Neutronic analysis of SFR lattices: Serpent vs. HELIOS-2

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Outline

- Introduction
- Results of the burnup calculations: Serpent vs. HELIOS
- Analysis of the observed differences
- Summary and conclusions

Introduction

- DYN3D nodal code
  - 3D full core steady-state and transient calculations
  - Developed at HZDR for LWR application
  - Is being adopted for SFR analysis

- An important tasks
  - Selection of appropriate lattice code
  - Establishing of the few-group XS generation procedure

- Candidate lattice codes
  - Serpent Monte Carlo transport code
  - HELIOS-2 deterministic lattice transport code

Why to consider HELIOS?

- Solves the transport equation on 2D unstructured mesh
  - High level of geometrical flexibility
  - Handles complex fuel lattice configurations
- Uses updated nuclear data
  - ENDF/B-VII based cross section library
- We know how to use it
- But…
  - HELIOS-2 is mainly LWR oriented code
  - Applicability for fast reactors not demonstrated

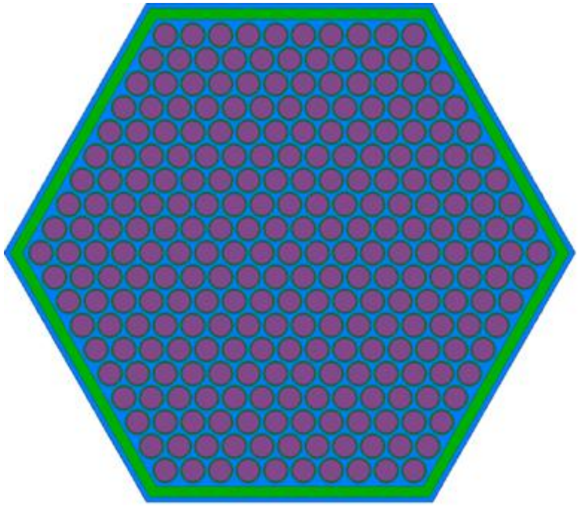
In this presentation…

- Investigation of HELIOS-2 applicability for the SFR analysis
  - Via fuel assembly level depletion calculations
  - Using Serpent as a reference

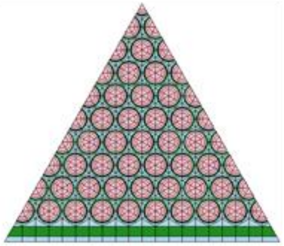
In the following presentation…

- Serpent as a few-group XS generator for SFR analysis

Reference SFR sub-assembly model



Serpent



HELIOS-2, 1/6th symmetry

- Fuel sub-assembly of ESFR (European SFR)
- 271 pins
- 14.5 wt% Pu MOX fuel
- 21.08 cm outer flat-to-flat

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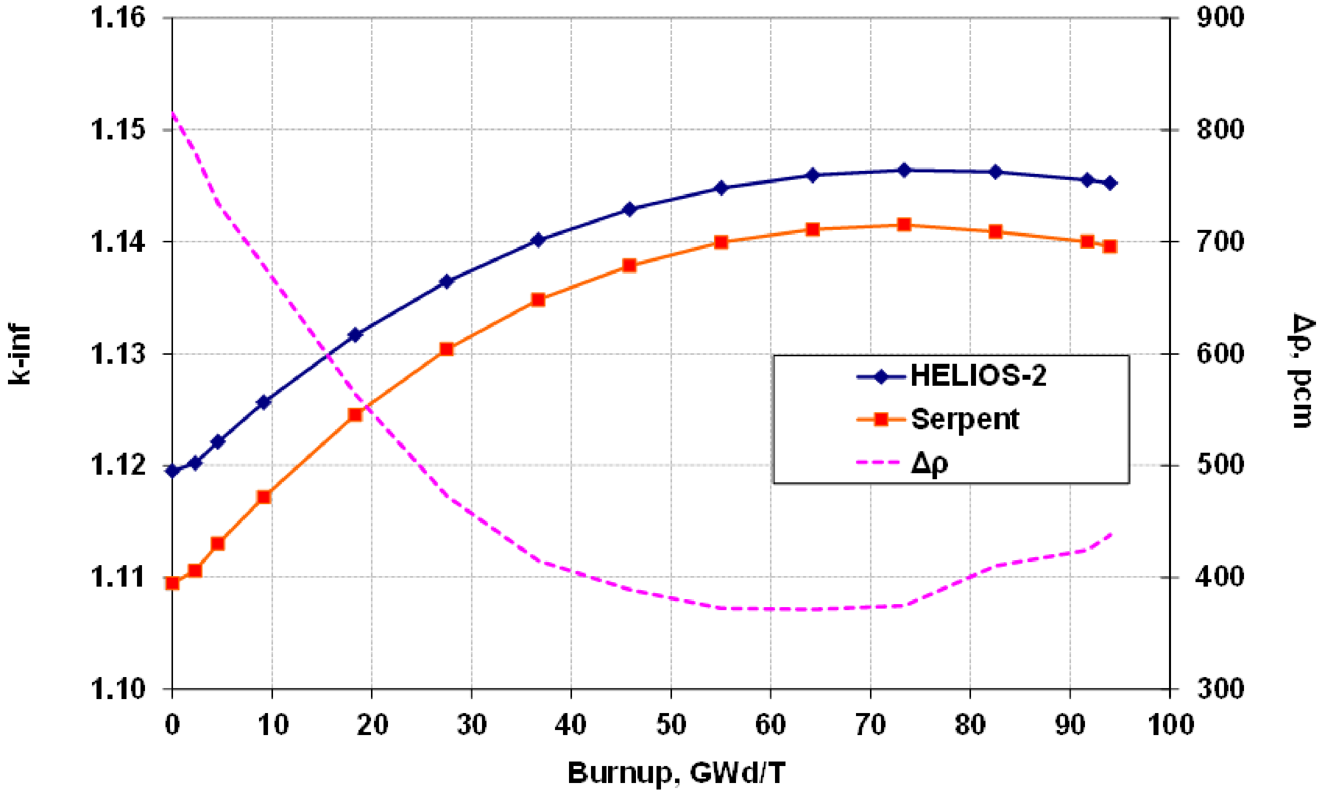
Results of burnup calculations

K-inf vs. burnup



- HELIOS-2 systematically overestimates k-inf
  - 800 pcm at BOL
  - 400 pcm at EOL

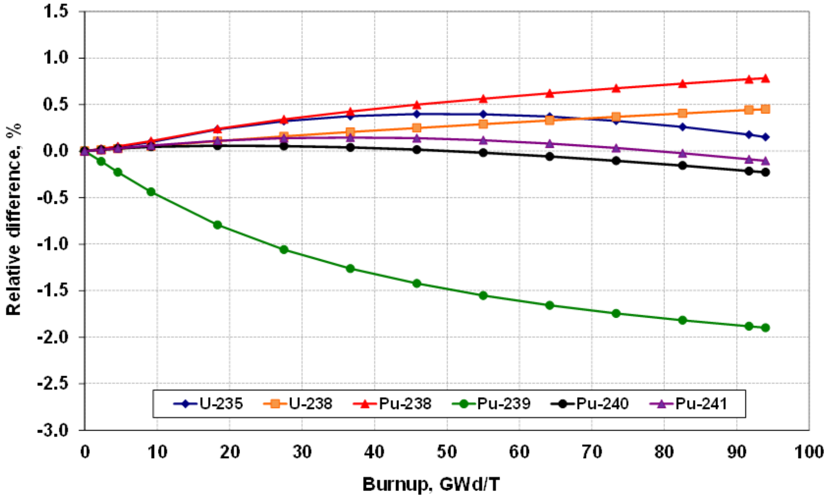
Safety related parameters at BOL

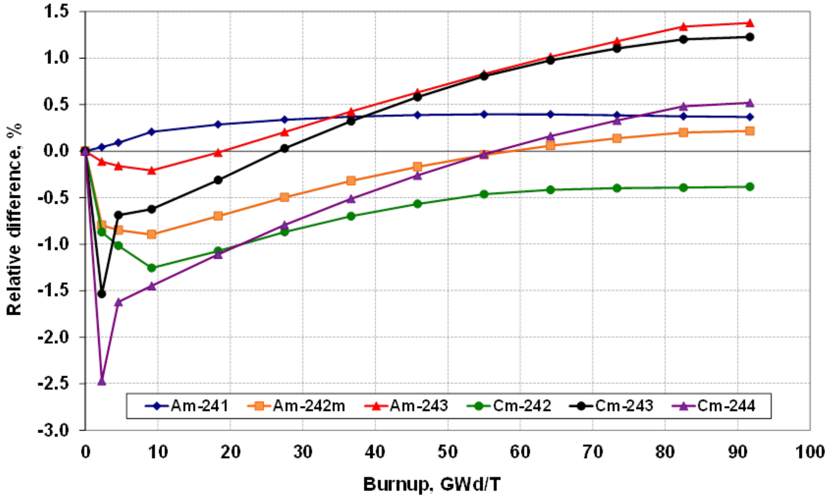
	Serpent	HELIOS-2	Rel. diff., pcm
Doppler constant, pcm	-1227	-1147	80
Coolant void reactivity, pcm	2968	2742	**-226**

Serpent, $\sigma_{k\text{-}inf}$ = 8 pcm

- In HELIOS-2
  - Doppler constant is “less” negative
  - Coolant void reactivity worth is underpredicted

Actinide inventory



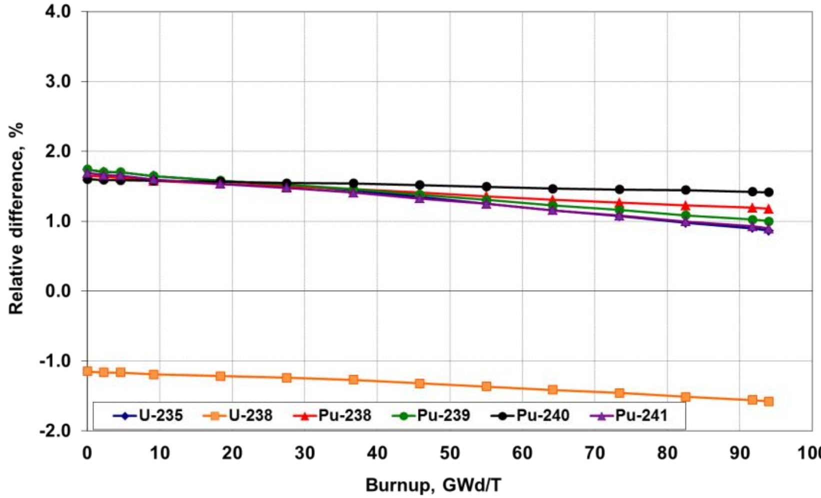


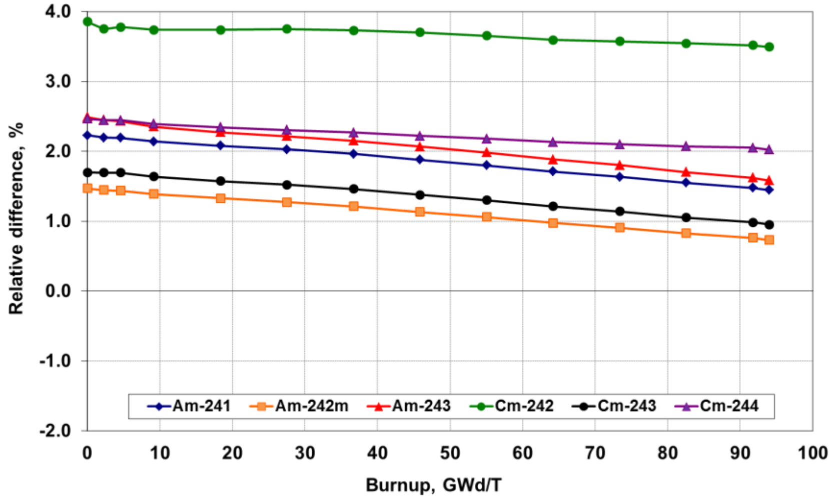
Relative difference = (HELIOS - Serpent)/Serpent

- Good agreement in actinide concentration
  - U and Pu inventories agree within 1% (excluding Pu-239)
  - Max. discrepancy for Pu-239 is ~2%
  - Cm and Am inventories agree within 2.5%

Some reasons for observed differences

Actinide one-group σ_a





Relative difference = (HELIOS - Serpent)/Serpent

- HELIOS-2 underestimates absorption in U-238
  - 40% of total capture rates
- HELIOS-2 overestimates absorption in Pu-239
  - 25% of total fission rates
- Result: k-inf $_{\text{HELIOS-2}}$ > k-inf $_{\text{Serpent}}$

Resonance parameters in HELIOS-2

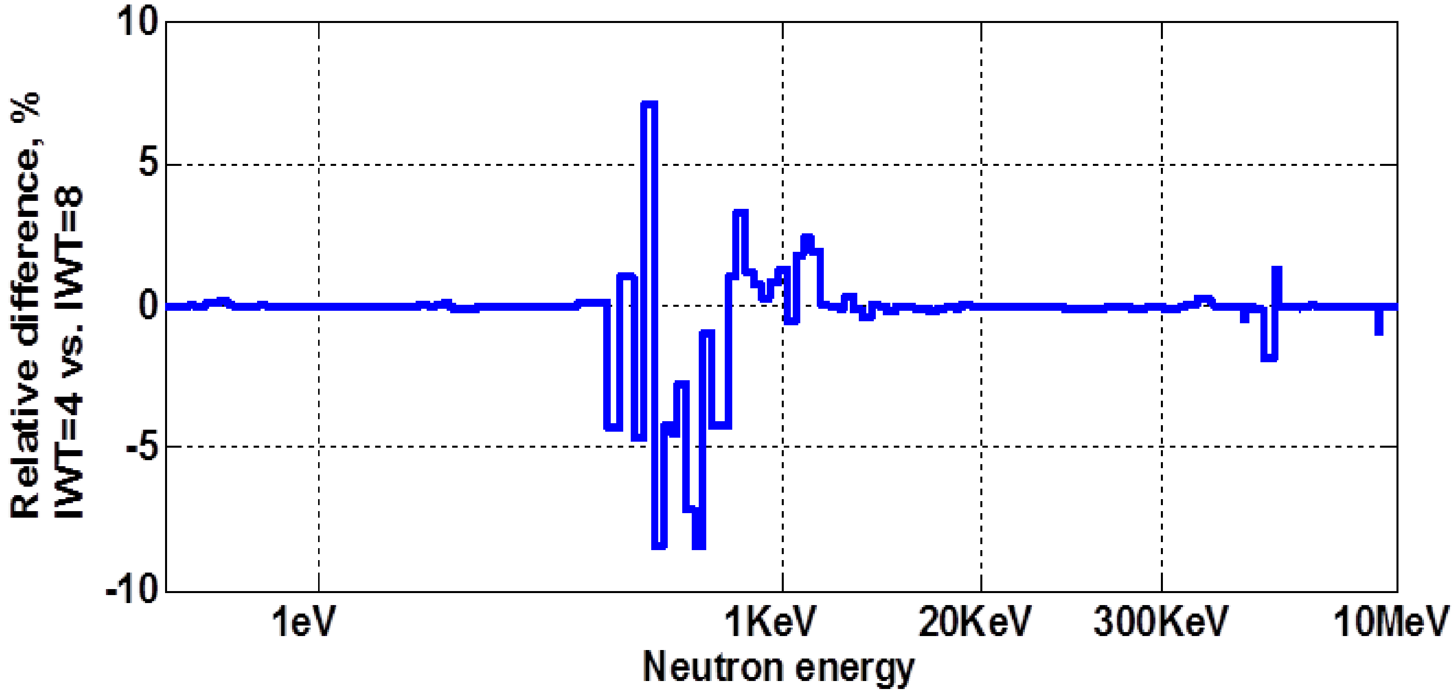
- The resonance parameters for HELIOS-2 were obtained by:
  - Solving the slowing-down equation
  - For mixtures of H and the resonance isotopes
  - Using different dilution levels.

- Slowing-down properties of H and Na-23 differ significantly
  - H-based resonance parameters are not fully appropriate for SFR applications
  - XS of resonance nuclides can be affected

Energy range	**σ_a U-238, barn**		**Rel. diff., %**	**% of total absorption rate**
	HELIOS-2	**Serpent**		
Fast: 302 KeV - 20 MeV	0.2262	0.2291	-1.3	19.6
Unresolved: 19 KeV - 302 KeV	0.2466	0.2473	-0.3	38.5
Resolved I: 1 KeV - 19 KeV	0.6844	0.7127	**-4.0**	36.2
Resolved II: 1 eV - 1 KeV	1.3377	1.4516	**-7.9**	5.7
Total	0.3335	0.3374	-1.2	100.0

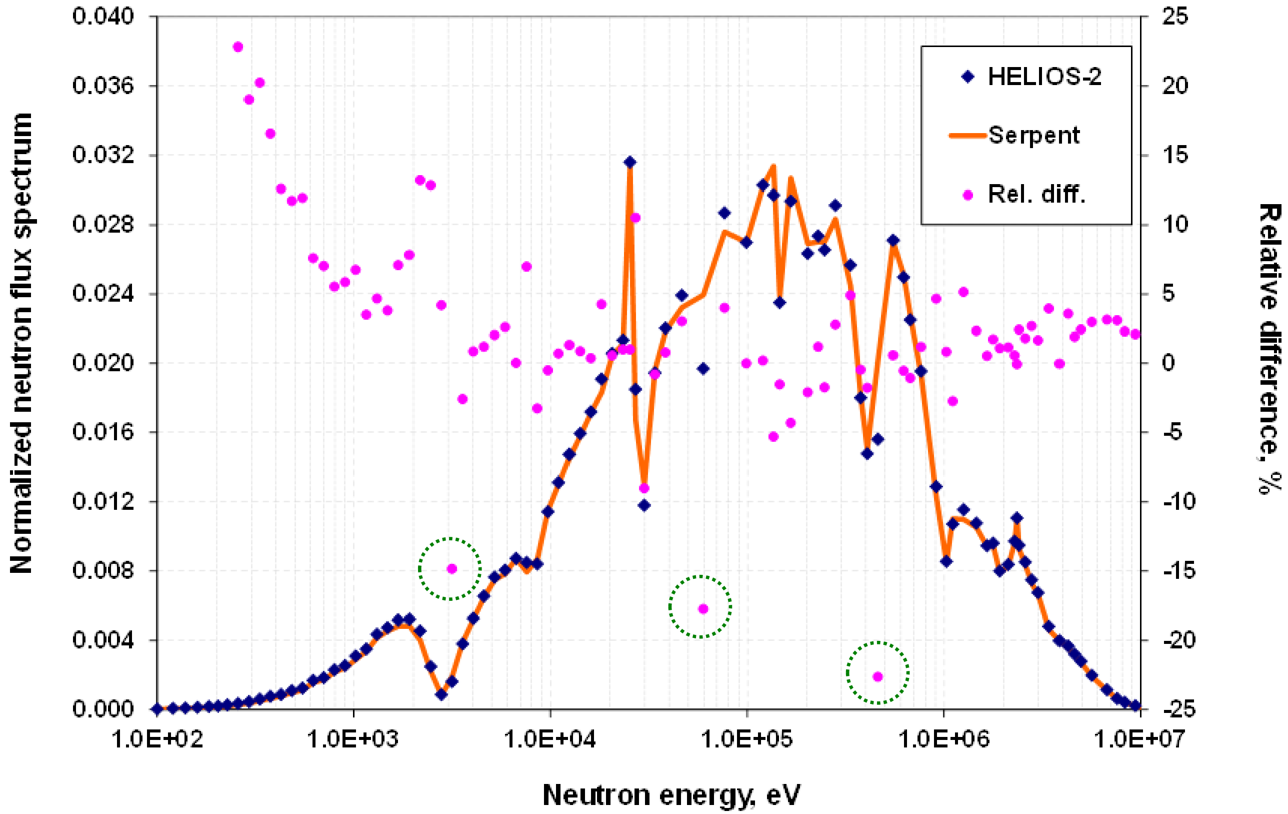
Effect of the flux weighting function in NJOY

- HELIOS-2 177-group XSs generated by NJOY
- Generic LWR spectrum is used to collapse pointwise ENDF data
- Not fully appropriate for fast reactor applications



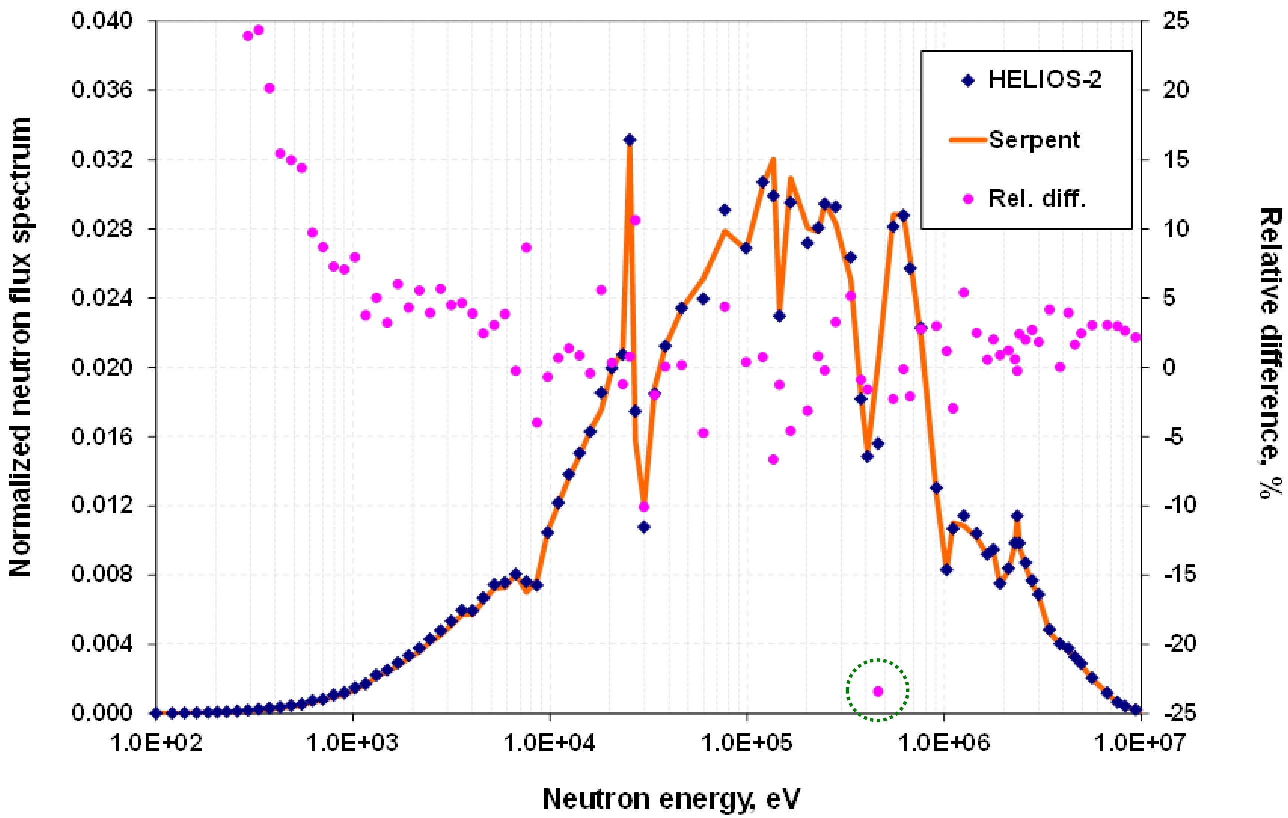
Difference in 177 group σ_a of U-238 collapsed by NJOY using:
LWR spectrum (IWT=4) and fast reactor spectrum (IWT=8)

Neutron flux spectrum – reference case



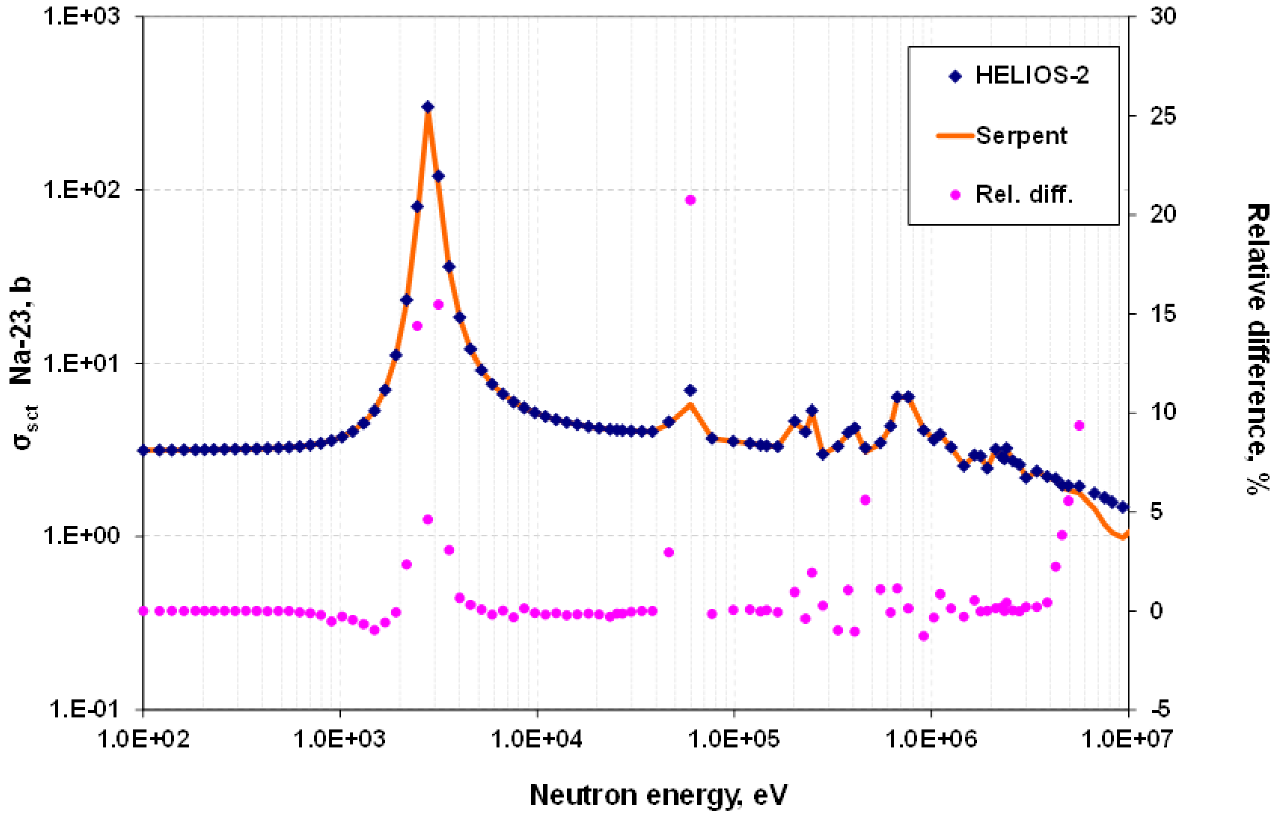
- High differences near elastic scattering resonances
  - **Na-23** at 2.8 KeV and 53.2 KeV,
  - **O-16** at 434.3 KeV

Neutron flux spectrum – voided assembly



- The difference in flux is reduced
  - At 2.8 KeV: from 14.8% to 4.5%
  - At 53.2 Kev: from 17.8% to 4.7%
  - Due to the absence of Na

Reasons for the differences in flux spectra



- In HELIOS-2 Na-23 and O-16 are not resonance nuclides
  - Infinitely diluted XS are used in calculations
  - **Self-shielding** of elastic scattering resonances is **ignored**

Summary and conclusions

- Burnup calculations of ESFR sub-assembly
  - Performed with HELIOS-2 and Serpent
  - Generally acceptable agreement between the codes
- HELIOS-2 can be used for scoping studies of SFR lattices
- But, HELIOS-2 modeling accuracy can be improved
- The following modifications are suggested:
  - Introduction of the resonance treatment for Na-23 and O-16
  - Generation of a master XS library using fast reactor weighting spectrum
  - Generation of the resonance parameter using Na-23 based mixtures

Thank you for your attention

and have a productive meeting!