ANALYSIS OF C/E RESULTS OF FISSION RATE RATIO MEASUREMENTS IN SEVERAL FAST LEAD VENUS-F CORES

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Introduction

- Five years of the EU FP7 project FREYA (Fast Reactor Experiments for hYbrid Applications) was recently (March 2016) accomplished
- Last two years, four critical cores were investigated in the VENUS-F reactor within project
- These zero power cores represented the features of the lead cooled fast core designs of ADS MYRRHA and LFR ALFRED
- For the ND improvement , fission rate ratios of minor actinides such as Np-237, Am-241 as well as Pu-239, Pu-240, Pu-242 and U-238 to U-235 were measured in these VENUS-F critical assemblies with small fission chambers (FC)

Introduction (prolongation)

- The first analysis of these measurements carried with deterministic (ERANOS) and stochastic (MCNP5, Serpent) codes all with JEFF-3.1 data set have been presented recently in PHYSOR conference (May 2016)*. C/E results are acceptable for the “fissile” rate ratio index F49/F25 but not for others which are “threshold” ones. It was proposed the following actions:
  - to perform the calculations with other data sets as JEFF-3.2, ENDF/B7.1, JENDL-4.0;
  - to measure and to estimate the influence of the impurities in the deposits of the fission chambers.
- Here the analysis have been complemented with MCNP 6.1.1 and different nuclear data sets like JEFF-3.2, ENDF/B7.1, and JENDL-4.0. Also the available passport data of U235 impurity in U238 deposits of FCs were checked in standard neutron field of BR1 reactor.

*A. Kochetkov et al., Spectrum Index and Minor Actinide Fission Rate Measurements in Several Fast Lead Critical Cores
in the Zero Power VENUS-F Reactor, PHYSOR2016, May 1-5, 2016, Sun Valley, Idaho, USA

VENUS-F cores description

- The composition of the fuel assemblies (FA) for these cores was consisted of metal enriched uranium, lead and Al2O3 rodlets to simulate the oxide fuel of MYRRHA and ALFRED :

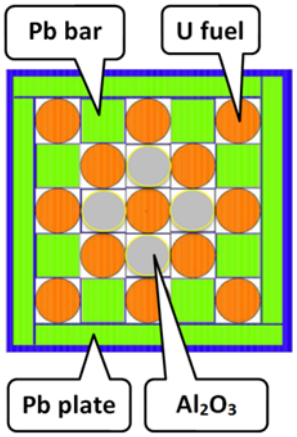
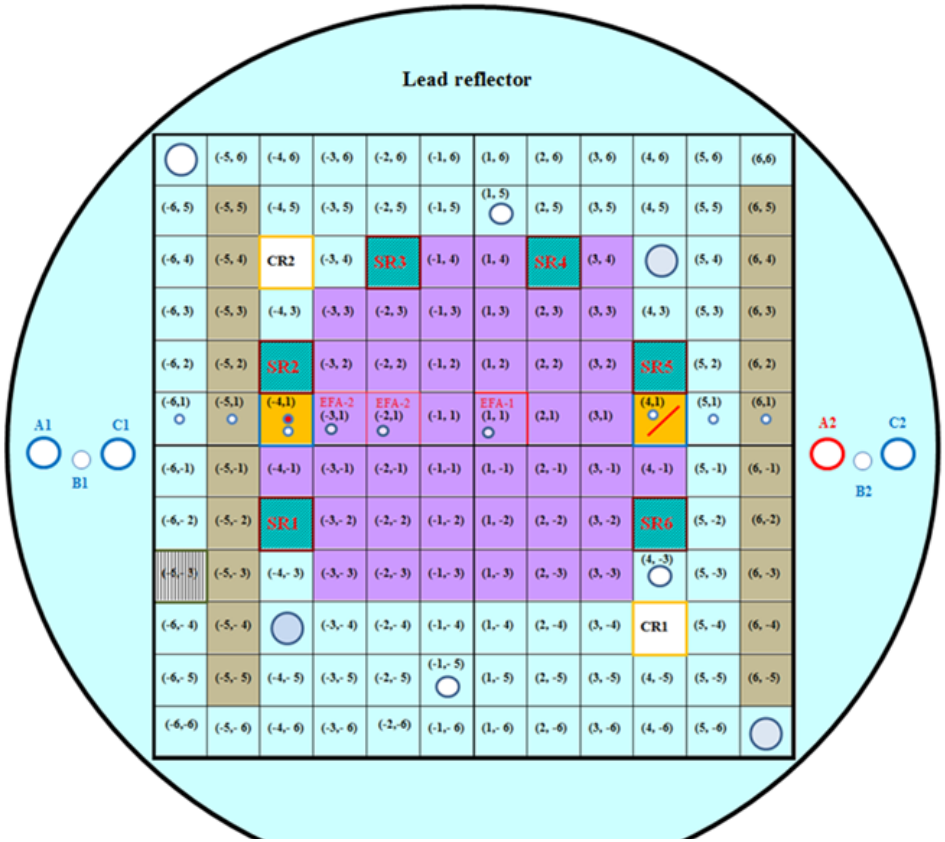


Figure 1 – FA of VENUS-F

- The MYRRHA related cores simulated step by step the design peculiarities like the reflector and in pile sections (IPS) and are called CC5, CC7 and CC8 (Fig.2). The VENUS-F core with the ALFRED island is called CC6.



	Type of assembly	Amount
	- PbA, lead assemblies	63
	- PbA with holes for detectors	9
	- GA, assemblies with graphite	20
	- FA fuel assemblies (including EFA)	41
	- CR control rods	2
	- POAR rod drop	1
	- SR , safety rods	6
	- IPS	2

Figure 2 – CC8 VENUS-F configuration

Experimental tools

- Spectrum indexes and the MA fission rate ratios were measured with small Fission Chambers (FC) having 4 mm outer diameter and small deposit mass (20-200 μg). FCs with following deposits were used for the measurements: U-235, U-238, Pu-239, Pu-240, Pu-242, Np-237 and Am-241.
- For the measurements these FCs were placed in specific experimental fuel assemblies or in reflector assemblies with appropriate holes in the middle plane of the core.
- As was presented in PHYSOR 2016 the tendency of all C/E results for all investigated cores (CC5, CC6, CC7 and CC8) in general were the same, so we focused here at the re-analysis of the results in CC8 core only and only in the central position (1,1)

Measurement of impurity in deposits of U-238 fission chamber

- Tiny amount of U-235, usually presented in U-238 FC deposits, should be taken into account especially when analyzing thermalized neutron spectra nearby graphite and inside polythene of IPS (see Fig. 3).
- FCs used for the measurements in VENUS-F were placed in standard thermal neutron filed of BR1 reactor to measure the real content of U235 in U238 deposits. It was obtained that for the FCs used, the content of U235 in U238 deposits is about 0.04%. This is well agree with the passport data (0.036%) and so as with calculations.

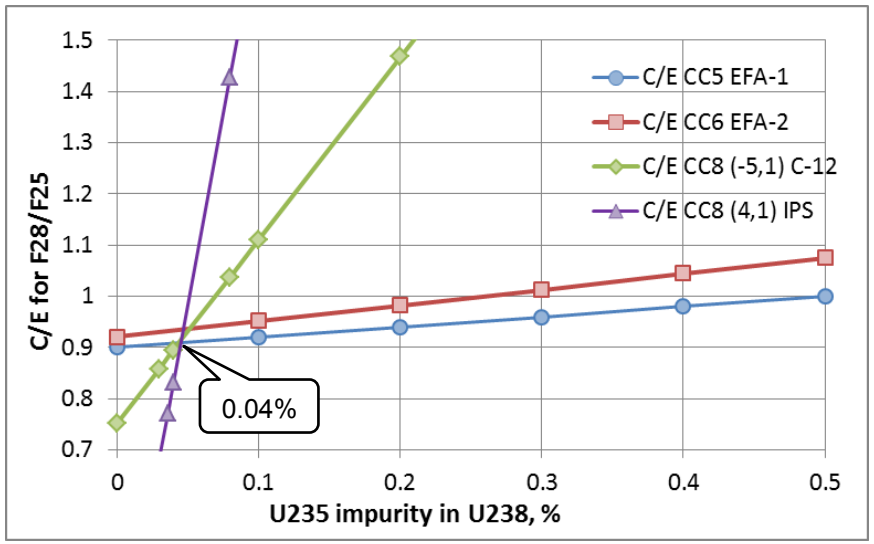


Figure 3 – C/E for F28/F25 index depending of the U235 content in U238 deposit of FC. Calculated results obtained with MCNP 5 and JEFF-3.1 data were used.

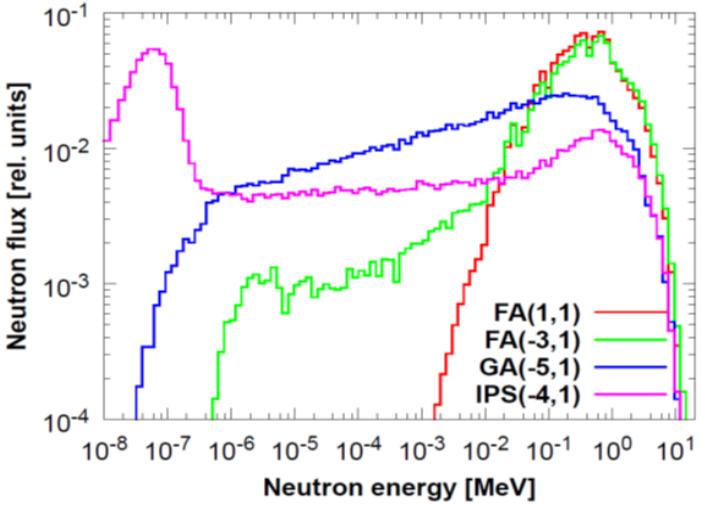


Figure 4 - Calculated flux in CC8.
FA(1,1) – middle of the core,
FA(-3,1) – periphery of the core,
GA(-5,1) – graphite reflector,
IPS(-4,1) – thermal spectrum in-pile section.

C/E and C/C analysis 1(2). *CC8 core, position (1,1).*

Table 1: Available calculational results

	CIEMAT	*HZDR*	*ENEA*
Data \ Code	**MCNP 6.1.1**	**SERPENT**	**ERANOS**
ENDF/B-VII.0	+		
JEFF-3.2	+		
JENDL-4.0	+		
JEFF-3.1	+	+	+

Table 2: C/E results obtained **with JEFF-3.1** and with different codes. *Uncertainties in MCNP better 0.8%*

CC8, EFA-1, JEFF-3.1				**Calculations**	st dev	Max-Min	Experiment
	MCNP 6.1.1	**SERPENT**	**ERANOS**	**averaged**	%	%	uncert. ± %
F28/F25	0.903	0.907	0.960	**0.923**	**2.8**	**6.2**	**2.0**
F49/F25	0.991	1.007	1.013	**1.004**	0.9	**2.2**	**2.1**
F37/F25	0.929	0.970	0.994	**0.964**	**2.8**	**6.7**	**2.4**
F40/F25	0.932	0.952	0.914	**0.933**	1.7	**4.1**	**2.1**
F42/F25	0.914	0.943	0.970	**0.942**	2.4	**6.0**	**2.5**
F51/F25	0.878	0.901	0.931	**0.903**	2.4	**5.9**	**2.3**

C/E and C/C analysis 2(2). *CC8 core, position (1,1).*

Table 3: C/E results obtained with **MCNP 6.1.1** and different data sets. *Uncertainties: 0.3- 0.8 %*

Index \ Data	MCNP 6.1.1 ENDF/B-VII.0	JEFF-3.2	JENDL-4.0	JEFF-3.1	C/E average	st dev %	Max-Min %	Exp. unc. ± %
F28/F25	0.914	0.914	0.923	0.903	**0.914**	0.8	**2.2**	**2.0**
F49/F25	0.987	0.979	1.002	0.991	**0.990**	0.8	**2.3**	**2.1**
F37/F25	0.957	0.912	0.967	0.929	**0.941**	2.3	**5.8**	**2.4**
F40/F25	0.924	0.942	0.909	0.932	**0.927**	1.3	**3.5**	**2.1**
F42/F25	0.877	0.898	0.914	0.914	**0.901**	1.7	**4.1**	**2.5**
F51/F25	0.879	0.846	0.902	0.878	**0.876**	2.3	**6.4**	**2.3**

Table 4: Uncertainties when averaging all (from Table 1) C/E results and ones without ERANOS .

	ALL		**Experiment**	**Without ERANOS**	
Index	st dev %	Max-Min %	**uncertainties ± %**	st dev %	Max-Min %
F28/F25	2.0	**6.2**	**2.0**	0.8	**2.2**
F49/F25	1.2	**3.5**	**2.1**	1.0	**2.8**
F37/F25	**2.8**	**8.6**	**2.4**	2.4	**6.2**
F40/F25	1.6	**4.7**	**2.1**	1.6	**4.7**
F42/F25	**3.3**	**10.1**	**2.5**	2.4	**7.2**
F51/F25	**3.0**	**9.6**	**2.3**	2.3	**6.4**

Discussion

- Taking into account the confirmed impurity of U-235 in U238 deposits of FCs someone can obtained similar C/E for different neutron spectrum conditions. Notice that these C/E(s) are still out of uncertainties (~ 0.92). Anyway it could be interesting to measure with pure isotope such as Np-237 in thermalized spectrum (C-12, IPS) to see or not C/E evolution
- In most of the C/E averaging the standard deviations are less than experimental uncertainties, especially when ERANOS results omitted
- Almost all of C/C Max-Min values are higher than experimental uncertainties. This is especially for the MA and Pu-242, Pu-240 fission rates ratios. The situation with C/C for F28/F25 and F49/F25 is much better
- Almost all C/E results still are essentially less than 1. This fact can't explain with wrong reference fission rate (F25), since first the C/E for the index F49/F25 is OK and second F25 was measured with 3 different FCs.
- An idea that the soft part of the neutron spectrum is not calculated properly still can easy solve all C/E problems

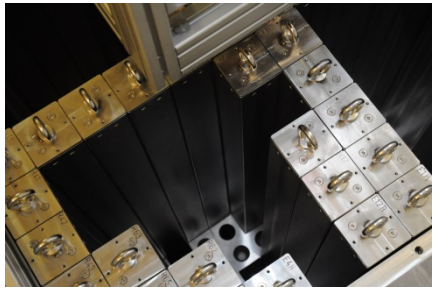
Conclusions

- The analysis of the C/E results of spectrum indices and MA fission rate ratios obtained with FCs in several VENUS-F critical assemblies have been prolonged using different ND sets and codes. In general, the problems with C/E remain. In addition, in some cases several significant C/C differences were observed and that should be discussed further.
- The U235 impurity in U238 deposits of FCs were checked in standard neutron filed of BR1 reactor. The results obtained are in agreement with the passport data and can't explain the C/E differences for the spectral index F28/F25
- The following activity are planned to solve the problem:
  - measuring the F28/F25 index with foils in the same conditions as for the FCs (on-going)
  - checking the effective masses of the deposits of FCs in additional experiments and calculations (measurements have done, analyzing)
  - measuring the F37/F25 fission rate ratio in the thermalized VENUS-F spectrum
  - carrying out MCNP 5 calculations with input file used for MCNP 6.1.1

Announcement for your attention:

- **08/12/2016 - FREYA** dissemination seminar on the received results for the open audience in SCK•CEN HQ in Brussels
- Everybody are welcome especially young scientists
- This is for free
- The amount of remains places are limited
- Contact for submission: anatoly.kochetkov@sckcen.be

- **Thank you for your attention!**



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