SCALE Open Mic: How I use SCALE for my work?

Use of SCALE for the analysis of Sodium Fast Reactors

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Use of SCALE for the analysis of Sodium Fast Reactors

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2. Processing of JEFF libraries (AMPX)
3. Neutronic performance of SFRs (KENO-VI)
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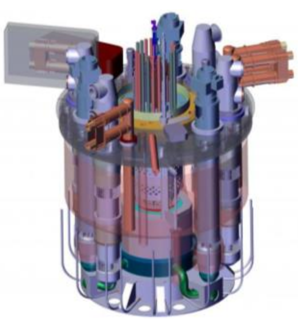
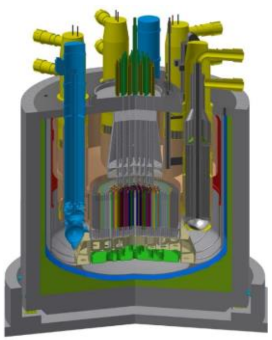
1. Introduction

In recent years, UPM has contributed to different European R&D projects using SCALE as main computational system.

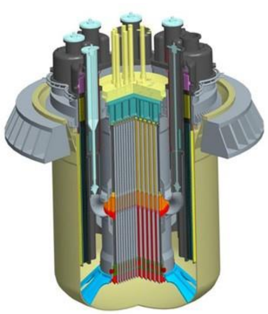
We have been focused on Sodium-cooled (ASTRID, ESFR) and Lead-cooled (MYRRHA and ALFRED) advanced fission systems.



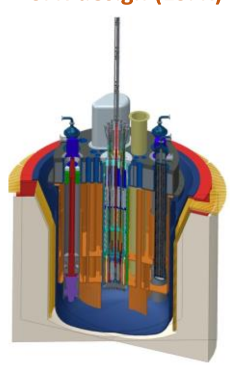
SFR prototype (ASTRID)



SFR design (ESFR)



LFR demonstrator (ALFRED)



LFR pilot plant (MYRRHA)

ESNII+

CHANDA
SOLVING CHALLENGES IN NUCLEAR DATA FOR THE SAFETY OF EUROPEAN NUCLEAR FACILITIES

SANDA
SUPLYING ACCURATE NUCLEAR DATA FOR ENERGY AND NON-ENERGY APPLICATIONS

ESFR-SMART
sodium fast reactor safety

1. Introduction

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We have been focused on Sodium-cooled (ASTRID, ESFR) and Lead-cooled (MYRRHA and ALFRED) advanced fission systems.

SCALE has been extensively used during the recent ESFR-SMART project and we contributed to the neutronic characterization of the most recent European Sodium Fast Reactor (ESFR) design.

ESFR-SMART
sodium fast reactor safety

https://esfr-smart.eu/

2. Processing of JEFF libraries (AMPX)

JEFF ND libraries targeted the needs for the SFR development programmes. JEFF-3.1 library was the reference library within the ESFR-SMART project. Thus, we addressed the processing of CE **JEFF-3.1** library.

Results included in this presentation were mainly obtained based on JEFF-3.1 library, which was processed with AMPX (SCALE-6.2.3).

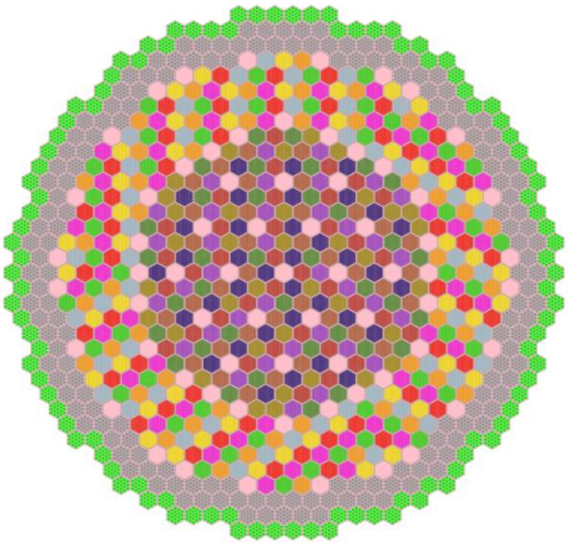
JEFF-3.3 library contains new evaluations for sodium and lead. Then, we also considered including that library to our calculation scheme:

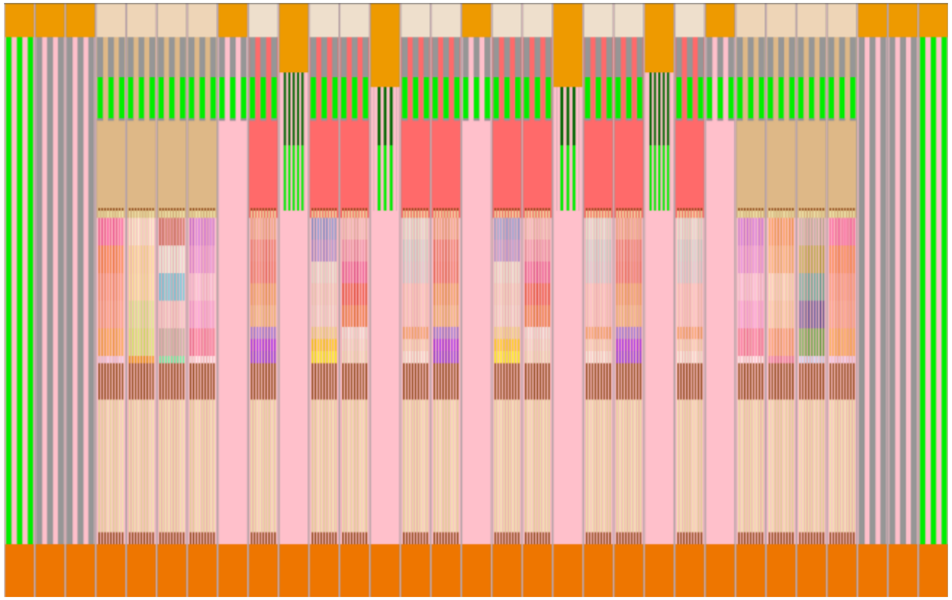
- AMPX processing in the frame of SCALE6.3b11 version (URR issue solved!).
- CE library is being tested using a set of around 200 criticality experiments. Relevant deviations are found for some benchmarks (conference paper under preparation).
- Associated covariance libraries were also generated and checked against NJOY-processed libraries.

A. Jiménez-Carrascosa, O. Cabellos, C.J. Díez, N. García-Herranz, 2021. "**Processing of JEFF nuclear data libraries for the SCALE Code System and testing with criticality experiments**", to be submitted to Spanish Nuclear Society Annual Meeting, Granada (Spain). .

3. Neutronic performance of SFRs (KENO-VI): ESFR model

Heterogeneous 3D full core model developed in SCALE



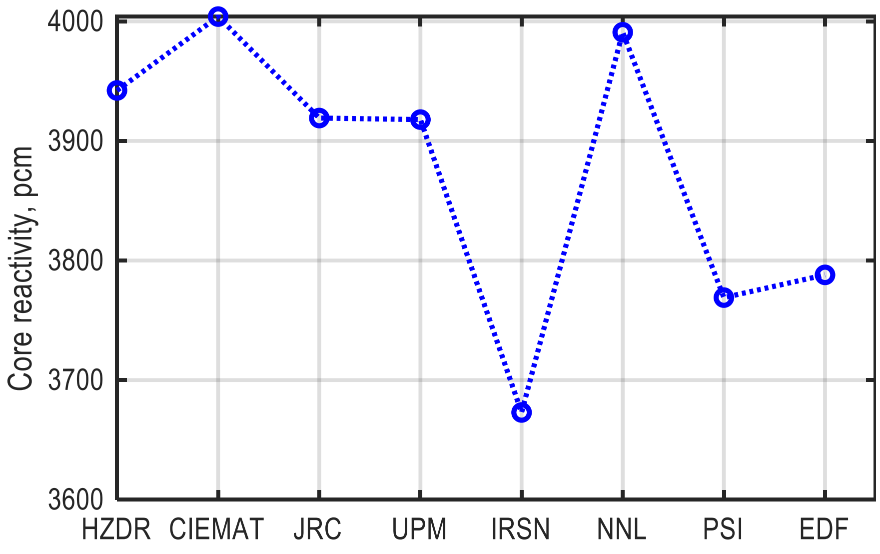


A. Jiménez-Carrascosa, N. García-Herranz, **"European Sodium Fast Reactor model"**, 2020 SCALE Users' Group Workshop: Best SCALE Model Contest.

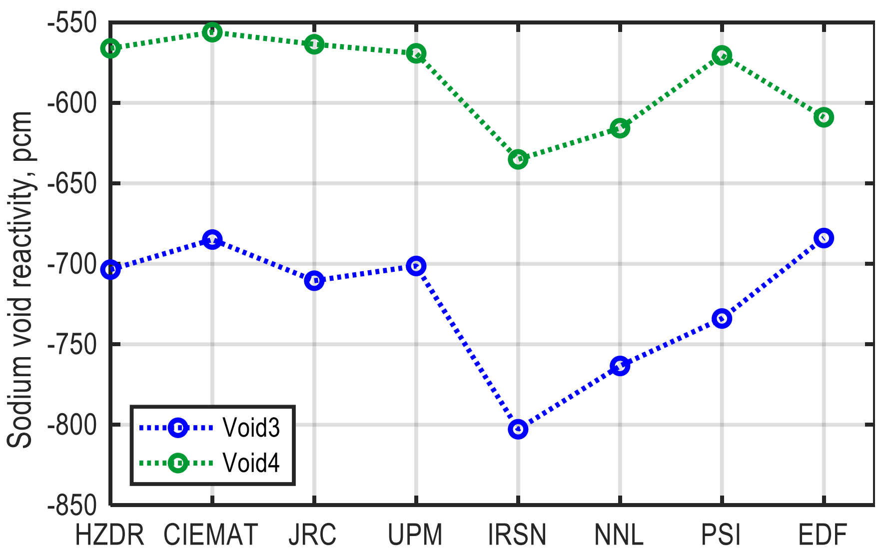
3. Neutronic performance of SFRs (KENO-VI): ESFR

Verification Code benchmarking for the ESFR at BoL. KENO-VI was used for its neutronic characterization: core reactivity, control rod worth, sodium void reactivity and Doppler constants.

KENO-VI performs direct full calculations using 3D heterogeneous geometry models and CE nuclear cross sections data (JEFF-3.1). In KENO-VI criticality calculations, sufficient number of histories were considered so standard deviations of multiplication factor is lower than 5 pcm.



Core reactivity at BoL



Sodium void reactivity corresponding to plenum void scenarios.

E. Fridman et al., 2022. "**Neutronic analysis of the European Sodium Fast Reactor: Part I – fresh core results**", Journal of Nuclear Engineering and Radiation Science, vol. 8(1).

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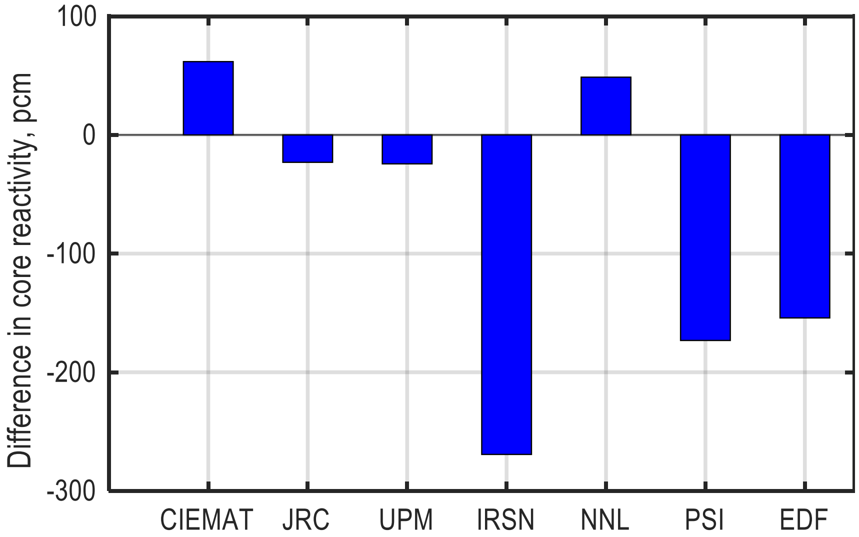
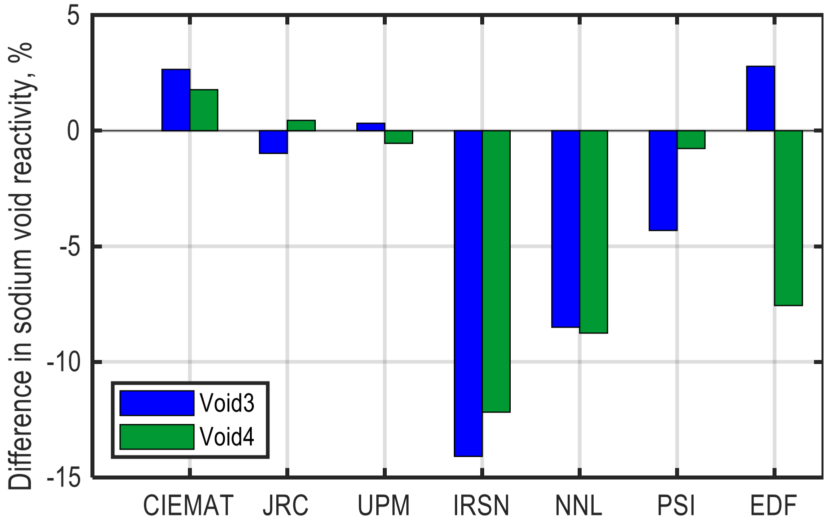


Core reactivity at BoL



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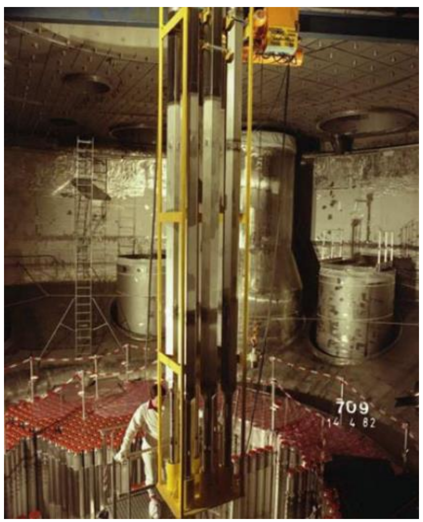
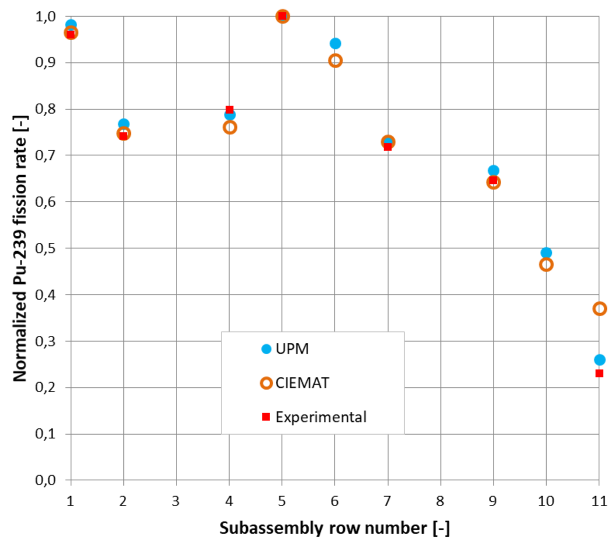
3. Neutronic performance of SFRs (KENO-VI): SPX benchmark

Validation Benchmarking using selected legacy data: Superphènix start-up tests.

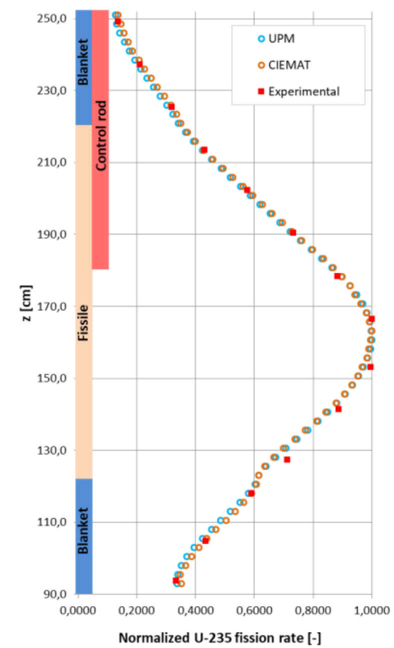
In the frame of the ESFR-SMART project, a comprehensive benchmark was carried out for cross validation of the tools used along the project. That benchmark, based on the Superphènix start-up core, was a great opportunity to test the applicability of KENO-VI to large SFR cores. A large set of cases were defined: criticality, reactivity coefficients, control rod worth curve, power distribution, reaction rates,…



Guidez, J. and Prêle, G., 2017. *Superphénix: Technical and Scientific Achievements*. Atlantis Press and the author(s), ISBN 978-94-6239-246-5, 2017.



Normalized radial Pu-239 fission rate in the upper blanket.



Normalized axial U-235 fission rate in a selected subassembly.

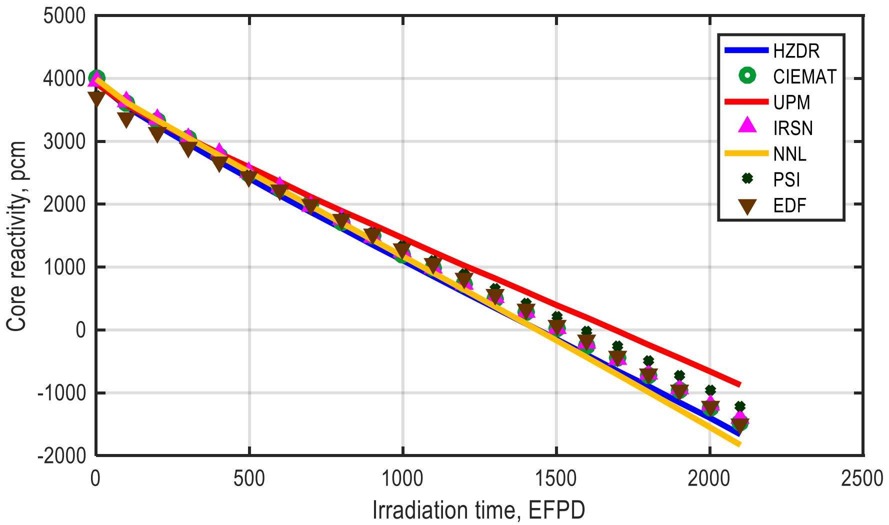
A. Ponomarev et al., 2022. "**SPX Benchmark Part I: Results of Static Neutronics**", Journal of Nuclear Engineering and Radiation Science, vol. 8(1).

4. Burn-up calculations (TRITON)

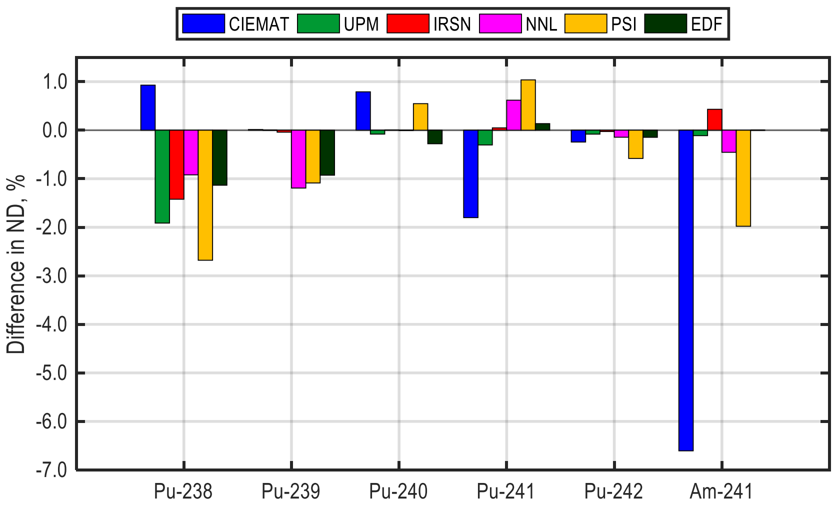
SCALE was used for performing once-through burn-up calculations: from BoL to EoL and from BoEC to EoEC. The EoEC core state is fundamental for decay heat analysis.

TRITON (t6-depl sequence), which enables the coupling between KENO-VI and ORIGEN, was applied for batch-wise burn-up calculations:

- 2100 days as length of depletion interval at an average specific power of about ~ 45 MW/MTHM
- Additional nuclides for depletion: *addnux=2*.



Core reactivity as a function of irradiation time



Differences in isotopic composition of IF-FI at EoL vs. Serpent.

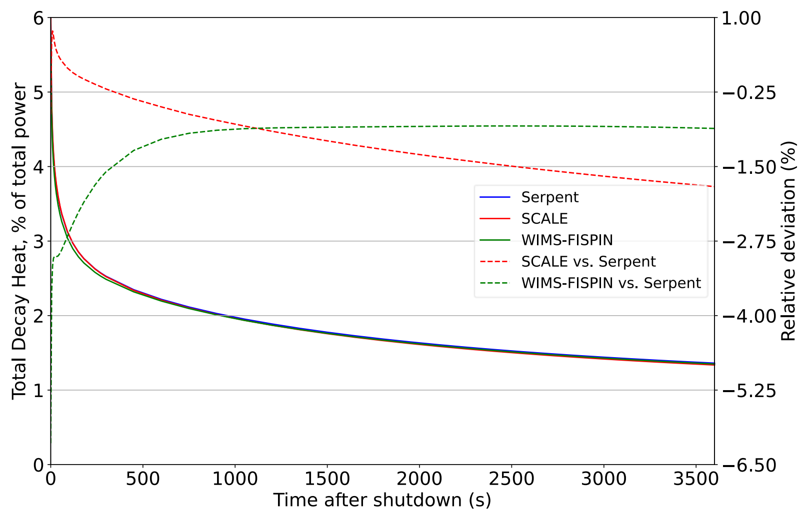
E. Fridman et al., 2022. "**Neutronic analysis of the European Sodium Fast Reactor: Part II – burnup calculations**", Journal of Nuclear Engineering and Radiation Science, vol. 8(1).

5. Decay heat characterization (ORIGEN)

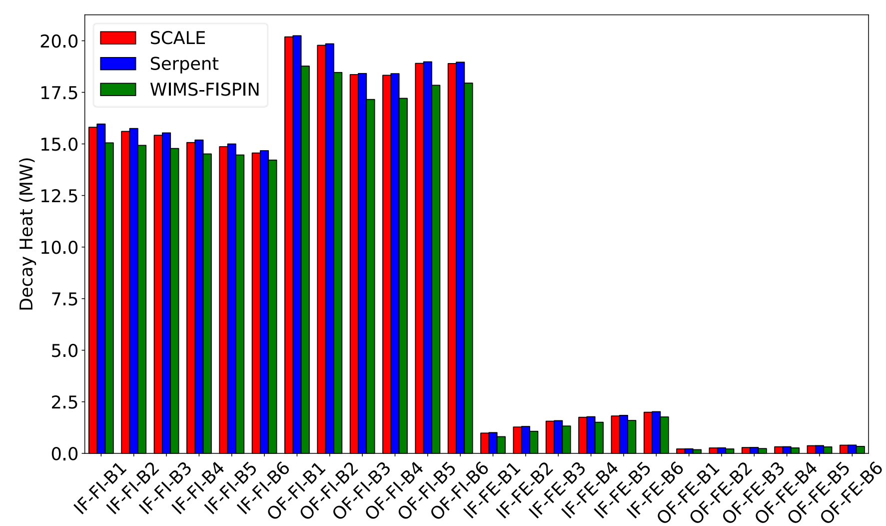
Transient analyses require a wide set of parameters as input such as a detailed description of the decay heat and its spatial and time dependence following the reactor shutdown. The explicit decay heat evaluation for the ESFR core was performed using stand-alone ORIGEN.

The decay heat calculation is divided into two steps:

- TRITON: burn-up calculation over the cycle length to account for the whole inventory at EoC.
- Stand-alone ORIGEN: nuclide decay calculation based on the inventory previously obtained.



Total decay heat normalized to power in the short-term (1 hour).



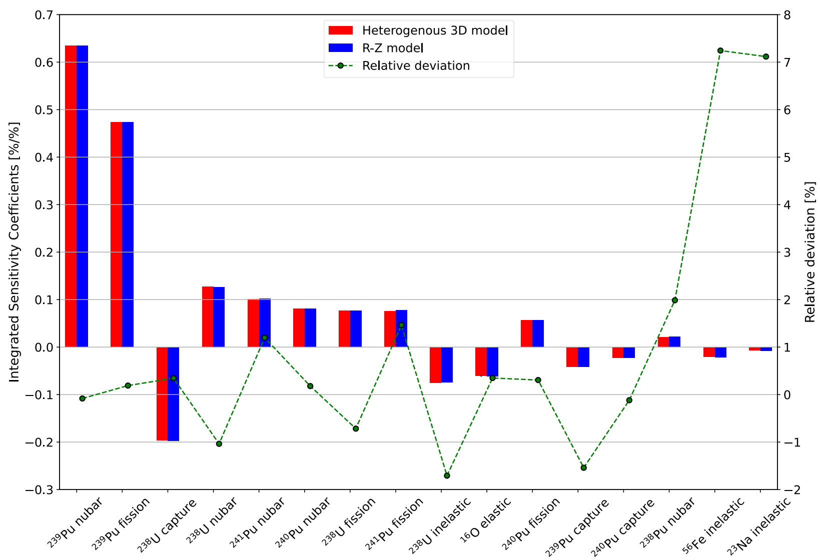
Zone-wise decay heat distribution just after shutdown.

A. Jiménez-Carrascosa et al., 2022. “**Decay heat characterization for the European Sodium Fast Reactor**”, Journal of Nuclear Engineering and Radiation Science, vol. 8(1).

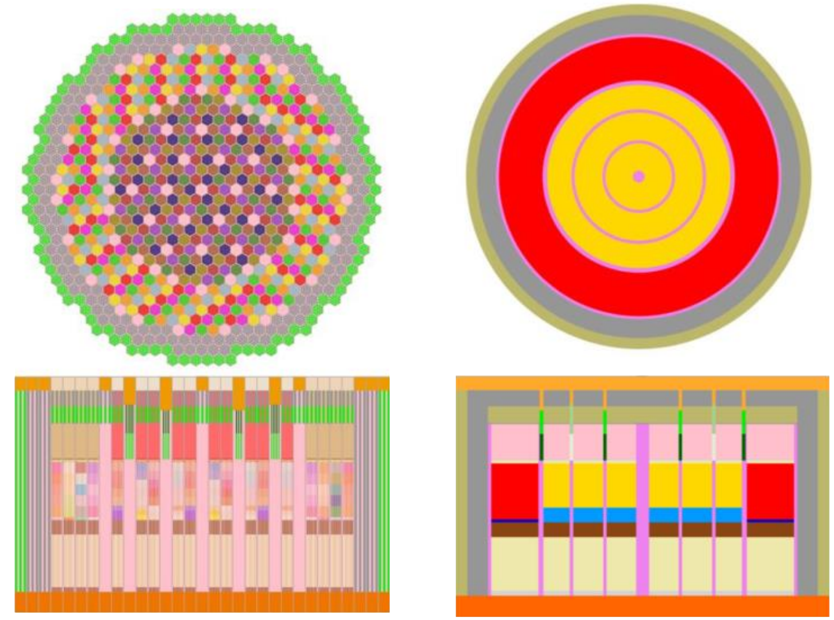
6. S/U analyses (TSUNAMI-3D): Uncertainty to nuclear data

S/U analyses applied for ND uncertainty quantification of the ESFR core parameters at EoC. The CE TSUNAMI-3D methodology was employed and specifically the CLUTCH approach.

- The CLUTCH method options were assessed against Direct Perturbation and IFP calculations.
- We recently included state-of-the-art covariances matrices (e.g., JEFF-3.3) to our calculation scheme using AMPX
- Problems concerning S/U for void scenarios: modelling simplifications were required: R-Z modelling



Comparison of ISC for the 3-D and R-Z ESFR core.



A. Jiménez-Carrascosa, N. García-Herranz, O. Cabellos, 2021. "**Nuclear data sensitivity and uncertainty for reactor physics parameters of the ESFR**", to be presented at European Nuclear Young Generation Forum (ENYGF) 2021, Tarragona, Spain.

6. S/U analyses (TSUNAMI-3D & TSAR): ND needs

Nuclear data target accuracy requirements (TARs) were evaluated through S/U analyses of R-Z model establishing evaluation priorities to the nuclear data community.

Parameter	TA* (%)	Unc. (%) SCALE-6.2	Unc. (%) JEFF-3.3	Unc. (%) ENDF/B-VIII.0
k_{eff}	0.3	**1.35**	**1.05**	**0.80**
Sodium void worth (void 5)	7	**11.5**	**8.5**	**11.2**
Doppler effect(+300 K)	7	**6.3**	**4.0**	**3.5**
Control rod worth	7	**2.4**	**1.9**	**1.3**

* Reference target accuracies for a fast reactor defined by the OECD/NEA WPEC-SG26 (Salvatores and Jacqmin, 2008)

Major nuclide-reactions contributing to the uncertainty in k_{eff} using JEFF-3.3 covariance data.

Quantity	$\Delta k/k$ (%)
Pu-240 fission	0.594
U-238 inelastic	0.480
Pu-239 χ	0.453
Pu-240 fission-capture	-0.417
U-238 inelastic-fission	-0.349

Nuclear data needs for SFR in JEFF-3.3 provided to OECD/NEA WPEC-SG46.

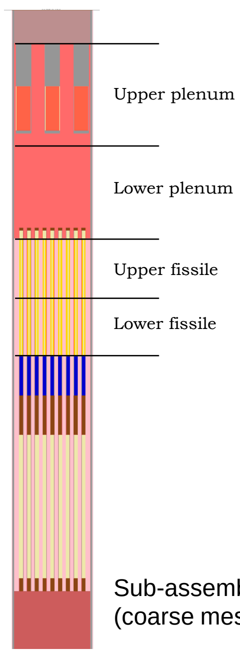
We are currently performing a detailed TAR exercise collecting information for both SFR and LFR designs.

A. Jiménez-Carrascosa, N. García-Herranz, O. Cabellos, 2021. "**Nuclear data sensitivity and uncertainty for reactor physics parameters of the ESFR**", to be presented at European Nuclear Young Generation Forum (ENYGF) 2021, Tarragona, Spain.

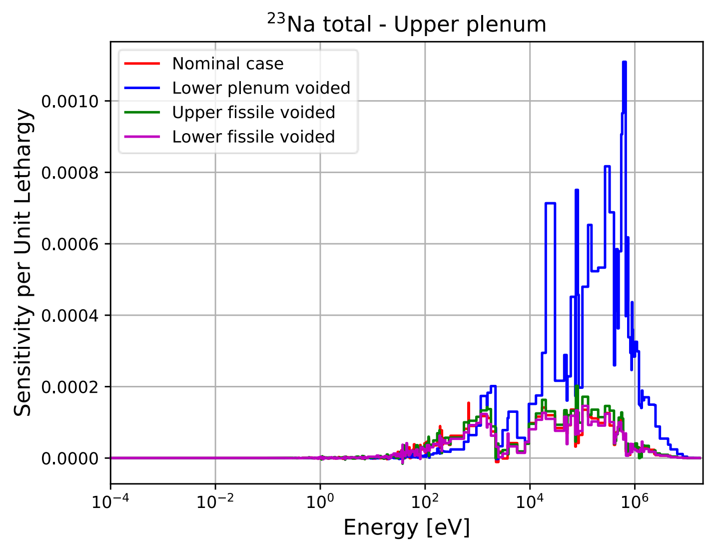
6. S/U analyses (TSUNAMI-3D & TSUNAMI-IP): Similarity indexes

Sensitivities provide insight into the physics of a problem: they were applied to develop a method to identify spatial correlations of sodium void reactivity coefficients.

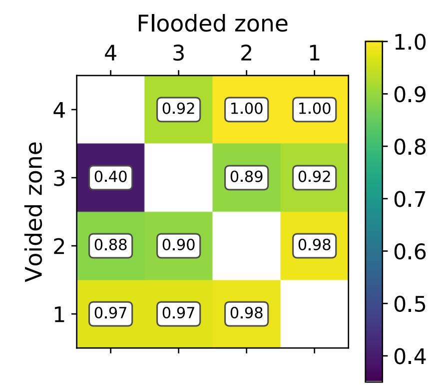
- Step 1: the model is discretized into several spatial regions and sensitivity calculations are carried out in order to compute sensitivities of k_{eff} both to sodium at nominal conditions and to sodium when neighbor regions are voided.
- Step 2: Similarity indexes are computed to quantify the differences in the sensitivity coefficients at every region due the perturbations in the neighboring regions. They provide information about spatial correlations.



Sub-assembly discretization (coarse mesh).



Sensitivity profiles of k_{eff} to Na-23 total reaction at the upper plenum, for the nominal state (all regions flooded) and for a voided state of its neighboring regions.



G index matrix for voided/flooded region pairs. To be read as follows: if zone 3 is voided, sensitivities in zone 4 dramatically change ($G = 0.4$) with respect to sensitivities in zone 4 when zone 3 was flooded.

A. Jiménez-Carrascosa, N. García-Herranz, 2020. "**Use of similarity indexes to identify spatial correlations of sodium void reactivity coefficients**", Nuclear Engineering and Technology, vol. 52(11), pp. 2442-2451.

7. Conclusions and future work

- SCALE is successfully being used for characterizing advanced fission systems. Benchmarking activities demonstrated that SCALE performs well for a large variety of calculations.
- We found limitations in performing S/U analyses with TSUNAMI for highly complex systems. Simplified models were created but the impact of core modelling strategies on sensitivities are currently under evaluation.
    - S/U analysis for kinetic parameters?
- As next step, TSURFER will be used to improve predictions based on integral experiments using data assimilation techniques (SANDA project).
- Use of Shift as main Monte Carlo code when SCALE6.3 version is released (future projects).

Thank you for your attention!

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