MUSIC
A UPM tool for cross-sections generation and uncertainty propagation

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Outline

1. **What is MUSIC**
2. **MUSIC applications**
    a. Lattice-physics modelling
    b. Cross-sections generation verification
    c. Stochastic uncertainty analysis
3. **Detected issues**
4. **Conclusions**

1. What is MUSIC

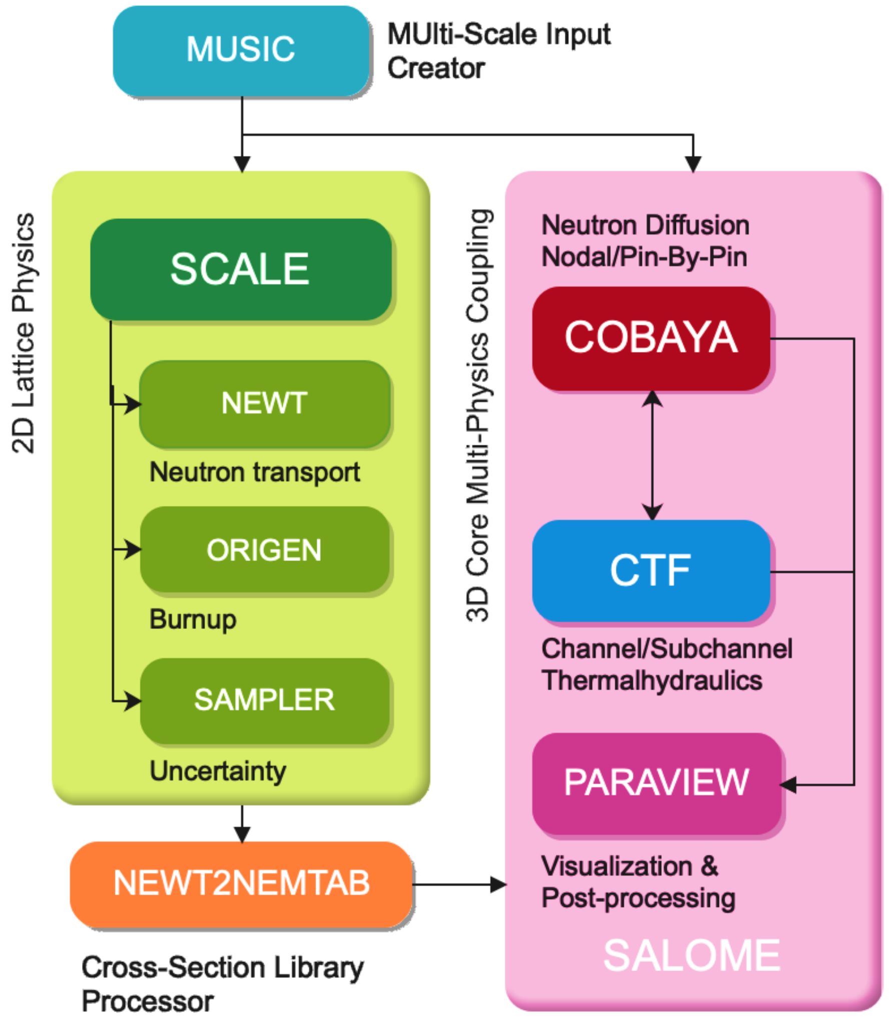
The UPM core simulation platform

- **Two-step standard approach to reactor simulation**
- **Multi-scale platform:** lattice and core simulation
- **Multi-physics platform:** neutron diffusion and subchannel thermal-hydraulics
- **Nodal and pin-by-pin resolution**

MUSIC: MUlti-Scale Input Creator – User-friendly tool

A suitable python tool to tackle lattice modelling analysis, cross-sections generation that warrants the consistency between multi-scale, multi-physics simulation, and uncertainty propagation.

Whole platform V&V



1. What is MUSIC

Modelling analysis

- Verification
- Discretization sensitivity analysis
- Branching

Cross-sections

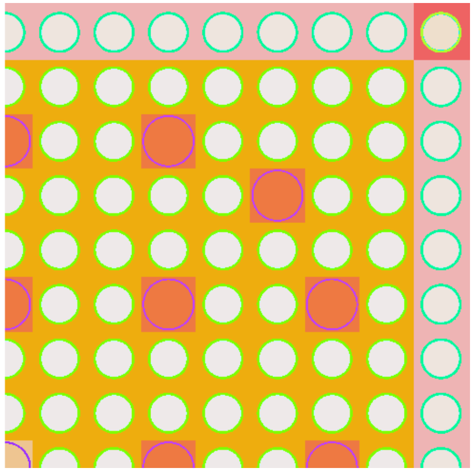
- Avoid user effect
- Freeze XS calculation process
- User friendly

Uncertainty

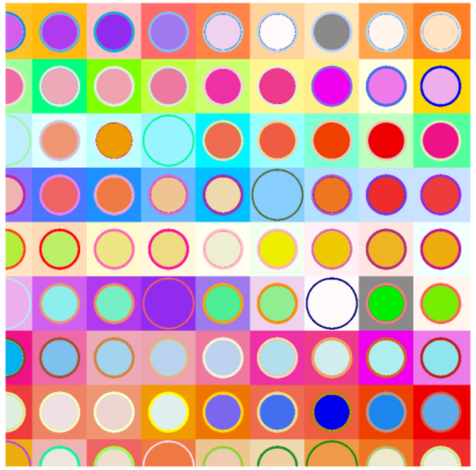
- Nuclear data ENDF/B-VII.1
- Geometry, compositions
- Sensitivity analysis based on stochastic methods

2. MUSIC Applications

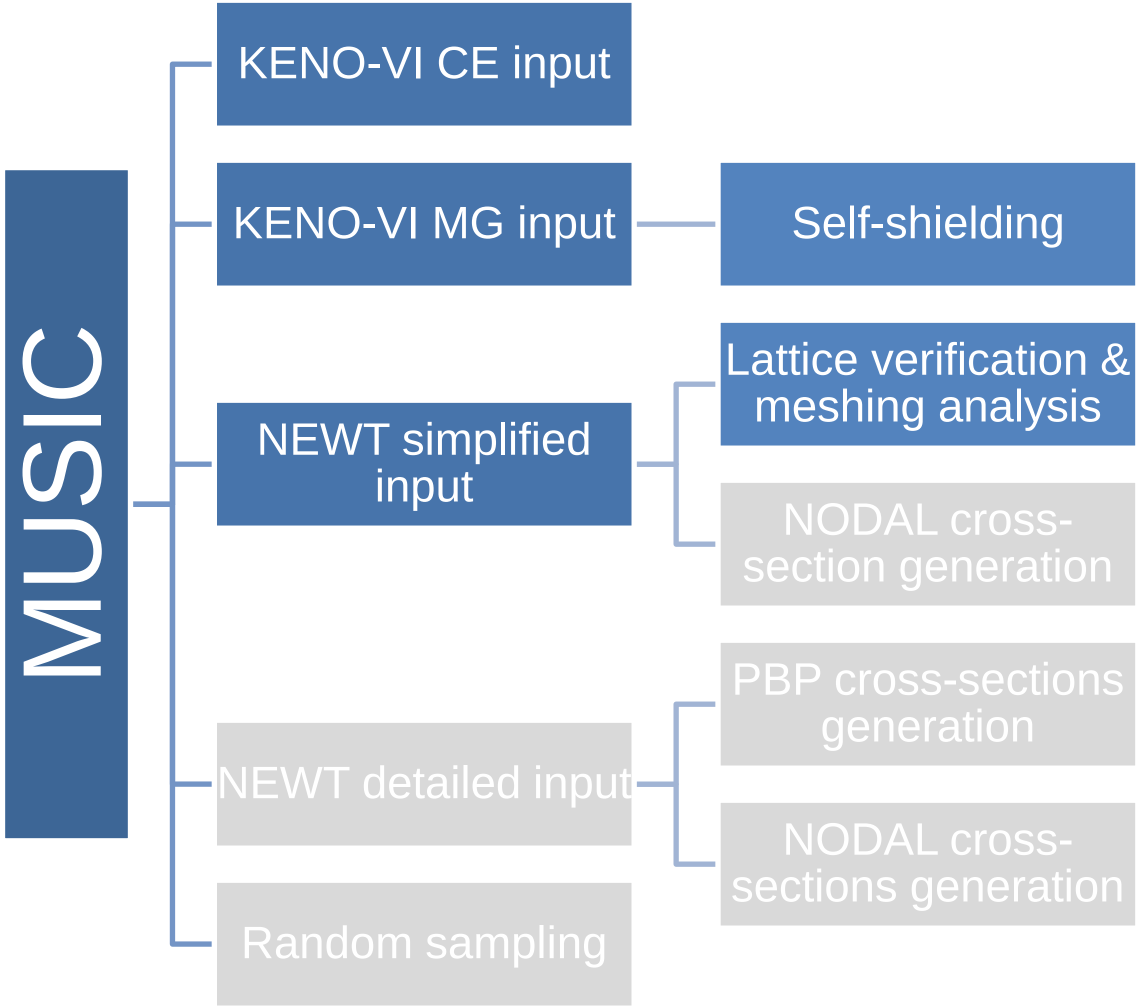
- **2a. Lattice-physics modelling analysis**
  - Lattice and self-shielding **model verification**
  - Angular and spatial discretization **optimization**
  - Optimized testing set-up: simplified vs detailed model



Simplified model



Detailed model

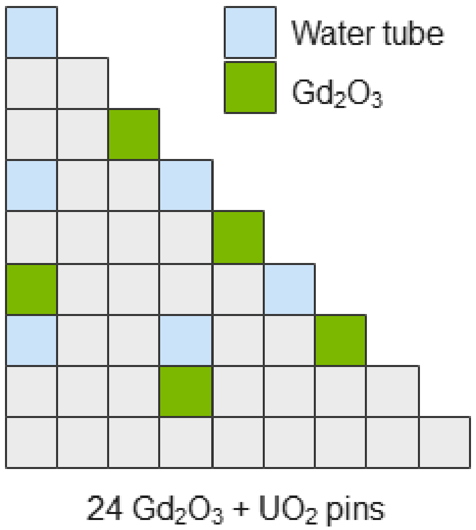


▪ 2a. Lattice-physics modelling analysis

VERIFICATION

Gd_2O_3 poisoned fuel assembly [1]

- 24 Gd rods: 1.8 % U^{235}, ρ = 10.256 g/cc
- Fuel rods: 3.1 % U^{235}, ρ = 10.111 g/cc



	K-eff	ΔK-eff (pcm)	Δfxy (%)	RMSE (%)
KENO-CE	0.92672 ± 5	-	-	-
KENO-MG	0.92737 ± 5	+65	+0.02	0.01
NEWT simplified	0.92570	-167	+0.78	0.15
NEWT detailed	0.92570	-167	+0.78	0.15
Target accuracy	-	*±200*	*±1.5*	*0.5*

2a. Lattice-physics modelling analysis

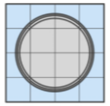
DISCRETIZATION SENSITIVITY

Meshing parameters influence dependence on the composition:

- Pin cell discretization
- S_N symmetry level quadrature order

Compositions in the same core with similar k-eff bias also **reduce flux distribution bias in the core simulation**.

D k-inf (pcm) / SN \ Pincell grid	4	6	8	10	12	14	16	18	20	22
6	-58	-45	-7	13	16	40	58	54	61	71
8	-122	-124	-95	-80	-87	-67	-55	-61	-56	-52
10	-145	-144	-114	-99	-107	-86	-74	-80	-74	-68
12	-165	-164	-138	-122	-133	-114	-102	-109	-103	-99
14	-170	-166	-141	-124	-135	-115	-103	-110	-104	-99
16	-176	-170	-148	-130	-143	-124	-113	-121	-114	-111

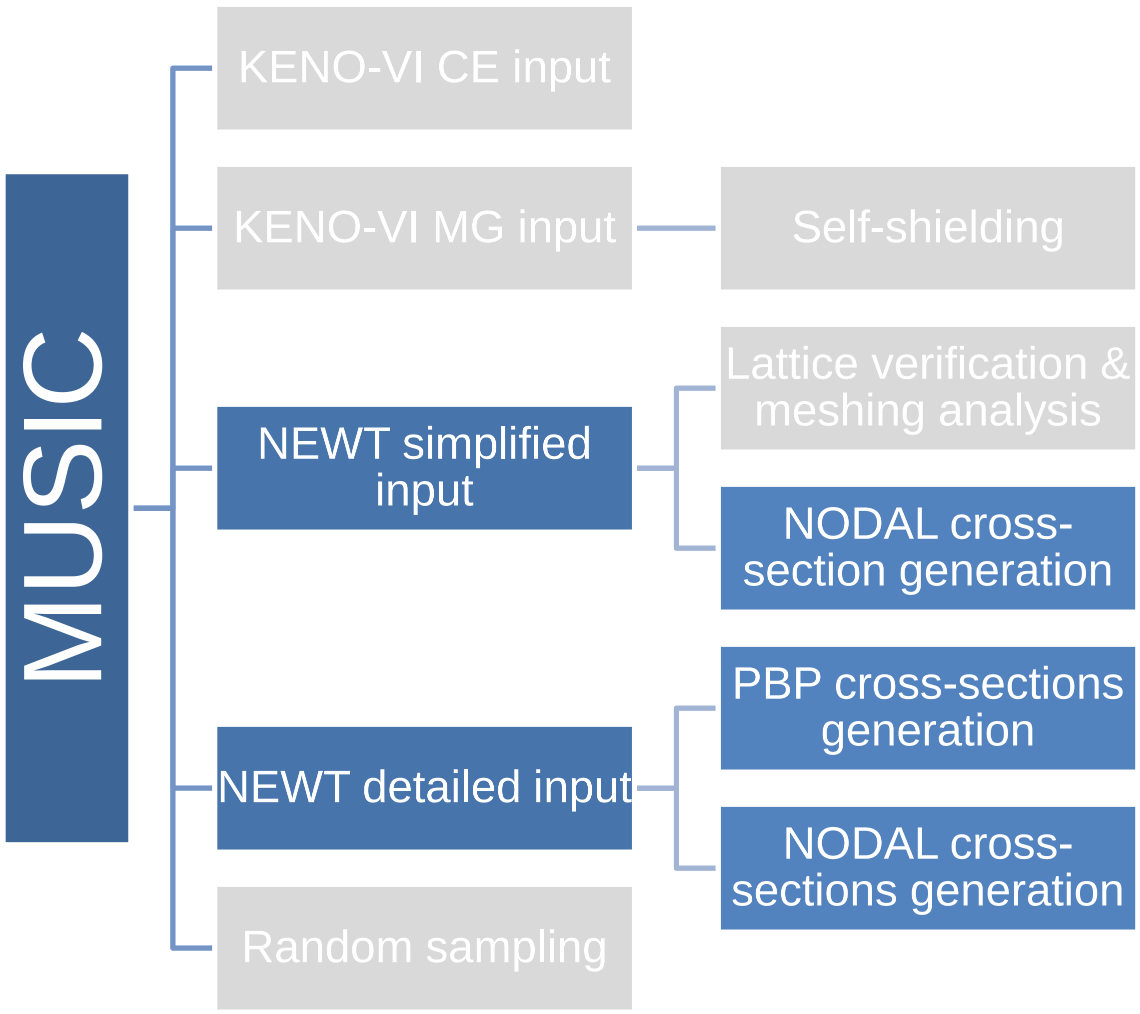

4 x 4


24 x 24

D fxy (%) / SN \ Pincell grid	4	6	8	10	12	14	16	18	20	22
6	0.85	0.91	1.01	1.03	1.06	1.08	1.08	1.1	1.11	1.12
8	0.79	0.85	0.92	0.95	0.96	0.98	0.99	1.01	1.01	1.02
10	0.78	0.83	0.9	0.92	0.95	0.96	0.96	0.98	0.99	0.99
12	0.75	0.81	0.86	0.9	0.91	0.93	0.94	0.95	0.96	0.96
14	0.74	0.79	0.85	0.89	0.9	0.91	0.92	0.94	0.95	0.95
16	0.73	0.79	0.84	0.87	0.89	0.9	0.9	0.92	0.93	0.93

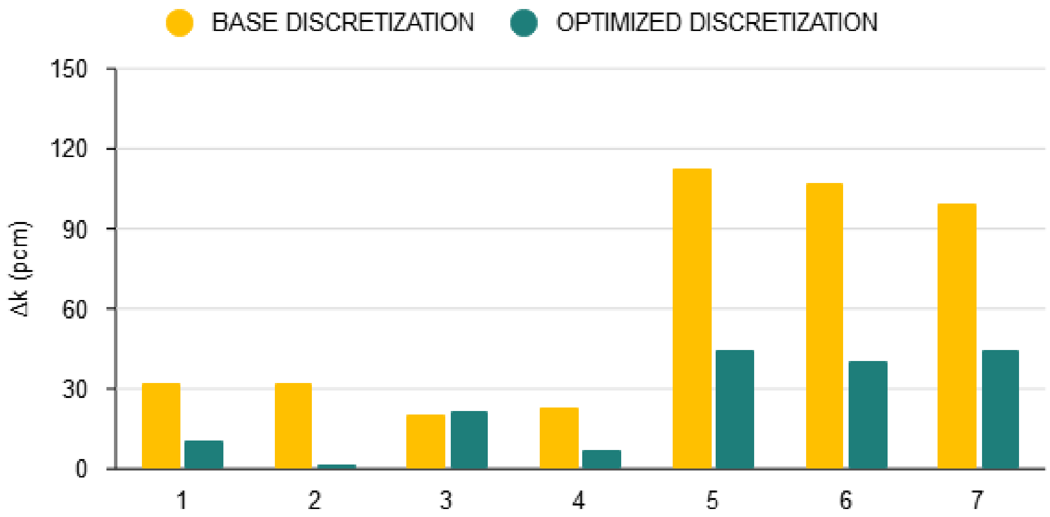
2. MUSIC Applications

- **2b. Cross-sections generation**
  - UO_2 fuel, Gd rods, control, Pyrex and WABA rods, and instrumentation/guide tubes
  - If only **NODAL XS**, a simplified model is used optimizing computing resources reducing self-shielding calculations
  - For **PBP XS**, a detailed model is used also, generating the equivalent NODAL XS
  - **Flux planes** and ADF card well implemented
  - **Branching** pseudo-parallelization



2. MUSIC Applications

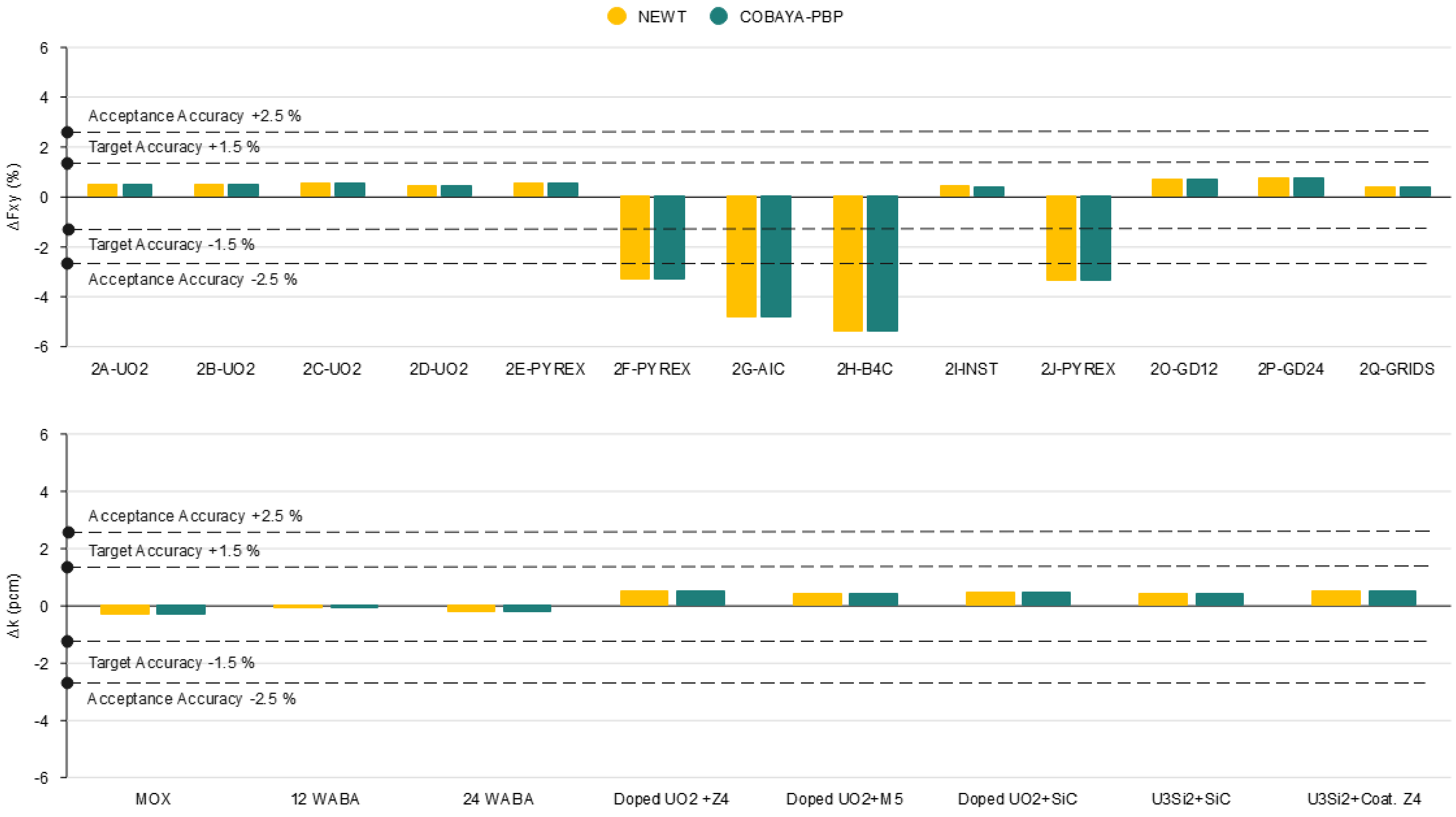
- **2b. Cross-sections generation**
  - **Optimized discretization** branching S_N 6 and 8x8 pin cell
  - Recommended discretization [2] S_N 6 and 4x4 pin cell
  - Increases 2.63 initial time
  - Improves 60 % k_{inf} accuracy



- **2b. Cross-sections generation**
  - Compositions modelling verification **NEWT, COBAYA NODAL and PBP vs. KENO-CE** (k-inf)

- UO2, Gd, Pyrex, AIC, B4C, Inst. Thimble, water tubes [1], WABA [3]
- Extendable use to ATF modelling [4]

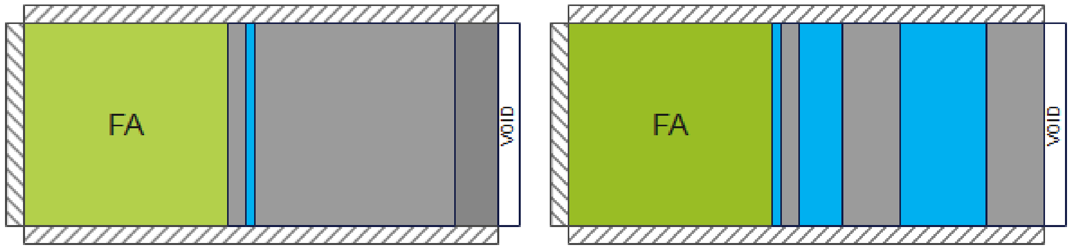
- ## 2b. Cross-sections generation
  - Compositions modelling verification **NEWT, COBAYA NODAL and PBP vs. KENO-CE**(F_{xy})

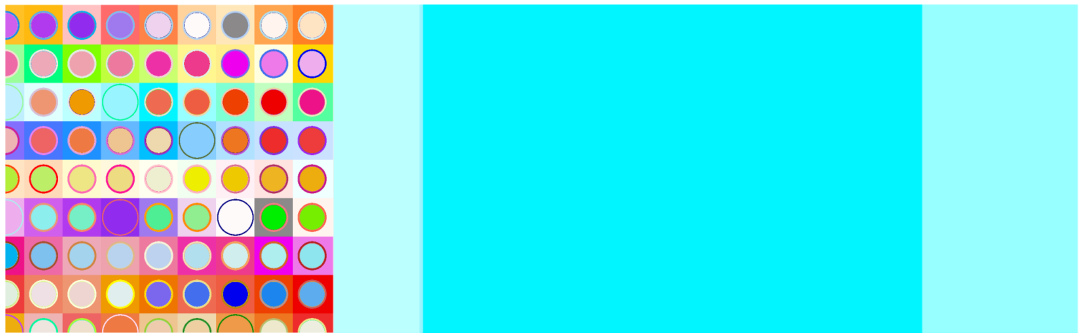


- UO2, Gd, Pyrex, AIC, B4C, Inst. Thimble, water tubes [1], WABA [3]
- Extendable use to ATF modelling [4]

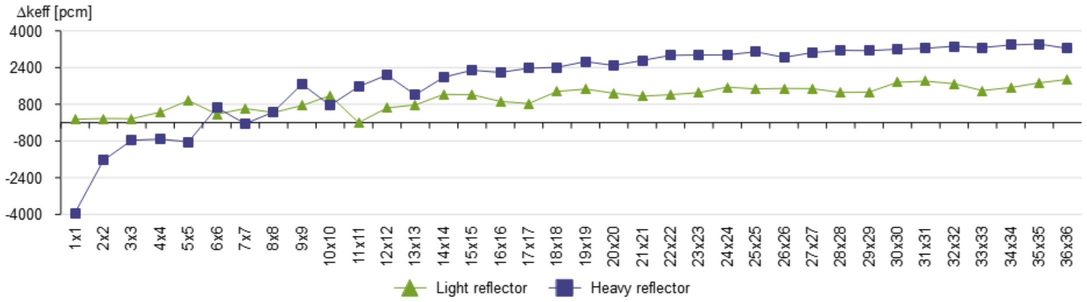
2. MUSIC Applications

- **2b. Cross-sections generation**
  - **Reflector 1D color set modelling** (quarter or full-fa model)
  - Water [5] and heavy [6] reflector





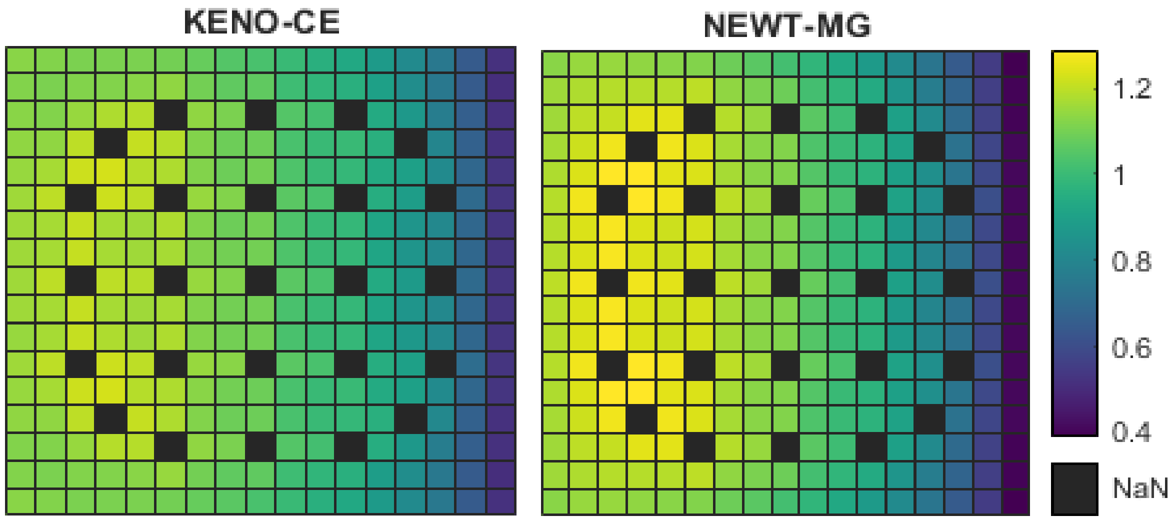
Quarter FA 1D colour set Heavy Ref. [6]	*keff*
KENO-CE	0.86989
KENO-MG	0.87105
NEWT-MG	**0.90224**

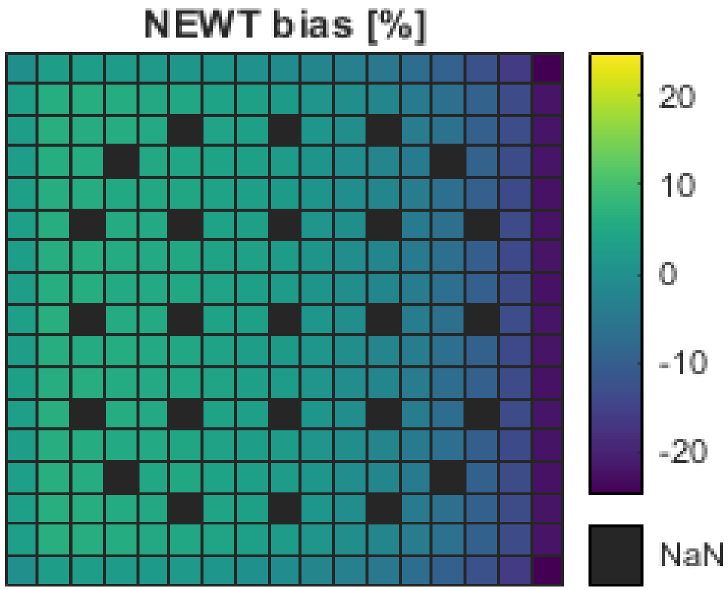


- K_{eff}, F_{xy} and RMS very sensitive to **global unit discretization** (100 – 1000 pcm)

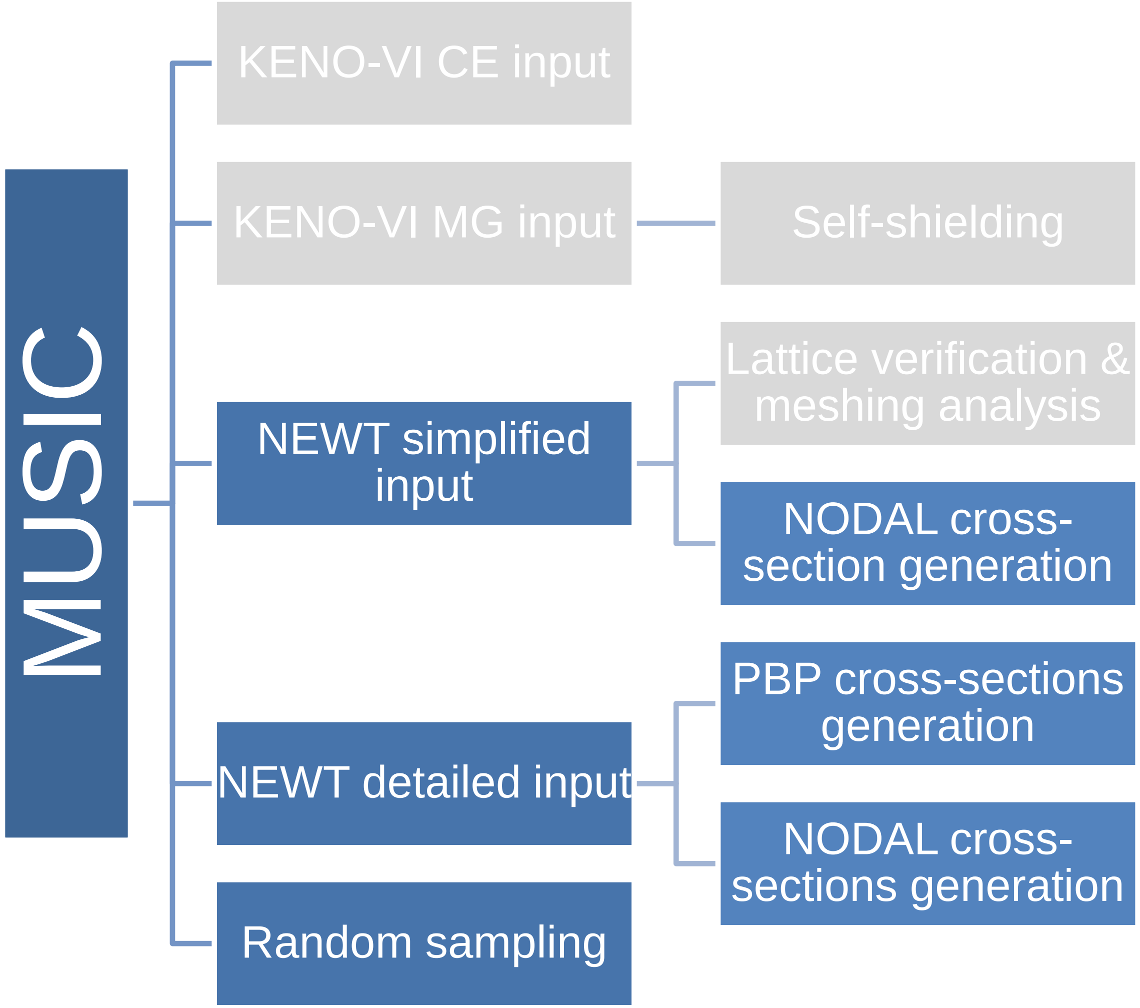
- **2b. Cross-sections generation**
  - **Reflector 1D color set modelling** (quarter or full-fa model)
  - Water [5] and heavy [6] reflector

Full FA 1D colour set Heavy Ref. [6]	*keff*		
KENO-CE	1.00747		
NEWT-MG	**1.02350**		
	ΔK-eff (pcm)	*Δfxy (%)*	*RMSE (%)*
NEWT-MG bias	*+1603*	*+5.37*	*0.46*



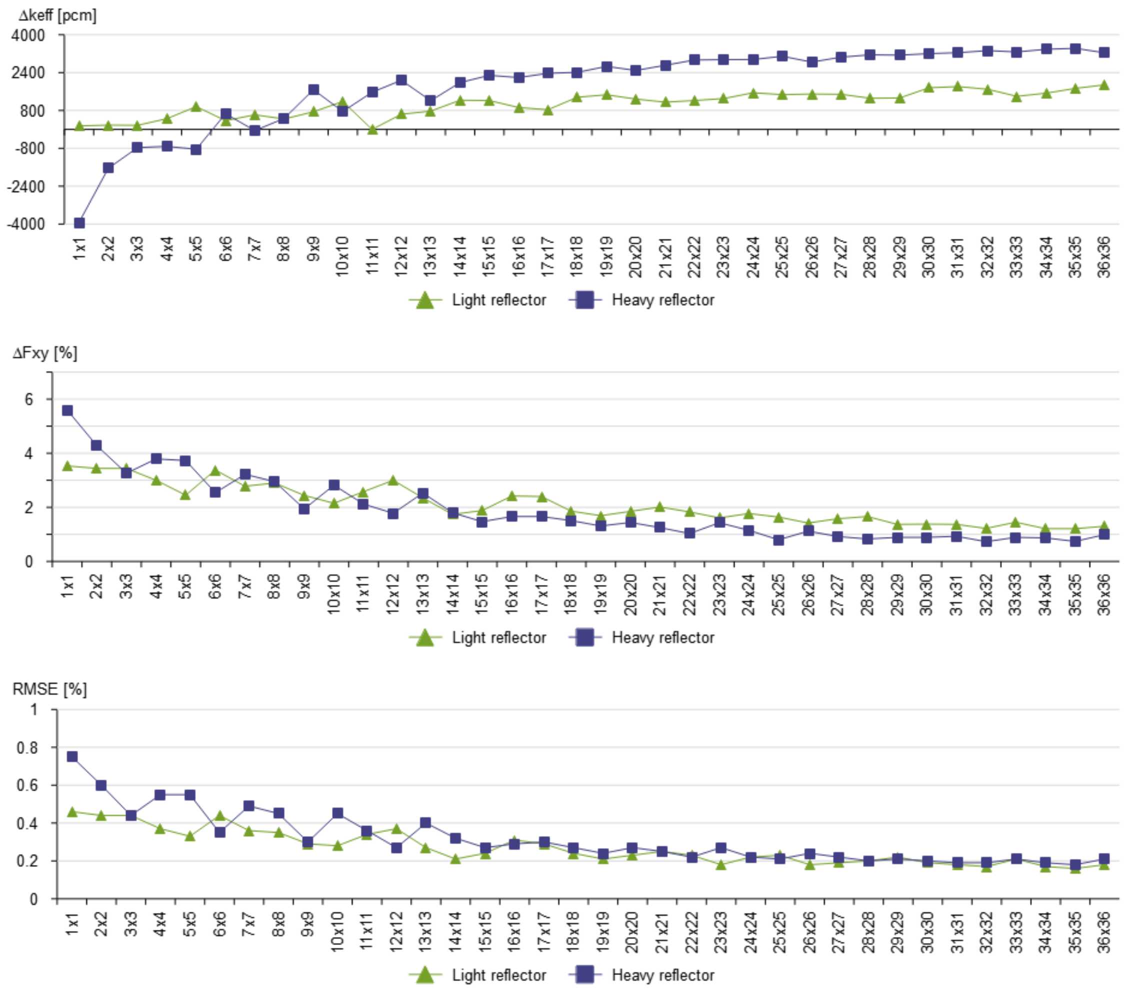


- **2c. Uncertainty analysis**
  - **Stochastic** uncertainty propagation
  - Pseudo-parallelization
  - Pre-generated **ENDF/B-VII.1 perturbations library**
  - Random perturbations
  - Flexible **parameter perturbation**
    - Geometry
    - Compositions



3. Detected issues

- **NEWT reflector modelling capabilities**
  - Great differences in keff, Fxy and RMSE
  - Acceptance criteria cannot be met
  - Great sensitivity to the global unit meshing
  - Is the SN approximation good enough to model a 1D color set?
  - Are we ignoring something?



QoI's sensitivity to **the global unit discretization**

3. Detected issues

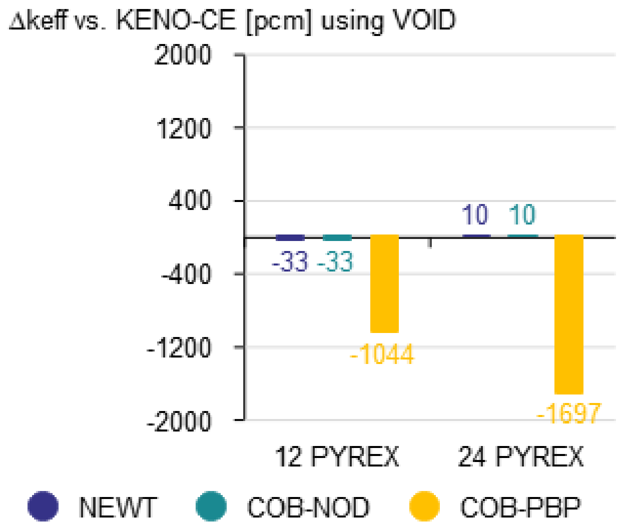
- **NEWT reflector modelling capabilities**
- **AIC control modelling**
  - Differences between KENO-CE and KENO-MG around -200 pcm
  - MT2022 greater than MT2 for nuclides: 47107, 47109, 48113 (Ag and Cd)
  - ENDF/B-VII.1 56G processing issue?

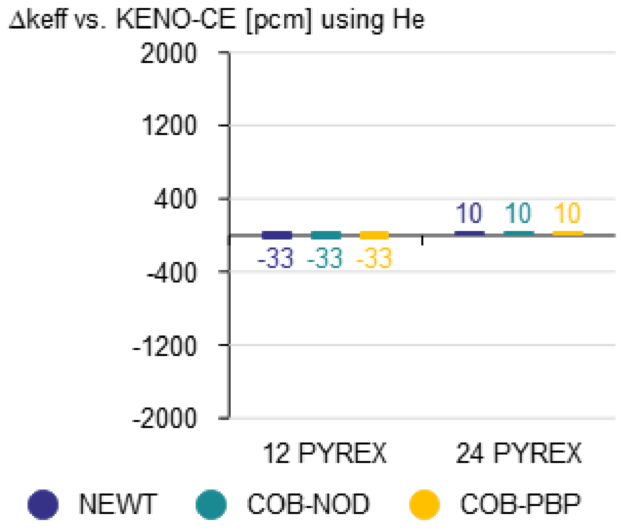
```
***Warning: Nuclide 8018 is missing cross sections. Introducing zero cross sections.
>>> Loading SCALE Standard Composition Library from /home/codes/scale/SCALE-6.2.2/data/scale.rev39.sclib
>>> Loading CE library /home/codes/scale/SCALE-6.2.3/bin/../data/ce_v7.1_endf.xml
MixMacros: MT 2022 greater than MT 2 for nuclide 47107.
MixMacros: MT 2022 greater than MT 2 for nuclide 47107.
MixMacros: MT 2022 greater than MT 2 for nuclide 47109.
MixMacros: MT 2022 greater than MT 2 for nuclide 48113.
    >>>> Csas56 initializes kenovi on 128 processors.

*** kenovi track calculation has been initialized on    127 MPI processes.
```

3. Detected issues

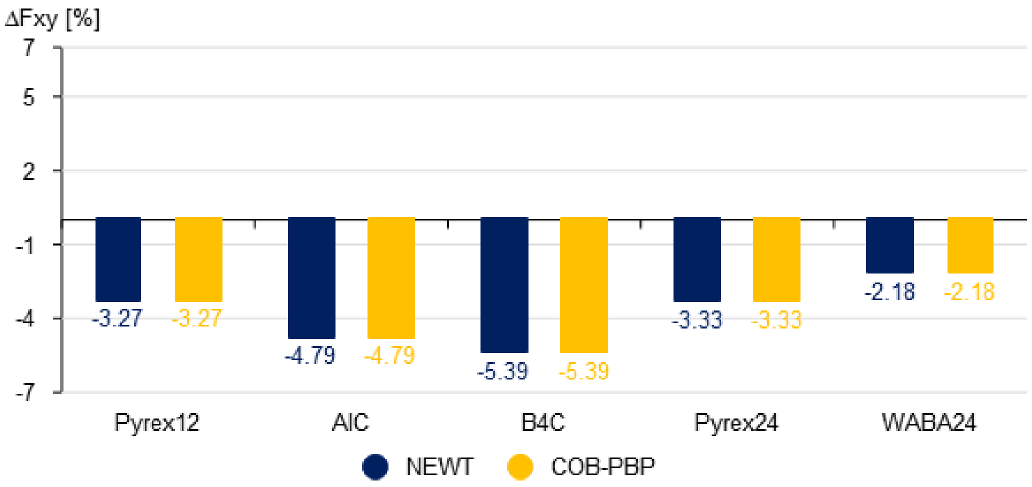
- **NEWT reflector modelling capabilities**
- **AIC control modelling**
- **Homogenization void material**
  - Compositions with **void layers** (Pyrex, or control rods)
  - Homogenization zones at the **pin cell level for PBP** (not observed at NODAL homog.)
  - Although the NEWT's solution is good, cross-sections generated at the PBP level are biased more than 1500 pcm
  - Solved using low-density helium





3. Detected issues

- **NEWT reflector modelling capabilities**
- **AIC control modelling**
- **Homogenization void material**
- **Control or strong poisoned compositions**
  - F_{xy} acceptance accuracy (±2.5 %) is not met
  - Sometimes target accuracy can be met using finer discretizations
  - Accuracy cannot be met even by refining angular and/or spatial meshing



4. Conclusions

MUSIC tested characteristics

- **User-friendly python tool** to generate KENO and NEWT inputs. Usable for the V&V
- **Verified for most frequent compositions in PWR**
  - Self-shielding models (verified)
  - Geometry and mixtures correspondence (verified)
  - Homogenization set up (verified)
  - Reflector modelling (verified)
- **Flexible modelling and analysis capabilities**
  - Uncertainty and sensitivity analysis
  - Discretization analysis
  - Consistent bias analysis capabilities
  - Reduce the user-effect

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MUSIC future implementations

- Building KENO FA and core 3D models
- Already tested ATF modelling procedures
- Already tested MOX modelling procedures
- Burn-up sequence set-up (ORIGEN cards)
- Burn-up history calculation (also needs NEWT to provide some Pu isotopes micro XS)

5. References

[1] A. T. Godfrey, **VERA Core Physics Benchmark Progression Problem Specifications.**

[2] B. J. Ade, **SCALE/TRITON Primer: A Primer for Light Water Reactor Lattice Physics Calculations, NUREG/CR-7041** (ORNL/TM-2011/21). Tennessee: prepared for the U.S.NRC by ORNL, 2012.

[3] T. Kozlowski and T. J. Downar, **OECD/NEA Pressurised water reactor MOX/UO2 core transient benchmark: final report**. Issy-les-Moulineaux, France: OECD Nuclear Energy Agency, 2006.

[4] U. Mertyurek, B. R. Betzler, M. A. Jessee, and S. M. Bowman, **SCALE 6.2 Lattice Physics Code Accuracy Assessment for Light Water Reactor Fuel**, Cancun, Mexico, 2018.

[5] T. Albagami et al., **TVA Watts bar Unit 1 Muli-Physics Multi-cycle Depletion Benchmark. Specifications and Support Data (Version 2.2)**, 2021.

[6] M. Burrell et al., **Equilibrium Core Design of a NuScale Designed Small Modular Reactor Using CASL's Virtual Environment for Reactor Applications (VERA)**, in Transactions of the American Nuclear Society - Volume 121, 2019, pp. 127–129. doi: 10.13182/T30988.

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