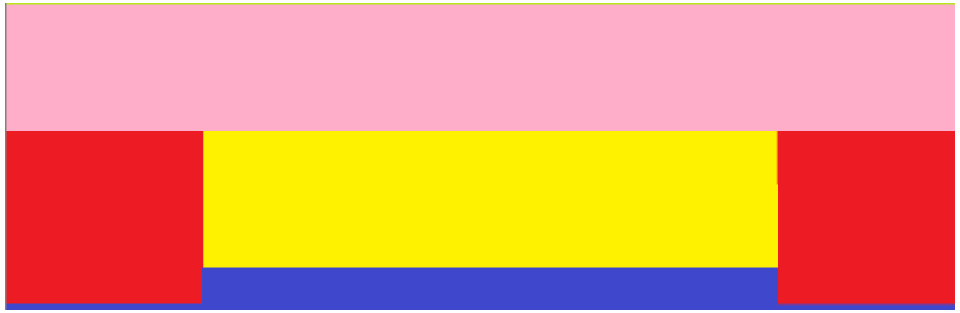
* Start-up core configuration

The impact of nuclear data depends on the specific design choices, even within a given “family” of systems

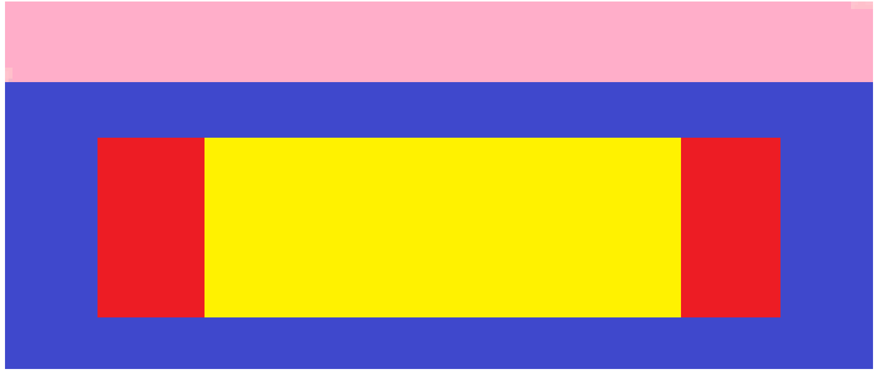
Main global parameters of the analyzed fast reactors



Layout ASTRID



Layout ESFR-SMART



Layout SPX

- Inner fissile region
- Outer fissile region
- Fertile Blankets
- Sodium plenum

2. Methodology for sensitivities

SCALE 6.2.3 or SCALE 6.1.3

Multiplication factor sensitivities:

- 1st order perturbation theory
- TSUNAMI-3D CE (CLUTCH) or TSUNAMI-3D MG

Reactivity coefficient sensitivities:

- Eigenvalue-difference responses
- TSAR module

ND libraries for transport:

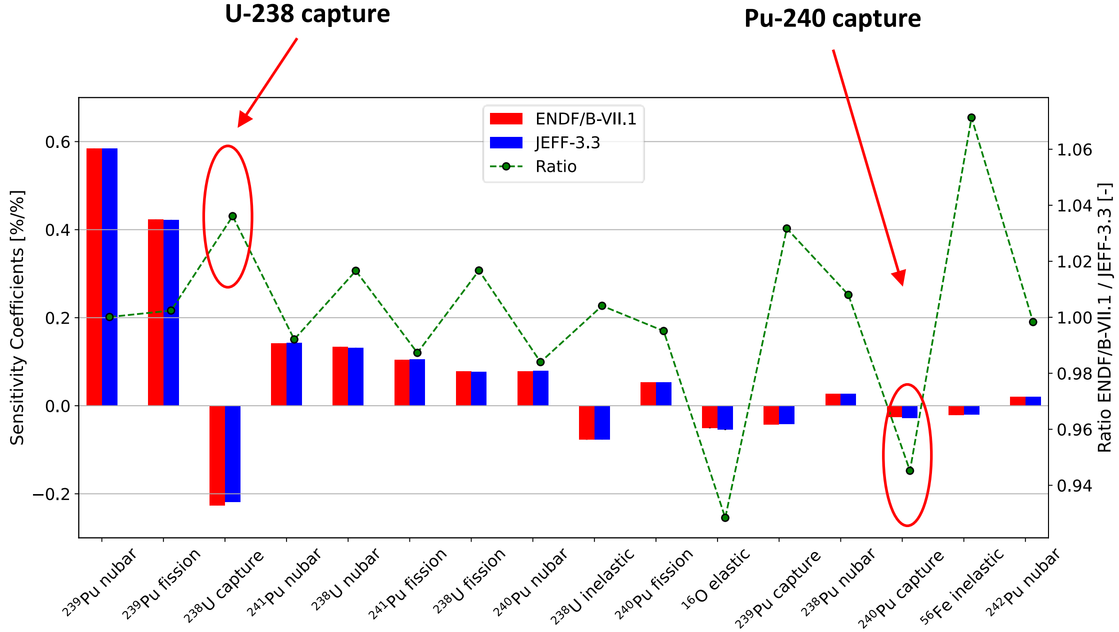
- CE JEFF-3.1.1 (AMPX-processed at UPM): sensitivities provided in 33g
- 252g ENDF/B-VII.1 (sensitivities in 252g), 238g ENDF/B-VII.0 (sensitivities provided in 238g)

2. Methodology for sensitivities

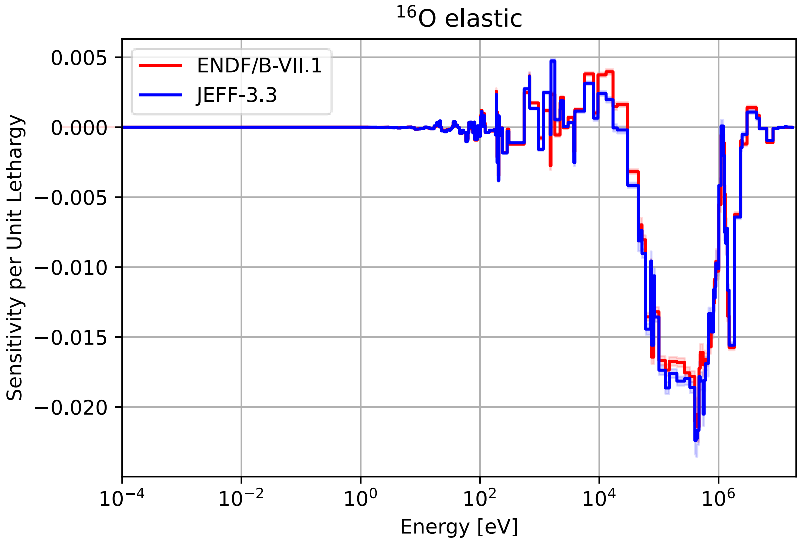
Bias analysis in sensitivity coefficients arising from nuclear data, methods and modelling approximations

1 Nuclear data

When performing UQ with the same covariances, overall uncertainty is quite similar but special attention should be paid to specific contributors



Top 16 integrated multiplication factor sensitivity coefficients for a supercell model determined with TSUNAMI-3D CE using different nuclear data libraries



Multiplication factor sensitivity profiles of the O-16 elastic for both ENDF/B-VII.1 and JEFF-3.3 nuclear data libraries

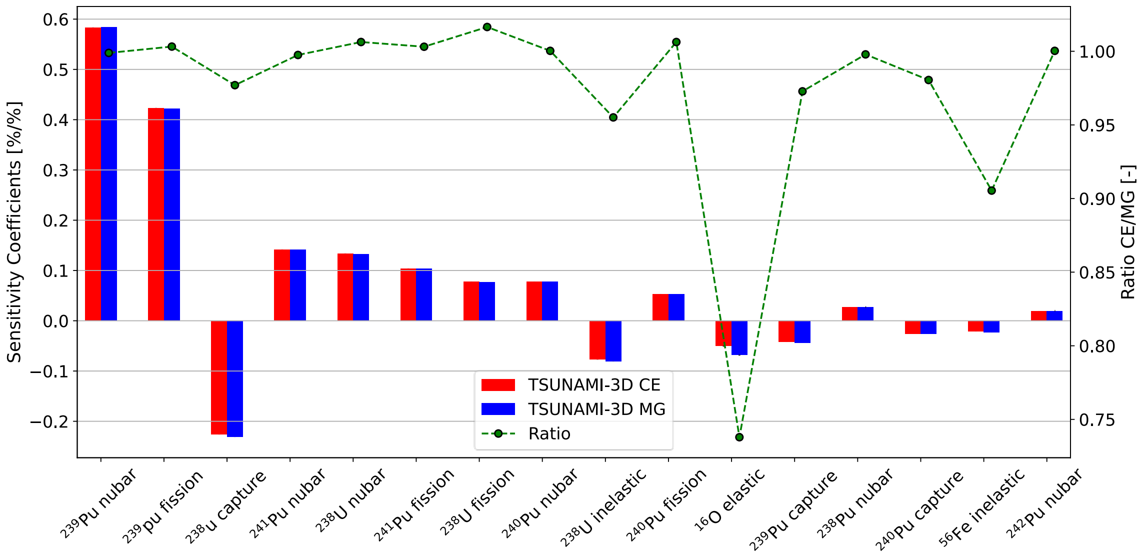
*A. Jiménez Carrascosa, N. García-Herranz, O. Cabellos, "On the characterization of biases arising from methods and approximations used for sensitivity analyses", to be presented at PHYSOR2022, May 15-20, 2022.

2. Methodology for sensitivities

Bias analysis in sensitivity coefficients arising from nuclear data, methods and modelling approximations

2 Methods

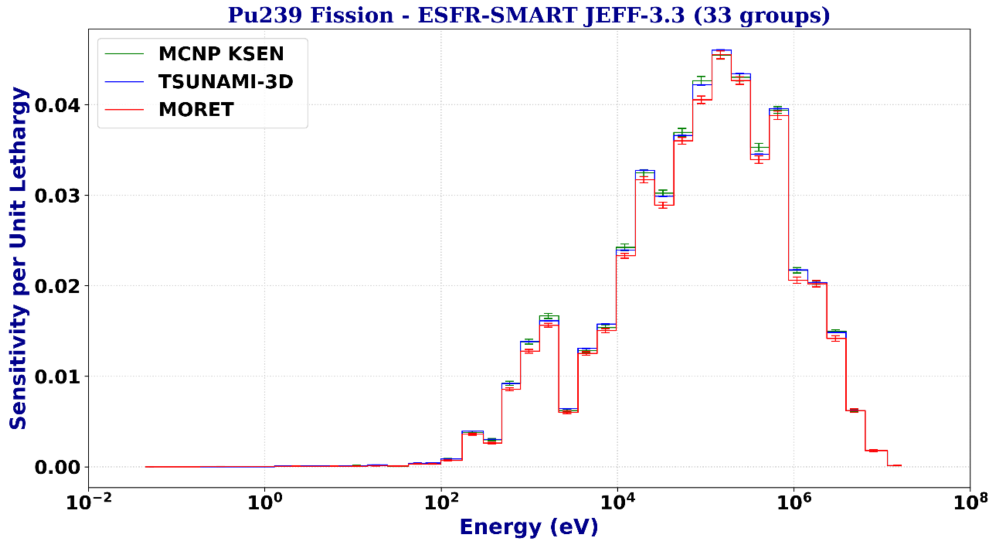
Comparison TSUNAMI-3D CE vs. TSUNAMI-3D MG



Top 16 integrated multiplication factor sensitivity coefficients with TSUNAMI-3D CE and TSUNAMI-3D MG for the heterogenous supercell model

Negligible deviations between TSUNAMI-3D CE and MG except for scattering cross-sections, that cannot be only explained by statistical errors (further investigation required)

Comparison TSUNAMI-3D CE vs. MCNP KSEN *



Sensitivity profiles of ESFR keff to the Pu239 fission cross section with MCNP KSEN, TSUNAMI-3D CE (CLUTCH) and MORET

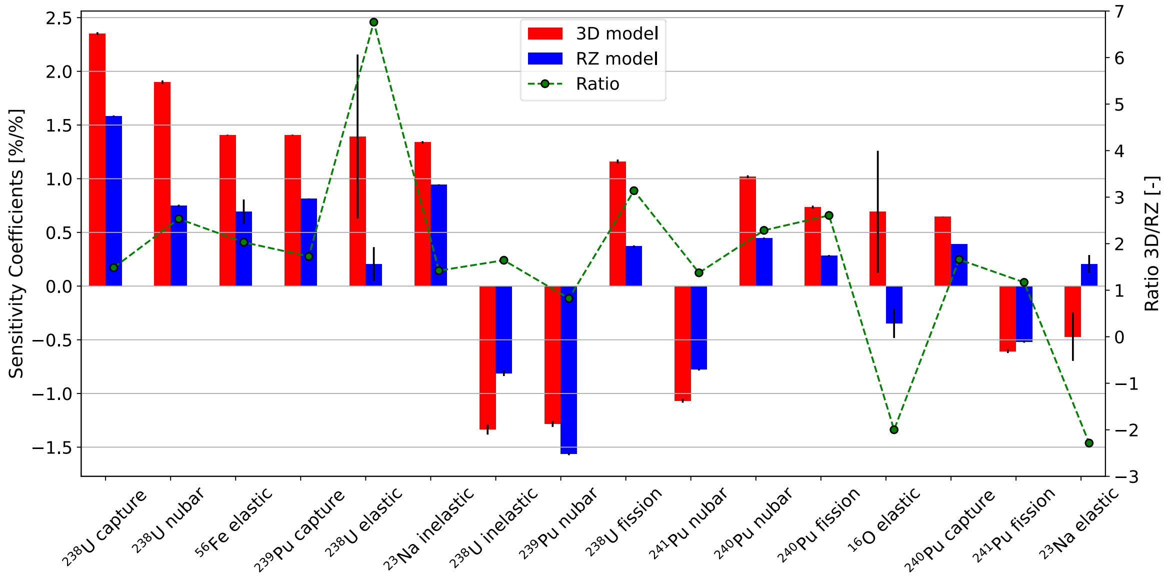
MCNP and TSUNAMI-3D CE sensitivities within ~1%.
The poorest agreement for scattering reactions

*S. Panizo et al., Comparison of Sensitivity/Uncertainty analysis methodologies in the ESFR. 46th Annual Meeting SNE, 6-8 Oct. 2021

2. Methodology for sensitivities

Bias analysis in sensitivity coefficients arising from nuclear data, methods and modelling approximations

❸ Modelling



Top 16 integrated full sodium void worth sensitivity coefficients determined with TSUNAMI-3D CE for the heterogeneous 3D and RZ models

Uncertainties in multiplication factor and reactivity effects

Parameter	Heterogenous 3D model	Homogeneous RZ model
Multiplication factor	1.417%	1.412%
Control rod worth	2.642%	2.818%
Na void: full void	32.620%	18.418%

3D heterogeneous models required for reactivity coefficient sensitivities; R-Z models only accurate enough to obtain k-eff sensitivities

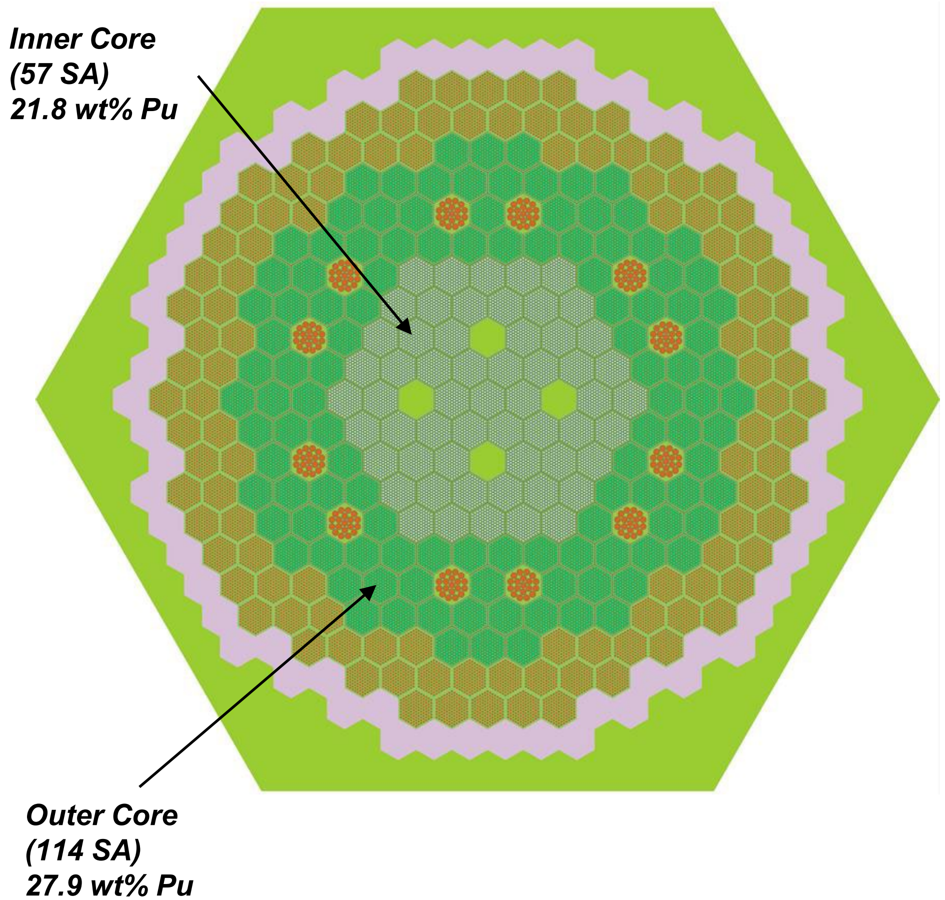
Conclusions in agreement with:

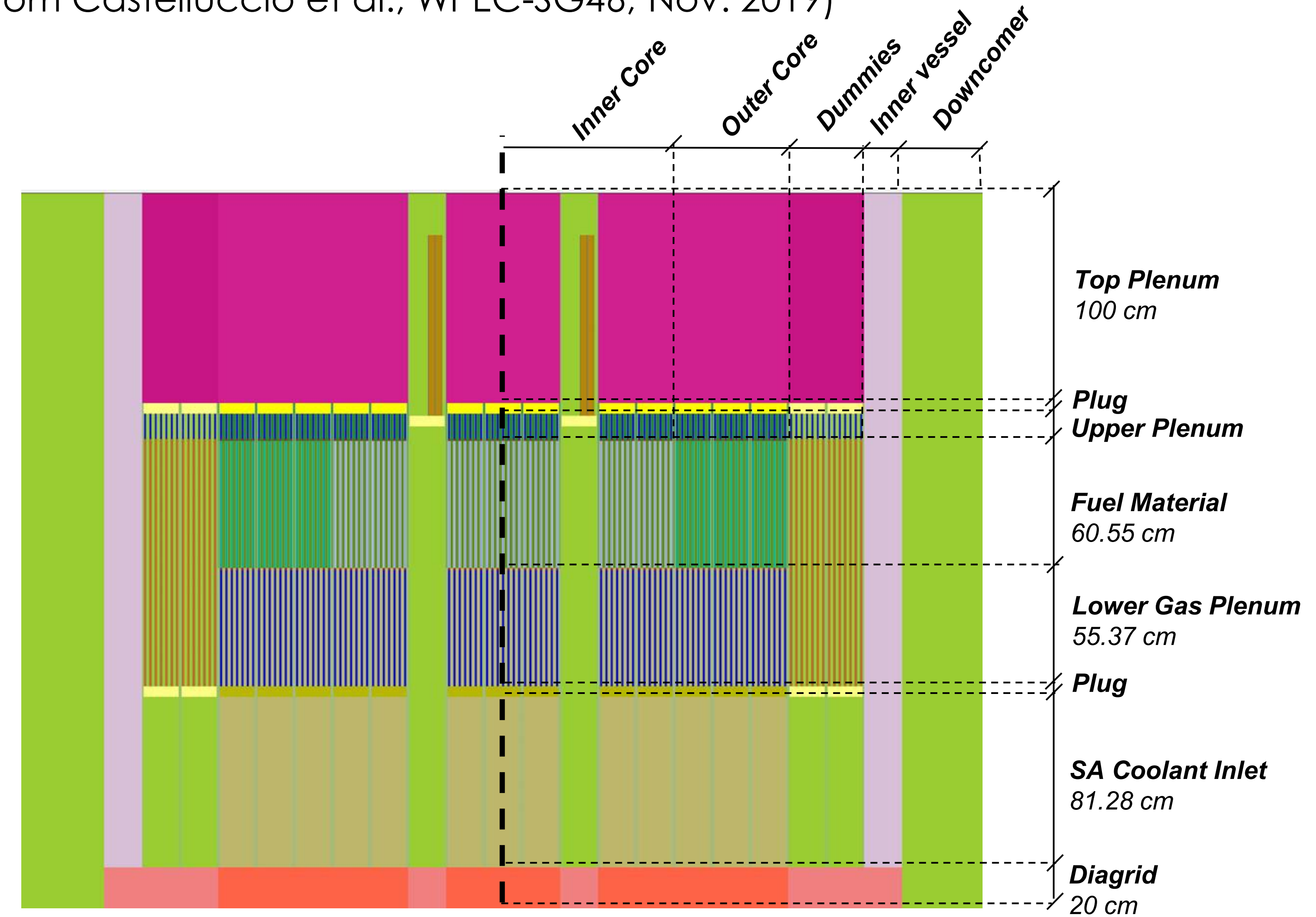
G. Aliberti et al., Impact on sensitivity coefficients of typical approximations used in scoping sensitivity analysis, In Proc. Int. Conf. on Mathematics and Computational Methods applied to Nuclear Science and Engineering, Rio de Janeiro (Brazil) May 8-12, 2011.

Option preferred: 3D heterogeneous models with TSUNAMI-3D MG

3. Modelling: ALFRED

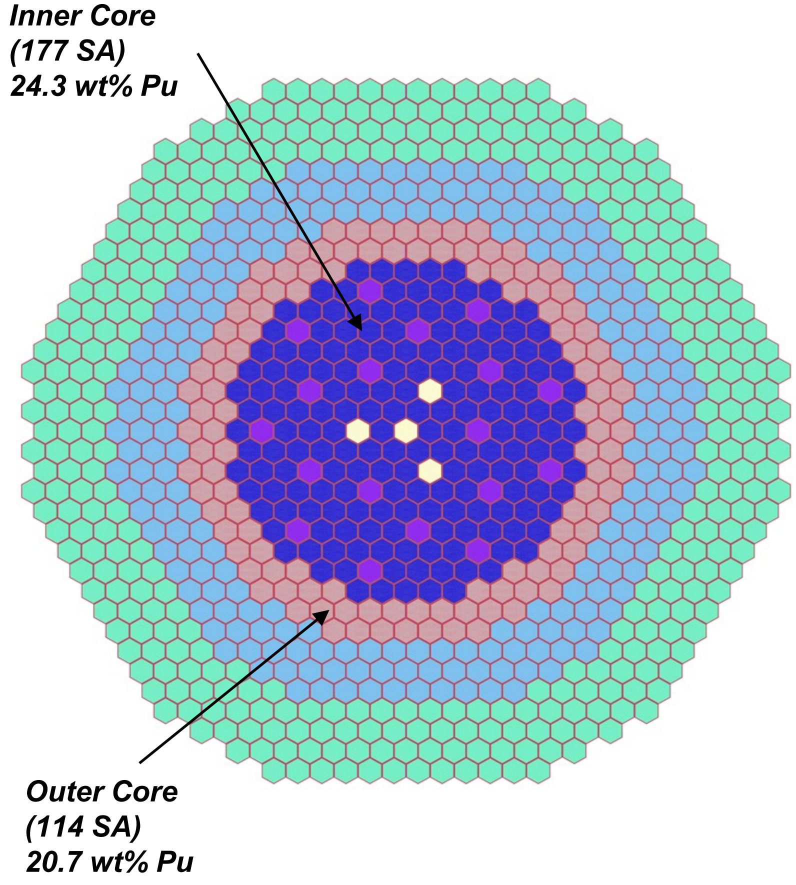
- **Reference:** G. Grasso et al., FP7 ESNII+ Project, deliverable D6.1.1-3, 2014 and Grasso et al., 2014, Nuc. Eng. Des. 278 (Specifications slightly different from Castelluccio et al., WPEC-SG46, Nov. 2019)
- **Model:** 3D Heterogeneous at BoC

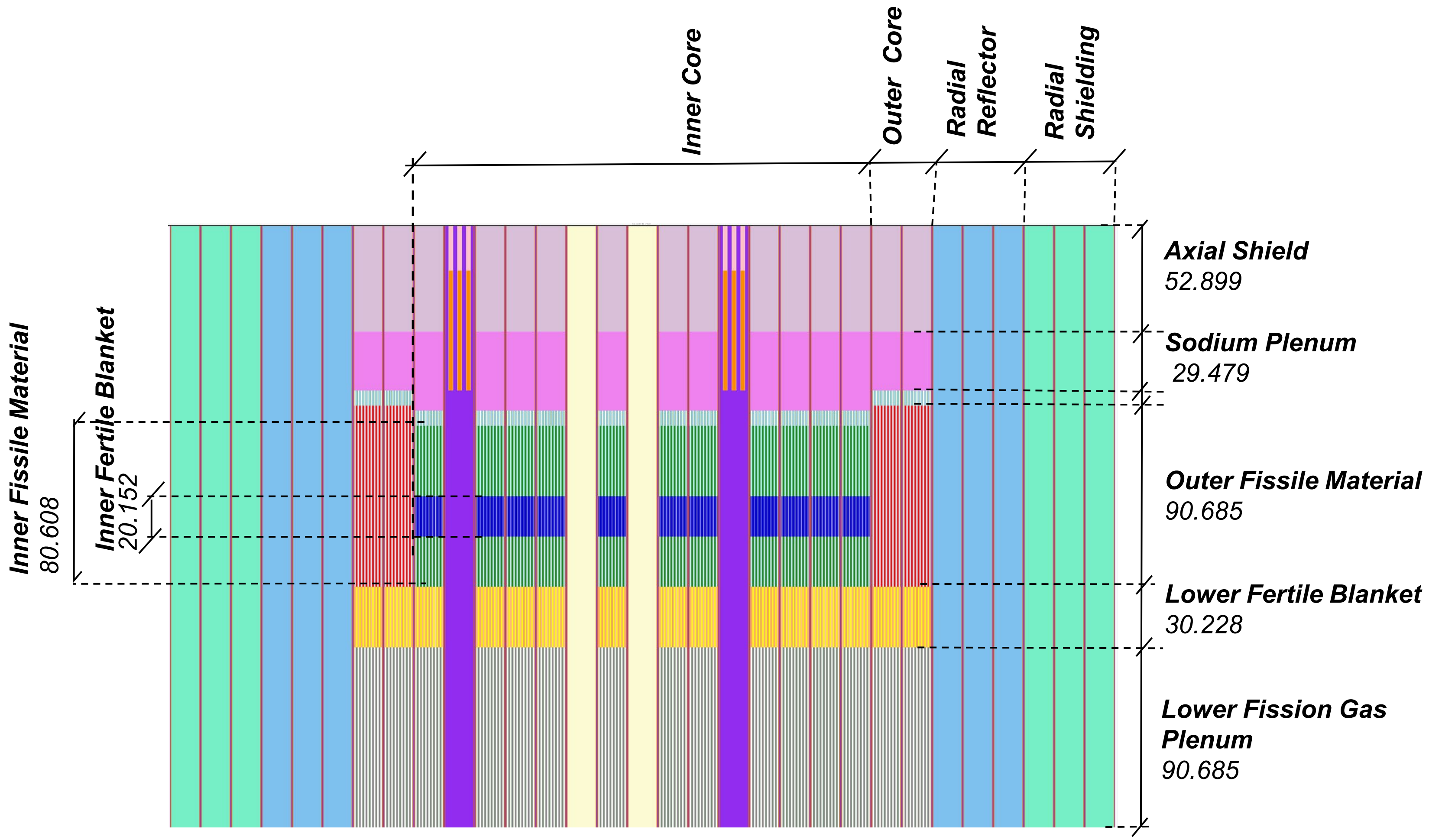




3. Modelling: ASTRID-like

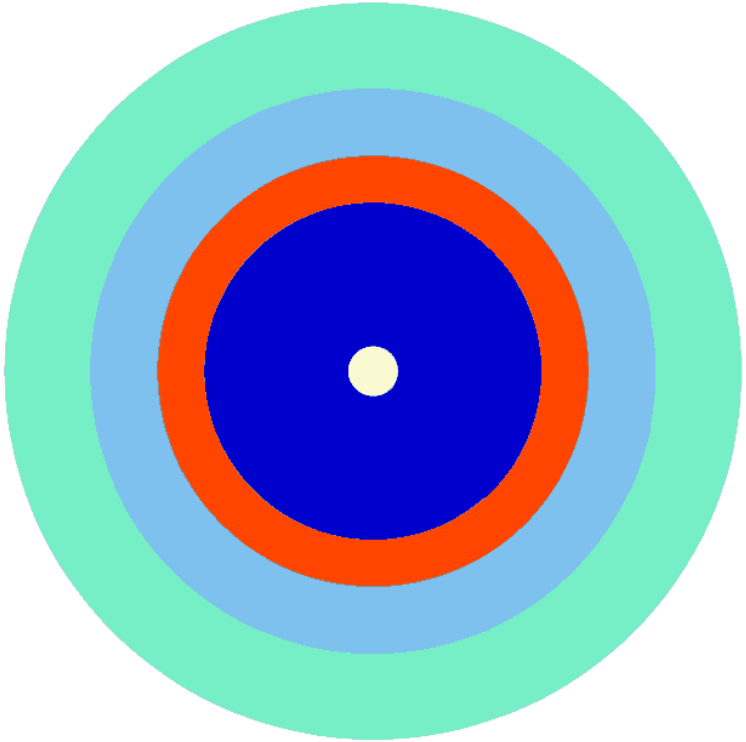
- **Reference:** P. Sciora, FP7 ESNII+ Project, deliverable D6.1.1-1, 2014 and L. Buiron et al., WPRS SFR UAM, 2019
- **Model:** 3D Heterogeneous at EoC

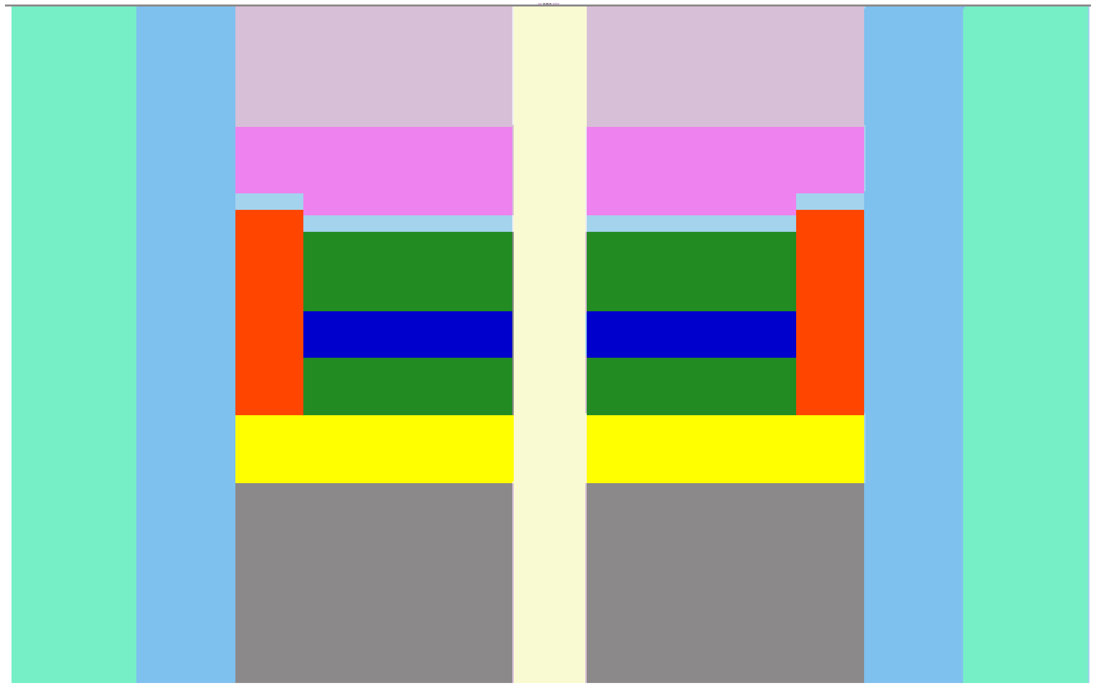




3. Modelling: ASTRID-like

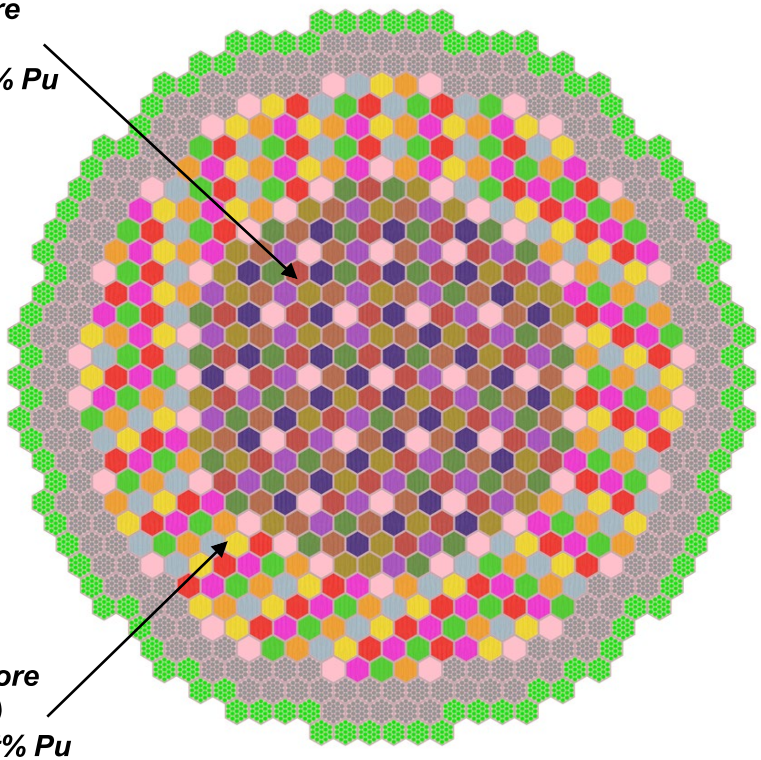
- **Reference:** A. Martínez, N. García-Herranz, available at WPEC/SG46 (sent to M. Fleming on 8/11/2019)
- **Model:** Homogeneous R-Z at EoC, dimensions and materials provided in an Excel spreadsheet

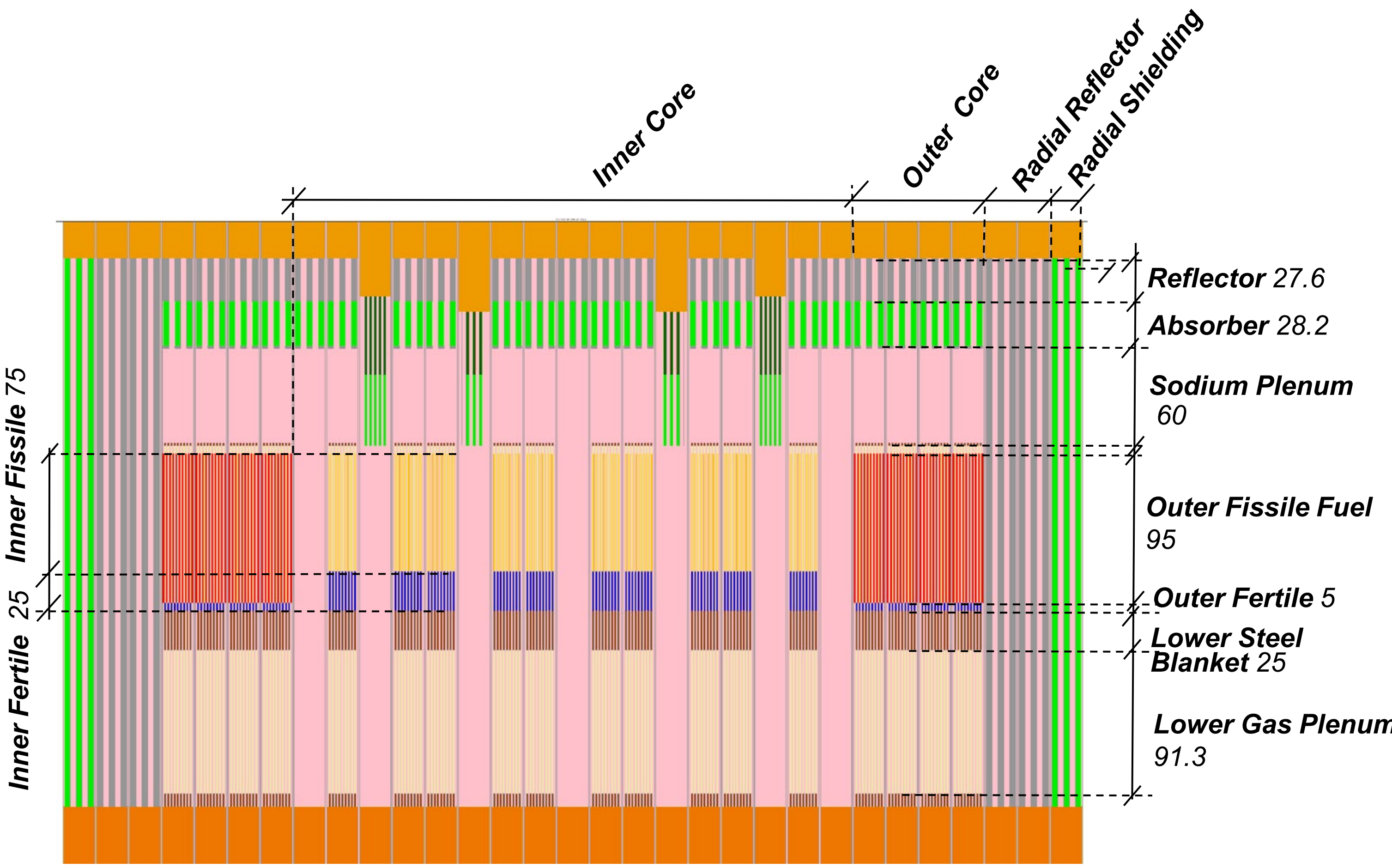




3. Modelling: ESFR

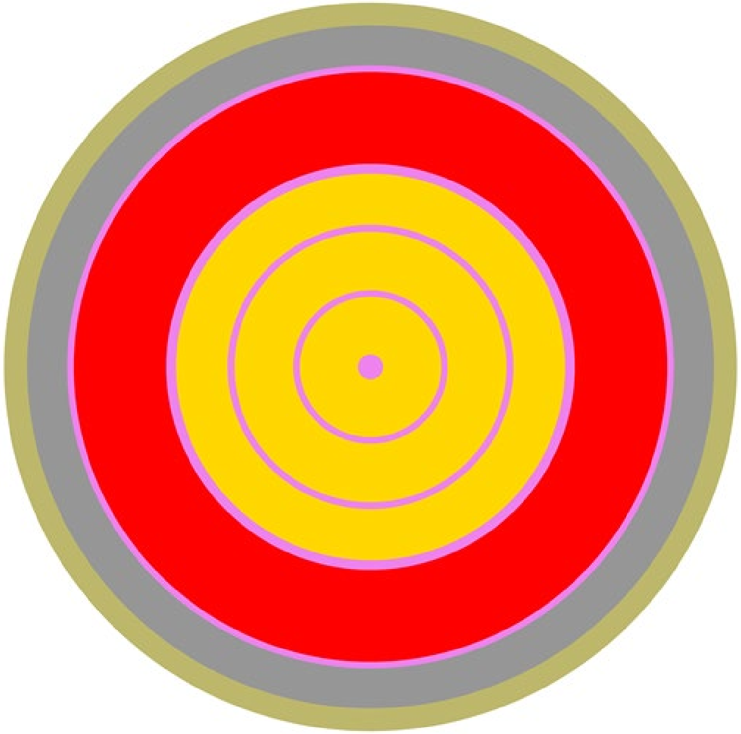
- **Reference:** A. Rineiski et al., H2020 ESFR-SMART Project, D1.1.2, for the heterogeneous core
- **Model:** 3D Heterogeneous at EoC

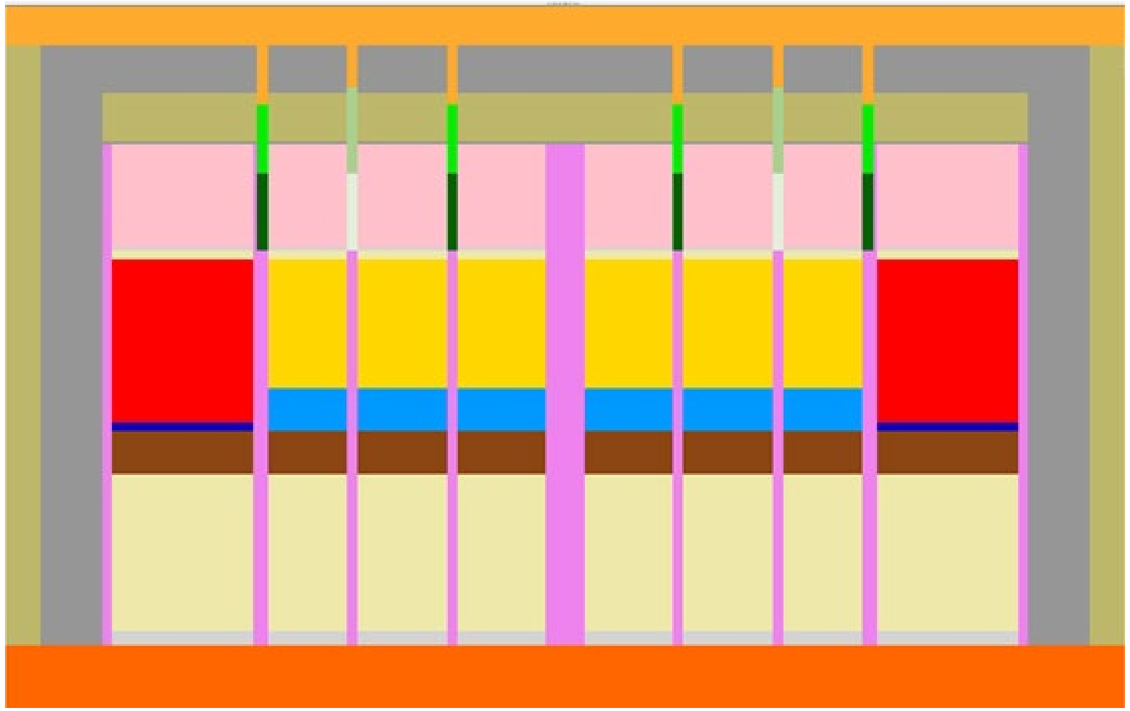




3. Modelling: ESFR

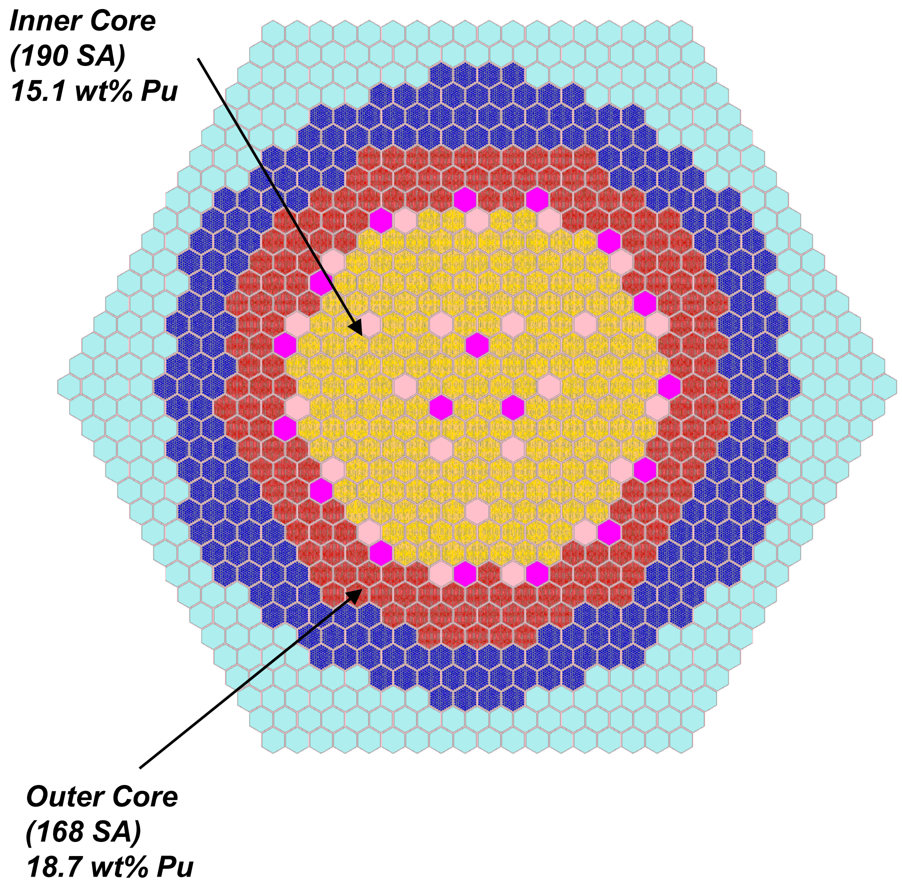
- **Reference:** A. Jiménez-Carrascosa, N. García-Herranz N., available at WPEC/SG46, 2020
- **Model:** Homogeneous R-Z at EoC, dimensions and materials provided in an Excel spreadsheet

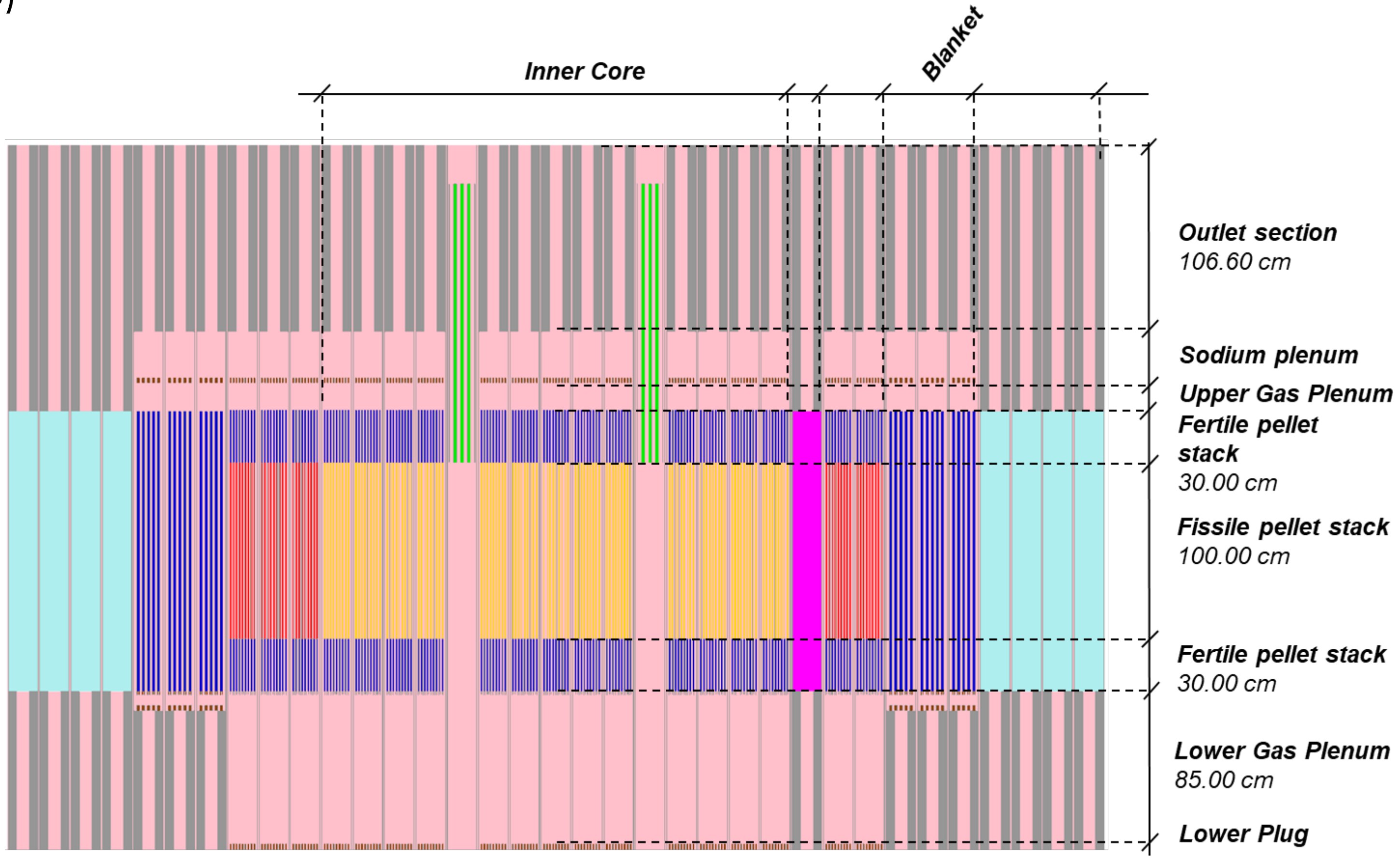




3. Modelling: Superphénix

- **Reference:** A. Ponomarev et al., *Superphénix Benchmark Part I: Results of Static Neutronics*, Journal of Nuclear Engineering and Radiation Science, Vol. 8, 2022 (DOI: 10.1115/1.4051449)
- **Model:** 3D Heterogeneous BoL (start-up tests)





*As-fabricated axial dimensions

4. Sensitivities available

	ALFRED [1]	ASTRID [2]		ESFR [3, 4]		SPX
Code version	SCALE 6.1.3	SCALE 6.1.3	SCALE 6.1.3	SCALE 6.2.3	SCALE 6.2.3	SCALE 6.2.3
Modelling	3D heterog.	3D heterog.	R-Z	3D heterog.	R-Z	3D heterog.
Condition	BoC	EoC	EoC	EoC	EoC	BoL
Methodology	TSUNAMI-3D MG	TSUNAMI-3D MG	TSUNAMI-3D MG	TSUNAMI-3D MG	TSUNAMI-3D CE	TSUNAMI-3D MG
Nuclear data for transport	238g ENDF/B-VII.0	238g ENDF/B-VII.0	238g ENDF/B-VII.0	252g ENDF/B-VII.1	CE JEFF-3.1.1	252g ENDF/B-VII.1
Sensitivities in	238g	238g	238g	252g	33g	252g
Evaluated parameters	k-eff Coolant density (±20% inner zone) Doppler (±300K)	k-eff Sodium void scenarios	k-eff	k-eff Sodium void scenarios Doppler (±300K) Control rod	k-eff	Ongoing

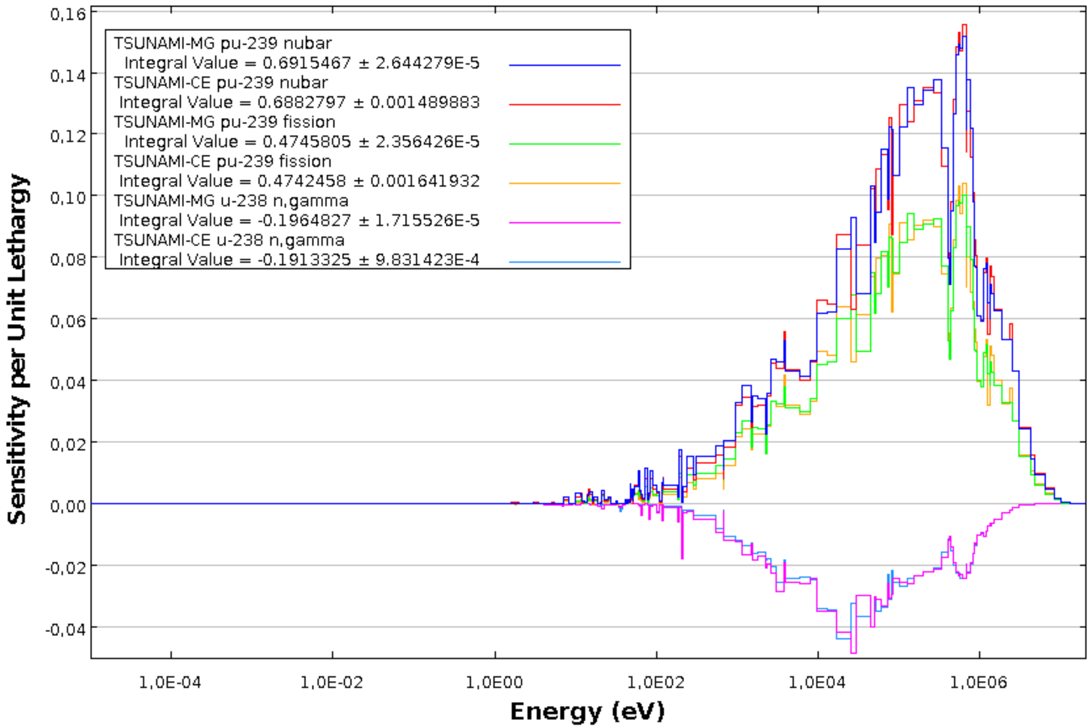
[1] Sensitivities for ALFRED: G. Grasso et al., "*Stress-testing the ALFRED design – Part I: Impact of nuclear data uncertainties on Design Extension Conditions Transients*," Prog. Nucl. Energ. 106 (2018) 372-386.

[2] Sensitivities for ASTRID: N. García-Herranz et al., "*Nuclear data sensitivity and uncertainty assessment of sodium voiding reactivity coefficients of an ASTRID-like SFR*," EPJ Web of Conf. 146 (2017) 09006.

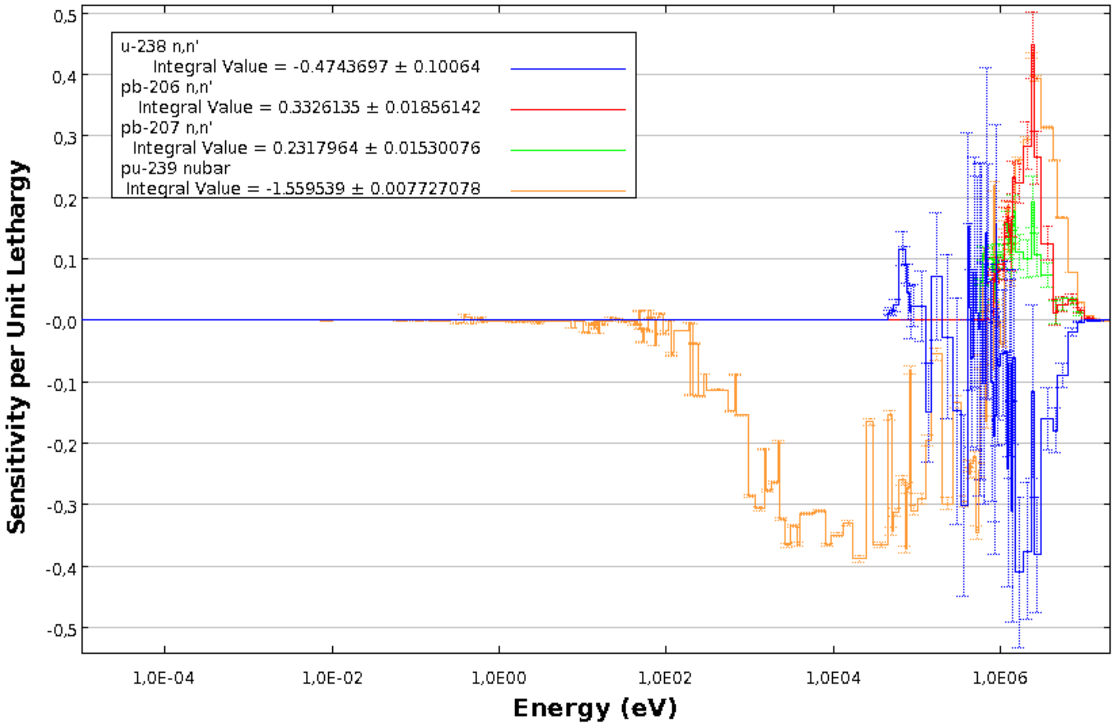
[3] Sensitivities for ESFR: N. García-Herranz et al., "*UPM contribution to EU SANDA Project, D5.2: Report on ESFR, ASTRID and ALFRED sensitivity and impact studies*", 2022

[4] Sensitivites for R-Z ESFR: A. Jiménez-Carrascosa et al., "*Nuclear data S/U analysis for reactor physics parameters of the ESFR*", Proceedings of the ENYG Forum 2021

4. Sensitivities available: examples for ALFRED



Sensitivity profiles for k-eff computed with MG and CE TSUNAMI-3D

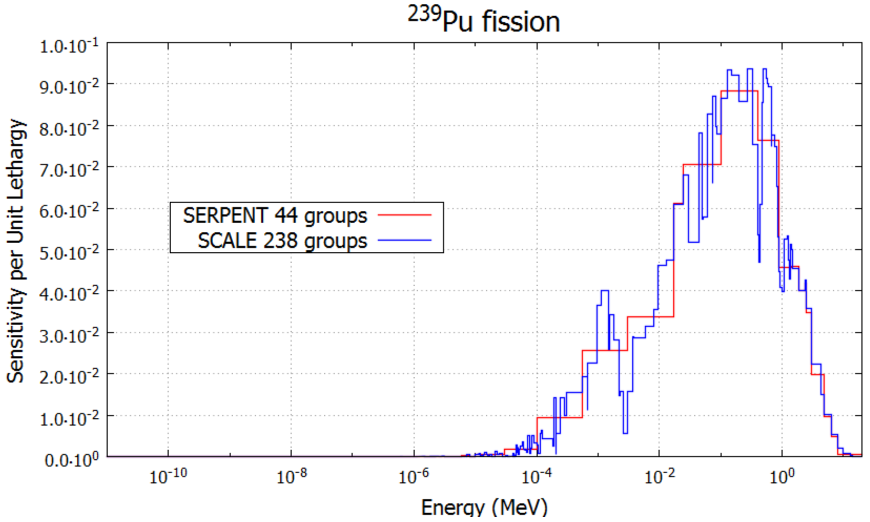


Sensitivity profiles for coolant decrease (-20%) at the inner active region

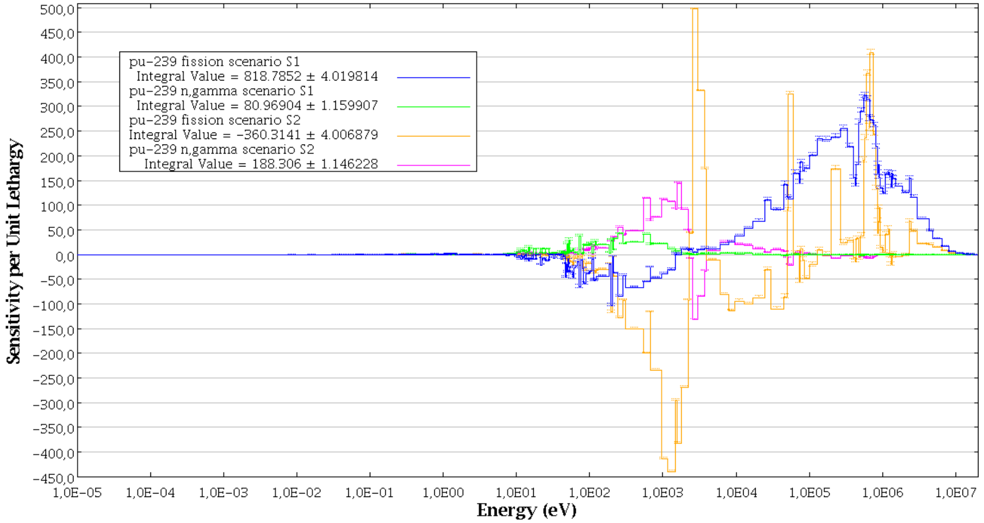
Large statistical uncertainties in sensitivities with respect to scattering cross-sections

4. Sensitivities available: examples for ASTRID

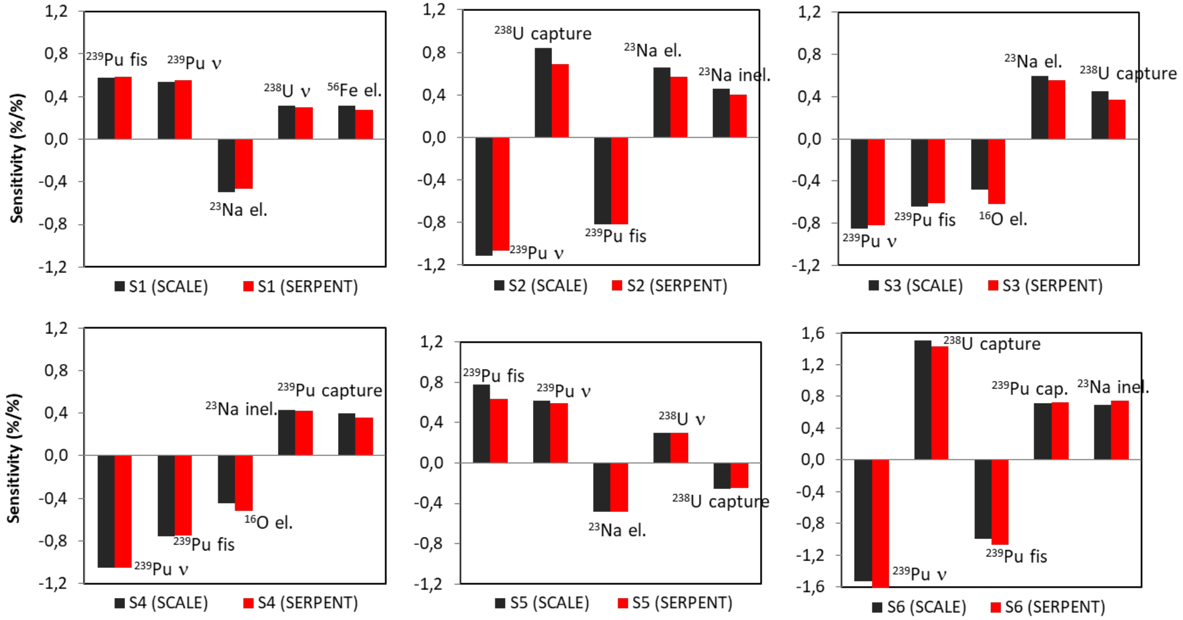
The largest discrepancies between SCALE and SERPENT are for ^{238}U capture and elastic xs

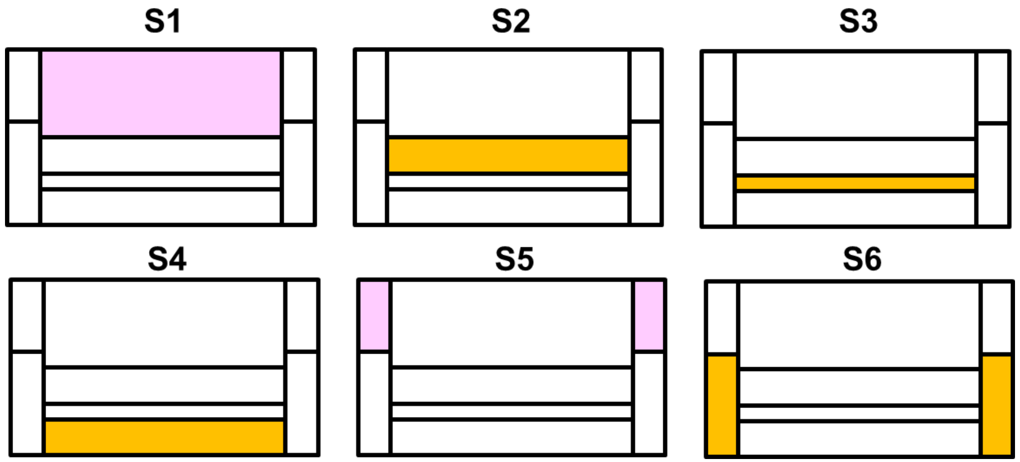


Sensitivity profiles for k-eff computed with MG TSUNAMI-3D and SERPENT

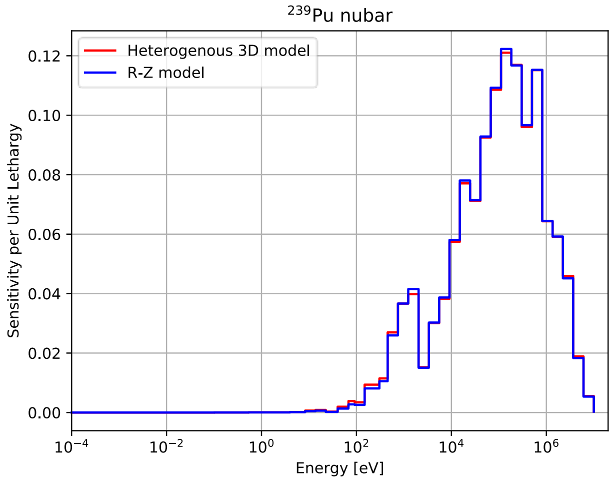


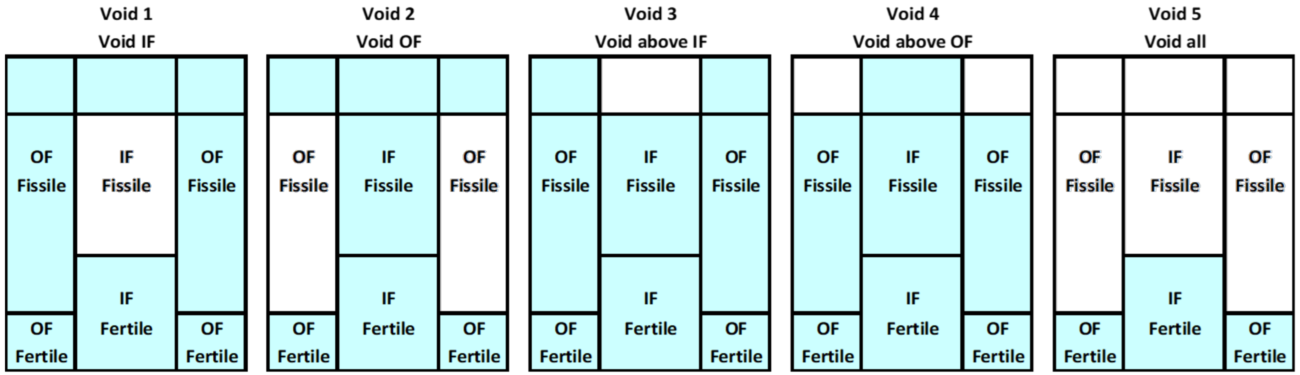
Sensitivity profiles for sodium void worth with MG TSUNAMI-3D

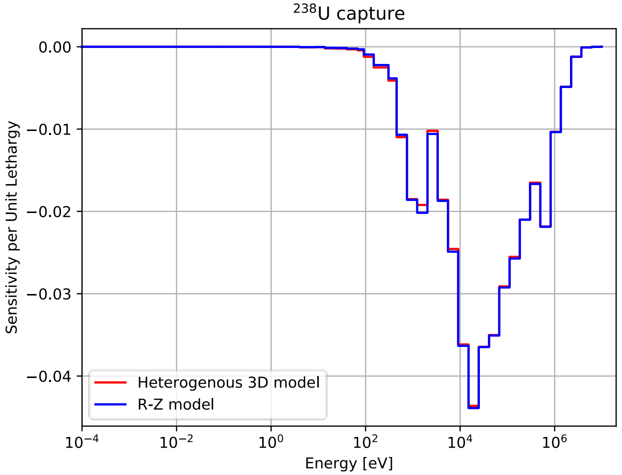


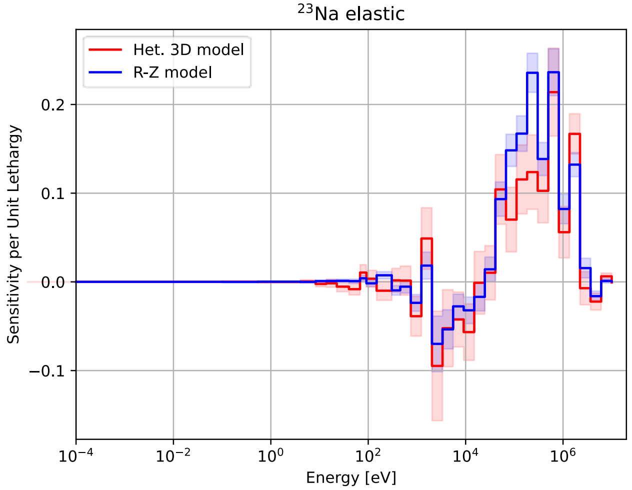


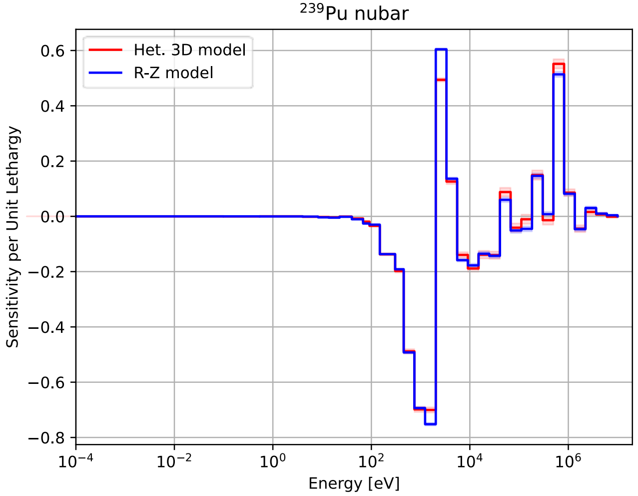
4. Sensitivities available: examples for ESFR











Sensitivity profiles for k-eff for the heterogeneous 3D and R-Z models

Sensitivity profiles for sodium void worth for the heterogeneous 3D and R-Z models

5. Summary

- **Sensitivities in .sdf format** available for ALFRED and different concepts of SFR: ASTRID-like, ESFR, SPX (soon)
  - All MOX-fuelled
  - No sensitivities to P1 angular scattering
  - Low confidence in reactivity coefficient sensitivities to scattering cross sections: poor precision (large statistical errors) and/or poor accuracy (systematic errors)

- For k-eff and different safety-related reactivity effects (not a complete list)

- Computed with 3D heterogeneous models and TSUNAMI-3D MG, but also provided with R-Z models for some cases