Application of Serpent in EU FP7 project FREYA: Fast Reactor Experiments for hYbrid Applications

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Outline

- Overview of FREYA project
- Serpent models of VENUS-F critical cores
- Serpent vs. MCNP
- Serpent vs. experimental data
- Summary

EU/FP7 FREYA project

- FREYA - Fast Reactor Experiments for hYbrid Applications
  - EURATOM 7th Framework Program

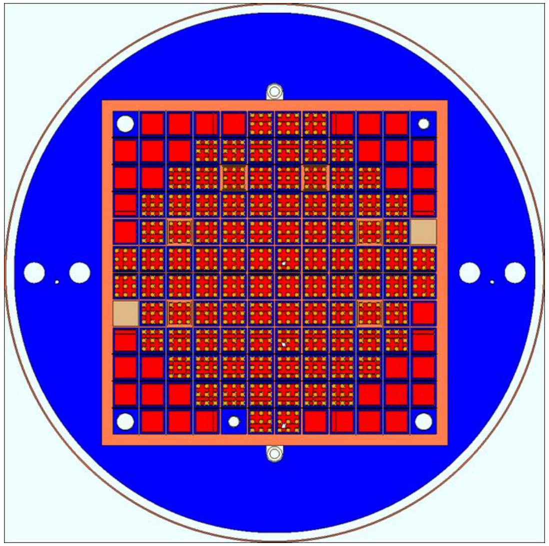
- Support for design and licensing of ADS and LFR systems
  - MYRRHA – Multi-purpose hYbrid Research Reactor for High-tech Applications
  - ALFRED – Advanced LFR European Demonstrator

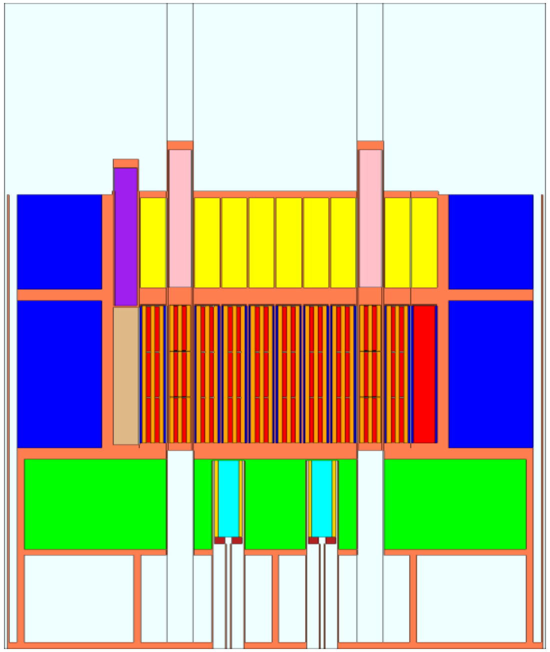
- Sub-critical and critical experiments in VENUS-F facility
  - SCK•CEN, Mol, Belgium

VENUS-F facility

- ***VENUS:*** water-moderated zero power facility
  - E.g. OECD VENUS-2 MOX benchmark

- ***VENUS-F:*** fast zero-power facility
  - Operation in critical or sub-critical mode
  - Fuel: metallic U rodlets, 30 w% U-235
  - “Coolant”: solid lead blocks
  - Core dimensions (xyz): 97 × 97 × 60 cm





Critical core configurations in FREYA

- Several **critical** VENUS-F cores have been investigated
  - Reflect some basic features of MYRRHA and ALFRED
  - **Most** of them were **modeled with Serpent**

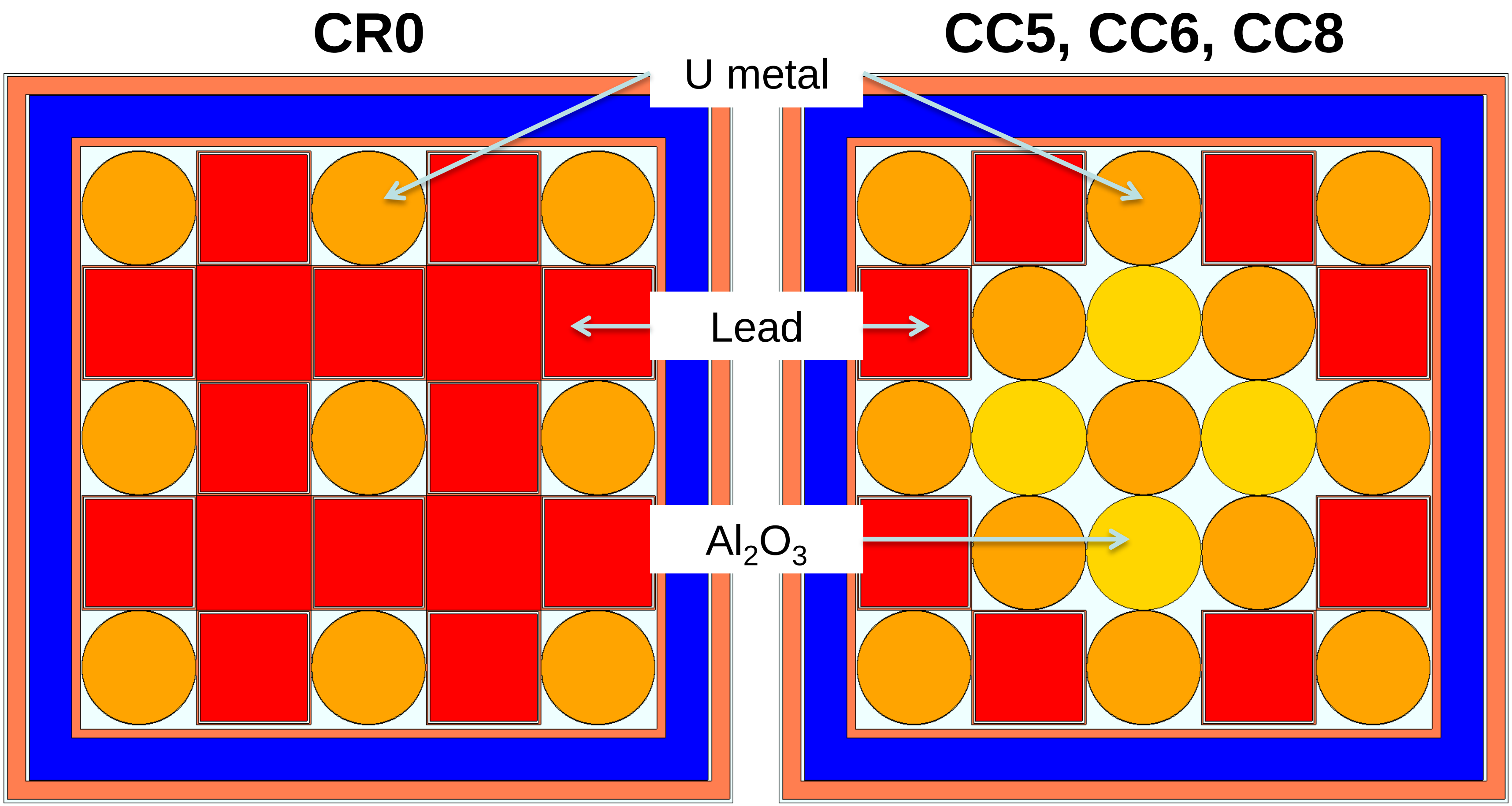
- CR0 – reference critical core

- CC5 – “clean” MYRRHA core mock-up

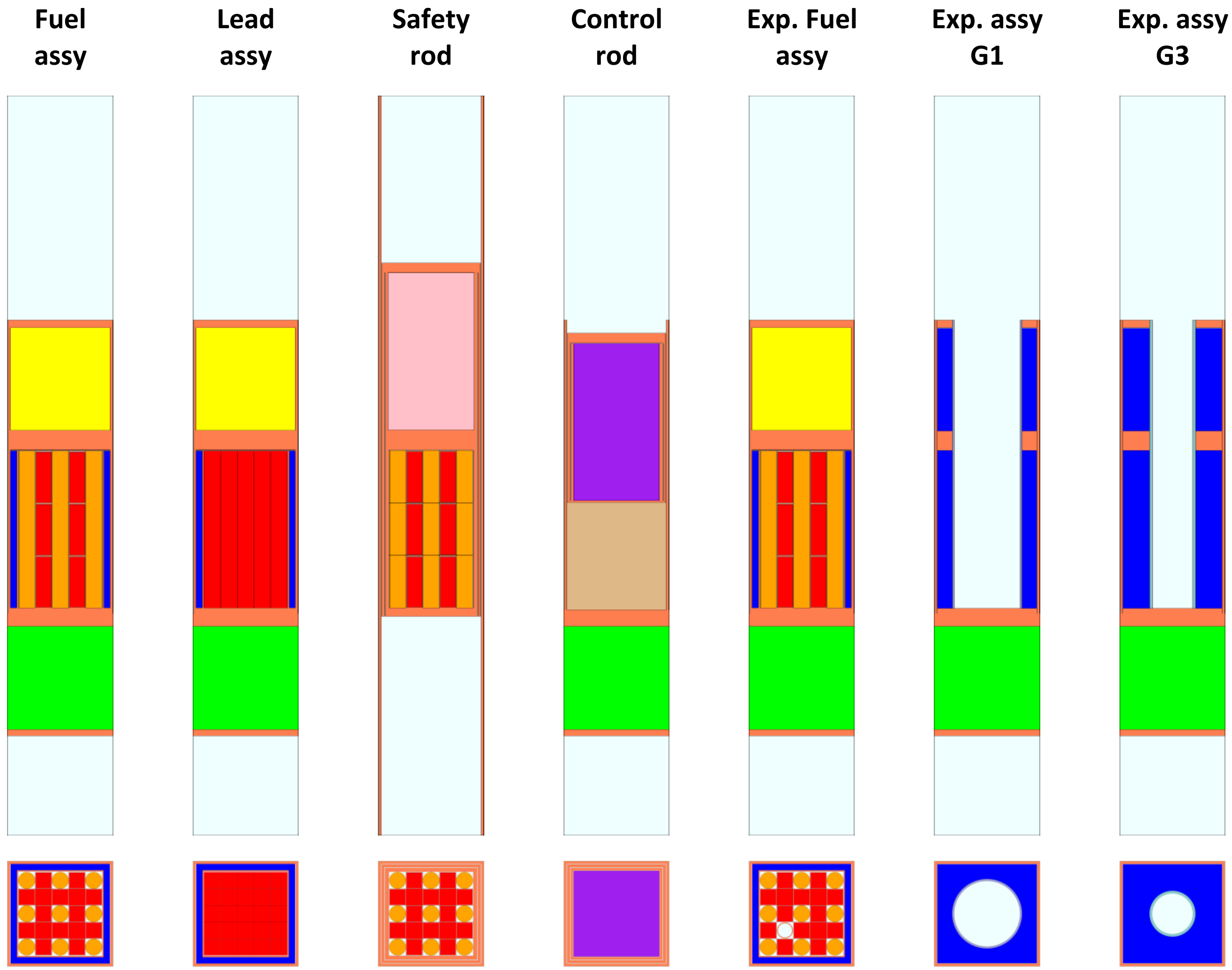
- CC8 – “full” MYRRHA core mock-up
  - several MYRRHA In-Pile Sections (IPSs)
  - graphite blocks simulating MYRRHA BeO reflector

- CC6 = CC5 core + ALFRED island

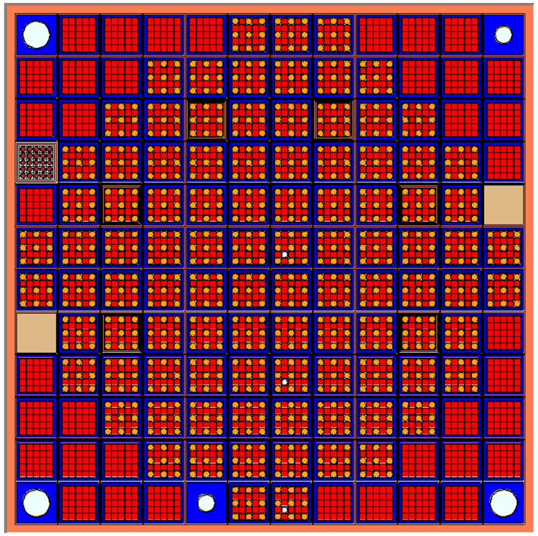
Fuel assembly configurations: transition from CR0 to CC's cores



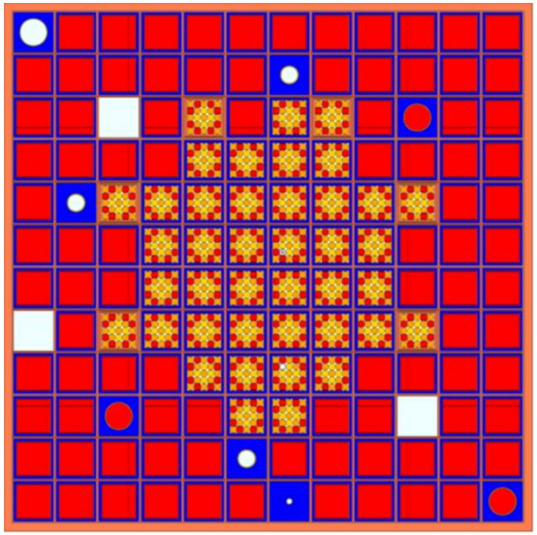
Axial core channels



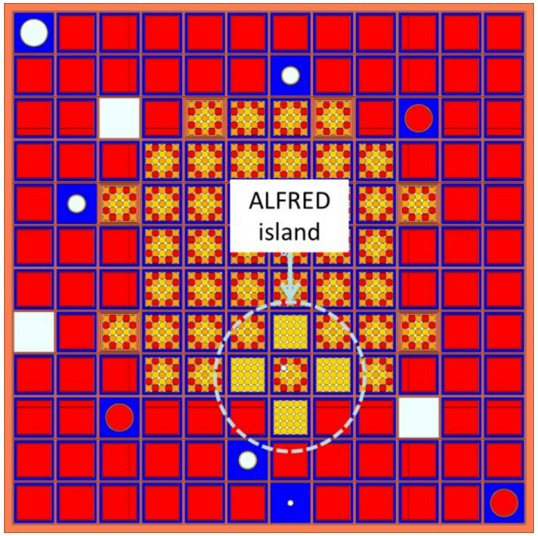
Considered FREYA cores



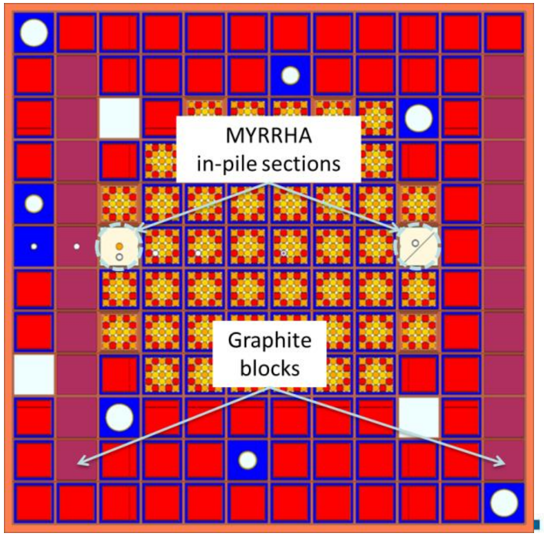
CR0 – reference critical core



CC5 – clean MYRRHA mock-up



CC6 – CC5 core with ALFRED siland



CC8 – full MYRRHA mock-up

Serpent models of VENUS-F critical cores

General setup

- Very detailed Serpent core models
  - Fully resolved fuel assemblies, control rods, and other structures
  - Based on MCNP input provided by SCK·CEN
- XS
  - Serpent JEFF3.1 library
- Neutron histories
  - ~4 billion active neutron histories
  - 1M neutron histories, 4000 active and 200 skipped cycles
  - 1σ uncertainty on k-eff is about 2-3 pcm

Serpent vs. MCNP: CR0 core

Approach to comparison

- Serpent model was built from the reference MCNP input
- Dimensions, material compositions, etc. were preserved
- Identical ACE files for Serpent and MCNP
- Identical number of neutron histories

The goals:

- To assure the consistency of the Serpent model
- To compare Serpent/MCNP performance

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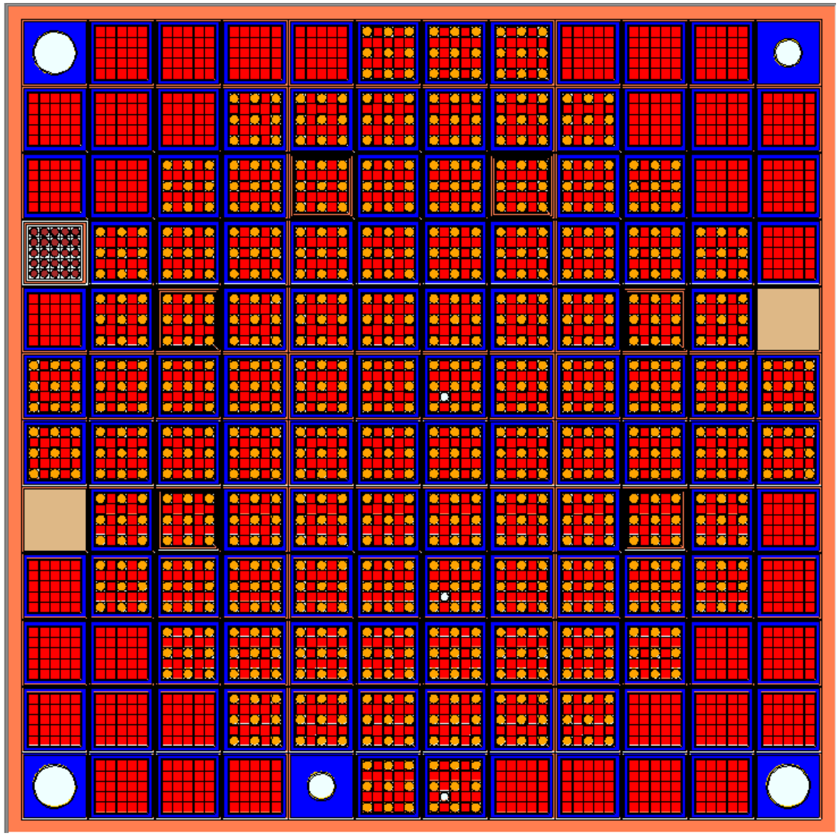
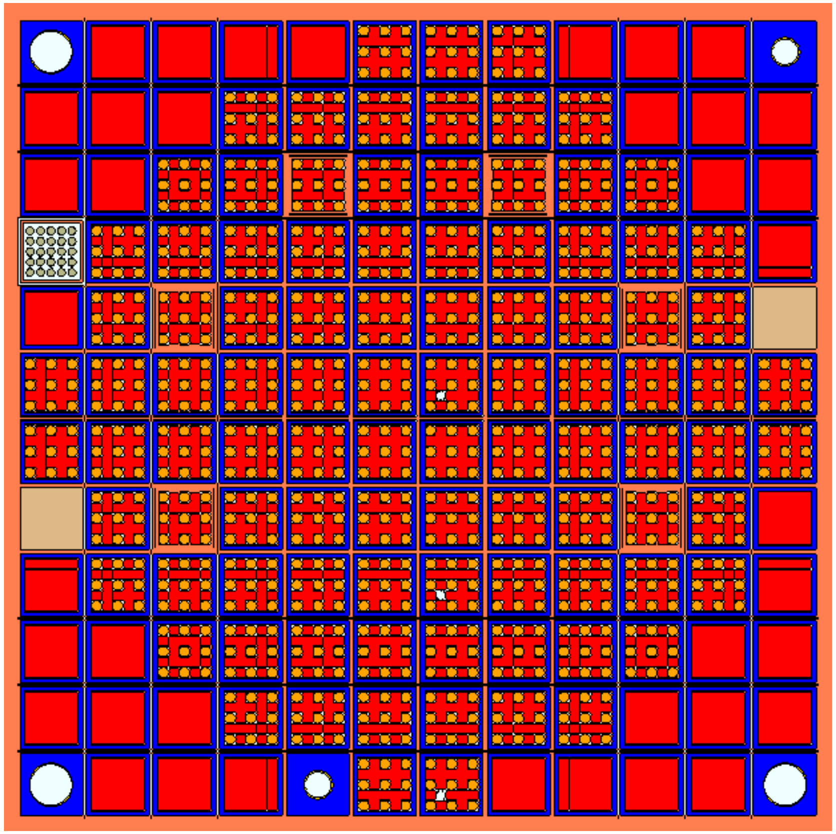
Serpent vs. MCNP: radial core layout

MCNP Vised plotter



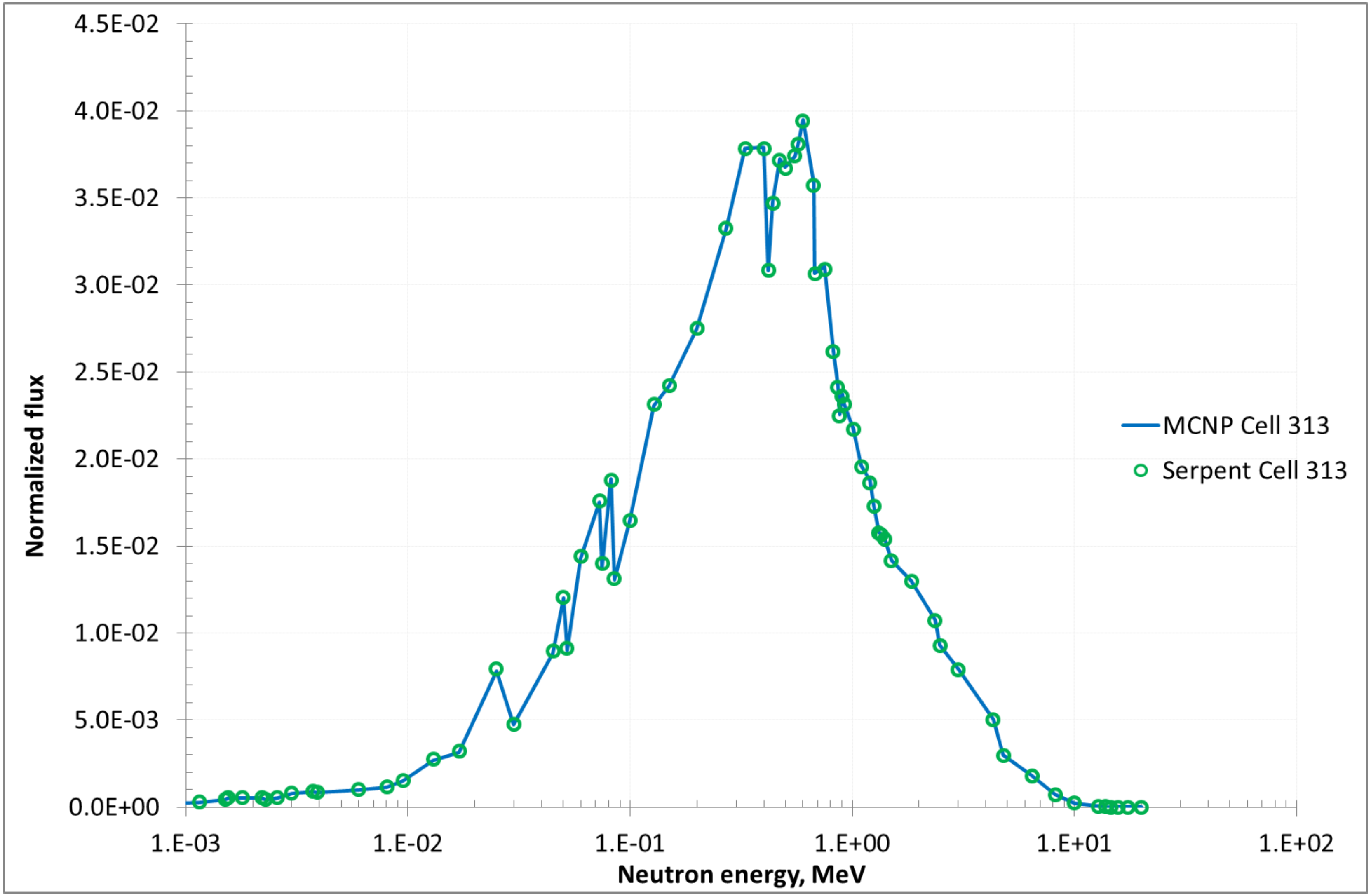
Serpent plotter



Serpent vs. MCNP: integral parameters

	Difference
k-eff	13 pcm
Gen. time, sec	0.2%
Beta-eff, pcm	3 pcm

Serpent vs. MCNP: neutron flux spectra in fuel



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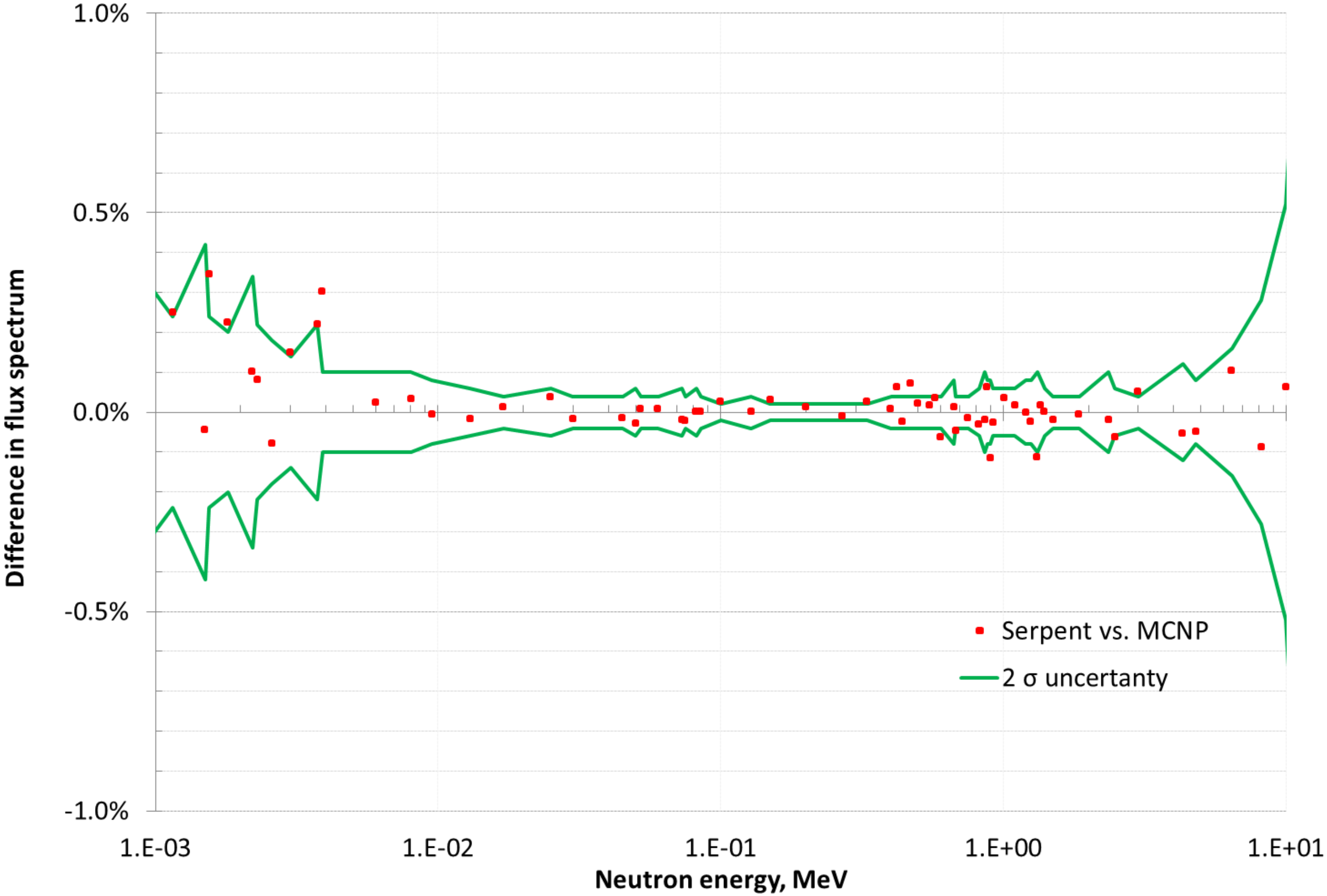
Serpent vs. MCNP: diff. in neutron flux spectra



Serpent vs. MCNP: Norm. power distribution

Normalized radial power

					0.75	0.74	0.69				
			0.77	0.85	0.88	0.88	0.84	0.77			
		0.80	0.91	1.00	1.06	1.06	1.01	0.91	0.79		
	0.76	0.91	1.05	1.16	1.21	1.21	1.16	1.05	0.90	0.74	
	0.82	0.99	1.15	1.26	1.33	1.33	1.26	1.15	0.98	0.79	
0.67	0.85	1.04	1.20	1.32	1.38	1.39	1.32	1.20	1.03	0.84	0.65
0.65	0.83	1.03	1.20	1.32	1.39	1.39	1.32	1.21	1.04	0.85	0.67
	0.78	0.97	1.14	1.26	1.33	1.33	1.27	1.16	0.99	0.82	
	0.73	0.89	1.04	1.16	1.22	1.22	1.16	1.06	0.91	0.76	
		0.79	0.91	1.01	1.06	1.06	1.01	0.92	0.81		
			0.77	0.84	0.88	0.88	0.85	0.78			
					0.74	0.75					

Relative difference

					0.02%	0.08%	0.02%				
			0.03%	0.02%	0.02%	0.07%	0.09%	0.04%			
		0.04%	0.01%	0.03%	0.06%	0.02%	0.08%	0.02%	0.05%		
	0.01%	0.03%	0.05%	0.05%	0.00%	0.02%	0.01%	0.04%	0.03%	0.01%	
	0.01%	0.01%	0.05%	0.01%	0.01%	0.03%	0.03%	0.01%	0.03%	0.07%	
0.01%	0.04%	0.02%	0.05%	0.01%	0.01%	0.02%	0.00%	0.07%	0.04%	0.04%	0.03%
0.03%	0.05%	0.04%	0.04%	0.02%	0.02%	0.04%	0.01%	0.03%	0.04%	0.05%	0.15%
	0.09%	0.03%	0.02%	0.05%	0.05%	0.01%	0.01%	0.03%	0.02%	0.09%	
	0.06%	0.02%	0.05%	0.06%	0.03%	0.00%	0.06%	0.03%	0.06%	0.04%	
		0.05%	0.00%	0.02%	0.08%	0.04%	0.01%	0.09%	0.06%		
			0.02%	0.15%	0.02%	0.04%	0.03%	0.06%			
					0.06%	0.06%					

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Serpent vs. MCNP: summary

- Very good agreement between Serpent and MCNP
  - Integral parameters, power distribution, flux spectra
  - Typically within statistics
- Consistency of the Serpent model is demonstrated
- Serpent outperforms MCNP
  - **Runs 9.3 times faster**

Serpent results vs. experimental data

Measured parameters calculated by Serpent

- Integral parameters
  - k-eff, β-eff, control rod worth

- Axial and radial traverses
  - Axial or radial distribution of fission rates

- Spectral indices - fission rates ratio e.g.:
  - F28 = Fission U238 / Fission U235
  - F49 = Fission Pu239 / Fission U235

- Lead void reactivity effect (CC6 core)

- Selected results are in the next slides

Selected results: CC5 core

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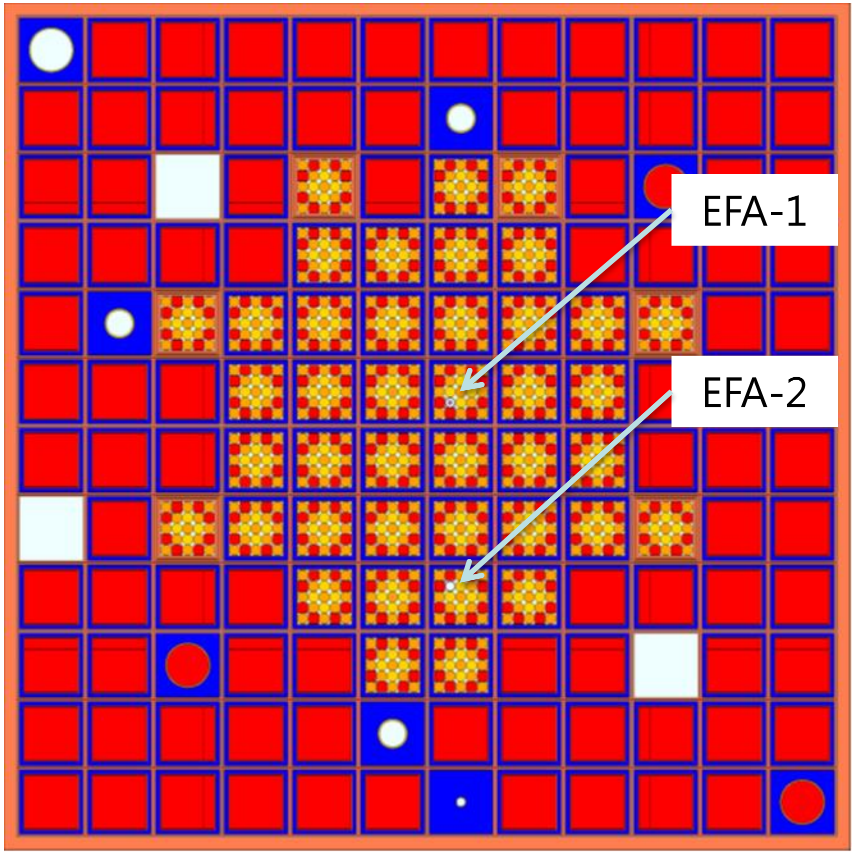
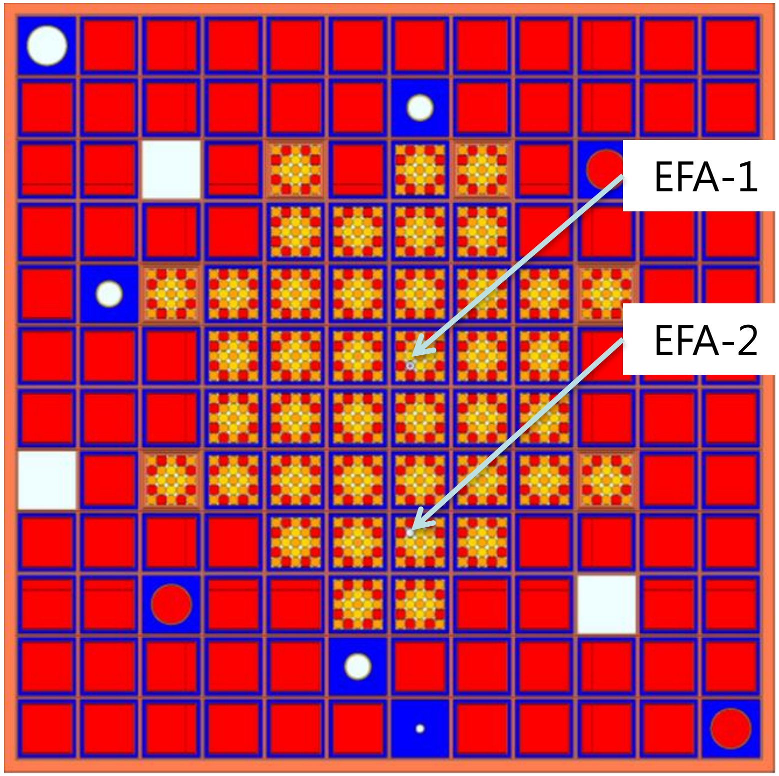
Spectral indices



C/E

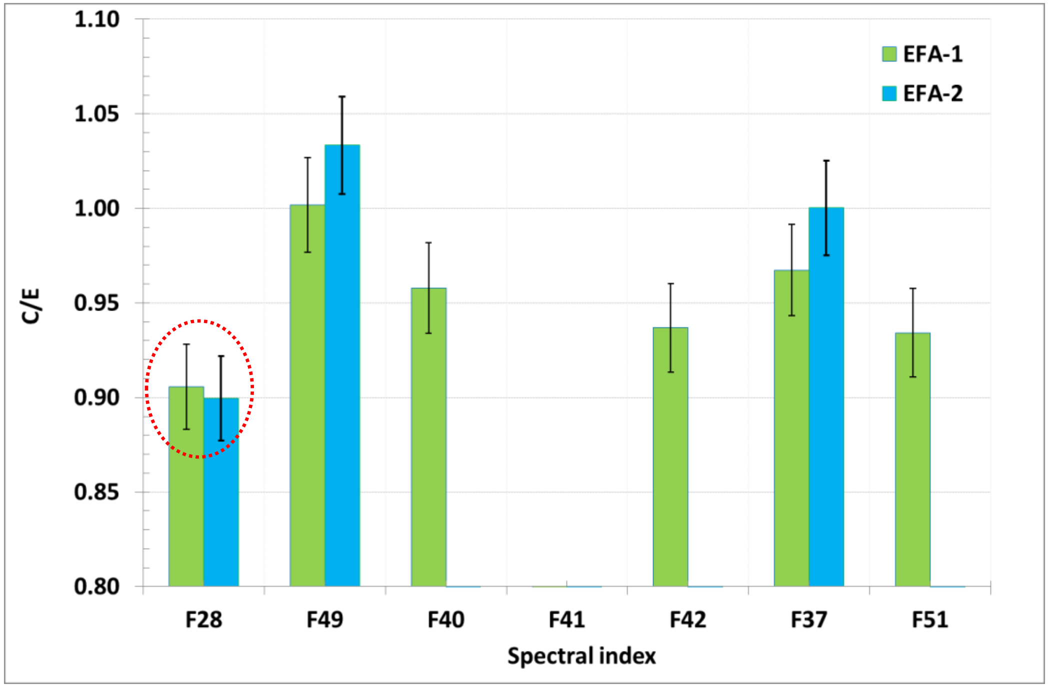
Position	EFA-1	EFA-2
F28/F25	0.91	0.90
F49/F25	1.00	1.03
F40/F25	0.96	
F42/F25	0.94	
F37/F25	0.97	1.00
F51/F25	0.93	

Spectral indices



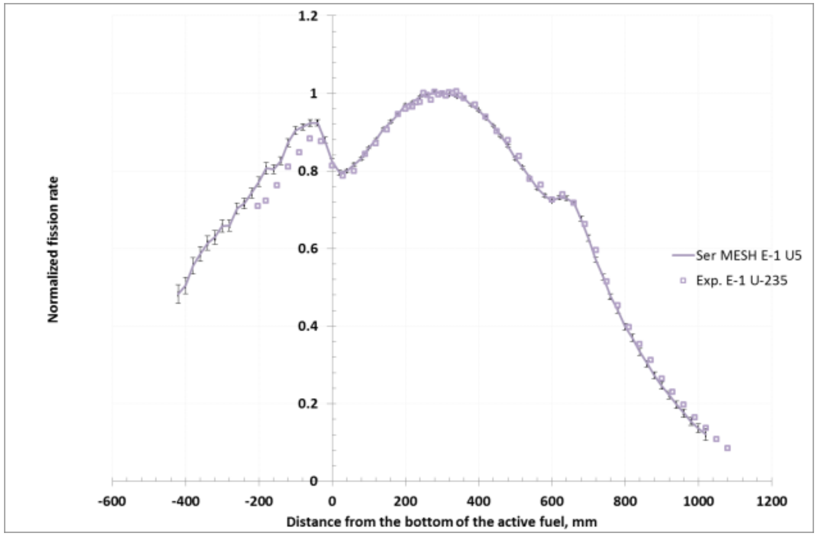
- Measured in experimental fuel assemblies (EFA-1&2)

Spectral indices

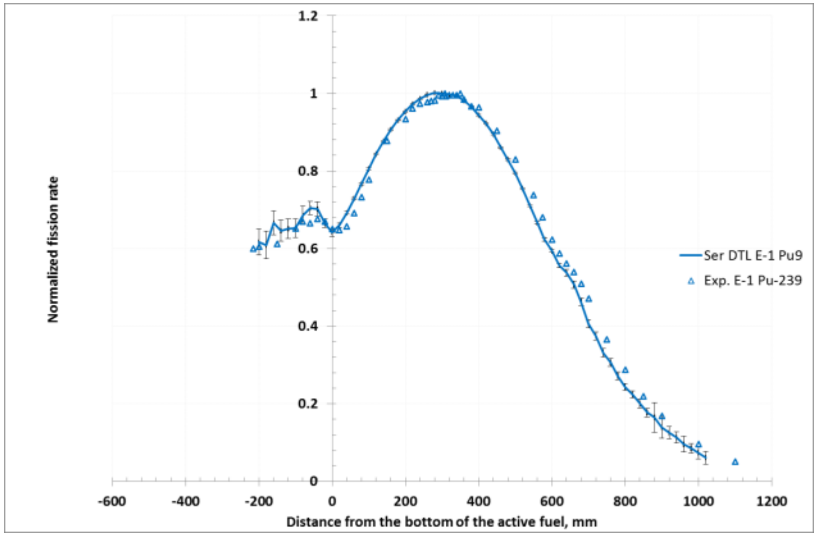


- About 10% discrepancy in F28/F25
- The reasons should be further investigated

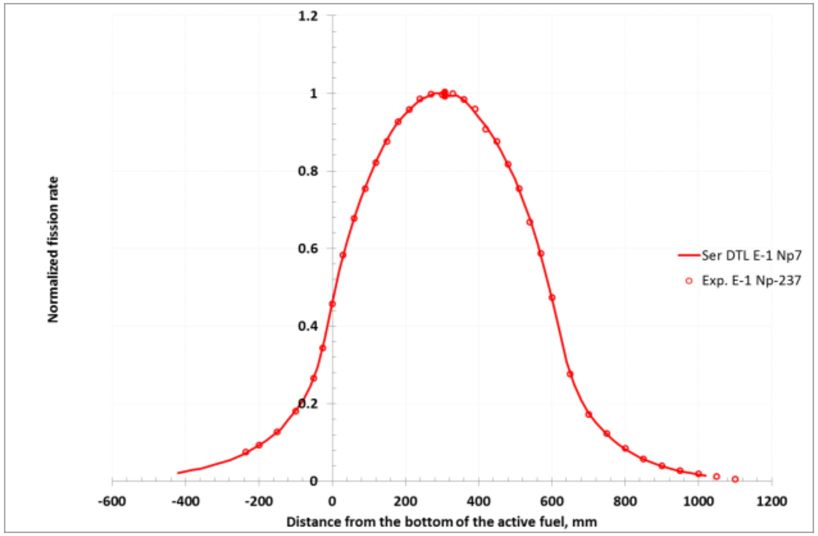
Axial traverses in EFA-1



U-235



Pu-239



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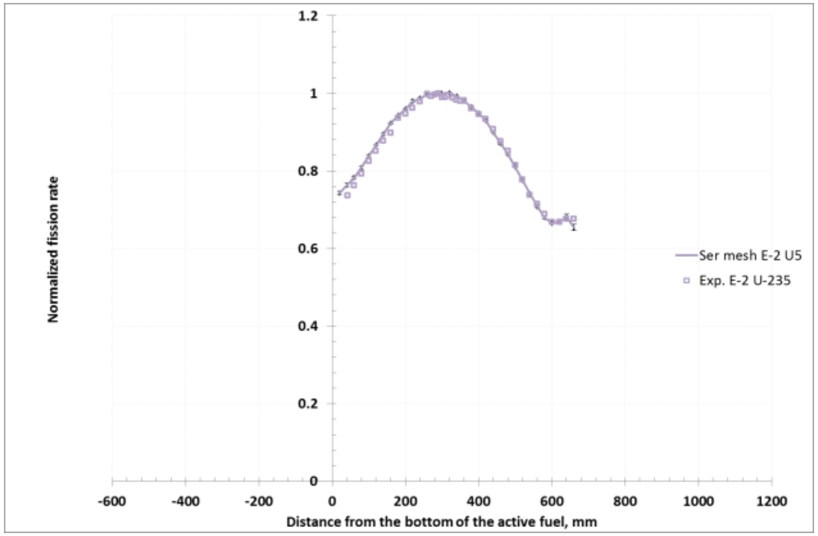
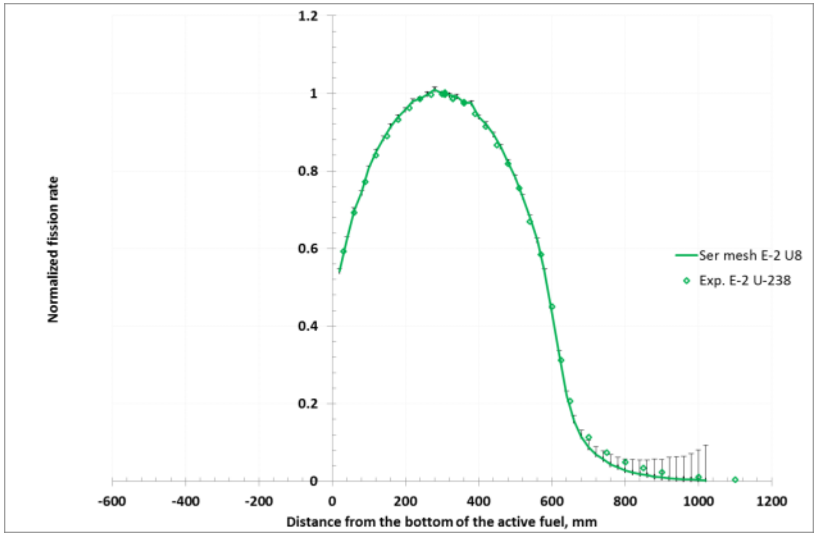
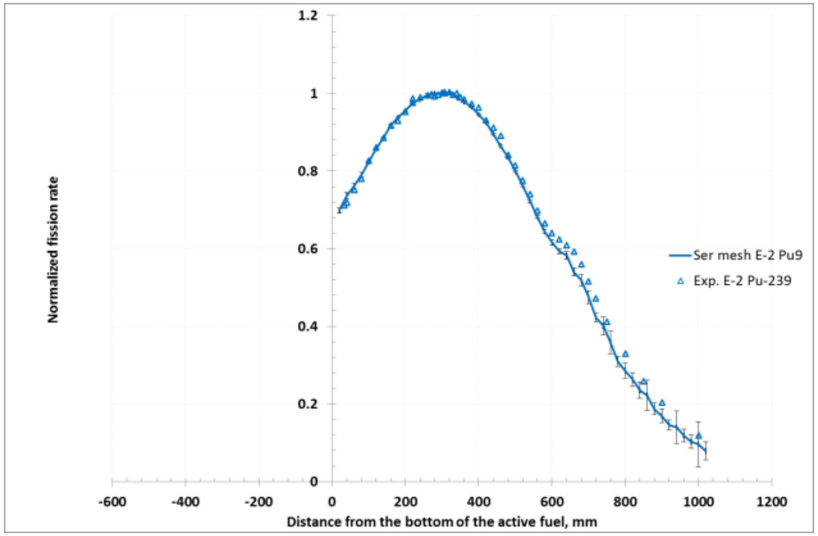
Axial traverses in EFA-2



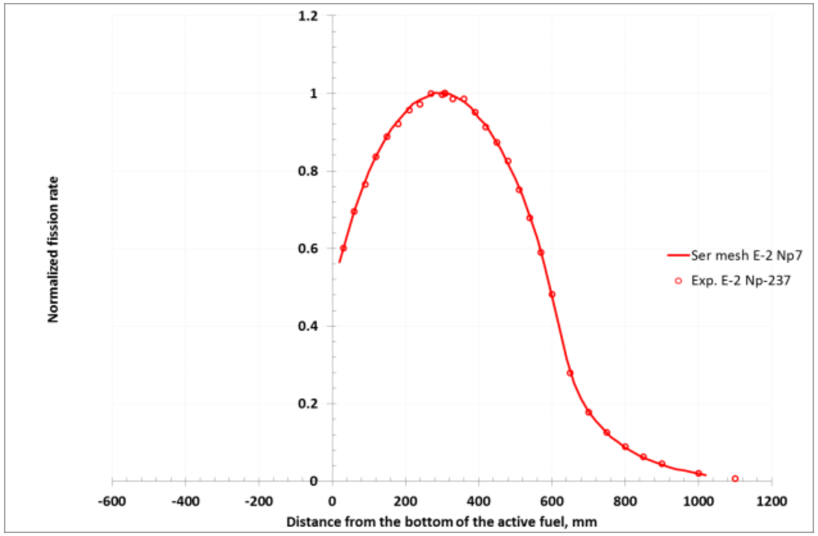
U-235



U-238



Pu-239



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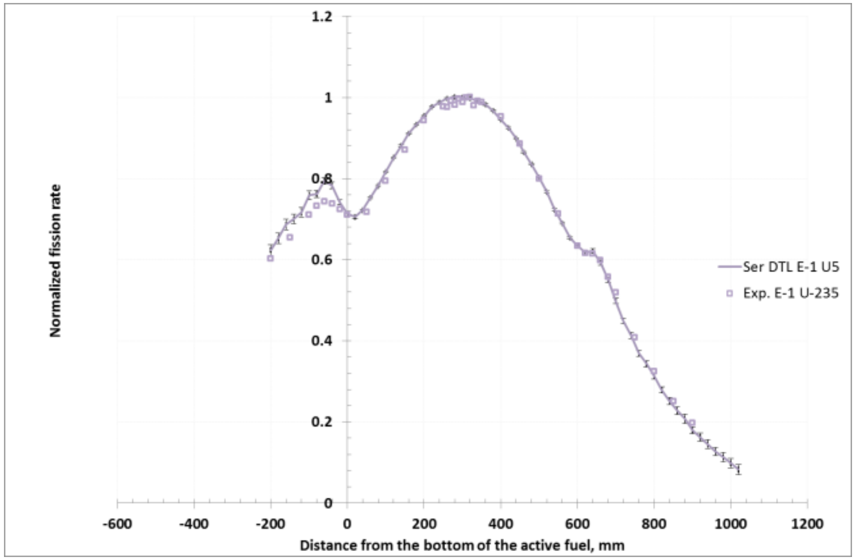
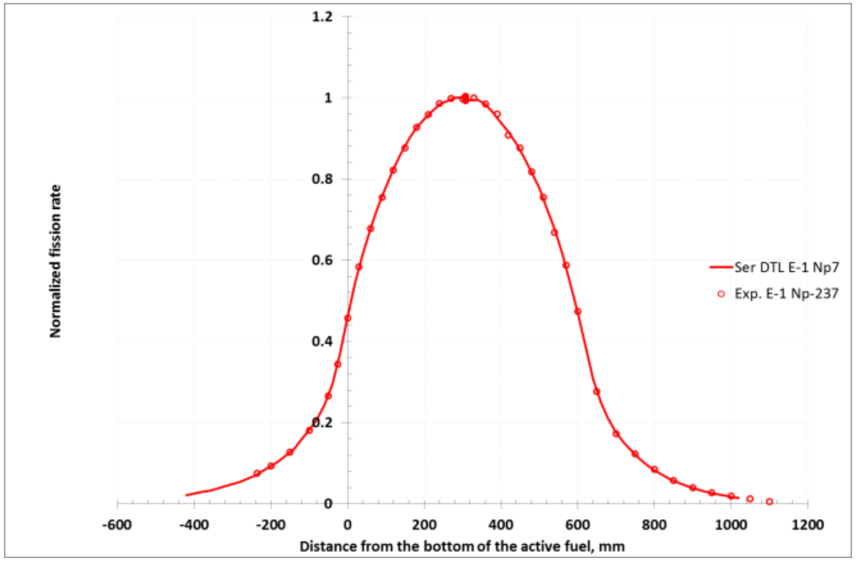
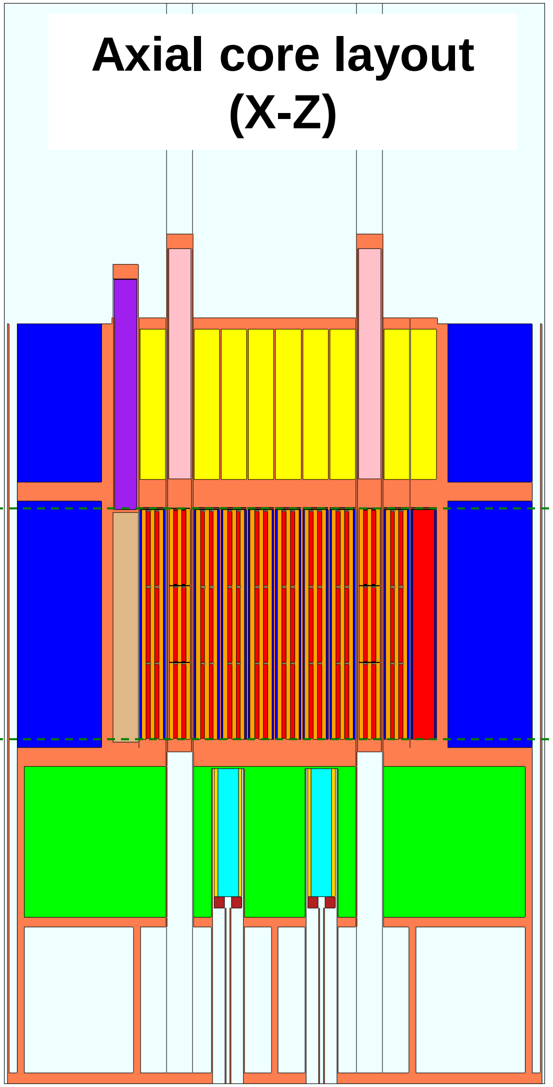
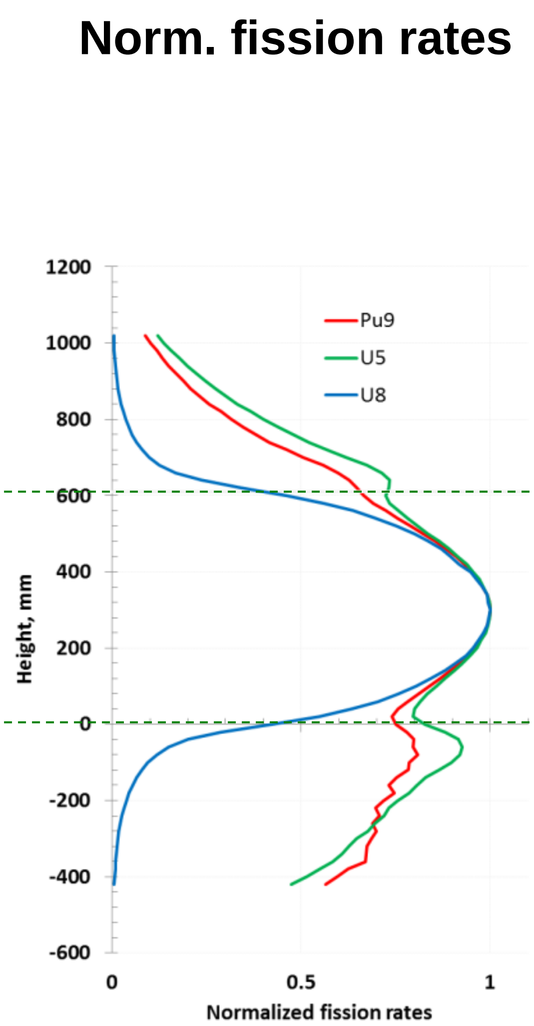
Axial traverses: fissile vs. fertile

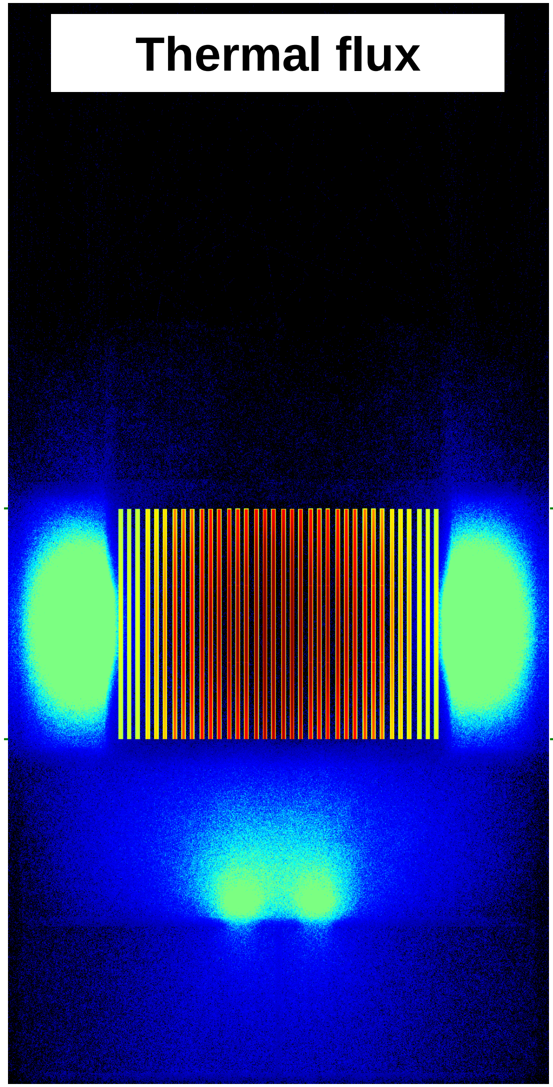




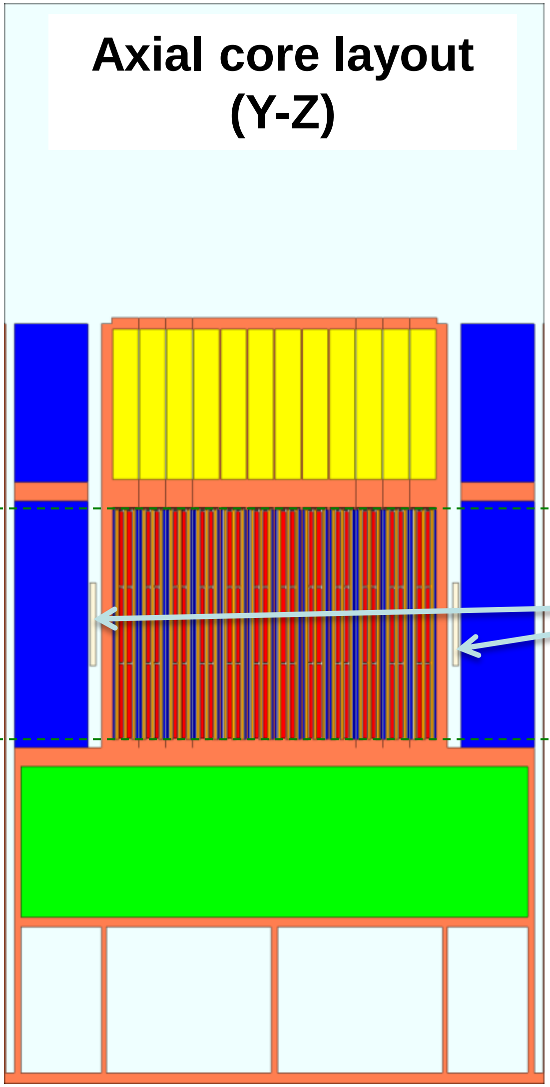
Neutron thermalization – lower reflector

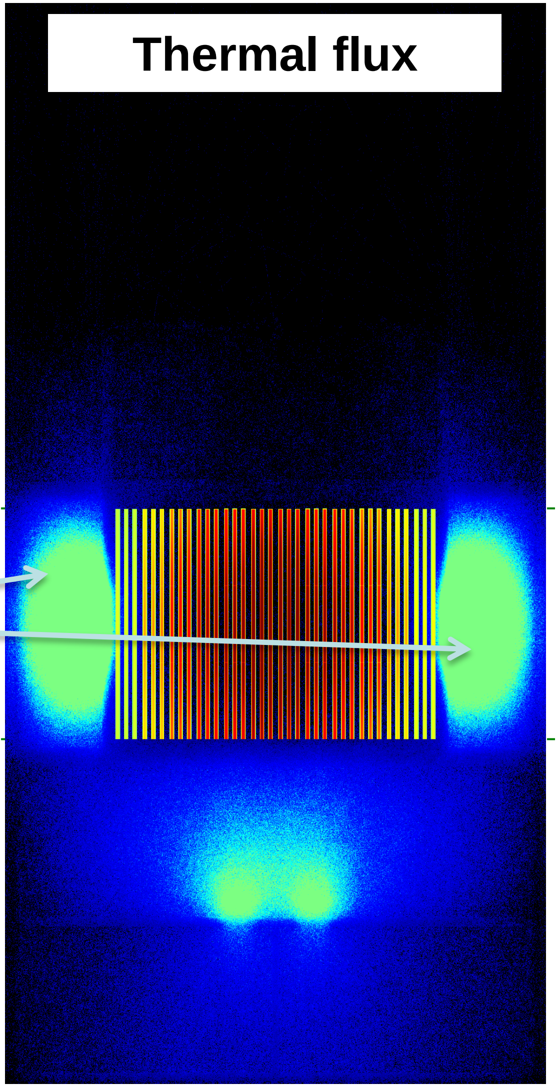




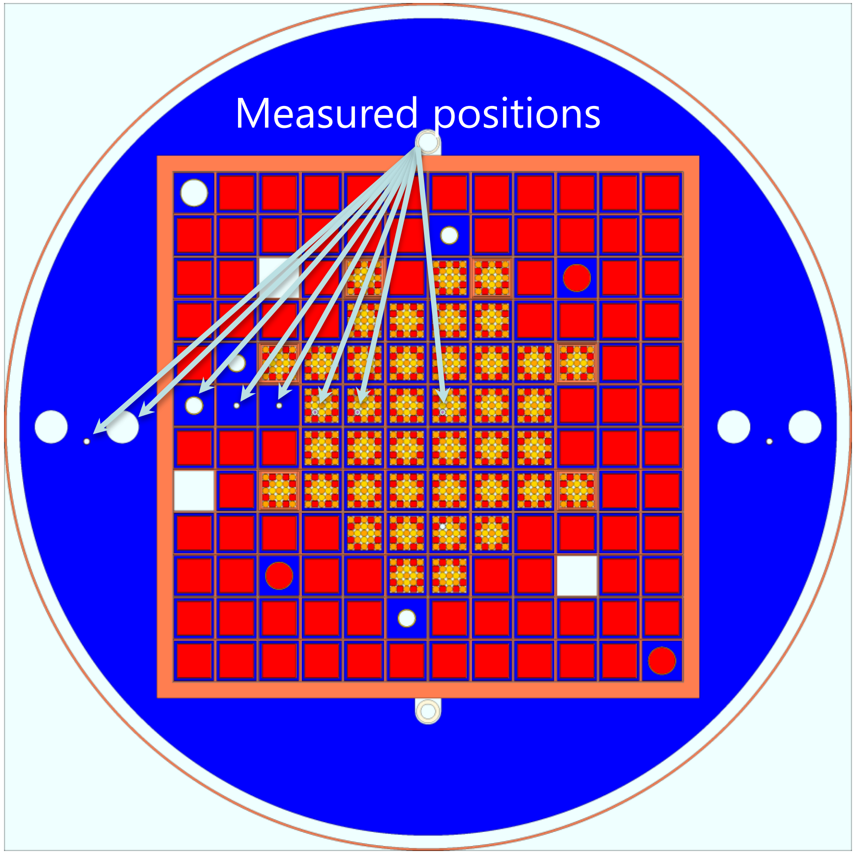


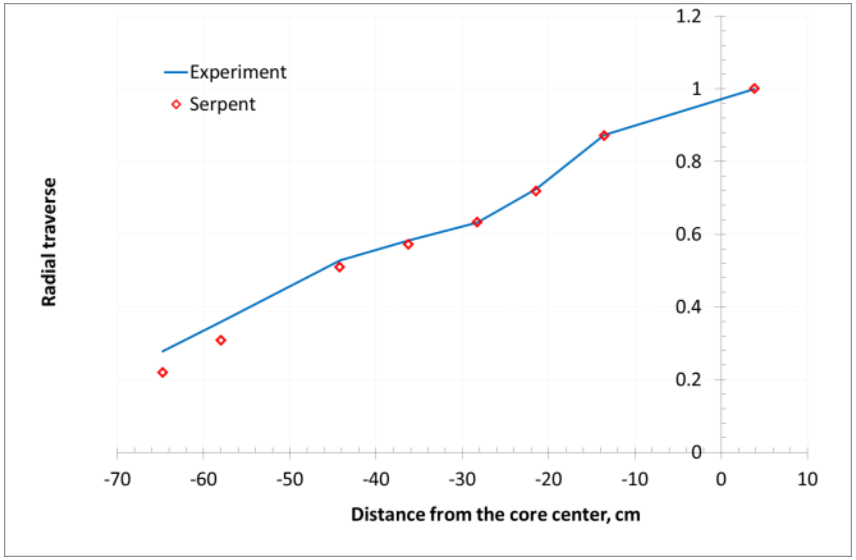
Neutron thermalization – radial reflector





Radial traverse

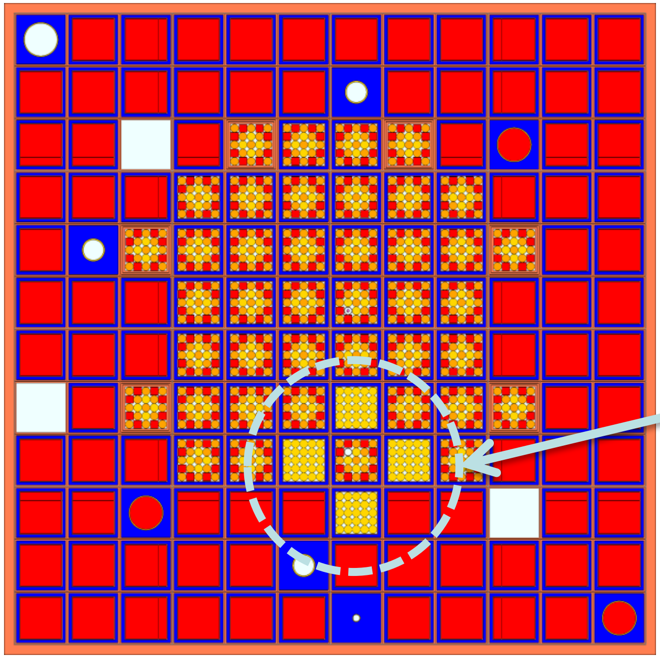


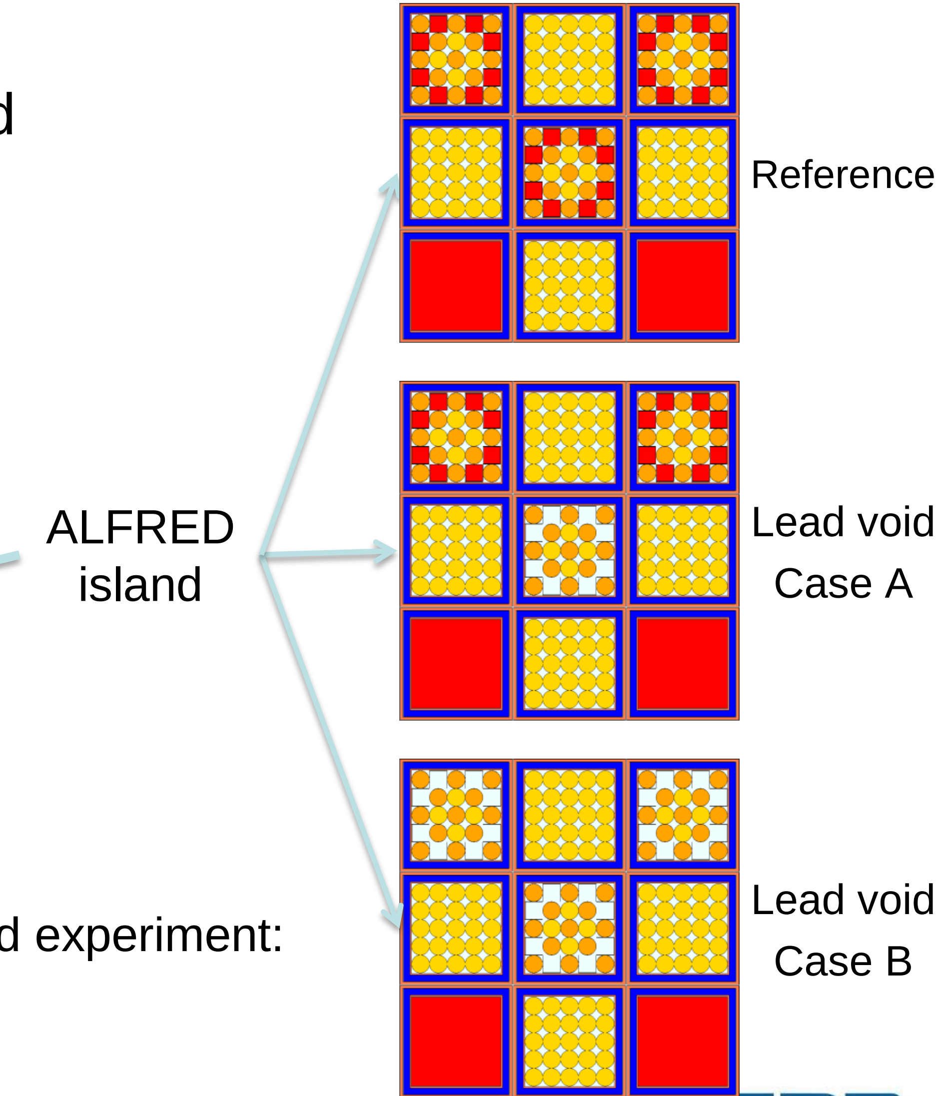


Selected results: CC6 core

Lead void reactivity

Estimated by “voiding”
fuel assemblies in ALFRED island



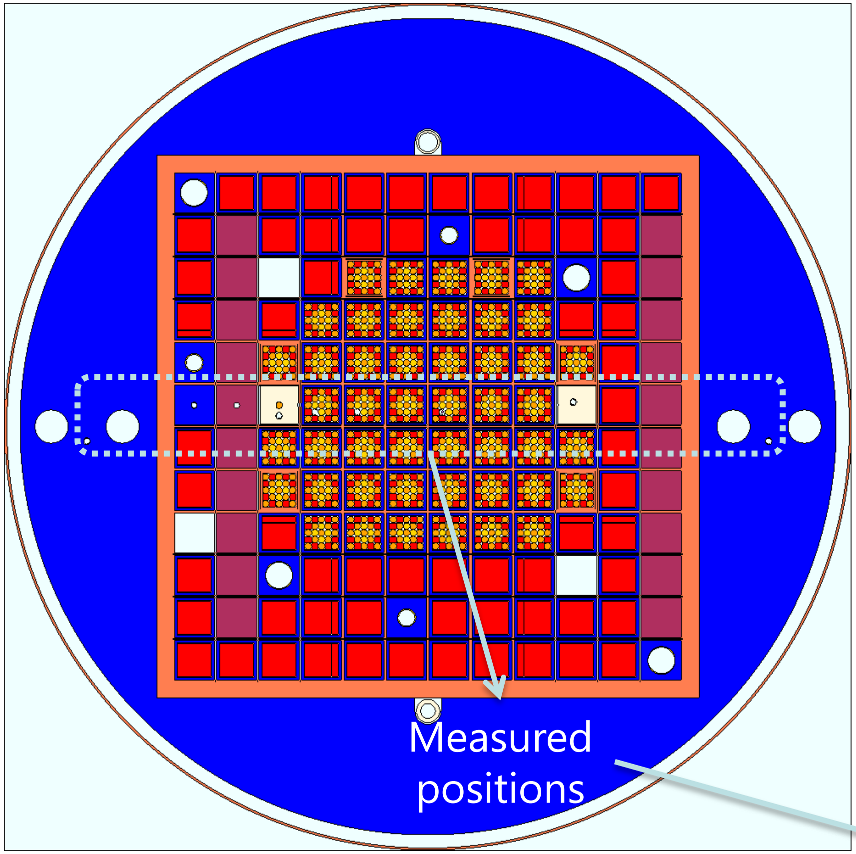


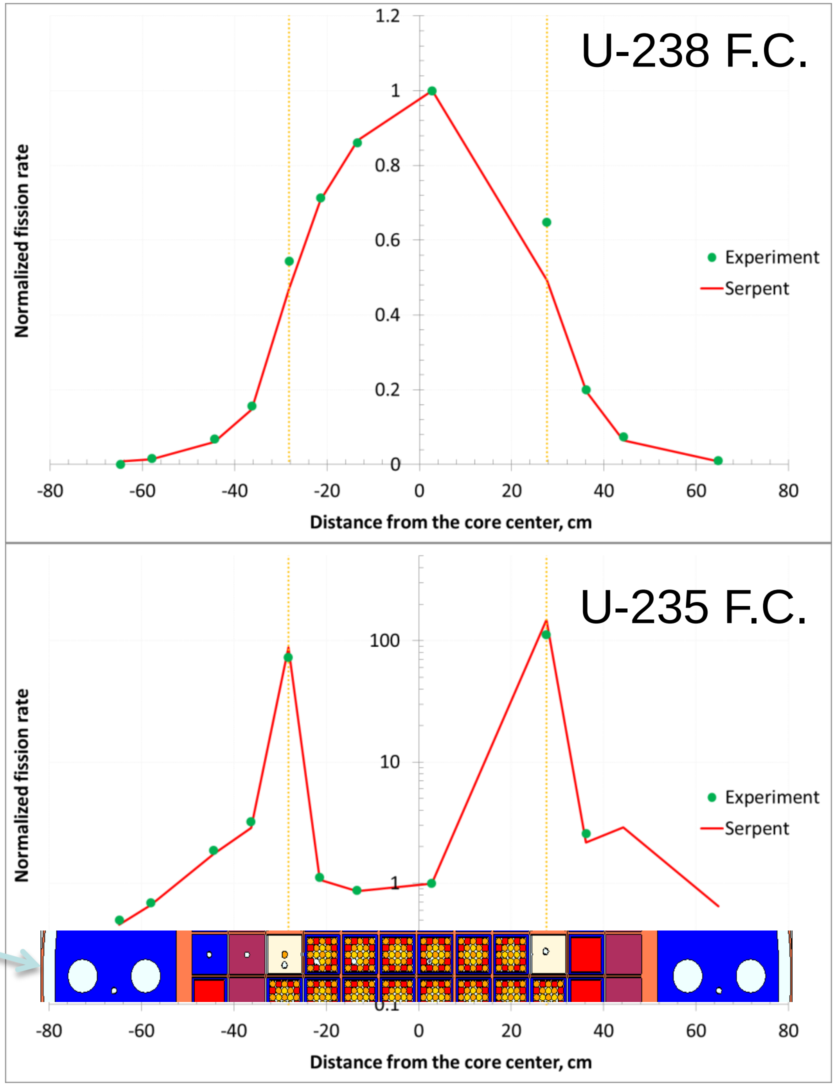
Good agreement between calculations and experiment:

- C/E Case A: **0.96**
- C/E Case B: **1.01**

Selected results: CC8 core

Radial traverse





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C/E: spectral indexes in CC8

Position	EFA-1	EFA-2	EFA-2	IPS-1	IPS-2	C-12
	(1,1)	(-2,1)	(-3,1)	(-4,1)	(4,1)	(-5,1)
F28/F25	0.91	0.98	0.92	0.43	0.33	0.78
F49/F25	1.01	-	1.01	1.01	1.01	1.00
F37/F25	0.97	-	-	-	-	-
F40/F25	0.95	-	-	-	-	-
F42/F25	0.94	-	-	-	-	-
F51/F25	0.90	-	-	-	-	-

Summary

- Serpent vs. MCNP – very good agreement (CR0 core)
  - Serpent runs much faster than MCNP (about 9 times)

- Serpent vs. experiment – generally good agreement
  - F49 and F37 spectral indexes
  - Axial and radial traverses, Lead void reactivity effect,

- But
  - Large differences in F28/F25 spectral index
  - Same trend for MCNP

Acknowledgment

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Thank you!