NEA Uncertainty Analysis in Modeling UAM program

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New Element

Uncertainty propagation is being estimated through the whole simulation process – the benchmark builds a framework of different phases, which can be used and followed in the future.

Objective

The chain of uncertainty propagation from basic data, and engineering uncertainties, across different scales (multi-scale), and physics phenomena (multi-physics) to be tested on a number of benchmark exercises for which experimental data is available and for which the power plant details have been released.
**Phase I (Neutronics Phase)**

- Exercise I-1: “Cell Physics”
- Exercise I-2: “Lattice Physics”
- Exercise I-3: “Core Physics”

**Phase II (Core Phase)**

- Exercise II-1: “Fuel Physics”
- Exercise II-2: “Time Dependent Neutronics”
- Exercise II-3: “Bundle Thermal-Hydraulics”

**Phase III (System Phase)**

- Exercise III-1: “Core Multi-Physics”
- Exercise III-2: “System Thermal-Hydraulics”
- Exercise III-3: “Coupled Core-System”
- Exercise III-4: “Comparison of BEPU vs. Conservative Calculations”
Establishing of comprehensive OECD/NEA LWR UAM benchmark framework for uncertainty propagation through multi-physics multi-scale calculations in order to compare different uncertainty/sensitivity analysis methods:

- **Focus on establishing a unified framework to estimate safety margins, which would provide more realistic, complete and logical measure of reactor safety;**

- **Further development of sensitivity and uncertainty analysis capabilities for comprehensive coupled code simulations with nonlinear feedback mechanisms.**
The principal objectives are to:

- **Subdivide the complex system/scenario into several exercises, each of which can contribute to the total uncertainty of the final coupled system calculation;**
- **Identify input, output and assumptions for each step;**
- **Calculate the resulting uncertainty in each step;**
- **Propagate the uncertainties in an integral systems simulation for the total assessment of the overall computer code uncertainty.**

Exercises are based on the three main types of LWRs selected in UAM (PWR, BWR, and VVER) represented by TMI-1 PWR, Gen III PWR, PB-2 BWR, Oskarshamn-2 BWR, Kozloduy6 VVER-1000 and Kalinin-3 VVER-1000.

Two types of test problems are defined:

- **The first type is numerical test problems, which are connected to the envisioned simulations in Phase III;**
- **Experimental test cases which are based on relevant high quality measured data.**
Phase I – Standalone multi-scale neutronics
Major focus on nuclear data uncertainty propagation

<table>
<thead>
<tr>
<th>Participant</th>
<th>Value</th>
<th>SD</th>
<th>RSD (%)</th>
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<td>NECSA-SCALE</td>
<td>1.074</td>
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<td>5.31E-03</td>
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<td>3.16E-03</td>
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</table>

PWR TMI-1 rodded case: k-inf
### Exercise I-3: TMI-1 Case

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Bank</th>
<th>No. rods</th>
<th>Purpose</th>
</tr>
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<tbody>
<tr>
<td>Total number of fuel assemblies</td>
<td>177</td>
<td>1</td>
<td>8</td>
<td>Safety</td>
</tr>
<tr>
<td>Total number of reflector assemblies</td>
<td>64</td>
<td>2</td>
<td>8</td>
<td>Safety</td>
</tr>
<tr>
<td>Fuel assembly pitch (mm)</td>
<td>218.110</td>
<td>3</td>
<td>8</td>
<td>Safety</td>
</tr>
<tr>
<td>Gap between fuel assemblies (mm)</td>
<td>1.702</td>
<td>4</td>
<td>8</td>
<td>Safety</td>
</tr>
<tr>
<td>Active core length (mm)</td>
<td>3571.24</td>
<td>5</td>
<td>12</td>
<td>Regulating</td>
</tr>
<tr>
<td>Total core length (mm)</td>
<td>4007.42</td>
<td>6</td>
<td>8</td>
<td>Regulating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>9</td>
<td>Regulating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>8</td>
<td>APSR</td>
</tr>
</tbody>
</table>

**Diagram:**

- **H:** Reflector
- **K:** Fuel assembly
- **L:** Fuel assembly with control rod
- **M:** Ejected rod

**Legend:**

- A – Fuel enrichment, unit: wt.%
- B – Gd and BP pin configuration
- C – Control rod type and group number

**Table:**

<table>
<thead>
<tr>
<th>Bank</th>
<th>No. rods</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>Safety</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>Safety</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
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<td>4</td>
<td>8</td>
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<td>Regulating</td>
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<td>6</td>
<td>8</td>
<td>Regulating</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>Regulating</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>APSR</td>
</tr>
</tbody>
</table>
Comments on Statistical Uncertainty Propagation

- Statistical methods have been used for single- and multi-physics uncertainty propagation
- One of the efficient methodologies is based on order statistics using formulas as the Wilks’ formula
- It is important to have correct interpretation of results obtained by statistical uncertainty analysis

Misleading “convergence” of the standard deviation

→ 8 calculations each with sample size $N = 1000$

Standard deviations after $N = 1000$:

- 0.575%
- 0.573%
- 0.571%
- 0.562%
- 0.560%
- 0.554%
- 0.550%
- 0.548%

XSUSA, $N = 10,000$: $\sigma = 0.560\%$
TSUNAMI-2D (w/o impl.): $\sigma = 0.564\%$

“Convergence” is not relevant. Use confidence intervals (see next slide)

4.8% rel. difference between min. and max. std. dev.
Determination of confidence interval for the output uncertainty

Relative 95% confidence interval of the standard deviation/uncertainty of the output quantity if the output quantity is normally distributed:

\[
\sigma \cdot \sqrt{\frac{N-1}{\chi^2_{\frac{\alpha}{2},N-1}}} ; \sigma \cdot \sqrt{\frac{N-1}{\chi^2_{1-\frac{\alpha}{2},N-1}}}
\]

<table>
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<tr>
<th>Sample size</th>
<th>Rel. interval</th>
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<tr>
<td>100</td>
<td>[-12.2%; 16.2%]</td>
</tr>
<tr>
<td>250</td>
<td>[-8.1%; 9.6%]</td>
</tr>
<tr>
<td>500</td>
<td>[-5.8%; 6.6%]</td>
</tr>
<tr>
<td>1000</td>
<td>[-4.2%; 4.6%]</td>
</tr>
<tr>
<td>10000</td>
<td>[-1.4%; 1.4%]</td>
</tr>
</tbody>
</table>

Example

1. Calculations, sample size N=1000
2. Determine output uncertainty: \( \sigma \)
3. Determine confidence interval of output uncertainty: \([\sigma_{\text{low}}, \sigma_{\text{top}}]\)
   \[
   \sigma_{\text{low}} = (100 - 4.2\%) \times \sigma \\
   \sigma_{\text{top}} = (100 + 4.6\%) \times \sigma
   \]
Interpretation of Confidence Interval of Output Uncertainty

→ 100 calculations each with sample size $N = 100$
→ 1 calculation with sample size $N = 10,000$

Interpretation
Approx. 95 of these 100 95% confidence intervals cover the unknown output uncertainty

NOT: There is a 95% probability that the unknown output uncertainty is included in one determined interval.
Statistical analysis for uncertainty propagation

- XSUSA approach:
  - Uncertainty analysis using sample size $N$ (determination of mean value and standard deviation of output quantity of interest)
  - Determination of 95% confidence intervals

- Differences in the results between perturbation theory and the sampling approach can often be justified by the interpretation of the statistical confidence intervals
- “Convergence“ of the standard deviation is not helpful for the UQ interpretation or comparison

- Why do we NOT use Wilks formula:
  - Wilks formula provides a sample size for the determination of e.g. 95%/95% one-sided or two-sided tolerance limits
  - But: We are (here/currently) interested in the population standard deviation, NOT in tolerance limits
TMI-1 Case: Tools used

- SCALE 6.2 Sampler/Polaris
  - Sampler: Stochastic sampling method
  - Polaris: LWR lattice physics transport code

- GenPMAXS: Conversion of format from txtfile16 to PMAXS

- PARCS: core simulation with thermal-hydraulic (TH) feedback
## TMI-1 Case: Lattice calculation

<table>
<thead>
<tr>
<th>Lattice type</th>
<th>$k_{\text{inf}} \pm \text{rel. } \sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E4.00</td>
<td>$1.12780 \pm 0.55%$</td>
</tr>
<tr>
<td>E4.40</td>
<td>$1.15704 \pm 0.54%$</td>
</tr>
<tr>
<td>E4.85+4GD</td>
<td>$1.15748 \pm 0.54%$</td>
</tr>
<tr>
<td>E4.95+BP</td>
<td>$1.06570 \pm 0.55%$</td>
</tr>
<tr>
<td>E4.95+BP+4GD</td>
<td>$1.03814 \pm 0.56%$</td>
</tr>
<tr>
<td>E4.95+4GD</td>
<td>$1.16358 \pm 0.53%$</td>
</tr>
<tr>
<td>E4.95+8GD</td>
<td>$1.13113 \pm 0.54%$</td>
</tr>
<tr>
<td>E5.00</td>
<td>$1.19453 \pm 0.53%$</td>
</tr>
<tr>
<td>E5.00+BP+4GD</td>
<td>$1.04129 \pm 0.56%$</td>
</tr>
<tr>
<td>E5.00+4GD</td>
<td>$1.16657 \pm 0.53%$</td>
</tr>
<tr>
<td>E5.00+8GD</td>
<td>$1.13422 \pm 0.54%$</td>
</tr>
</tbody>
</table>

For all fuel assembly lattices, the uncertainty in $k_{\text{inf}}$ is ~0.55% or ~600 pcm for fresh fuel.
TMI-1 Case: Core $k_{\text{eff}}$

- 2-group cross sections generated for 1 nominal + 1000 samples
- Core condition: fresh, HZP, ARI
- Running mean core $k_{\text{eff}}$ is stable after ~150 samples

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Nominal $k_{\text{eff}}$</strong></td>
<td>1.00361</td>
</tr>
<tr>
<td><strong>Sample mean $k_{\text{eff}} \pm \text{rel. } \sigma$ (1000 samples)</strong></td>
<td>1.00340 ± 0.51%</td>
</tr>
<tr>
<td><strong>Sample mean $k_{\text{eff}} \pm \text{rel. } \sigma$ (150 samples)</strong></td>
<td>1.00374 ± 0.51%</td>
</tr>
<tr>
<td><strong>Diff. compared to nominal $k_{\text{eff}}$</strong></td>
<td>0.01%</td>
</tr>
<tr>
<td><strong>Diff. compared to mean $k_{\text{eff}}$ of 1000 samples</strong></td>
<td>0.03%</td>
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</tbody>
</table>
TMI-1 Case: core simulation

Axial power profile

Radial power distribution
Sample size determination for Exercise III-1

- Exercise I-3: 1000 samples, “brute-force”
- Exercise III-1: computational load is higher
  - Depletion
  - Various branches (thermal-hydraulics variables)
- How to properly determine number of samples?
  - Wilks’ formula
  - Two-sided intervals, 95%/95%: 93 samples
  - A recent study*: 146 samples → 150 samples used in this study

**Phase II – Introduces other physics in the core and time-dependence phenomena**

Content of Phase II:

**Exercise II-1 - Fuel Physics**
- Steady State - Exercise II-1a
- Transient - Exercise II-1b

**Exercise II-2 – Time-dependent Neutronics**
- Assembly Depletion – Exercise II-2a
- Neutron Kinetics – Exercise II-2b

**Exercise II-3 – Bundle Thermal-Hydraulics**
- Steady State – Exercise II-3a
- Transient – Exercise II-3b
Exercise II-1 – Propagation of uncertainties using fuel performance codes

- Modelling of a single pin - propagate uncertainties within fuel performance codes consistently;
- Focus on manufacturing, boundary conditions, and subset of modelling (material properties) uncertainties;
- Perform a hot channel/pin analysis for transient cases – cooperation with OECD/NEA NSC EGRFP;
- Special test case (modeling of one axial node/rodlet of single pin) to evaluate the capability of simplified fuel rod models of system and subchannel thermal-hydraulics codes to predict fuel temperature as compared to fuel performance codes.
Connection of Exercise II-1 to Phase III

- Prepare the selected propagated parameters plus uncertainties with a fuel performance code to be used in the standard/simplified fuel rod models of system and subchannel codes in Phase III:
  - Fuel conductivity as function burnup - $k_f$
  - Gap conductance as function burnup and power/LHR - $h_g$
  - Cladding conductivity - $k_c$
- Using High-to-Low (Hi2Lo) fidelity model information approach.
Connection of Exercise II-1 to Phase III
**Hi2Lo** approach – Using high-fidelity fuel performance codes to inform low-fidelity fuel rod models of thermal-hydraulics codes

**Exercise III-1**

- **Fuel Uncertainties**
  - Boundary Conditions
  - Geometry Uncertainties

- **Experimental Data**
  - Conductivity Correlations

- **Multi-physics Input Uncertainties**
  - Boundary Conditions
  - Modeling Uncertainties
  - Geometry Uncertainties

- **Coupled Simulation**
  - Neutronics
  - Thermal Hydraulics
Exercise II-3 – propagation of uncertainties in bundle thermal-hydraulics

- Considers uncertainties in boundary conditions, geometry, and modelling uncertainties;

- Thermal-hydraulics calculations of single assembly/bundle;

- Establishing a framework to estimate parameter distributions based on experimental data (Data Driven Parameter Estimation);

- Using Bayesian Calibration to estimate sensitive model parameters, which can then be propagated through the statistical UQ process.
Phase III – Introduces multi-physics coupling in the core and coupling between core and system

**Exercise III-1 Core Multi-Physics:**
Coupled neutronics/thermal-hydraulics core performance

**Exercise III-2 System Thermal-Hydraulics:**
Thermal-hydraulics system performance

**Exercise III-3 Coupled Core/System:**
Coupled neutronics kinetics thermal-hydraulic core/thermal-hydraulic system performance

**Exercise III-4 Comparison of BEPU vs. Conservative Calculations**
Interactions between Phase II and Phase III
Phase III focus

- Propagation of multiple uncertainties in coupled (multi-physics) steady-state, cycle depletion, and transient calculations;
- The envisioned transient scenarios to be simulated are:
  - PWR Rod Ejection Accident (REA) and Main Steam Line Break (MSLB);
  - BWR Turbine Trip (TT) and Stability transients;
  - VVER-1000 coolant transients (Switching of one Main Coolant Pump).
- PIRT for each transient application in order to identify which parameters plus uncertainties to be propagated;
- As a first step for Exercise III-1 a PWR REA mini-core test case will be analyzed;
- Joint cooperation activities on uncertain propagation in system thermal-hydraulics with the OECD/NEA NCSI WGAMA SAPIUM project.
Exercise III-1: TMI-1 PWR REA Case

• HFP condition
  – Reactor power = 100% rated power (2771.9 MW);
  – Average fuel temperature = 921 K, inlet moderator temperature = 562.67 K, outlet moderator temperature = 592.7 K;
  – Control rod groups 1–6 completely withdrawn, group 7 completely inserted and group 8 (APSR) 53.8% inserted;
  – Core inlet pressure = 15.36 MPa;
  – Core flow rate = 16546.04 kg/s.

• HZP condition
  – Fuel temperature = 551 K, moderator temperature = 551 K and moderator density = 766 kg/m³;
  – Control rod groups 1–4 completely withdrawn, groups 5–7 completely inserted and group 8 (APSR) 70% inserted.

EOC assembly burnup map
• SCALE 6.2.1 Sampler/Polaris
  – Sampler: Stochastic sampling method
  – Polaris: LWR lattice physics transport code

• GenPMAXS: Conversion of format from txtfile16 to PMAXS developed by University of Michigan.

• TXT2NTAB: Conversion of format from txtfile16 to NEMTAB developed by UPV.
**Branch information**

40 Branches for non-APSР lattices

- **PC = 1935 ppm**
- **PC = 5 ppm**

- **Fuel assembly**
- **BP-loaded assembly**
- **Fuel assembly with APSР configuration**
- **Reflector models**

**Legend**:
- Purple circle: Reference state
- Black circle: CR branch
- Blue circle: DC branch
- Green circle: TF branch

**Branch Details**:

- **Fuel enrichment**, unit: wt.%
- **Control rod type and group number**
- **Gd and BP pin configuration**
- **APSR configuration**
- **Reflector models**

**Diagram**:

- **A** – Control rod type and group number
- **B** – Gd and BP pin configuration
- **C** – Fuel enrichment, unit: wt.%

**Table**:

<table>
<thead>
<tr>
<th>Branch</th>
<th>Enrichment</th>
<th>Control Rod Type</th>
<th>Gd and BP Configuration</th>
<th>APSR Configuration</th>
<th>Reflectors</th>
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<tr>
<td>H</td>
<td>4.00</td>
<td>CR(7)</td>
<td>4Gd+BP</td>
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<td></td>
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<td>K</td>
<td>4.95</td>
<td>CR(4)</td>
<td>4Gd+BP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>4.95</td>
<td>CR(6)</td>
<td>4Gd+BP</td>
<td>APSR(8)</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>4.95</td>
<td>CR(5)</td>
<td>BP</td>
<td></td>
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<tr>
<td>N</td>
<td>5.00</td>
<td>CR(7)</td>
<td>4Gd</td>
<td></td>
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<tr>
<td>O</td>
<td>5.00</td>
<td></td>
<td>4Gd+BP</td>
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<tr>
<td>P</td>
<td>4.85</td>
<td></td>
<td>4Gd</td>
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</tbody>
</table>

**Notes**:

- Reference state
- CR branch
- DC branch
- TF branch

**PC Values**:
- 1935 ppm
- 5 ppm
150 samples are sufficient for the stabilization of core $k_{\text{eff}}$
errors of 150 samples mean $k_{\text{eff}}$ compare to the unperturbed $k_{\text{eff}}$

The statistical errors < 0.02% : 150 samples are sufficient to stabilized $k_{\text{eff}}$. 
• The distribution of core $k_{\text{eff}}$ with 150 samples could be regarded as normally distributed.

• The uncertainties for $k_{\text{eff}}$ is 0.44-0.47%.

• They are smaller than the uncertainty of Exercise I-3 fresh core $k_{\text{eff}}$ (0.51%), because there are more heavy metal in fresh core and only the perturbation in cross section is taken into account at this stage.

<table>
<thead>
<tr>
<th>State</th>
<th>Nominal $k_{\text{eff}}$</th>
<th>Sample mean $k_{\text{eff}} \pm$ rel. $\sigma$</th>
<th>Anderson-Darling normality test</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOC HZP</td>
<td>1.01979</td>
<td>1.01986 ± 0.44%</td>
<td>Pass</td>
</tr>
<tr>
<td>EOC HZP</td>
<td>1.04263</td>
<td>1.04276 ± 0.45%</td>
<td>Pass</td>
</tr>
<tr>
<td>BOC HFP</td>
<td>1.01125</td>
<td>1.01136 ± 0.46%</td>
<td>Pass</td>
</tr>
<tr>
<td>EOC HFP</td>
<td>1.02885</td>
<td>1.02902 ± 0.47%</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Axial power profiles for HZP and HFP
Radial power distribution at BOC vs. EOC

Larger uncertainties were observed at BOC than EOC

### HFP BOC state

<table>
<thead>
<tr>
<th></th>
<th>0.333 ±1.06%</th>
<th>0.401 ±0.78%</th>
<th>0.349 ±0.85%</th>
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<tbody>
<tr>
<td>0.333</td>
<td>0.813 ±0.72%</td>
<td>1.210 ±1.56%</td>
<td>1.188 ±1.87%</td>
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<tr>
<td></td>
<td>0.669 ±0.97%</td>
<td>0.393 ±0.79%</td>
<td></td>
</tr>
<tr>
<td>1.133</td>
<td>0.986 ±0.97%</td>
<td>1.095 ±1.49%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.542 ±1.14%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.775</td>
<td>1.216 ±0.50%</td>
<td>1.149 ±0.32%</td>
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</tr>
<tr>
<td></td>
<td>1.243 ±0.34%</td>
<td>0.801 ±0.41%</td>
<td></td>
</tr>
<tr>
<td>1.253</td>
<td>1.197 ±1.18%</td>
<td>1.348 ±0.63%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.237 ±1.26%</td>
<td>1.348 ±0.63%</td>
<td></td>
</tr>
<tr>
<td>1.267</td>
<td>1.159 ±1.86%</td>
<td>1.348 ±1.18%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.216 ±1.56%</td>
<td>1.253 ±1.32%</td>
<td></td>
</tr>
<tr>
<td>0.677</td>
<td>1.216 ±1.86%</td>
<td>1.237 ±1.19%</td>
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</table>

### HFP EOC state

<table>
<thead>
<tr>
<th></th>
<th>0.445 ±0.47%</th>
<th>0.496 ±0.84%</th>
<th>0.405 ±0.91%</th>
</tr>
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<tbody>
<tr>
<td>0.445</td>
<td>1.248 ±0.48%</td>
<td>1.218 ±0.47%</td>
<td>1.097 ±1.65%</td>
</tr>
<tr>
<td></td>
<td>0.901 ±0.81%</td>
<td>1.097 ±1.65%</td>
<td>0.671 ±0.92%</td>
</tr>
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<td>1.218</td>
<td>0.919 ±0.57%</td>
<td>0.871 ±0.94%</td>
<td>0.467 ±0.79%</td>
</tr>
<tr>
<td></td>
<td>0.741 ±0.40%</td>
<td>0.871 ±0.94%</td>
<td></td>
</tr>
<tr>
<td>1.324</td>
<td>1.168 ±1.08%</td>
<td>1.135 ±0.54%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.208 ±1.44%</td>
<td>1.135 ±0.54%</td>
<td></td>
</tr>
<tr>
<td>1.323</td>
<td>1.160 ±1.04%</td>
<td>1.297 ±0.33%</td>
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<td></td>
<td>1.323 ±1.54%</td>
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<tr>
<td>0.694</td>
<td>1.323 ±1.54%</td>
<td>1.324 ±0.99%</td>
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</table>

OECD/NEA LWR UAM Benchmark
Radial power distribution at HZP vs. HFP

Uncertainties of HZP states are more pronounced than those of the HFP states

HZP BOC state

HFP BOC state
Multi-Physics Uncertainty Propagation

Figure 1: Schematic description of a heat transfer model in core multi-physics

Figure 4: Schematic propagation of uncertainties between Exercises II-1 and III-1
OECD/NEA LWR UAM Benchmark

Multi-Physics Uncertainty Propagation
Technical contributions

- The LWR-UAM benchmark activity has stimulated:
  - extension and re-evaluation of nuclear data (cross-sections, burnup and kinetics parameters) uncertainties;
  - better and more precise uncertainty quantification of the rest of input parameters (modeling, boundary conditions, and manufacturing/geometry);
  - improvement of deterministic and statistical methodologies for uncertainty and sensitivity analysis as well as the development of hybrid methods;
  - introduction of reduced order modeling and sub-space methods for efficient uncertainty propagation through highly-dimensional multi-physics models;
  - utilization to Hi2Lo approach to address the multi-scale modeling uncertainties.

- The LWR-UAM benchmark activity has created community of experts, which has developed state-of-the-art UAM concepts and practices, and has helped knowledge transfer and educating/training graduate students and young professional in this field.
Conclusions

– Uncertainty and sensitivity analysis methods are considered as an integral part in the development of multi-physics methods.

– OECD/NEA LWR UAM is a comprehensive benchmark framework which is needed to verify/validate sensitivity and uncertainty analysis methods for multi-physics applications.

– The benchmark activity is driving the development of UAM methods in two directions:
  
  • to allow for combination of different high-dimensional input sources of uncertainties as well as to efficiently handle large data intensive simulations;

  • to be higher order (than first order/linear) for comprehensive coupled code simulations with nonlinear feedback and depletion mechanisms.

– OECD/NEA LWR UAM benchmark and its success has stimulated similar activities for other major reactor types such as IAEA HTGR UAM CRP and OECD/NEA SFR UAM benchmark.
OECD/NEA LWR UAM Benchmark Workshops

- The latest LWR-UAM-11 benchmark workshop took place on May 10-12, 2017 in Erlangen, Germany with 85 participants, and was hosted by AREVA GmbH;

- The next LWR-UAM-12 benchmark workshop will take place in conjunction with the ANS BEPU 2018 conference - Lucca, Italy - May 13-18, 2018, and will be hosted by N.IN.E