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](image1)

![Detailed model](image2)
2. MUSIC Applications

▪ 2a. Lattice-physics modelling analysis

VERIFICATION

Gd$_2$O$_3$ poisoned fuel assembly [1]

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

<table>
<thead>
<tr>
<th></th>
<th>K-eff</th>
<th>$\Delta$K-eff (pcm)</th>
<th>$\Delta$f$_{xy}$ (%)</th>
<th>RMSE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KENO-CE</td>
<td>0.92672 ± 5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>KENO-MG</td>
<td>0.92737 ± 5</td>
<td>+65</td>
<td>+0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>NEWT simplified</td>
<td>0.92570</td>
<td>-167</td>
<td>+0.78</td>
<td>0.15</td>
</tr>
<tr>
<td>NEWT detailed</td>
<td>0.92570</td>
<td>-167</td>
<td>+0.78</td>
<td>0.15</td>
</tr>
<tr>
<td>Target accuracy</td>
<td>-</td>
<td>±200</td>
<td>±1.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
2. MUSIC Applications

- 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.
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

MUSIC

KENO-VI CE input

KENO-VI MG input

Self-shielding

NEWT simplified input

Lattice verification & meshing analysis

NEWT detailed input

NODAL cross-section generation

Random sampling

PBP cross-sections generation

NODAL cross-sections generation

Random sampling
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
2. MUSIC Applications

- **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]
2. MUSIC Applications

- 2b. Cross-sections generation
  - Compositions modelling verification NEWT, COBAYA NODAL and PBP vs. KENO-CE($F_{xy}$)
    - UO$2$, Gd, Pyrex, AlC, 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)

<table>
<thead>
<tr>
<th>Quarter FA 1D colour set Heavy Ref. [6]</th>
<th>$k_{\text{eff}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>KENO-CE</td>
<td>0.86989</td>
</tr>
<tr>
<td>KENO-MG</td>
<td>0.87105</td>
</tr>
<tr>
<td>NEWT-MG</td>
<td>0.90224</td>
</tr>
</tbody>
</table>

- $k_{\text{eff}}$, $F_{xy}$ and RMS very sensitive to **global unit discretization** (100 – 1000 pcm)
2. MUSIC Applications

- 2b. Cross-sections generation
  - Reflector 1D color set modelling (quarter or full-fa model)

<table>
<thead>
<tr>
<th>Full FA 1D colour set Heavy Ref. [6]</th>
<th>$k_{\text{eff}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>KENO-CE</td>
<td>1.00747</td>
</tr>
<tr>
<td>NEWT-MG</td>
<td>1.02350</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NEWT-MG bias</th>
<th>$\Delta k_{\text{eff}}$ (pcm)</th>
<th>$\Delta f_{xy}$ (%)</th>
<th>RMSE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1603 +5.37 0.46</td>
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</table>

**NEWT bias [%]**

**KENO-CE**

**NEWT-MG**
2. MUSIC Applications

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 $\text{keff}$, $F_{xy}$ 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?
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 ($\pm 2.5\%$) is not met
  - Sometimes target accuracy can be met using finer discretizations
  - Accuracy cannot be met even by refining angular and/or spatial meshing

![Graph showing $\Delta F_{xy}$ values for Pyrex12, AIC, B4C, Pyrex24, WABA24]
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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  - Consistent bias analysis capabilities
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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


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