COMPARATIVE ANALYSIS OF SELECTED ASPECTS OF THE MUSE-4 EXPERIMENTS WITH THE JEF-2.2 AND JEFF-3.1 LIBRARIES

[1]J.F. Lebrat - [2]M. Plaschy - [1]J. Tommasi
[1]C.Suteau - [1]D. Plisson-Rieunier - [1]C. De Saint Jean

[1]CEA/DEN/DER, St Paul lez Durance, France
[2]PSI, Villigen, Switzerland

ABSTRACT

This paper presents the analysis of some selected experiments of the MUSE-4 program with the ERANOS-2.1 code system using either the JEF-2.2 library or the more recent JEFF-3.1 one; focus has been given to the reactivities calculations and to the spectral indices of the MUSE-4-Reference and SC3-Pb core configurations.

Both libraries provide comparable results on the k_{eff} of the Reference configuration due to large negative and positive compensating reactivity effects, whereas there is a –400 pcm effect on SC3-Pb. A perturbation analysis demonstrates that the large negative total reactivity effect in this configuration comes from the increase of the lead contribution and from the decrease of the sodium contribution.

The new library improves the C/E for all the spectral indices in the fuel zone and for most of them in the lead zone except for ^{238}U and ^{243}Am.

1. INTRODUCTION

The MUSE-4 program [1] is a series of zero-power experiments carried out at the CEA-Cadarache MASURCA nuclear facility from 1999 to 2004, to study the neutronics of Accelerator Driven Systems (ADS). This program was supported and partially funded by the European Commission and constituted an essential link of the ADOPT project. The aim of the MUSE-4 experiment was to test and develop new measurement techniques specific to the evaluation of reactivity in an ADS and to define a reference calculation route for such systems. Indeed, both the measurement techniques and calculation tools of reactor physics have been developed and used on critical reactors and their performances concerning subcritical systems driven by an external source needed be demonstrated.

In MUSE-4, the fuel of the reactor was UO_2-PuO_2, the simulated coolant was sodium or lead and the multiplication factor k_{eff} ranged from 1 to 0.95. The program has investigated the coupling of a multiplying medium to neutron sources of 2.6 or 14 MeV provided by an accelerator (GENEPI) via $D(d,n)^3He$ or $T(d,n)^4He$ nuclear fusion reactions respectively. A first phase of the program was a full characterization of the critical (Reference) configuration, which was representative of a typical ADS, with the presence of a large lead zone and heterogeneities due to the accelerator channel. Then several subcritical phases (SC0, SC2 and SC3) have been studied to investigate the ability of calculations tools to reproduce various parameters in large subcritical states. In the last deeply subcritical configuration - SC3-Pb - some of the sodium has been replaced by lead.

The analysis of MUSE-4 has already been performed [2] and this paper presents the interpretation of some selected aspects of the experiments with the familiar JEF-2.2 [3] and the newly released JEFF-3.1 [4] libraries; we focus on the effect of the library change on the reactivity calculations and the spectral indices in the reference and SC3-Pb configurations.

2. CALCULATION CODE AND LIBRARIES

The JEFF-3.1 Nuclear Data Library [4] is the latest version of the Joint Evaluated Fission and Fusion Library. The complete suite of data was released in May 2005, and contains general purpose nuclear data evaluations compiled at the NEA Data Bank in co-operation with several laboratories in NEA Data Bank member countries. JEFF-3.1 contains also radioactive decay data, activation data and fission yields data. It combines the efforts of the JEFF and EFF Working Groups who have contributed to this combined fission and fusion file. The library contains neutron reaction data, incident proton data and thermal neutron scattering law data in the ENDF-6 format.

The ERANOS-2.1 [5] system has been developed and validated to establish a suitable basis for reliable neutronic calculations of current, as well as advanced fast reactor cores of the GEN IV Forum. This code package contains several cross section libraries, all derived from the JEF2.2, JEFF-3.1, JENDL3.3 and ENDFB6.8 nuclear data evaluated files. Cell calculations are performed by the ECCO cell/lattice code [6], which prepares self-shielded cross sections and matrices by combining a slowing-down treatment in many groups with the subgroup method within each fine group. The sub-group method takes into account the resonance structure of heavy nuclides by means of probability tables and by assuming that the neutron source is uniform in lethargy within a given fine group. Core and shielding calculation codes [7, 8] offer various possibilities, such as: 1-D, 2-D or 3-D diffusion, 1-D or 2-D (X- Y, R-Z, R-θ) Sn transport, 2-D or 3-D (Cartesian and hexagonal) Variational Nodal Transport.

3. CRITICAL MASS

Figures 1 and 2 show the XYZ geometry of the Reference and SC3-Pb configurations. The Reference configuration (Figure 1) is critical, whereas the SC3-Pb configuration has been made subcritical by removing fuel assemblies and replacing some of the sodium by lead (Figure 2). Reactivity measurements have been performed with the MSM method, and calculations have been performed in the XYZ Variational Nodal Transport module of ERANOS-2.1 [8].

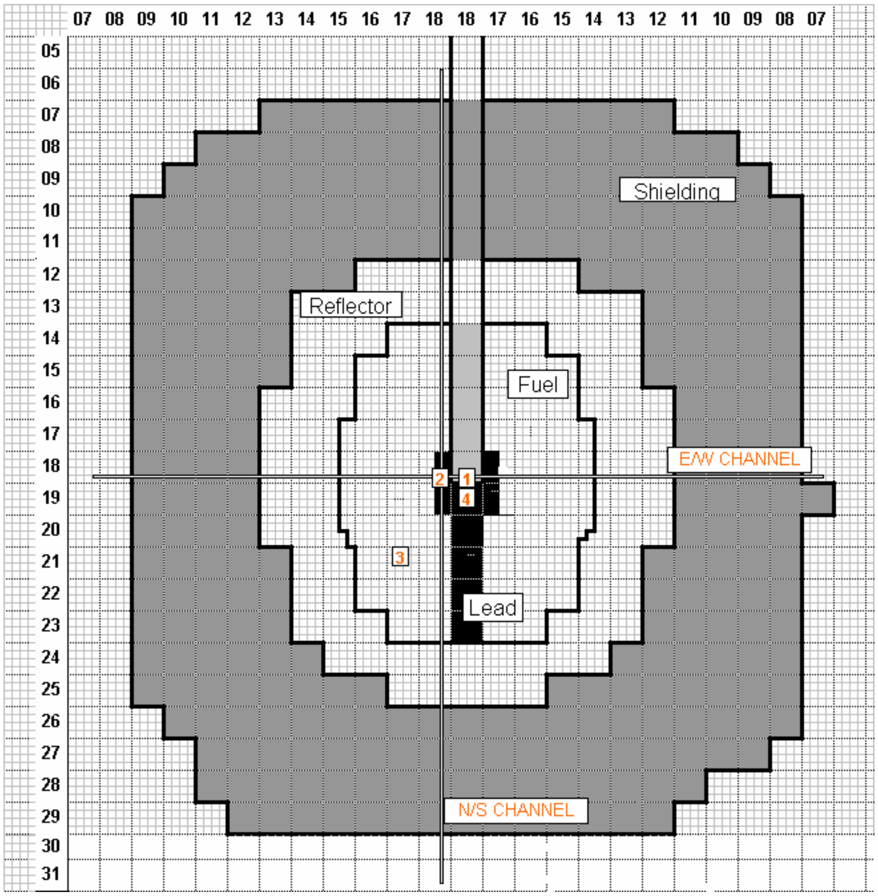

Figure 1: MUSE-4 Reference configuration

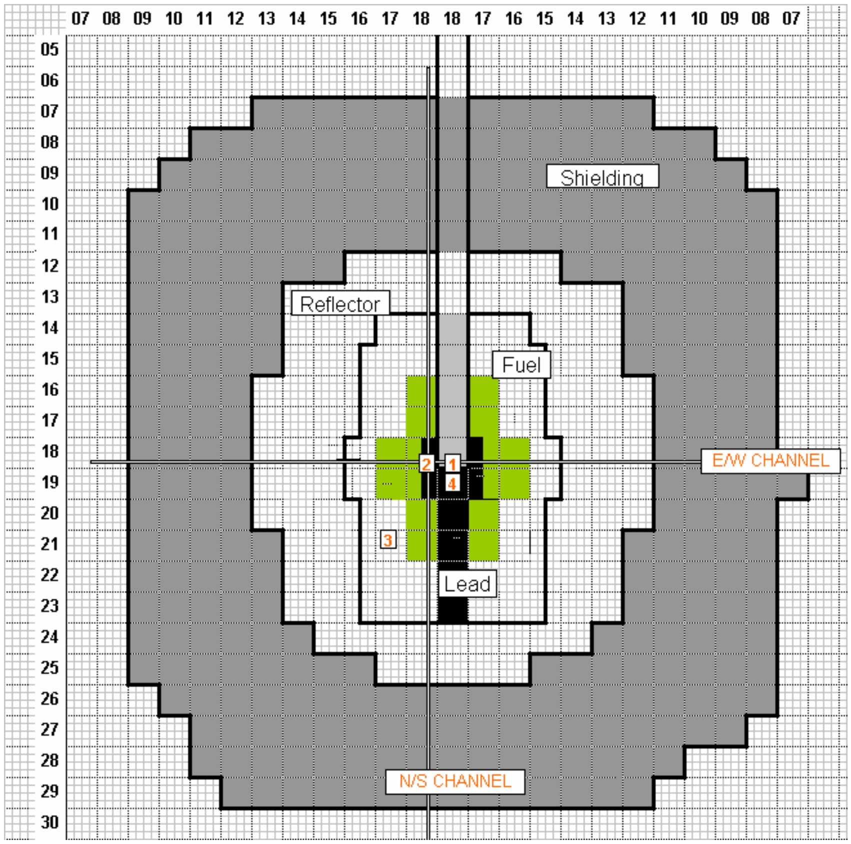

Figure 2: MUSE-4 SC3-Pb configuration (the lead-cooled part of the fuel is in green)

The comparison of reactivity calculations performed with JEF-2.2 and JEFF-3.1 is shown in Table 1:.

	Reactivity JEF-2.2	Reactivity JEFF-3.1	Δρ (JEF2.2 → JEFF3.1)
MUSE4-Reference	-357	-340	+17
MUSE4-SC3-Pb	-3123	-3518	-395

Table 1: calculated reactivities (in pcm)

We observe that both libraries provide comparable results on the Reference configuration, whereas there is a –400 pcm effect on SC3-Pb. To compare these calculated reactivities to measurements, they must be corrected by several effects, which cannot be calculated [2]. Table 2 demonstrates that the corrected calculations obtained with both libraries are compatible with the measurements (the uncertainties on the JEFF-3.1 calculations are still under study).

	Calculation (JEF-2.2)	Calculation (JEFF-3.1)	Measurement (MSM)
MUSE4-Reference	-200	-182	-80 ± 5
MUSE4-SC3-Pb	-3646	-4041	-3661 ± 300

Table 2: Corrected reactivities compared to measurements (in pcm)

To study the impact of the various isotopes and reactions on the global reactivity variations of Table 1, we have set up cylindrical models of the Reference and SC3-Pb configurations. These models are shown in Figure 3 and 4 and are based on the conservation of the volumes of each medium; only the radius of the fuel has been adjusted by a few millimetres to obtain a k_{eff} identical to the XYZ case.

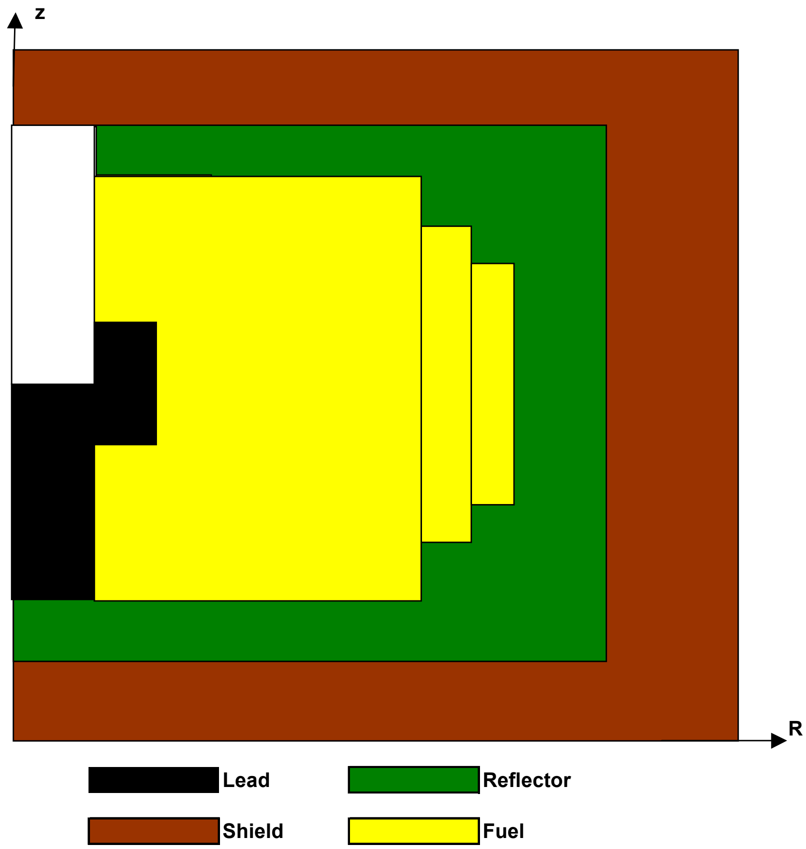

Figure 3: cylindrical model of MUSE-4-Reference

Figure 4: cylindrical model of MUSE-4-SC3-Pb

Table 3 shows the results of the perturbation analysis performed on the Reference configuration: we consider the calculations performed with JEF-2.2 as the reference case and the use of JEFF-3.1 as a perturbation to that situation. The ERANOS perturbation module - used as recommended in [9] - allows to split the reactivity effect of the library change in all the isotopes and reactions. The cylindrical model being a little different from the exact XYZ core, the reactivity effect is of course a little different (-46 pcm instead of +17), but we are only interested in the order of magnitude of the different components.

Table 3 show effects which are coherent with the analysis of other experiments performed with JEFF-3.1 [9], namely :

- the small total effect is the compensation of large positive and negative components (several hundreds of pcm's each),
- the large positive component comes mainly from the capture of ^{240}Pu, ^{239}Pu, ^{55}Mn, ^{57}Fe and ^{241}Am,
- the large negative component comes mainly from the elastic diffusion of ^{56}Fe and ^{52}Cr,

- There are quite large effects from the fission of ^{239}Pu and ^{240}Pu, capture of ^{59}Co, diffusion of ^{23}Na, ^{56}Fe, ^{238}Pu and ^{238}U.

ISOTOPE	CAPTURE	FISSION	ELASTIC	INELASTIC	N,XN	SUM
U235	-3	-4	0	0	0	-7
U238	15	76	119	-157	13	66
Pu239	103	-210	18	69	2	-18
Pu240	229	100	-9	1	0	320
Am241	63	-14	4	-4	0	48
Fe54	65	0	-79	-2	0	-17
Fe56	-19	0	-474	126	0	-368
Fe57	75	0	31	0	0	106
Cr52	-4	0	-399	19	0	-384
Cr53	12	0	-91	-1	0	-81
Co59	-95	0	-5	0	0	-100
Mn55	118	0	5	11	0	135
Na23	0	0	157	118	0	276
Si	-4	0	-42	0	0	-47
O	17	0	-28	0	0	-11
Pb	-1	0	-19	-12	1	-31
SUM	579	-34	-776	172	14	-46

Table 3: decomposition of the JEF-2.2 → JEFF-3.1 reactivity effect
in MUSE4-Reference (pcm)

Table 4 shows the same decomposition for the SC3-Pb configuration; the same conclusions can be drawn and in addition we observe a large negative reactivity effect coming from the elastic diffusion cross section of lead, whose quantity has been increased in SC3-Pb.

ISOTOPE	CAPTURE	FISSION	ELASTIC	INELASTIC	N,XN	SUM
U235	-3	-4	0	0	0	-7
U238	8	82	121	-131	11	92
Pu239	129	-172	16	68	2	44
Pu240	224	107	-7	0	0	324
Am241	71	-14	4	-4	0	56
Fe54	65	0	-82	-2	0	-19
Fe56	-21	0	-504	125	0	-400
Fe57	76	0	31	1	0	108
Cr52	-6	0	-437	19	0	-424
Cr53	13	0	-98	-1	0	-86
Co59	-102	0	-6	0	0	-108
Mn55	124	0	5	13	0	141
Na23	0	0	154	40	0	193
Si	-4	0	-46	0	0	-51
O	14	0	-88	0	0	-74
Pb	-8	0	-144	-74	5	-222
SUM	591	19	-1045	56	17	-362

Table 4: decomposition of the JEF-2.2 → JEFF-3.1 reactivity effect
in MUSE4-SC3-Pb (pcm)

The large negative total reactivity effect in this configuration comes from the increase of the quantity of lead (whose effect is negative) and from the decrease of the quantity of sodium (whose effect is positive).

We have investigated the possible influence of the large ^{56}Fe and ^{52}Cr diffusion cross-sections changes between JEF-2.2 and JEFF-3.1 on the flux shape near and inside the stainless steel reflector. Figure 5 shows the measured and calculated ^{235}U fission rate traverse in an axial channel going from to core center through the reflector. We see that a library change does not affect the fission rate traverse more than 1.5% in the middle of the reflector and does not improve the C/E agreement.

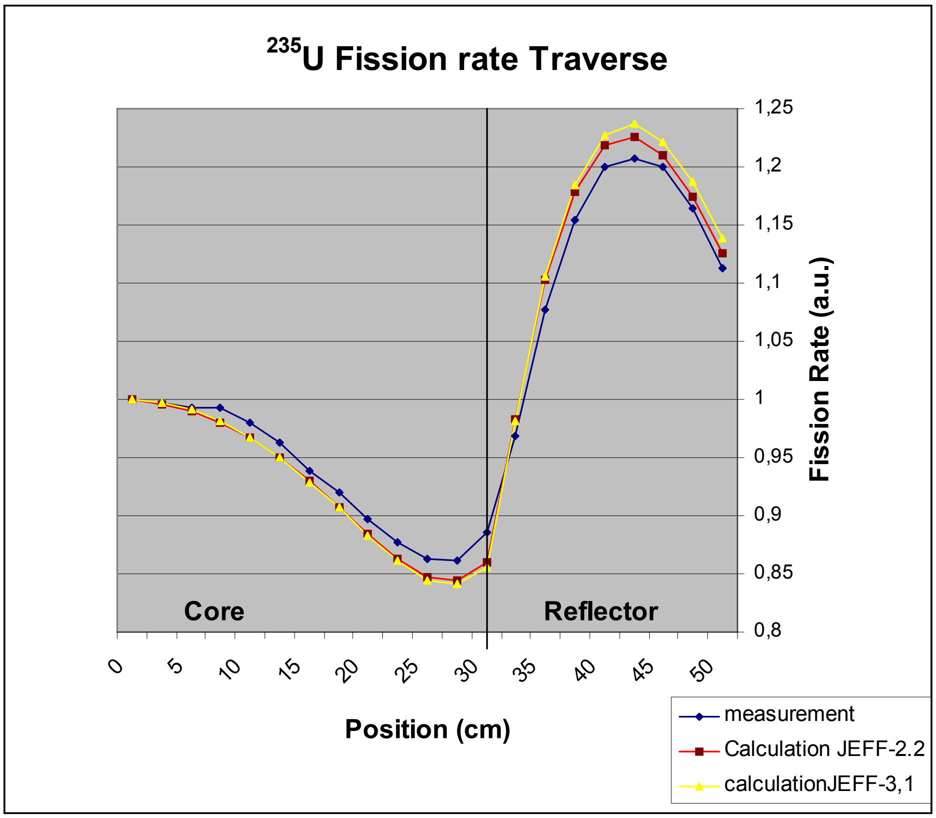

Figure 5: ^{235}U fission rate traverse

4. SPECTRAL INDICES

Several spectral indices have been measured with fission chambers in the lead (position 4 of Figure 1) or the fuel (position 3 of Figure 1) of the MUSE-4-Reference configuration. They are defined as the ratio of the fission cross-section of a given isotope to the fission cross-section of ^{235}U. The experimental uncertainties on these spectral indices are 2 to 3%. These measurements are compared to JEF-2.2 and JEFF-3.1 calculations in tables 5 and 6.

In the lead	**JEF-2.2**	**JEFF-3.1**
^{238}U	0.91	0.89
^{239}Pu	0.92	0.93
^{241}Am	0.92	0.96
^{243}Am	0.99	0.95
^{237}Np	0.92	0.98
^{232}Th	0.83	0.86

Table 5: C/E for spectral indices in the lead zone

In the fuel	**JEF-2.2**	**JEFF-3.1**
^{240}Pu	1.01	1.02
^{239}Pu	0.97	0.97
^{241}Am	0.96	0.99
^{242}Pu	0.98	1.02
^{237}Np	0.91	0.97
^{232}Th	0.89	0.92

Table 6 : C/E for spectral indices in the fuel zone

From the analysis of these tables, we observe that the new library ameliorates the C/E for all the spectral indices in the fuel and for most of them in the lead except for ^{238}U and ^{243}Am.

CONCLUSION

The analysis of some selected experiments of the MUSE-4 program with the ERANOS-2.1 code system using either the JEF-2.2 library or the more recent JEFF-3.1 one has shown limited improvements of the newest libraries. This is not obvious since some compensating effects - especially on reactivities - are hiding the improvement, which is particularly obvious for all the spectral indices except for ^{238}U and ^{243}Am in the lead zone. The MUSE4 Pb configuration is predicted with less accuracy with JEFF3.1 than JEF2.2 but still within the experimental uncertainty.

REFERENCES

[1] R. SOULE ET AL.
Neutronic Studies in Support to ADS: The Muse Experiments in the MASURCA Facility
Nuclear Science and Engineering, Vol. 148 (2004) 124-152

[2] J.F. LEBRAT ET AL.
Global Results from Deterministic and Stochastic Analysis of the MUSE-4 Experiments on the Neutronics of ADS
Submitted to Nuclear Science and Engineering

[3] *The JEF2.2 Nuclear Data Library*
JEF Report17, OECD/NEA, April 2000

[4] *The JEFF-3.1 library*
JEFF report 20, NEA/OECD, 2006, to be published.
http://www.nea.fr/html/dbdata/projects/nds_jef.htm.

[5] J.M. RUGGIERI ET AL.
ERANOS-2.1 : International Code System for GEN IV Fast Reactor Analysis
Proceedings of ICAPP '06 Reno, NV USA, June 4-8, 2006

[6] G. RIMPAULT
Algorithmic features of the ECCO cell code for treating heterogeneous fast reactor Subassemblies
Int. topic meeting on reactor physics and computations, Portland, USA, 1995.

[7] G. PALMIOTI, C.B CARRICO ET E.E. LEWIS
TGV : Nodal variational method for the solution of the diffusion and transport equation in two and three dimensions geometries,
DER/SPRC/LEPh 91.208.

[8] G. PALMIOTI, J.M. RIEUNIER
Optimized two-dimensional Sn transport (BISTRO)
Nuclear Science and Engineering 104-26, 1990.
AccAPP/ADTTA'01, ANS 2001 Winter Meeting, Reno, Nevada (USA), 2001.

[9] J. TOMMASI ET AL.
Present status of JEFF-3.1 validation for Fast Reactors using the ERANOS-2.1 code system
This conference