JEFF-3.1.1 Nuclear Data Validation

for Sodium Fast Reactors

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J.F. Lebrat, J. Tommasi, P. Archier, J.M. Ruggieri

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Nuclear Energy Division
Cadarache Center
Reactor Studies Department

Presented by F. Varaine

Outline

- The JEFF-3.1.1 Nuclear Data Library
- The Set of Integral Experiments
- Calculation Results: Monte Carlo on Core Criticality
- Calculation Results: Separate Samples Irradiations
- Conclusion

The JEFF-3.1.1 Nuclear Data Library

The JEFF-3.1.1 Nuclear Data Library is the latest version of the Joint Evaluated Fission and Fusion Library.

- **The complete suite of data was released in 2008 and contains general purpose nuclear data evaluations compiled at the NEA Data Bank in co-operation with several laboratories/countries.**
- **JEFF-3.1.1 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.**

We present the status of the validation of this library for fast reactor calculations;

we therefore re-analyse a selected set of integral experiments

The Set of Integral Experiments 1/2

- **CIRANO (1990's)**

  A program set up in MASURCA (CEA Cadarache) to study Pu-burning fast reactors (CAPRA project) via the progressive substitution of fertile blankets by steel reflectors and a Pu/(U+Pu) content up to 45% for oxyde and 100% for nitride fuel.

- **MASURCA 1B (1968)**

  The MASURCA core was loaded with enriched uranium fuel (30%) and graphite, while the axial and radial blankets were made of depleted Uranium. This experiment is interesting for the study of GFR's with a softer spectrum than standard sodium fast reactors.

- **PRE-RACINE and RACINE (1976-1984)**

  For the study of heterogeneous cores with both outsides and insides radial fertile zones, in order to optimize the breeding gain and the void effect. MASURCA (CEA) was loaded with a plutonium central zone, surrounded by an enriched Uranium zone (R1) of similar reactivity. In some configurations, a central fertile zone was loaded and two different qualities of Pu were used. The core was surrounded by fertile UO2-Na axial blankets and UO2 radial blankets.

The Set of Integral Experiments 2/2

- **SUPERPHENIX**

  We have focused on the start up configuration of October 1985 (CMP).

- **ZPPR10A (1978-1988)**

  Performed in ANL-Idaho between 1978 and 1988 to study Large Fast Breeder Reactor Cores. It is of particular interest because sodium void effects have been measured and are available; its soft spectrum is interesting to validate sodium data in an energy range representative of GEN-IV large SFR's.

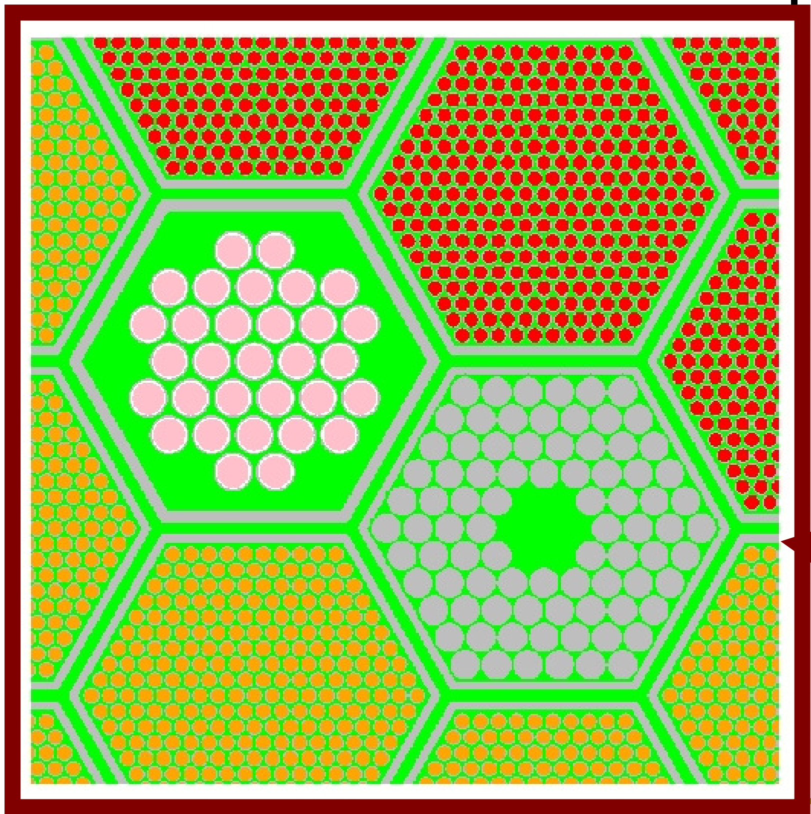
- **The PROFIL and PROFIL-2 experiments in PHENIX (1974-1980)**

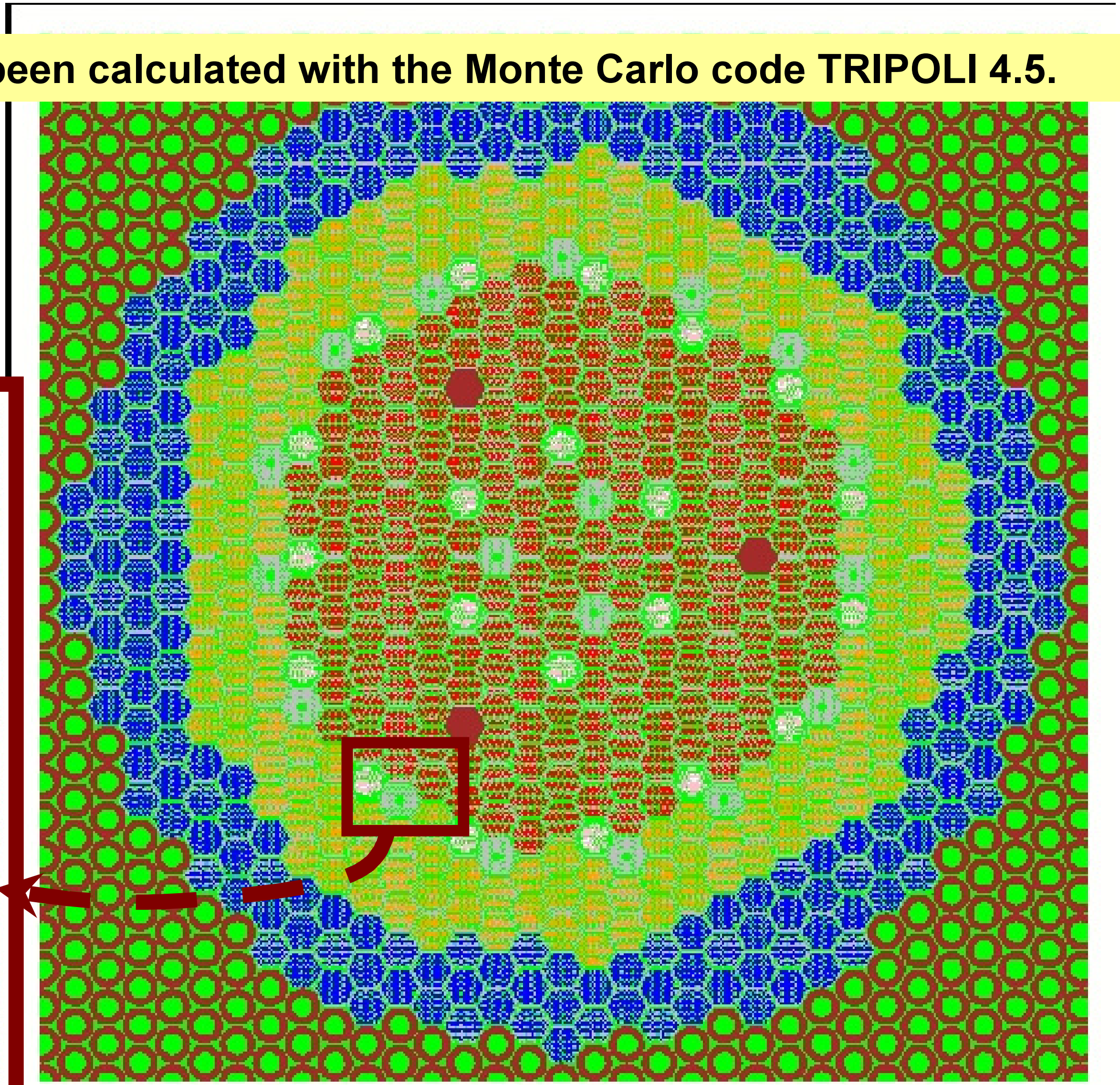
  Extensive and accurate measurements of integral capture rates are best performed by irradiating separate isotope samples in a well-characterized flux within a power reactor. The separate samples (almost pure isotopes) were put in individual containers stacked in a standard pin of a standard fuel subassembly .

Calculation Results : Monte-Carlo on core criticality

The experiments have been calculated with the Monte Carlo code TRIPOLI 4.5.

SUPER-PHENIX description





Calculation Results : Monte-Carlo on core criticality

Experiment	r	E	TRIPOLI 4.5 + JEFF 3.1.1	JEFF 3.1.1-JEFF 3.1 (pcm)	T*-E (pcm)
CIRANO ZONA2A	0.54	0.99945 ± 0.00005	1.00758 ± 0.00008[b]	66	813
CIRANO ZONA2B	0.54	0.99883 ± 0.00005	1.00742 ± 0.00008[b]	84	860
PRE-RACINE Het., 8% ^{240}Pu	0.43	0.99930 ± 0.00070[a]	1.00420 ± 0.00008[b]	72	500
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PRE-RACINE Hom. 18% ^{240}Pu	0.43	0.99930 ± 0.00070[a]	1.00359 ± 0.00009[b]	58	358
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RACINE 1A	0.43	0.99930 ± 0.00005	0.99971 ± 0.00005[b]	61	40
RACINE 1D Na	0.43	0.99930 ± 0.00070[a]	1.00483 ± 0.00005[b]	66	484
RACINE 1D B_4C	0.43	0.99930 ± 0.00070[a]	1.00540 ± 0.00005[b]	69	541
ZPPR 10A	0.31/0.4	1.00100 ± 0.00068	1.00216 ± 0.00005	42	117
SUPERPHENIX CMP	0.32/ 0.38	1.00000 ± 0.00010	1.00627 ± 0.00005[t]	-27	119
MASURCA 1B	0.33	1.00000 ± 0.00070	1.00446 ± 0.00005	5	446

Calculation Results : Monte-Carlo on core criticality

The results obtained with JEFF-3.1.1 are consistent with those obtained using JEFF-3.1 within 80 pcm. The difference between the two libraries is mainly the decrease in 16O(n,α) reaction at high energy.

The general trend is to overestimate the experimental reactivity, but with varying amplitudes that may apparently be correlated to the spectrum hardness and fuel nature :

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- **In intermediate spectrum (r ≈ 0.4) with MOX fuel surrounded by enriched U fuel (PRE-RACINE and RACINE), the reactivity is overestimated by ≈ 450 pcm, with the outstanding exception of RACINE 1A.**

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- **In intermediate spectrum (r $\approx$ 0.4) with MOX fuel surrounded by enriched U fuel (PRE-RACINE and RACINE), the reactivity is overestimated by $\approx$ 450 pcm, with the outstanding exception of RACINE 1A.**
- **In soft spectrum cores (r $\approx$ 0.3 for the inner core and r $\approx$ 0.4 for the outer core) with pure MOX fuel (ZPPR 10A, Super-Phénix), the reactivity is overestimated by 120 pcm.**
- **In soft spectrum (r $\approx$ 0.3) with enriched uranium fuel (MASURCA 1B) the reactivity is overestimated by $\approx$ 450 pcm.**

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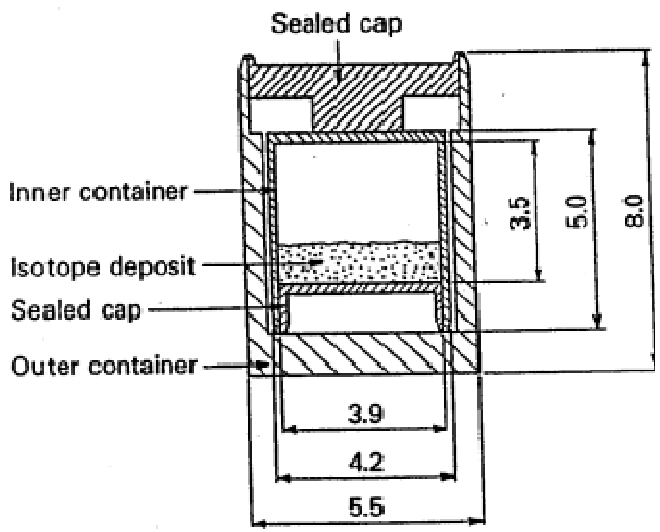
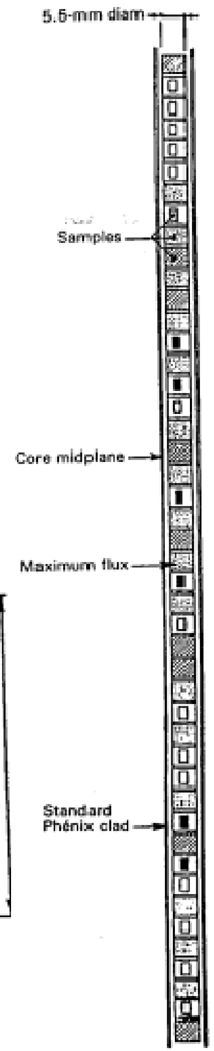
As the PROFIL and PROFIL-2 experiments have been performed near the core center (fondamental mode), the analysis has been performed using the ERANOS 2.2 code system, which furthermore has the advantage on stochastic codes to yield sensitivities of burnt compositions to nuclear data .

The results were scaled using the fluence predicted using the 235U/238U and 236U/235U ratios.





Position (mm)	Isotope	Chemical form	Mass (mg)
180	^{235}U	UO_2	22
170	^{145}Nd	Nd_2O_3	22
160	^{105}Pd	Palladium	21.7
150	^{133}Cs	CsF	23.4
140	^{101}Ru	Ruthenium	19.6
130	^{95}Mo	Molybdenum	21.5
120	^{238}Pu	PuO_2	14
110	^{97}Mo	Molybdenum	21.7
100	^{239}Pu	PuO_2	~10
90	^{235}U	UO_2	22.5
80	^{241}Am	AmO_2	10.0
70	^{238}U	UO_2	22.3
60	^{240}Pu	PuO_2	3.7
50	Natural lithium	LiF	3.8
40	^{242}Pu	PuO_2	29
30	Natural boron	Boron	1.1
20	^{149}Sm	Sm_2O_3	25.8
10	^{241}Pu	PuO_2	4.3
0	^{235}U	UO_2	24.1
−10	^{239}Pu	PuO_2	~10
−20	Natural boron	Boron	1.0
−30	^{240}Pu	PuO_2	6
−40	^{238}U	UO_2	23
−50	^{241}Pu	PuO_2	5
−60	Natural lithium	LiF	3.7
−70	^{239}Pu	PuO_2	~10
−80	^{101}Ru	Ruthenium	20
−90	^{235}U	UO_2	23.9
−100	^{238}U	UO_2	23.7
−110	^{240}Pu	PuO_2	6.3
−120	^{133}Cs	CsF	22.4
−130	^{242}Pu	PuO_2	27
−140	^{95}Mo	Molybdenum	21.9
−150	^{105}Pd	Palladium	20
−160	^{241}Pu	PuO_2	12.5
−170	Natural boron	Boron	1.3
−180	^{235}U	UO_2	24.5
−190	Natural lithium	LiF	4.2
−200	^{101}Ru	Ruthenium	19
−210	^{242}Pu	PuO_2	25
−220	^{145}Nd	Nd_2O_3	20.2
−230	^{238}Pu	PuO_2	12.6
−240	^{97}Mo	Molybdenum	19.7
−250	^{241}Am	AmO_2	13.7
−260	^{149}Sm	Sm_2O_3	22.9
−270	^{235}U	UO_2	25

Calculation Results: Separate Sample Irradiations 2/3

- Very close agreement on the 238U, 239Pu and 240Pu integral capture rates and even on the 238Pu integral capture rate
- Large overestimations for the 241Pu and 242Pu integral capture rates.
- For 242Pu, this has lead to re-evaluate the nuclear data of this nuclide.

Nuclide	Reaction	Ratio	C/E
^{235}U	fission	$^{235}U/^{238}U$	**1 : 1.007 ± 0.020** **2A : 1.000 ± 0.001** **2B : 0.993 ± 0.003**
	capture	$^{236}U/^{235}U$	**1 : 1.000 ± 0.001** **2A : 1.000 ± 0.001** **2B : 1.000 ± 0.001**
^{238}U	capture	$^{239}Pu/^{238}U$	1.018 ± 0.002
	(n,2n)	$^{237}Np/^{238}U$	*0.927 ± 0.028*
^{238}Pu	capture	$^{239}Pu/^{238}Pu$	1.024 ± 0.005
^{239}Pu	capture	$^{240}Pu/^{239}Pu$	0.981 ± 0.001
	(n,2n)	$^{238}Pu/^{239}Pu$	*0.793 ± 0.034*
^{240}Pu	capture	$^{241}Pu/^{240}Pu$	0.970 ± 0.004
	(n,2n)	$^{239}Pu/^{240}Pu$	*0.719 ± 0.044*
^{241}Pu	capture	$^{242}Pu/^{241}Pu$	**1.083 ± 0.001**
^{242}Pu	capture	$^{243}Am/^{242}Pu$	**1.175 ± 0.016**

Calculation Results: Separate Sample Irradiations 3/3

- The level of the 241Am capture rate appears well predicted, consistently with an important revision effort for this nuclide between JEF-2.2 and JEFF-3.1.
- Moreover, the results of the PROFIL and PROFIL-2 experiments were used to scale adequately the branching ratios of 241Am capture
- The integral capture rates of 237Np and 243Am appear underestimated, while the capture rates of 244Cm and 246Cm are overestimated

Nuclide	Reaction	Ratio	C/E
^{237}Np	capture	^{238}Pu/^{237}Np	0.915 ± 0.011
^{241}Am	capture	^{242m}Am/^{241}Am ^{242}Pu/^{241}Am ^{238}Pu/^{241}Am ^{242}Cm/^{241}Am	0.992 ± 0.005 (global average)
^{243}Am	capture	^{244}Cm/^{243}Am	0.933 ± 0.036
^{244}Cm	capture	^{245}Cm/^{244}Cm	**1.354 ± 0.003**
^{246}Cm	capture	^{247}Cm/^{246}Cm	**1.208 ± 0.035**

Conclusions

- The analysis of several types of experiments with JEFF-3.1.1 nuclear data associated to stochastic (TRIPOLI4.5) or deterministic (ERANOS2.2) code systems, shows the good predictability of these calculation tools for criticality calculations and fuel inventory prediction. From this validation work, some required improvements on nuclear data are highlighted, as well as the need for new specific integral experiments.

- Reactivity of clean and fresh cores: the results obtained with JEFF-3.1.1 are consistent with those obtained using JEFF-3.1 within 80 pcm, but there is still an overestimation of the calculated reactivity of all the experiments between 40 and 800 pcm depending on the spectrum hardness (Pu content) and fuel composition, the discrepancy being larger in hard spectra. Additional investigations are in progress to understand this behaviour.

- Integral capture cross-sections (PROFIL and PROFIL-2): , except for 241Pu (C/E ≈ 1.08), 242Pu (C/E ≈ 1.18), 237Np (C/E ≈ 0.92), 243Am(C/E ≈ 0.93), 244Cm(C/E ≈ 1.35); impact of the trends observed on the individual fission products put in PROFIL and PROFIL-2 is ≈4% on the part of $\Delta\rho$burnup due to fission products.