Karlsruhe Institute of Technology

KIT contribution to the UAM PHASE-I: modeling and updated results

***L. Mercatali*, V. Sanchez, J. Basualdo**

KIT – Institute for Neutron Physics and Reactor Technology

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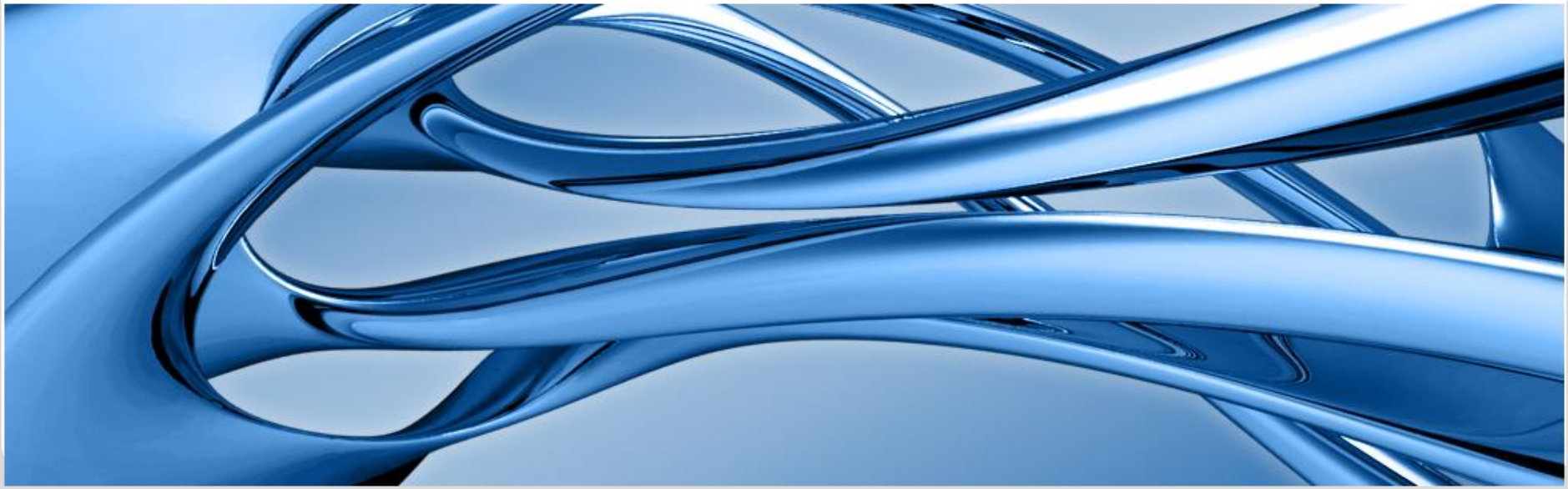
Institute for Neutron Physics and Reactor Technology

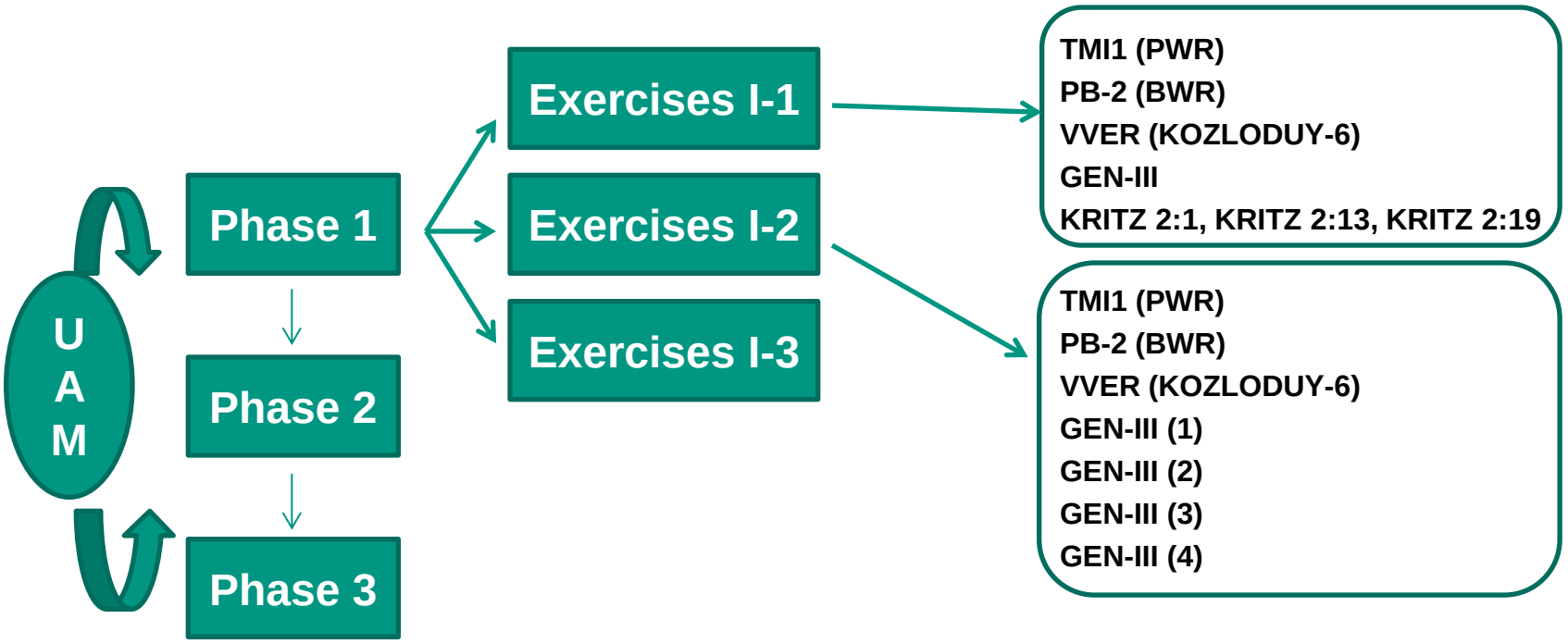
luigi.mercatali@kit.edu



Introduction

KIT-INR/RPD contribution to the UAM Neutronics Exercises:

- **Monte Carlo** (reference) solutions ⟶ **SERPENT 1.18** code
- **Deterministic** solutions ⟶ **SCALE 6.1** code



Computational methodologies

- **SERPENT code (version 1.1.18)**
  - Different NDLs: JEFF3.1, JEFF3.1.1, ENDF/B-7
  - Statistics: 5.0e+06 neutrons sources over 1000 cycles

- **SCALE code (version 6.1)**
  - ENDF/B-7
  - Transport (NEWT, XSDRNPM)
  - S/U analysis via perturbation theory: TSUNAMI

$$Q = f(\sigma_1, \sigma_2, \ldots, \sigma_n)$$ **Integral parameter**

$$\frac{\delta Q}{Q} = \sum_j S_j \frac{\delta \sigma_j}{\sigma_j} \Longrightarrow S_j = \frac{\partial Q}{\partial \sigma_j} \cdot \frac{\sigma_j}{Q}$$ **Sensitivity coefficient**

$$var(Q) = \sum_{j,i}^{J} S_j S_i d_{ij}$$ **Uncertainty**

$$D_\sigma = \begin{bmatrix} d_{11} & \cdots & d_{1J} \\ \vdots & \ddots & \vdots \\ d_{1J} & \cdots & d_{JJ} \end{bmatrix}$$ **Covariance matrix**

Monte-Carlo (reference) solutions: results

Test cases I-1		Kinf		
		JEFF3.1	JEFF 3.1.1	ENDFB-7
VVER	HZP	1.34764 ± 0.00028	1.34937 ± 0.00026	1.34986 ± 0.00027
	HFP	1.33152 ± 0.00028	1.33356 ± 0.00029	1.33435 ± 0.00029
PWR	HZP	1.42785 ± 0.00027	1.42888 ± 0.00025	1.42923 ± 0.00027
	HFP	1.41136 ± 0.00026	1.41315 ± 0.00028	1.41401 ± 0.00026
BWR	HZP	1.34541 ± 0.00027	1.34673 ± 0.00025	1.34691 ± 0.00026
	HFP	1.23046 ± 0.00032	1.23080 ± 0.00032	1.23295 ± 0.00032
KRITZ-2:1	Cold	1.23762 ± 0.00028	1.23846 ± 0.00027	1.23984 ± 0.00027
	Hot	1.22632 ± 0.00028	1.22864 ± 0.00026	1.22863 ± 0.00027
GEN-III	HFP	1.01485 ± 0.00039	1.01602 ± 0.00039	1.01805 ± 0.00037

Test cases I-2		Kinf		
		JEFF3.1	JEFF 3.1.1	ENDFB-7
PWR	HZP	1.41569 ± 0.00019	1.41733 ± 0.00019	1.41839 ± 0.00019
	HFP	1.40616 ± 0.00020	1.40765 ± 0.00019	1.40852 ± 0.00018
BWR	HZP	1.11771 ± 0.00025	1.11830 ± 0.00025	1.11913 ± 0.00025
	HFP	1.07503 ± 0.00028	1.07663 ± 0.00029	1.07739 ± 0.00027
GEN-III type 1 (UOX 2.1%)		1.04854 ± 0.00022	1.05043 ± 0.00021	1.05159 ± 0.00022
GEN-III type 1 (UOX 4.2%)		1.25708 ± 0.00019	1.25951 ± 0.00019	1.25997 ± 0.00020
GEN-III type 2		1.12760 ± 0.00027	1.12937 ± 0.00026	1.13048 ± 0.00026
GEN-III type 3		1.05005 ± 0.00030	1.05148 ± 0.00029	1.13048 ± 0.00026
GEN-III type 4		1.11595 ± 0.00025	1.11706 ± 0.00025	1.11697 ± 0.00025

Good agreement within different data libraires and with previous MCNP (PSU) results

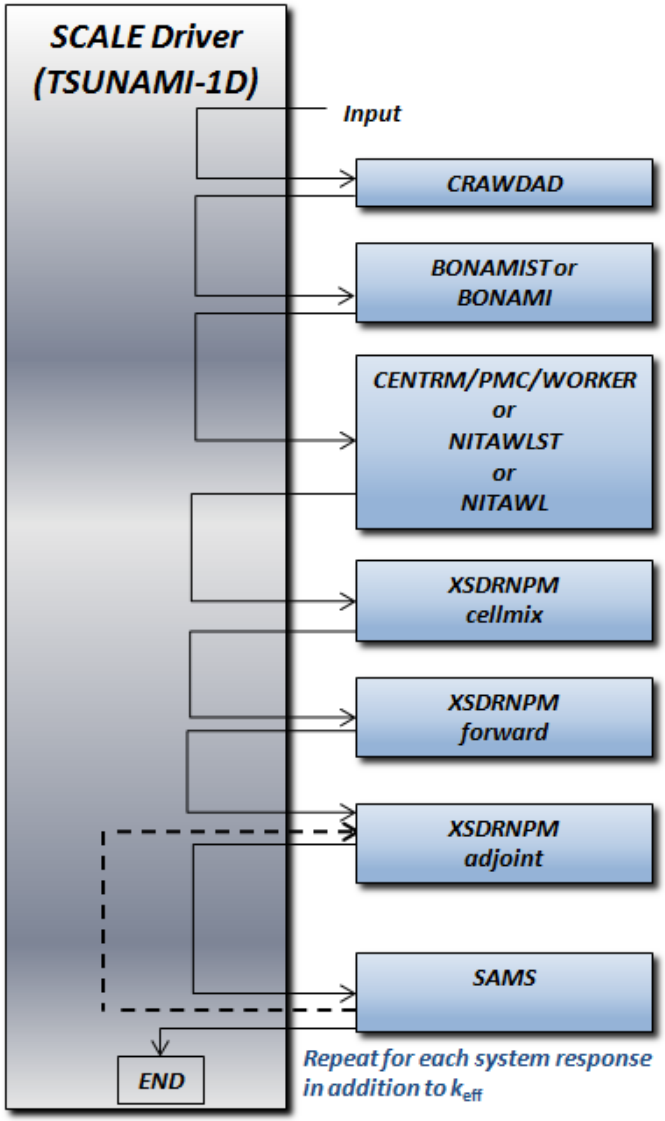
Computational method: TSUNAMI-1d flow diagram

ENDF/B-VII.0

Transport Discrete Ord. 238-groups

Sensitivities via GPT

44GROUPCV



Pointwise Cross-section Preparation (not called for NITAWL or NITAWLST sequences)

Unresolved Resonance Cross-section Processor

Resolved Resonance Cross-section Processor

Cross-section Cell Weighting (optional)

Forward Transport Calculation

Adjoint Transport Calculation

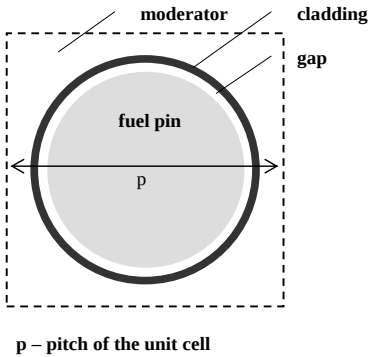
Sensitivity and Uncertainty Calculation

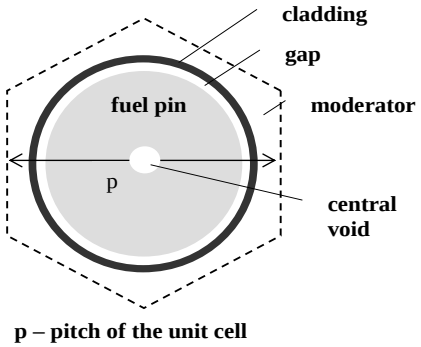
Exercises I-1: Cell Physics

Focuses on the derivation of the multi-group microscopic cross section libraries (in the way used as inputs by the lattice physics codes) and their uncertainties

Test cases:

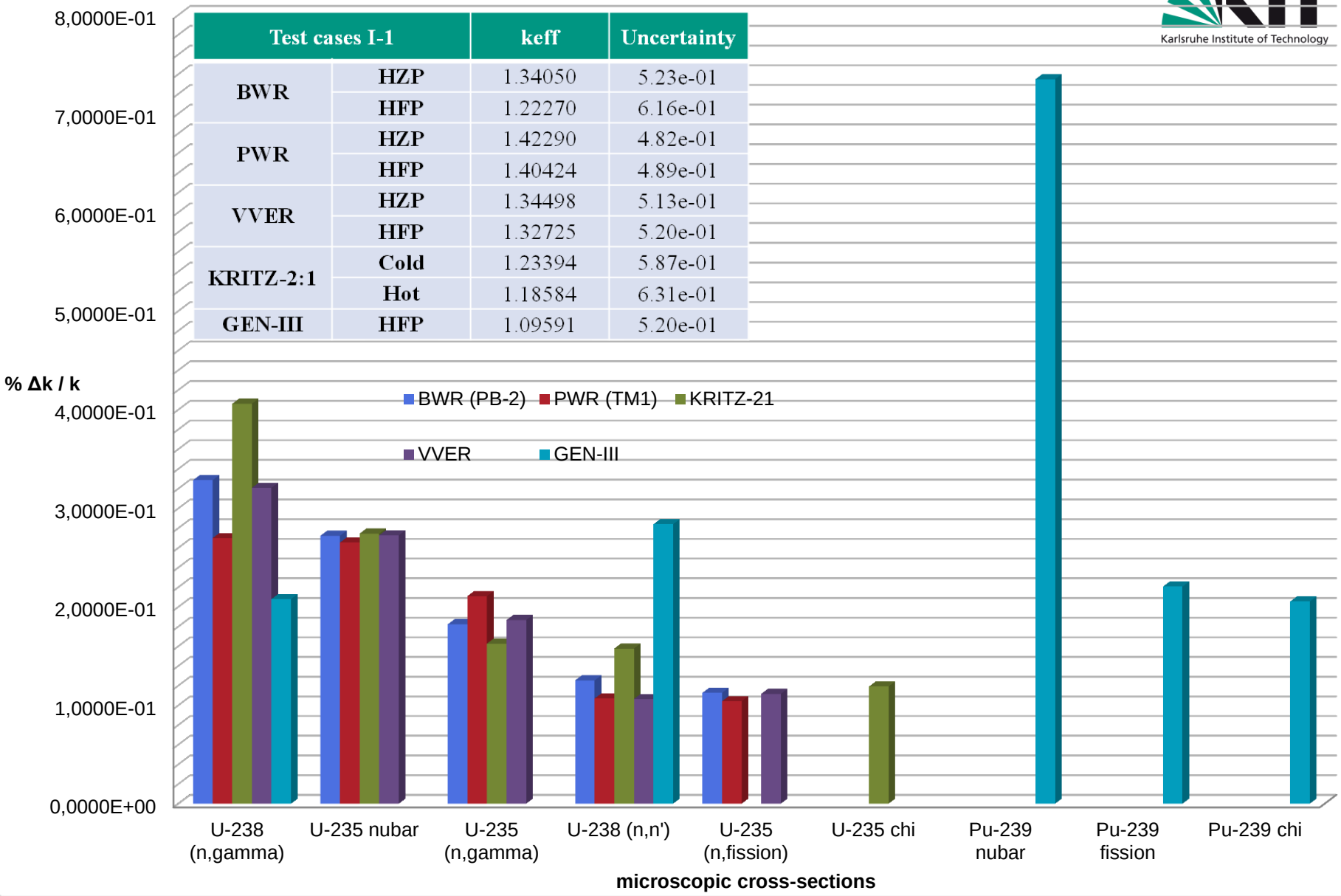
- PB-2 (BWR)
- TMI1 (PWR)
- GEN-III (MOX fuel)
- KRITZ 21, KRITZ 213, KRITZ 219
- VVER (KOZLODUY-6)





Exercise I-1: k-inf

Test cases I-1		keff	Uncertainty
BWR	HZP	1.34050	5.23e-01
	HFP	1.22270	6.16e-01
PWR	HZP	1.42290	4.82e-01
	HFP	1.40424	4.89e-01
VVER	HZP	1.34498	5.13e-01
	HFP	1.32725	5.20e-01
KRITZ-2:1	Cold	1.23394	5.87e-01
	Hot	1.18584	6.31e-01
GEN-III	HFP	1.09591	5.20e-01

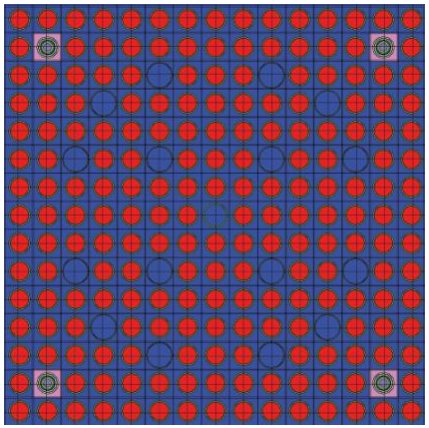


SCALE vs. SERPENT

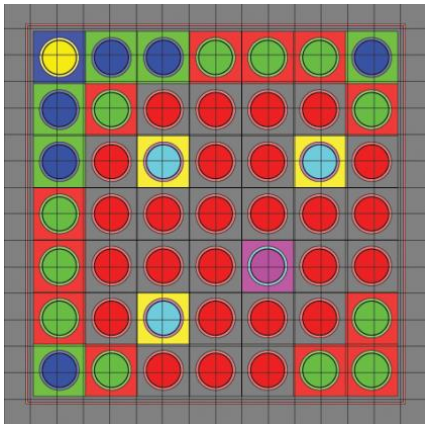
Micro-XS	SCALE 6.1 [barns]	SERPENT [barns]	Uncertainty (%)	Unit cell
U-235 abs.	41.48	40.41 ± 0.0086	1.22	BWR
U-238 abs.	0.88	0.80 ± 0.0011	0.97	
U-235 fission	33.43	32.56 ± 0.00069	1.22	
U-238 fission	0.086	0.089 ± 0.00097	4.79	
U-235 abs.	42.95	42.18 ± 0.00088	1.09	PWR
U-238 abs.	0.96	0.93 ± 0.0011	0.97	
U-235 fission	34.72	34.10 ± 0.00064	1.11	
U-238 fission	0.099	0.10 ± 0.00096	3.94	
U-235 abs.	58.13	57.26 ± 0.00085	1.03	VVER
U-238 abs.	1.042	1.005 ± 0.0012	0.99	
U-235 fission	47.84	47.76 ± 0.00063	1.05	
U-238 fission	0.093	0.095 ± 0.00100	3.88	

Exercises I-2: Lattice Physics

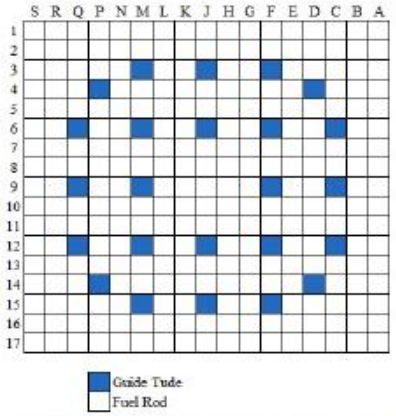
Multigroup cross-section uncertainties from Exercise I-1 are propagated through lattice physics calculations to 2 groups (Ecutoff = 0.625 eV) microscopic uncertainties



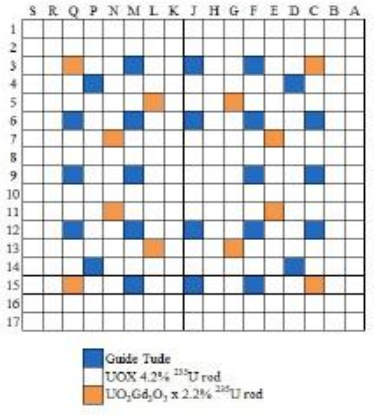
PWR



BWR

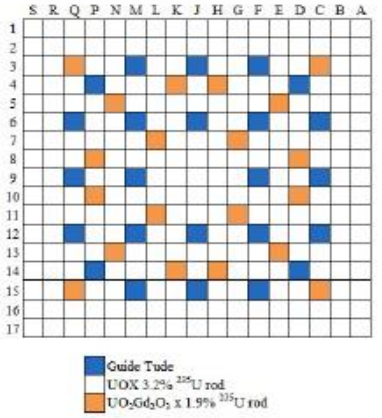


Type 1: UOX 2.1% ^{252}U without UO_2-Gd_2O_3 rods UOX 4.2% ^{235}U assembly without UO_2-Gd_2O_3 rods

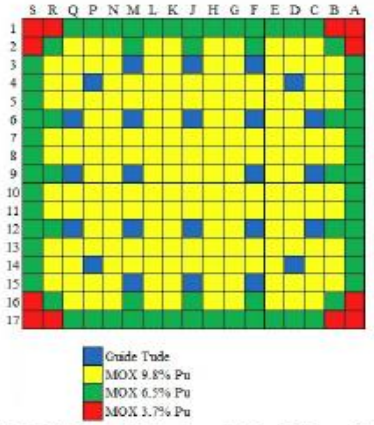


Type 2: UOX 4.2% ^{235}U assembly with 12 UO_2 Gd_2O_3 (2.2% ^{235}U) rods

GEN-III



Type 3: UOX 3.2% ^{252}U assembly with 20 UO_2-Gd_2O_3 (1.9% ^{235}U) rods



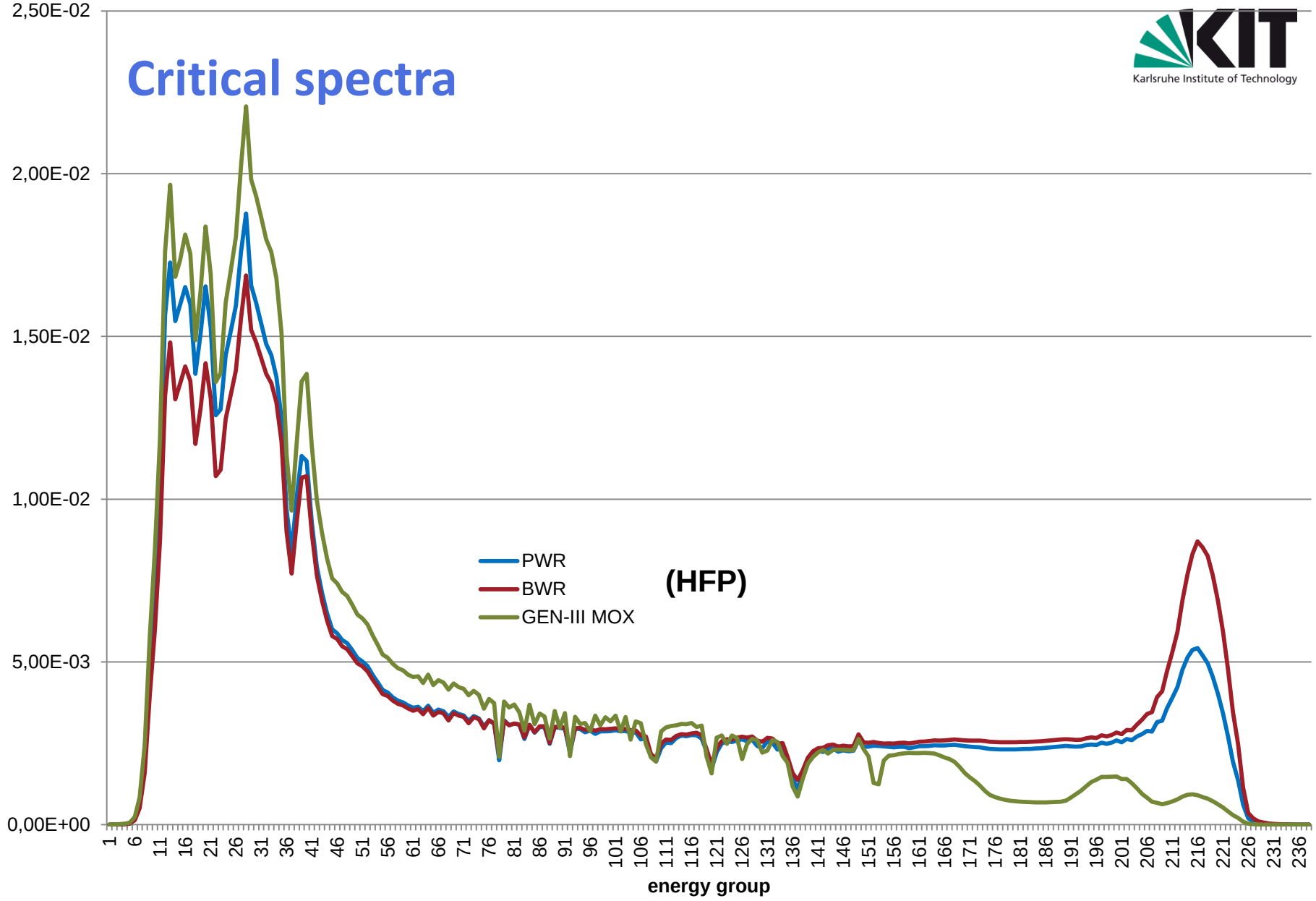
Type 4: MOX assembly (without UO_2-Gd_2O_3 rods)

Exercises I-2: results

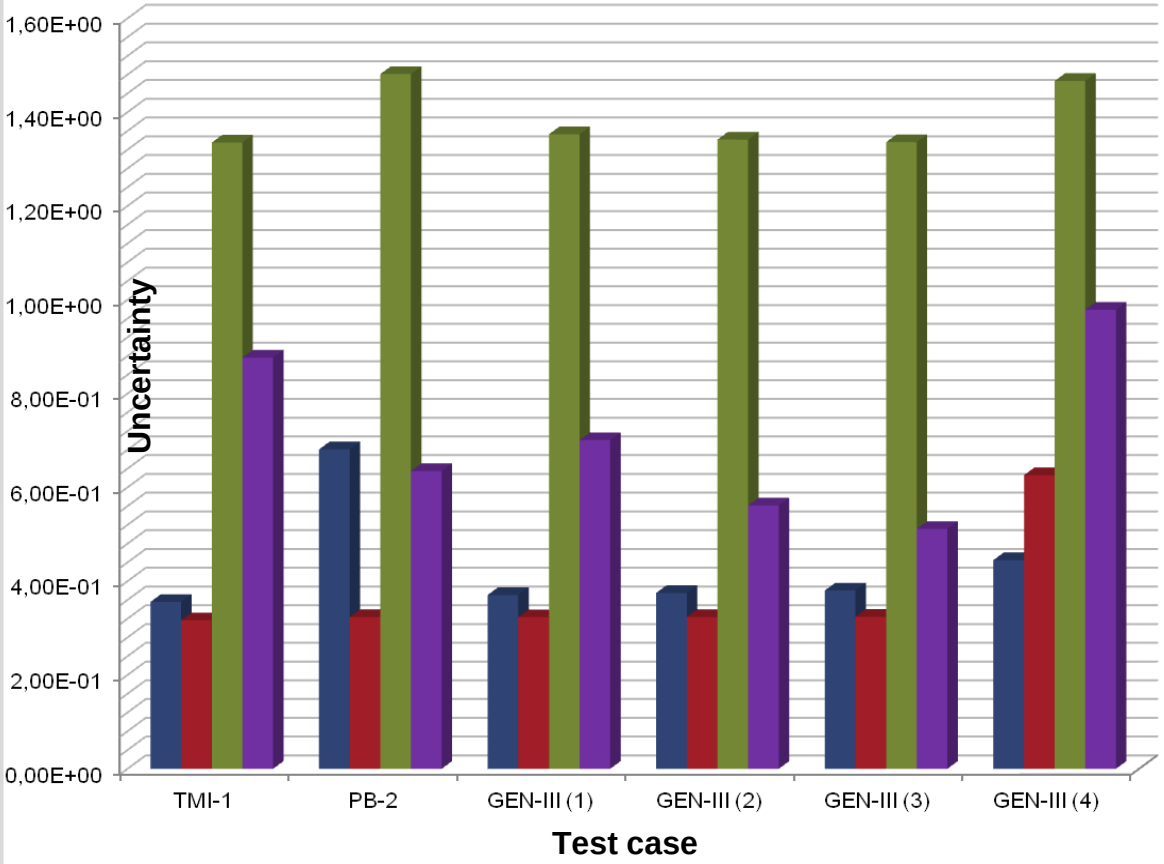
Test Case		k-eff	Uncertainty
BWR	HZP	1.11029	5.00E-01
	HFP	1.07736	5.56E-01
PWR	HZP	1.41009	4.64E-01
	HFP	1.39351	4.71E-01
GEN-III (1)	HFP	1.25325	4.87E-01
GEN-III (2)	HFP	1.12304	4.94E-01
GEN-III (3)	HFP	1.04501	5.03E-01
GEN-III (4)	HFP	1.07008	9.68E-01

Keff Sensitivities			Keff Uncertainties		
XS	BWR	PWR	XS	BWR	PWR
U-235 nubar	9.19E-1	9.45E-1	U-238 (n,ɣ)	3.20E-1	2.56E-1
U-235 fission	4.15E-1	2.73E-1	U-235 nubar	2.65E-1	2.68E-1
U-235 total	3.08E-1	1.25E-1	U-238 (n,n')	2.06E-1	9.72E-2
H-1 elastic	1.66E-1	1.66E-1	U-235 chi	1.47E-1	8.79E-2
H-1 scatter	1.65E-1	1.66E-1	U-235 (n,ɣ)	1.44E-1	2.00E-1

Critical spectra



Exercises I-2: Homogenized XS Uncertainties



Cross-section	Energy group	Value (cm^{-1}) (Uncertainty %)					
		PWR	BWR	GEN-III Type 1	GEN-III Type 2	GEN-III Type 3	GEN-III Type 4
Total	1	1.44E + 00	1.58E + 00	1.31E + 00	1.32E + 00	1.33E + 00	1.50E + 00
		(1.38E – 01)	(1.29E – 01)	(1.41E – 01)	(1.39E – 01)	(1.39E – 01)	(1.39E – 01)
	2	5.69E – 01	5.79E – 01	5.33E – 01	5.34E – 01	5.34E – 01	5.24E – 01
		(8.78E – 01)	(8.40E – 01)	(9.04E – 01)	(9.03E – 01)	(9.01E – 01)	(9.73E – 01)
Absorption	1	1.11E – 01	5.72E – 02	1.07E – 01	1.17E – 01	3.45E – 1	1.24E – 01
		(8.77E – 01)	(6.06E – 01)	(7.00E – 01)	(5.61E – 01)	(9.79E – 01)	(5.11E – 01)
	2	1.06E – 02	7.32E – 03	1.04E – 02	1.06E – 02	5.09E – 01	1.07E – 02
		(1.33E + 00)	(1.38E + 00)	(1.35E + 00)	(1.34E + 00)	(1.47E + 00)	(1.34E + 00)
Fission	1	7.95E – 01	2.94E – 02	6.86E – 02	6.60E – 02	1.90E – 01	6.42E – 02
		(3.17E – 03)	(3.23E – 01)	(3.23E – 01)	(3.24E – 01)	(6.26E – 01)	(3.24E – 01)
	2	3.59E – 03	1.95E – 03	3.17E – 03	3.10E – 03	4.97E – 01	3.05E – 03
		(3.55E – 01)	(6.81E – 01)	(3.71E – 01)	(3.75E – 01)	(4.45E – 01)	(3.80E – 01)
Nufission	1	1.94E – 01	7.02E – 02	1.67E – 1	1.61E – 01	5.45E – 01	1.56E – 01
		(4.44E – 01)	(4.49E – 01)	(4.48E – 01)	(4.49E – 01)	(1.09E + 00)	(4.49E – 01)
	2	9.08E – 03	4.69E – 03	8.02E – 03	7.86E – 03	1.44E – 02	7.73E – 3
		(5.12E – 01)	(1.01E + 00)	(5.71E – 01)	(5.82E – 01)	(7.75E – 01)	(5.92E – 01)

Summary

- The complete set of updated results for Exercises I-1 and I-2 has been provided to the benchmark team according to the new template specifications
- Uncertainties in the order of ~0.5% (k_{eff}) and ~4% (XSs)
- U-238 (n,ɣ) and Pu-239 nubar major contributors to the uncertainties for UOX and MOX LWR's test cases
- Good agreement with the Monte-Carlo solutions, especially for microscopic XSs
- Work in progress:
  - Validation of the capabilities of the statistical sampling methodology implementd in SCALE 6.1.2
  - Exercise I-3 test cases
  - Pin-cell burn-up test case I-1