Karlsruhe Institute of Technology

Updated KIT contribution to UAM PHASE-I

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Institute for Neutron Physics and Reactor Technology

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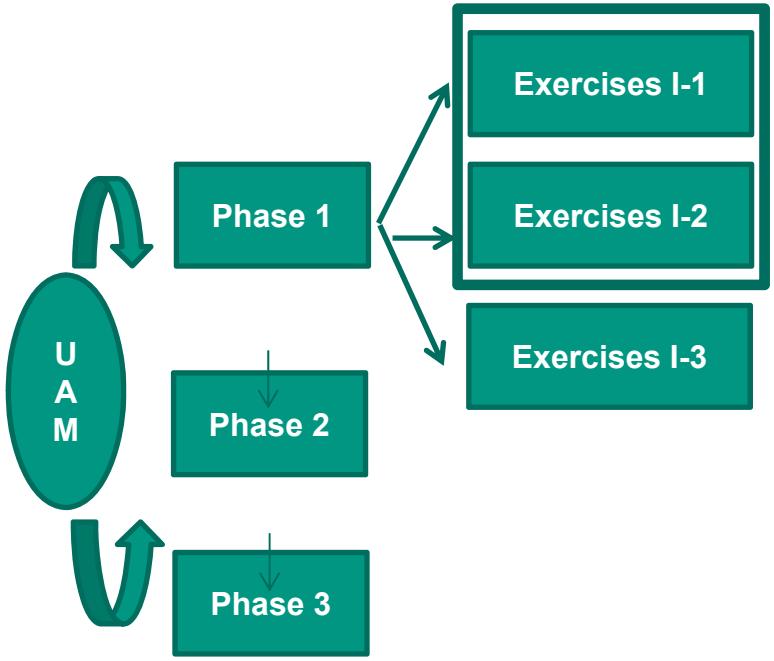
Introduction

- KIT contribution to the UAM neutronics exercises since 2011:
  - **Monte Carlo** (reference) solutions ⟶ **SERPENT** code
  - **Deterministic** solutions ⟶ **SCALE** code

- **SCALE code (v. 6.1, 6.2)**
  - ENDF/B-VII.0, ENDF/B-VII.1
  - Transport (NEWT, XSDRNPM)
  - S/U analysis
    - ✓ Perturbation theory (**TSUNAMI**)
    - ✓ Stocastic sampling (**SAMPLER**)

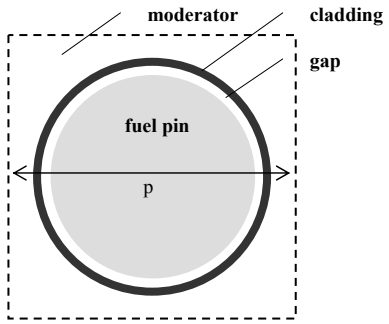


- Solutions provided for:
  - **Exercise I**: PWR, BWR, VVER, KRITZ 2:1, KRITZ 2:13, KRITZ 2:19
  - **Exercise II**: PWR, BWR, VVER, GEN-III
  - **Exercise I-b**: PWR

Exercises I-2: Lattice Physics

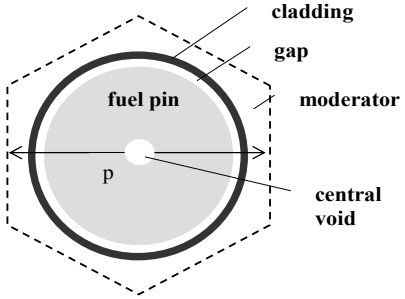
Ex. I-1: Cell Physics

multi-group micro XS's → **2 groups (0.625 eV: cutoff)**



p – pitch of the unit cell

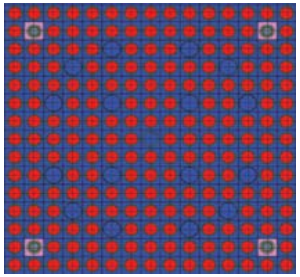
PWR, BWR



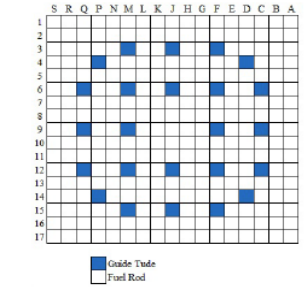
p – pitch of the unit cell

VVER

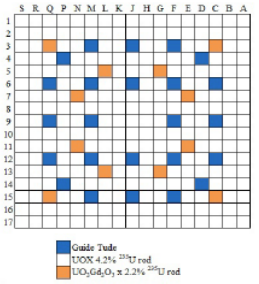
Ex. I-2: Lattice Pysics



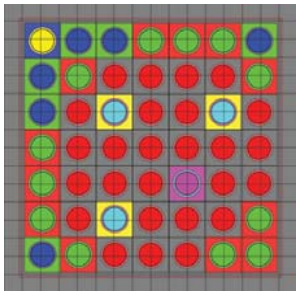
PWR



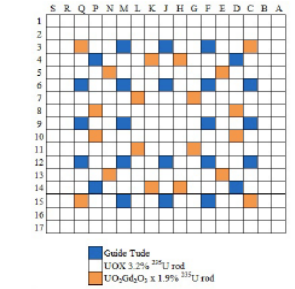
Type 1: UOX 2.1% ^{235}U without UO_2-Gd_2O_3 rods UOX 4.2% ^{235}U assembly without UO_2-Gd_2O_3 rods



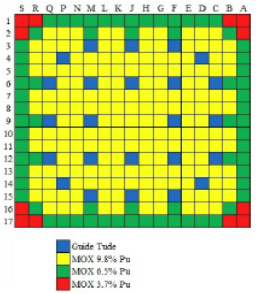
Type 2: UOX 4.2% ^{235}U assembly with 12 UO_2 Gd_2O_3 (2.2% ^{235}U) rods



BWR



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

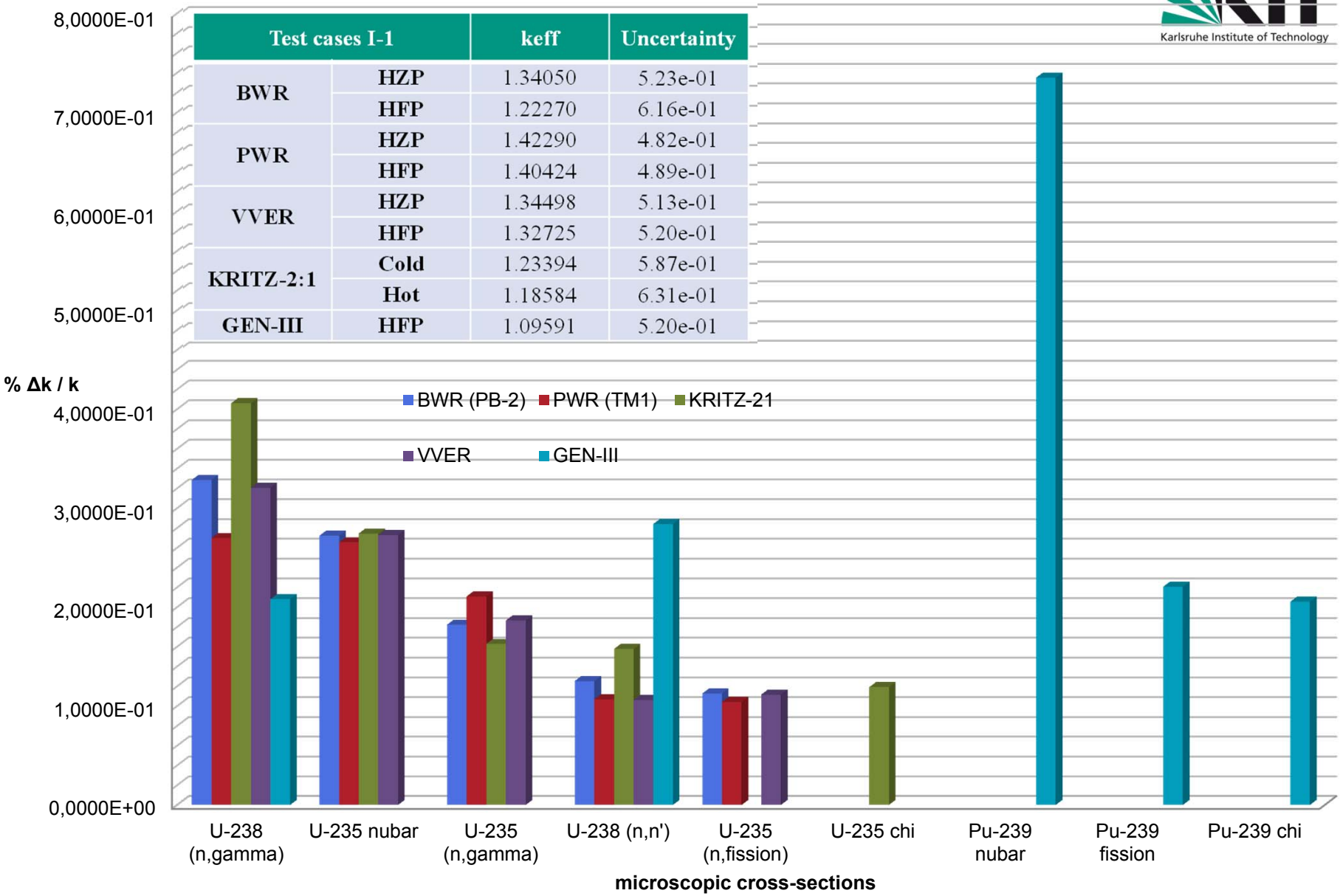


Type 4: MOX assembly (without UO_2-Gd_2O_3 rods)

GEN-III

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



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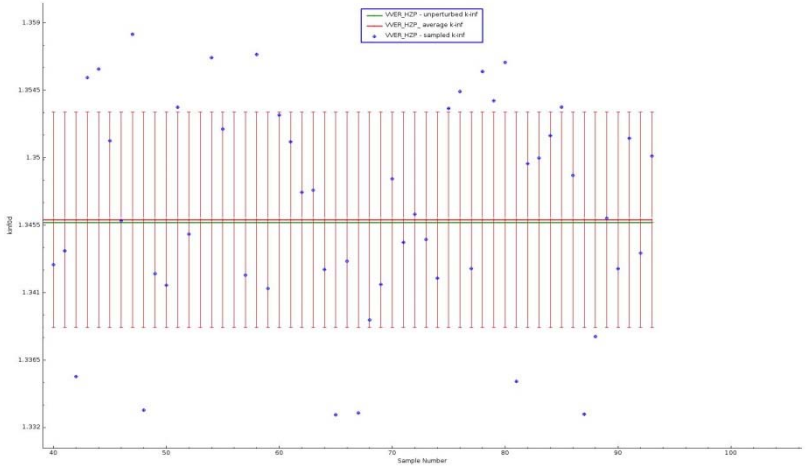
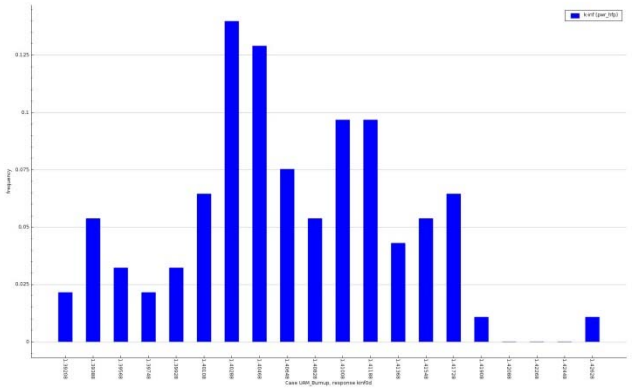
Exercise I-1: k-inf (TSUNAMI vs. SAMPLER)

SCALE v6.2.1

- v6.2.1 provides higher k-inf with respect to v6.1 (~ 100 - 200 pcm)
- Excellent agreement between TSUNAMI and SAMPLER

Test cases (Ex. I-1)		k-inf (TSUNAMI)	Uncertainty	k-inf (SAMPLER)	Uncertainty
BWR	HZP	1.3428	6.8E-01	1.3430	5.4E-01
	HFP	1.2249	5.9E-01	1.2252	5.7E-01
PWR	HZP	1.4253	5.4E-01	1.4254	5.0E-01
	HFP	1.4063	5.5E-01	1.4064	5.0E-01
VVER	HZP	1.3457	5.8E-01	1.3458	5.3E-1
	HFP	1.3276	5.8E-01	1.3278	5.4E-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	

Uncertainties on micro-XSs higher by an order of magnitude with respect to those on K-inf

Exercises I-2: results

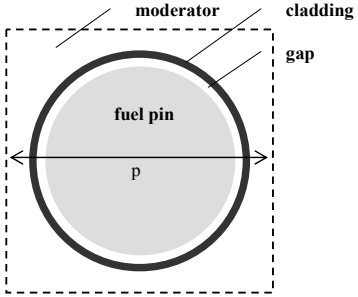
Test Case		k-eff	Uncertainty
BWR	HZP	1.11029	5.00E-01
	HFP	1.07736	5.56E-01
PWR	HZP	1.41009	4.64E-01
	HFP	1.39351	4.71E-01
GEN-III (1)	HFP	1.25325	4.87E-01
GEN-III (2)	HFP	1.12304	4.94E-01
GEN-III (3)	HFP	1.04501	5.03E-01
GEN-III (4)	HFP	1.07008	9.68E-01

Keff Sensitivities		
XS	BWR	PWR
U-235 nubar	9.19E-1	9.45E-1
U-235 fission	4.15E-1	2.73E-1
U-235 total	3.08E-1	1.25E-1
H-1 elastic	1.66E-1	1.66E-1
H-1 scatter	1.65E-1	1.66E-1

Keff Uncertainties		
XS	BWR	PWR
U-238 (n,ɣ)	3.20E-1	2.56E-1
U-235 nubar	2.65E-1	2.68E-1
U-238 (n,n')	2.06E-1	9.72E-2
U-235 chi	1.47E-1	8.79E-2
U-235 (n,ɣ)	1.44E-1	2.00E-1

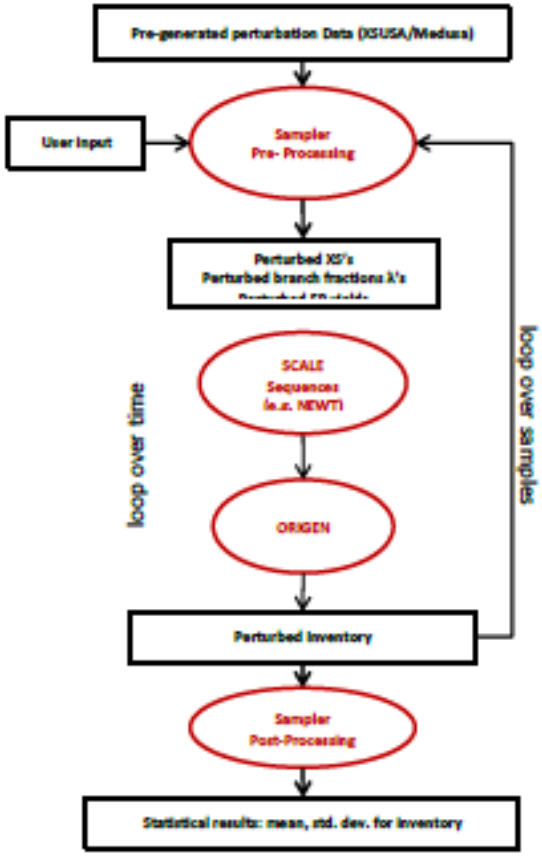
Ex. I-b: Burnup pin-cell

- Requested output (at 0 - 60 GWd/MTU + 100 years cooling time)
  - k-inf
  - One-group (n,f) and (n,γ) reaction rates for U and Pu
  - Two energy group constants (fuel region)
  - Actinide and fission product isotopic concentrations

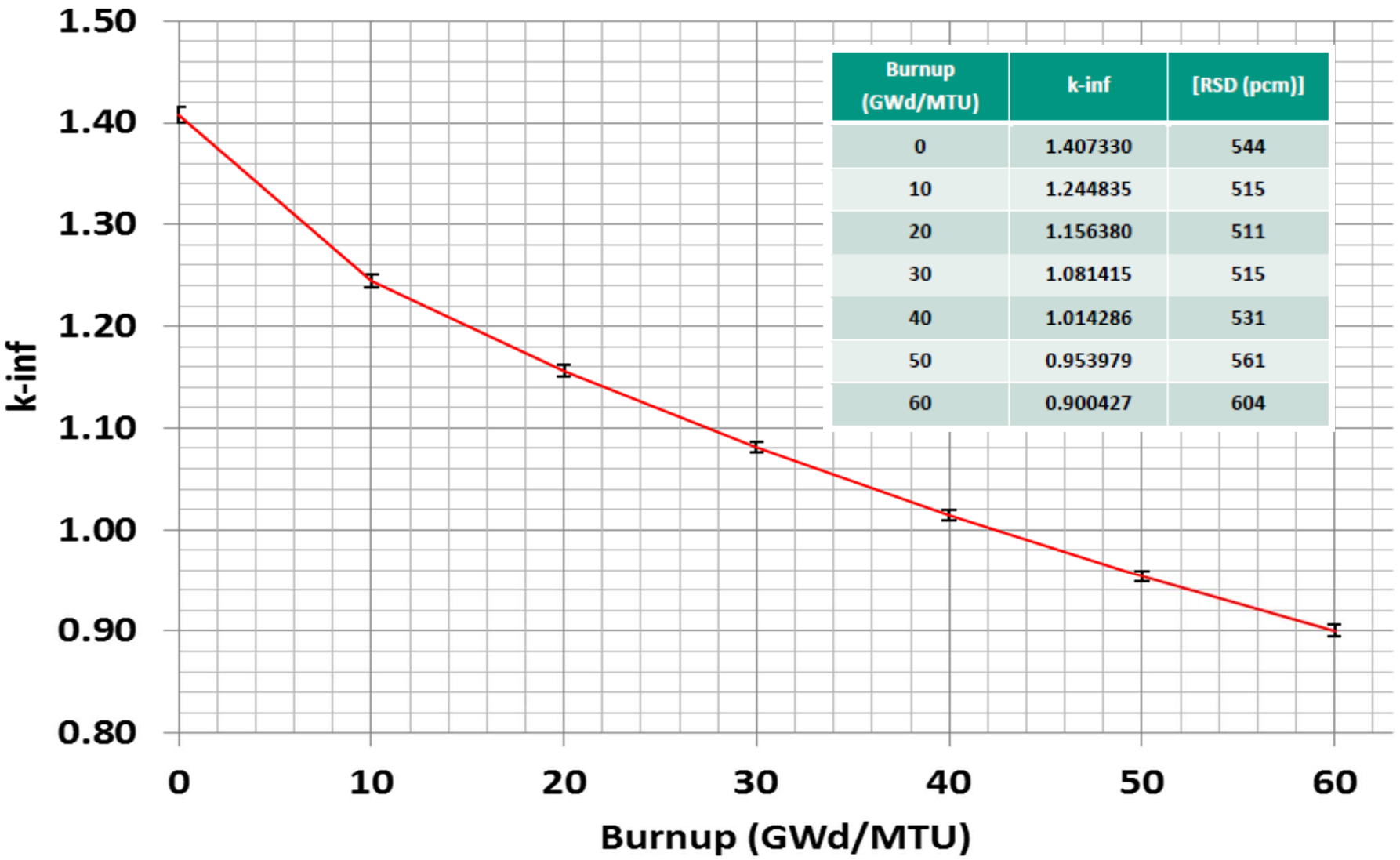


p – pitch of the unit cell

- **Modelling**
  - SCALE 6.2.1
  - Sampler
  - 56 ENDF-VII.1 XS library.
  - 56 ENDF-VII.1 XS COV. data
  - NEWT transport sequence (T-DEPL)
  - 93 samples (Wilk's formula)



Ex. I-b: k-inf



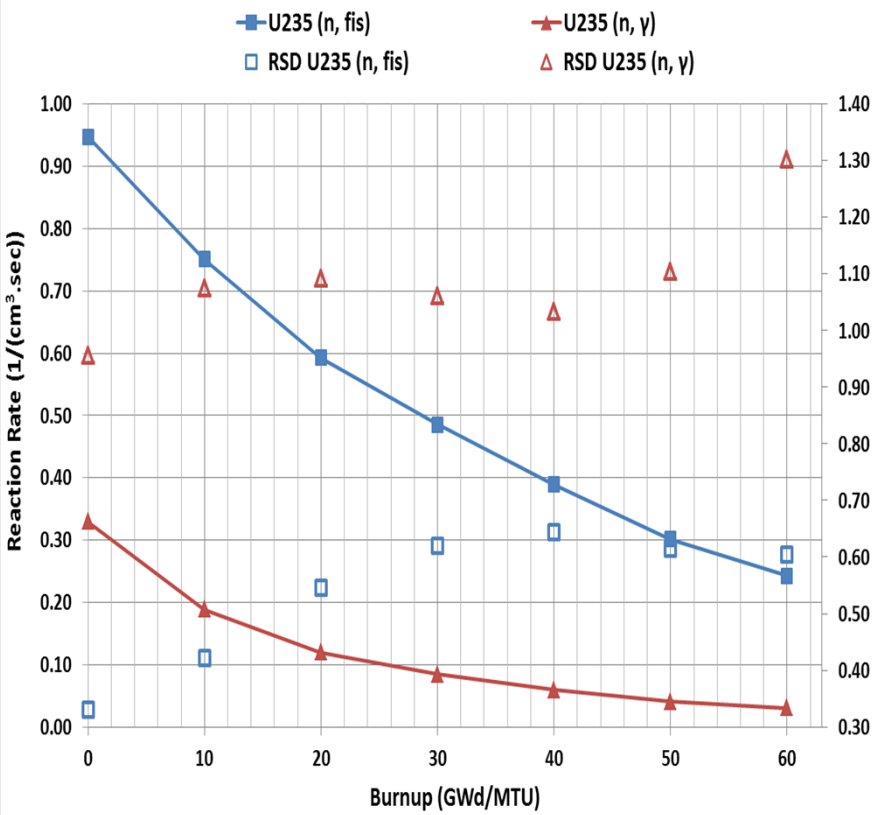
Burnup (GWd/MTU)	k-inf	[RSD (pcm)]
0	1.407330	544
10	1.244835	515
20	1.156380	511
30	1.081415	515
40	1.014286	531
50	0.953979	561
60	0.900427	604

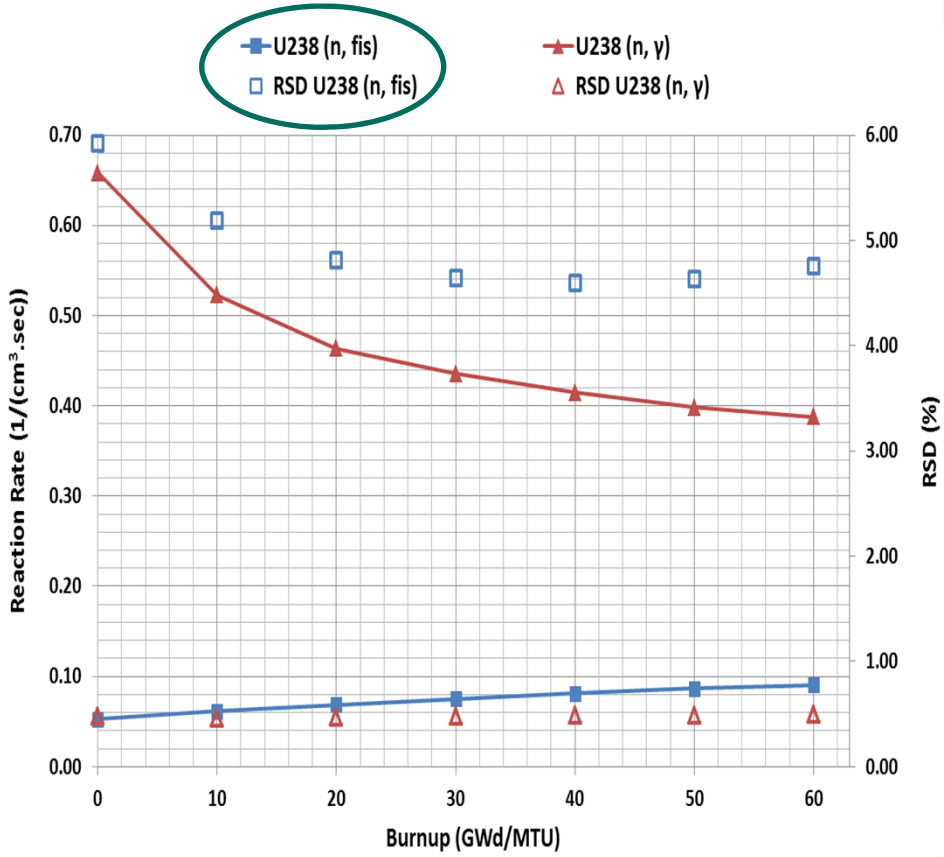
Ex. I-b: Two energy group constants correlation matrix

(COV:0 GWd/MTU)	kinf	Σa,1	Σa,2	Σf,1	Σf,2	νΣf,1	νΣf,2	D1	D2
kinf	1.000								
Σa,1	-0.489	1.000							
Σa,2	-0.309	0.187	1.000						
Σf,1	0.278	0.148	-0.004	1.000					
Σf,2	0.311	0.079	0.242	0.304	1.000				
νΣf,1	0.531	-0.152	-0.022	0.765	0.107	1.000			
νΣf,2	0.682	0.057	0.207	0.133	0.525	0.321	1.000		
D1	0.232	-0.836	-0.046	-0.310	-0.163	0.093	-0.065	1.000	
D2	-0.019	-0.198	-0.055	-0.227	-0.044	-0.141	-0.098	0.332	1.000

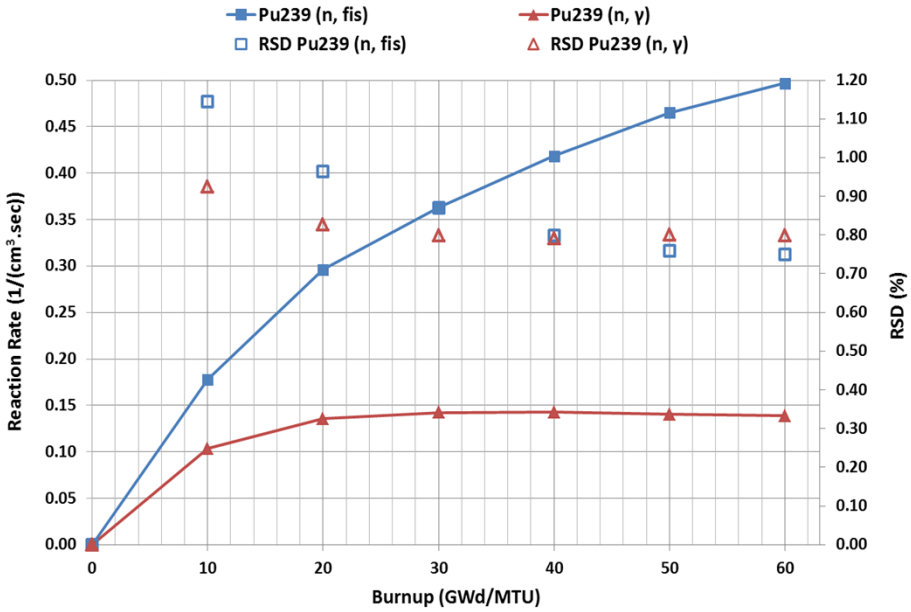
(COV:60 GWd/MTU)	kinf	Σa,1	Σa,2	Σf,1	Σf,2	νΣf,1	νΣf,2	D1	D2
kinf	1.000								
Σa,1	-0.682	1.000							
Σa,2	0.080	0.353	1.000						
Σf,1	0.596	-0.302	0.706	1.000					
Σf,2	0.272	0.292	0.959	0.732	1.000				
νΣf,1	0.635	-0.328	0.669	0.977	0.696	1.000			
νΣf,2	0.270	0.307	0.956	0.714	0.997	0.680	1.000		
D1	0.719	-0.755	0.254	0.760	0.308	0.758	0.291	1.000	
D2	0.260	-0.402	-0.207	-0.002	-0.167	0.020	-0.185	0.308	1.000

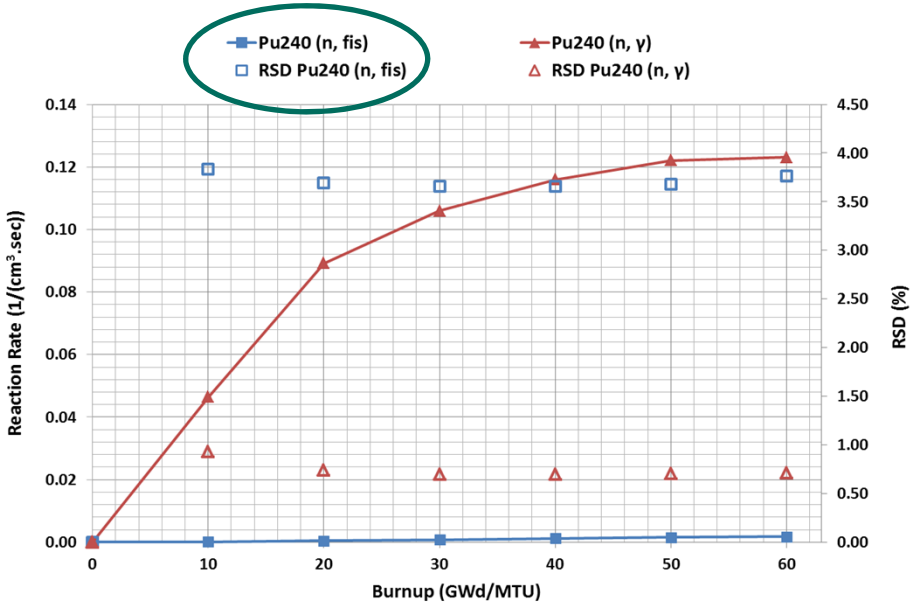
Ex I-b: one-group fission and absorption reaction rates (1)

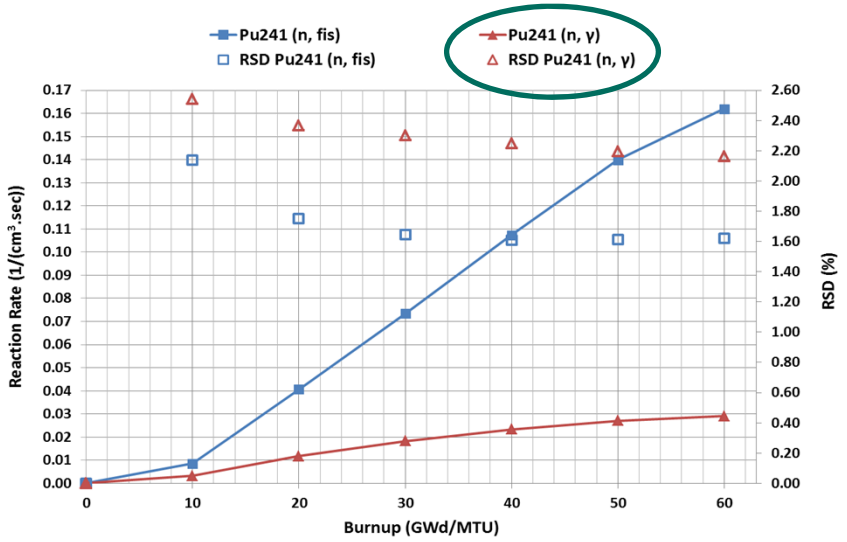




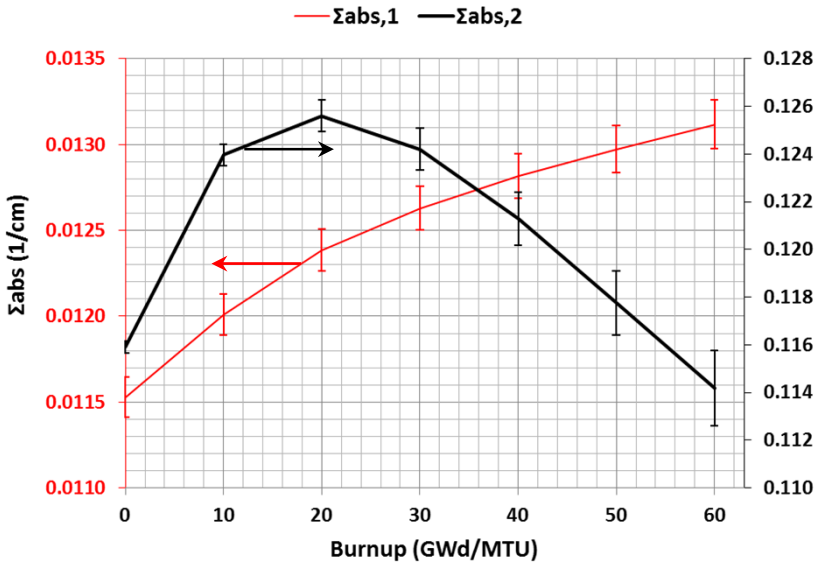
Ex I-b: one-group fission and absorption reaction rates (2)

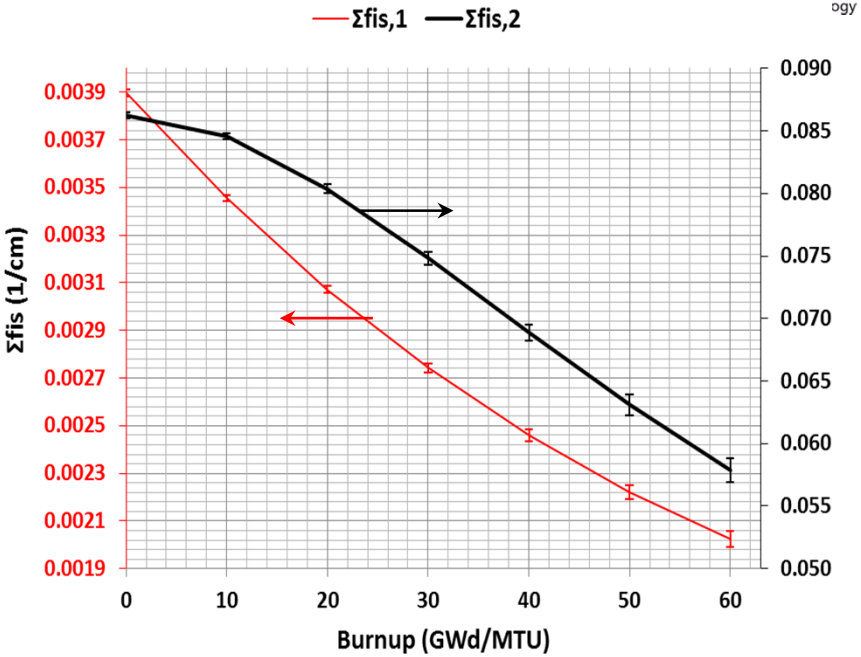


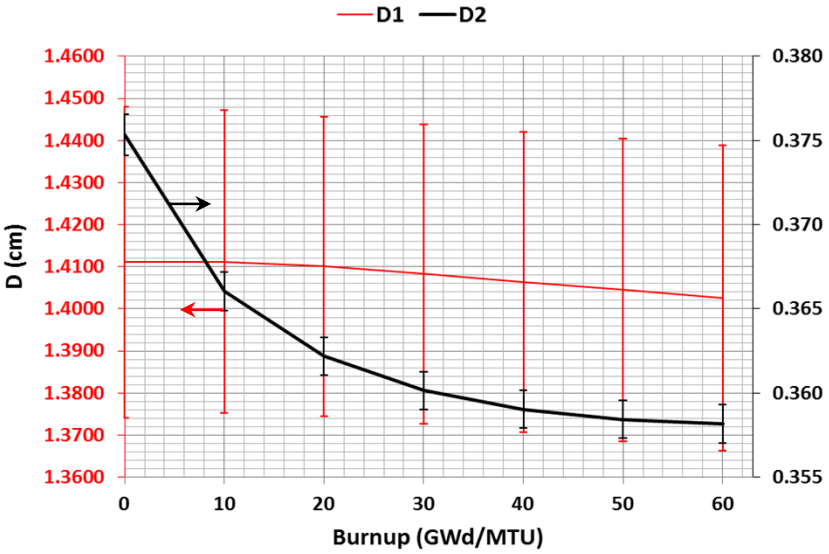




Ex I-b: two-group constants

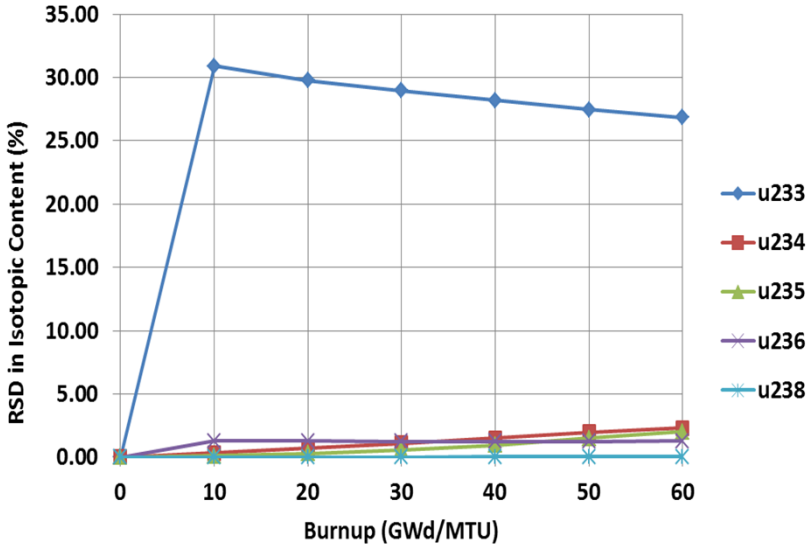


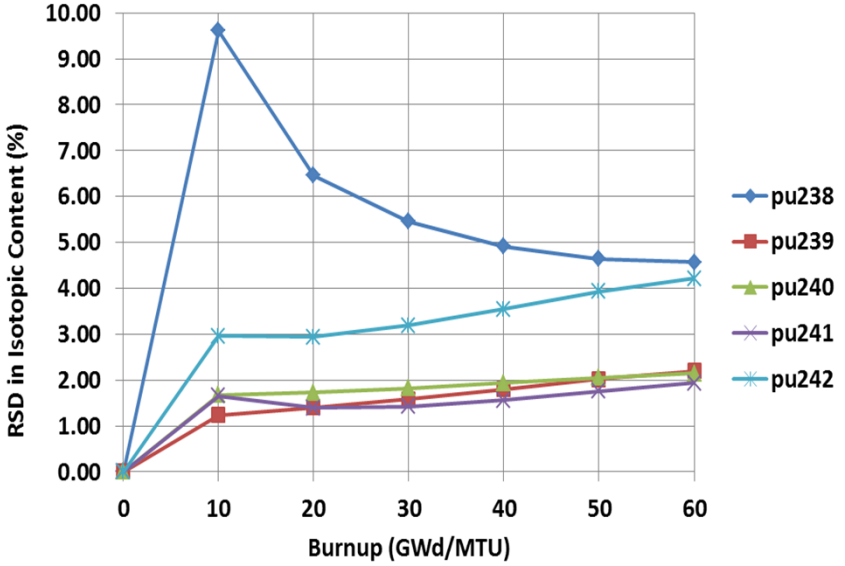


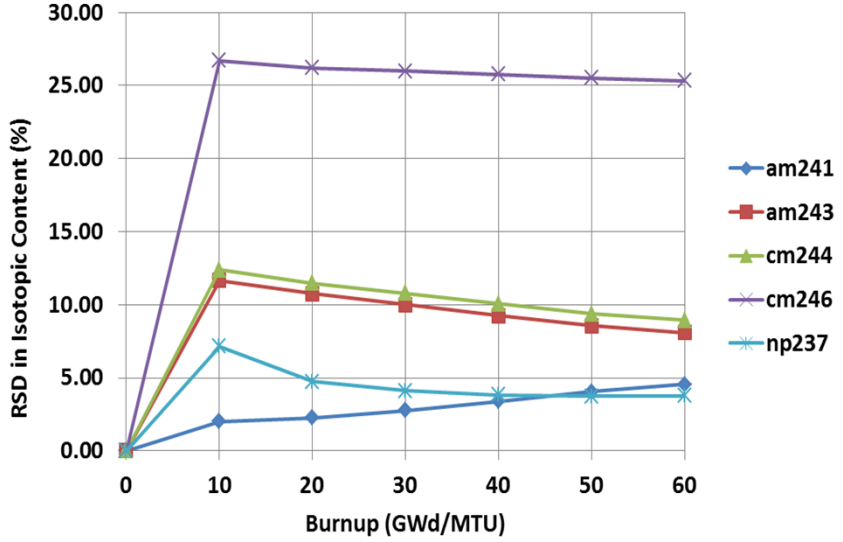


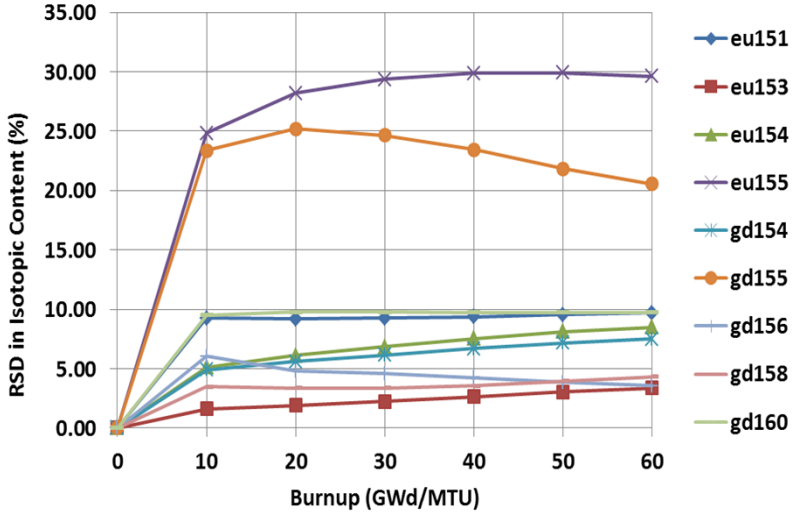
Burnup (GWd/MTU)	Σa,2 (1/cm) [RSD (%)]	Σf,2 (1/cm) [RSD (%)]	D1 (cm) [RSD (%)]	D2 (cm) [RSD (%)]
0	1.16E-01 [0.22]	8.63E-02 [0.29]	1.41E+00 [2.62]	3.75E-01 [0.32]
60	1.14E-01 [1.38]	5.79E-02 [1.62]	1.40E+00 [2.58]	3.58E-01 [0.32]

Ex I-b: nuclide concentrations









Ex I-b: nuclide concentrations (2)

RSD Range (%)	Isotopes Within the RSD Range
0 – 1	U^{238}, Mo^{95}, Tc^{99}, $Ru^{101,106}$, $Cs^{133,137}$, La^{139}, $Ce^{140,142,144}$, Nd^{148}
1 – 3	$U^{234,235,236}$, $Pu^{239,240,241}$, Am^{241}, Ru^{103}, Cs^{135}, $Nd^{143,145,146,150}$, $Sm^{147,149,150,152,154}$, Eu^{153}
3 – 5	Np^{237}, Pu^{242}, Cs^{134}, Nd^{142}, $Sm^{148,151}$, $Gd^{156,158}$
5 – 10	Pu^{238}, Am^{243}, Ag^{109}, $Eu^{151,154}$, $Gd^{154,160}$
> 10	U^{233}, $Cm^{244,246}$, Eu^{155}, Gd^{155}

The complete set of the updated KIT results for PHASE I will be submitted to the benchmark team by end of June 2017

Thanks for the attention!!