EXPERIMENTAL VALIDATION OF U_{235} EVALUATIONS RECOMMENDATIONS FOR JEFF3

JEFF Meeting

A. Courcelle, A. Santamarina, C. Chabert, O. Litaize

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Contents

1 Introduction

The new U_{235} evaluation proposed by Leal, Derrien, Wright and Larson (LDWL) in august 1997 is adopted in the JEFF3.0 starter file and in the release 5 of ENDF/BVI. The main differences between JEF2.2 and JEF3.0 are summarized in the following table :

Data	Symbol	JEF2.2	LDWL	(LDWL-J2.2)/J2.2
0.253 eV thermal capture (barn)	σ_γ	98.76	98.69	-0.1%
0.253 eV thermal fission (barn)	σ_f	584.18	585.03	+0.1%
0.253 eV thermal eta	η	2.085	2.085	+0.0%
average capture width	$< \Gamma_\gamma >$	35 meV	40 meV	+14%
capture resonance integral (barn)	I_γ	132.88	140.49	+5.7%
fission resonance integral (barn)	I_f	278.61	276.04	-0.9%
thermal total multiplicity	$\overline{\nu}$	2.4374	2.4367	-0.03%
epithermal alpha	$\alpha = I_\gamma / I_f$	0.477	0.509	+6.7%

Table 1: Comparison of JEF2.2 and LDWL U235 evaluation

An extensive work has been previously carried out to test the new evaluation [2], [3]. A previous document [4] has investigated french integral experiments (spent fuel, buckling measurements) to qualify the new cross-section. The aim of this paper is to extend this analysis. Various kind of measurements such as irradiated fuel analysis, lattice criticality, high enriched U235 systems, U235 samples reactivity worth measurements, spectral indices measurements and temperature effects can be used to validate LDWL evaluation. Furthermore, more accurate modelling are proposed to investigate relevant integral experiments : spent fuel analysis based on assembly depletion calculation, k_{eff} experiments analysed through 3D Monte-Carlo model.

2 Calculation methods

Deterministic calculations were performed with the french multigroup transport code APOLLO2. Pin cell and assemblies calculational schemes were defined to avoid significant biases, main options are summarised below :

- 172 energy group library based on JEF2.2 ;
- accurate space dependent self-shielding formalism ;
- collision probability methods (Pij) for the flux calculation. Calculations of Pij can be performed in the exact geometry. Several module using interface currents methods have also been introduced allowing the use of UP1 approximation (interface currents are linearly isotropic).

Deterministic core calculations were carried out with APOLLO2 using SN discrete ordinate method in two dimensions. Common optimised options are summarized below :

- S8 Quadrature, P1 anisotropic scattering ;
- 20 energy groups (12 fast and 8 thermal) ;

Furthermore, core calulations were also performed with TRIPOLI4 continuous energy Monte Carlo code. We noticed that the deterministic multigroup approach leads to a systematic over-prediction of about 100 pcm for UOX systems.

3 Qualification of σ_γ and I_γ : analysis of $\frac{U_{236}}{U_{238}}$ isotopic ratio from spent fuel experiments

Analysis of U236 build-up from spent fuel experiments provides a direct validation of thermal U235 capture cross-section σ_γ and capture integral resonance I_γ . A first analysis presented in [4] was based on a simplified modelling.
A new accurate modelling for depletion calculations has been defined [10]. The influence of sensitive physical parameters has been studied in details such as MOX/UOX interface, irradiation history, radial distribution of the fuel temperature within the pellet and its variation during irradiation (calculated with METEOR thermo-mechanical code), concentration of soluble boron, "stretch-out" operating mode.
Burnup of samples are deduced from fluence indicators such as $\frac{Nd_{148}}{U_{238}}\frac{Nd_{145}}{U_{238}}\frac{Nd_{150}}{U_{238}}$ ratios. Furthermore, uncertainties has been evaluated from a detailed sensitivity study.

3.1 Resonance integral : MOX PWR irradiated fuel

U236 build-up in MOX spectrum gives an accurate validation of U235 capture resonance integral. Indeed, $\frac{U_{236}}{U_{238}}$ isotopic ratio is mainly sensitive to U235 epithermal capture up to 40 GWj/t (at higher burn-up, U236 build-up is also sensitive to U236 capture cross section). In MOX spectrum, about 70% of U235 capture occurs in resonance region.

The investigated MOX assembly was irradiated in the SLB1 reactor, a 900 MWe PWR with a 30% MOX fuel loading. MOX assemblies include three zones with different Pu enrichments : a central zone (2.9% Pu), an intermediate zone (4.4% Pu) and a peripheral zone (5.7% Pu) [11].

rods	P14	I13	I02	N13	L14	A04	Q14	Q17	P16
cycle	1	2	2	3	3	1	2	3	3
zone	Interm	Central	Interm	Interm	central	Periph	Periph	Periph	Periph
BU (MWj/t)	12868	28368	28453	41493	45005	9556	24664	37683	42013
U236/U238 (JEF2)	-10.13	-7.10	-8.24	-7.84	-6.45	-7.76	-8.00	-5.63	-5.18
uncert. 1σ	$\pm$3%	$\pm$2%	$\pm$2%	$\pm$1.5%	$\pm$1.5%	$\pm$4%	$\pm$3%	$\pm$3%	$\pm$3%
U236/U238 (LDWL)	-5.68	-2.65	-3.79	-3.39	-2.00	-3.31	-3.55	-1.18	-0.73

Table 2: C/E-1 in % using JEF2.2 and LDWL cross-sections for SLB1 experiment

The C/E values given by the peripheral rods are less reliable than the central rods owing to the mismatched spectrum at the MOX/UOX boundary and to the local burnup knowledge. The results from the new accurate calculational scheme confirm the conclusions of the previous analysis. Table 2 demonstrates that the new LDL capture resonance integral (about 6% larger than in JEF2.2) reduces the discrepancy on U236 build-up : the mean bias over central + intermediate rods (2 and 3 cycles) decreases from $-7.4\% \pm 2\%$ to $-2.9\% \pm 2\%$. These results confirm the strong $< \Gamma_\gamma >$ increase proposed by the LDWL evaluation. A stronger correction of the $< \Gamma_\gamma >$ JEF2.2 value could be supported by this integral information, however the $< \Gamma_\gamma >= 40\ meV$ deduced from SAMMY analysis is probably the maximum value supported by the differential measurements.

3.2 thermal capture cross-section : UOX PWR irradiated fuel

Three UOX experiments have been investigated : BUGEY3, GRAVELINES and FESSENHEIM2.

NAME	enrichment	maximum burn-up
BUGEY3	3.1%	38 GWj/t
GRAVELINES	4.5%	60 GWj/t
FESSENHEIM	3.1%	58 GWj/t

Table 3: Characteristics of UOX spent fuel experiments

The following table shows the discrepancies between calculation and experiment on $\frac{U_{236}}{U_{238}}$ isotopic ratio.

rods	K08	K11	G07	G11	G10	K08	J09	J07
BU (MWj/t)	26570	26900	38360	50800	49800	59850	59850	59850
U236/U238 (JEF2.2)	-3.90	-5.27	-4.49	-4.94	-4.19	-3.87	-4.10	-4.56
uncert. 1σ	$\pm$1.2%	$\pm$1.2%	$\pm$1.0%	$\pm$0.9%	$\pm$0.9%	$\pm$0.9%	$\pm$0.9%	$\pm$0.9%
U236/U238 (LDWL)	-0.69	-2.06	-1.28	-1.66	-0.98	-0.66	-0.89	-1.36

Table 4: C/E-1 in % using JEF2.2 and LDWL cross-sections for Gravelines experiment

rods	H09	G11	K07	K11	I10	G08	J09
cycle	2	2	2	3	3	3	3
BU (MWj/t)	20000	20400	24700	38300	38300	38300	38300
U236/U238 (JEF2.2)	-3.41	-3.55	-3.66	-2.45	-3.66	-4.35	-2.60
uncert. 1σ	$\pm$1.3%	$\pm$1.3%	$\pm$1.2%	$\pm$1.0%	$\pm$1.0%	$\pm$1.0%	$\pm$1.0%
U236/U238 (LDWL)	-0.76	-0.90	-1.01	+0.20	-1.01	-1.70	+0.05

Table 5: C/E-1 in % using JEF2.2 and LDWL cross-sections for Bugey experiment

rods	H11	J07	H08	J10	G10	G07	K11	H10	F52-K11
cycle	4	4	4	5	5	5	5	5	5
BU (MWj/t)	49100	49100	49100	57700	57700	57700	57700	57700	57700
U236/U238 (JEF2)	-4.51	-3.88	-4.26	-3.96	-4.41	-3.77	-3.21	-3.56	-3.87
uncert. 1σ	$\pm$1.0%	$\pm$1.0%	$\pm$1.0%	$\pm$1.2%	$\pm$1.2%	$\pm$1.2%	$\pm$1.2%	$\pm$1.2%	$\pm$1.2%
U236/U238 (LDWL)	-1.87	-1.23	-1.62	-1.31	-1.76	-1.12	-0.56	-0.91	-1.22

Table 6: C/E-1 in % using JEF2.2 and LDWL cross-sections for Fessenheim II experiment

Trends between the three UOX experiments are consistent. One can notice that the increase of the (n,γ) resonance integral can explain C/E dicrepancies in UOX spectra. Considering that for UOX experiments, most of U235 captures ($\approx$ 70%) occurs in thermal region, we can conclude that **thermal capture cross-section in JEF2.2 and LDL evaluations ($\sigma_\gamma^{2200} = 98.8\ b$) is in good agreement with spent fuel information** : (σ_γ^{2200} in the range 99-100 b).

4 Qualification of σ_a^{U235} and $\sigma_f^{U_{235}}$

Although it is difficult to validate fission cross-sections $\sigma_f^{U_{235}}$ by integral experiments, some information can be provided by spent fuel experiments and spectral index analysis.

4.1 analysis of $\frac{U_{235}}{U_{238}}$ isotopic ratio from spent fuel experiments

U235 depletion is very sensitive to total absorption (capture + fission) cross-section (for Gravelines experiment, the sensitivity coefficient of $\frac{U_{235}}{U_{238}}$ to total U235 absorption rate reaches about 1.5 %/% at 60 GWj/t). However, experimental uncertainty of $\frac{U_{235}}{U_{238}}$ is relatively large at high burn-up (mainly because of its high sensitivity to the fluence normalisation and to thermo-mechanical effects), consequently it is not easy to extract clear trends for U235 absorption cross-sections.

The following table summarizes the discrepancies between calculation and experiment on $\frac{U_{235}}{U_{238}}$ isotopic ratio (average on severals samples) for the different irradiated fuel experiments.

Experiment	20 GWj/t	40 GWj/t	50 GWj/t	60 GWj/t
Bugey	0.5 [-0.32 1.26]	1.7 [-0.10 3.85]		
Fessenheim			-4.2 [-1.94 -6.98]	2.3 [-2.37 10.6]
Gravelines	1.0 [-0.05 1.95]	1.8	2.1 [1.01 3.16]	3.0 [-3.45 8.10]
exp. uncert. 1σ	$\pm$1.0%	$\pm$2.0%	$\pm$3.0%	$\pm$3.5%

Table 7: C/E-1 in % on $\frac{U_{235}}{U_{238}}$ using JEF2.2 cross-sections for UOX spent-fuel experiments. The values given in bracket show a discrepancy spread among the various samples

U235 depletion is calculated within experimental margins (a slight overestimation is observed), indicating that the absorption cross-section in JEF2.2 is satisfactory in PWR spectrum. For high burn-up samples, because of the larger experimental uncertainty, a wide range of discrepancies is observed. The use of the LDWL evaluation leads to smaller C/E : $+0.9\% \pm 2\%$, instead of $+1.7\% \pm 2\%$ with JEF2.2 on UOX experiment at 40 GWj/t.

4.2 $\frac{\sigma_f^{Pu239}}{\sigma_f^{U235}}$ spectral index

An indication of the accuracy of fission cross-section is given by $\frac{\sigma_f^{Pu239}}{\sigma_f^{U235}}$ spectral index. This spectral indices is generally used to validate the Pu239 fission cross-section (especially the large 0.3 eV resonance of σ_f^{PU239}). The ratio of Pu239 fission to U235 fission was measured in ERASME and MISTRAL2 experiments, giving a wide range of spectra.

Experiment	MISTRAL2	ERASME/L	ERASME/R	ERASME/S
Rmod	1.7	2.1	0.9	0.5
(C-E)/E	+2.1% $\pm$ 2%	-2.5% $\pm$ 2%	-0.4% $\pm$ 2%	+ 0.9% $\pm$ 2%

Table 8: (C-E)/E in % for $\frac{Pu_{239}}{U_{235}}$ spectral indices in MOX experiments (JEF2.2)

The calculation-experiment agreement observed in the epithermal spectrum of ERASME/S can be considered as a validation of the ratio of Pu239 fission to U235 fission resonance integral. The calculations were not performed again with the new LDWL evaluation, however the slight modification -0.9% of the fission resonance integral will change the C/E value by about 0.4%.

5 Qualification of $\eta^{U_{235}}$: Reactivity measurements

5.1 UOX Core

5.1.1 Buckling measurements in French UOX critical experiments

Several buckling measurements has been performed in the EOLE facility. We have selected seven UOX experiments that were carried out in a square lattice with PWR-type fuel pins. Results of calculation-experiment discrepancies calculated with APOLLO2 (Version 2.5) are summarised in table 9.

Experiment name	Lattice Pitch (cm)	V_{UO2}/V_{H2O}	q (4eV)	Bore (ppm)	B^2 $cm^{-2} * 10^3$	uncert. 1σ (pcm)	keff-1 JEF2.2 (pcm)	keff -1 (LDWL) (pcm)
CRISTO3	0.96	0.45	0.37	750	1.950	700	+1267	+491
UH1.2	1.26	1.25	0.51	569	6.05	300	+415	-75
MISTRAL1	1.32	1.75	0.53	294	8.89	600	-256	-667
CAMELEON	1.26	1.80	0.57	610	5.085	400	+885	+462
CRISTO2	1.58	3.56	0.76	832	3.575	300	-161	-351
CRISTO2L	1.71	4.40	0.79	672	3.020	300	-4	-226
CRISTO1	1.86	5.46	0.89	750	-0.09	300	+217	+94

Table 9: EOLE buckling experiments : Keff -1 in pcm

Trends are similar to the previous analysis [4] :

- For the hardest spectrum (CRISTO3), a large overestimation is observed using JEF2.2. This overestimation is corrected by the new LDWL evaluation of U235.
- In the LWR spectrum range corresponding to medium moderation ratio experiments (water to UO2 ratio in the range 1.25-1.80) The lattice reactivity is also overestimated with JEF2.2 cross-sections. Results are well improved with LDWL evaluation. The MISTRAL1 measurements are less reliable because of the small size of the core.
- For well-moderated systems such as CRISTO2, CRISTO2L and CRISTO1, the effect of η^{U235} change is small. JEF2.2 and LDWL give consistent results in agreement with buckling measurements.

5.1.2 Keff measurements in French UOX experiments

A set of ten french UOX cores was analysed. UH1.2, MISTRAL1 and CAMELEON were performed in the EOLE facility. Interpretation of these experiments used deterministic core calculations in two dimensions (Measured axial buckling was used to simulate 3D effects). UH1.2 was also calculated with TRIPOLI4 code (Monte-carlo method) and the results show same trend to reactivity overestimation as the APOLLO2 Sn calculations ($keff_{T4} = 1.00403 \pm 65\ pcm$ and $keff_{A2} = 1.00599$ compared to the experimental value $keff_{exp} = 1.00055$).

We have investigated VALDUC experiments (LEU-COMP-THERM-007 in ICSBEP) which involves three UOX lattices experiments performed in the framework of Safety-Criticality. Calculations were carried out both with APOLLO2 Sn and TRIPOLI4. We have noticed that in the JEF-REPORT-17, TRIPOLI4 results presented do not take account of the revision of this benchmark in 2000 [9], it probably explains the discrepancies observed between TRIPOLI4 and MONK calculations. The results presented here include the nuclide concentration modifications of this benchmark.

A 3D monte-carlo calculation (with TRIPOLI4 code) of the N4 PWR (CHOOZ-B1) start-up configuration is also analysed [13]. In this fresh fuel core calculation, the heterogeneous geometry (pin, clad, moderator, fuel assembly) is represented without any geometrical approximations.

We have included the analysis of MARACAS (LEU-COMP-THERM-049) critical configurations, performed in VALDUC. This involved arrays of contiguous cubic cans (20*20*20) loaded with low enriched uranium powders with an H/U ratio of 2, 2.5 and 3, reflected with polyethylene. Calculations were not performed in this study, the results presented here comes from reference [6] and represents the C/E value averaged over the various configurations (For a given H/U ratio, the calculation-experiment discrepancies show the same trends to overestimation). Calculations are based on TRIPOLI4 and LDWL impact is taken from reference [8] (Moret4 code in the framework of Criticality-Safety).

Experiment name	Lattice Pitch (cm)	V_{UO2}/V_{H2O}	q (4eV)	Bore (ppm)	uncert. σ (pcm)	(C-E) (JEF2.2) (pcm)	(C-E) (LDWL) (pcm)
MARACAS1	powder	H/U=2		0	340	+290(100)	-510(200)
MARACAS2	powder	H/U=2.5		0	420	+430(100)	-382(200)
MARACAS3	powder	H/U=3		0	370	+290(100)	-316(200)
UH1.2	1.26	1.25	0.51	569	200	+347(70)	-113
N4	1.26	1.4	0.60	1214	300	+397(15)	-188
MISTRAL1	1.32	1.75	0.53	294	150	+417	+6
CAMELEON	1.26	1.80	0.57	610	300	+801	+378
VALDUC1	1.26	1.82	0.71	0	300	-326(50)	-619
VALDUC2	1.60	3.81	0.83	0	300	-143(50)	-236
VALDUC3	2.10	7.58	0.91	0	300	-379(50)	-384

Table 10: C/E discrepancies on keff for french UOX regular cores

From the results presented in table 10, the following conclusions can be drawn :

- Except for MISTRAL1, table 10 and 9 show consistent results between buckling and reactivity measurements in the experiments performed in EOLE.
- A trend to reactivity overestimation with JEF2.2 is observed for the six hardest spectrum UOX experiments. This overestimation is well corrected with the new evaluation (a small underestimation seems to be observed with LDWL evaluation).
- In the case of VALDUC lattices (well thermalised systems), a large reactivity underprediction is obtained with LDWL.

5.1.3 Conclusion on reactivity measurements from UOX experiment

→ In under-moderated UOX systems characterised by an intermediate spectrum, the reactivity is overestimated by JEF2.2 evaluations. Due to the dominant resonant absorption rates, we can conclude that the $< \Gamma_\gamma >$ value in U_{235} and U_{238} (or ν_{U235}) should be modified.

→ The use of the LDWL evaluation with its suitable $< \Gamma_\gamma >= 40\ meV$ value leads to slight underestimation of UOX reactivity. Consequently, this result could mean that the U_{238} resonant capture is overestimated (a reduction of Γ_γ in JEF2.2 would improve the C/E agreement in both reactivity experiments and spectral index C8/F5 measurements).

→ In well-thermalised systems, the EOLE experiments indicate that the thermal η_{U235} value is satisfactory in JEF2.2 and LDWL evaluation. The VALDUC experiment shows an underprediction of the reactivity, however the small size of the configuration limits the validity of conclusions.

5.2 Highly enriched uranium homogeneous systems

In order to have the maximum U235 resonance integral effect and to avoid possible problems with U238 cross-sections, two set of experiments have been chosen.
The first includes, as proposed in [5], The two TOPSY reflected uranium hybride systems UH3-NI and UH2-UR and the HISS system (k_{inf} experiment). Reactivity Calculations were performed with TRIPOLI4 and the impact of LDWL evaluation was calculated with APOLLO2 (infinite medium calculation).

Experiment	q_{inf}	exp. uncert. 1σ pcm	(C-E) pcm TRIPOLI4 JEF2.2	(C-E) pcm JEF2.2+LDWL
HISS	0.14	600	+2921(40)	+901
TOPSY-NI	0.09	≈ 500	+2279(40)	+550
TOPSY-UR	0.09	≈ 500	+1567(40)	-160

Table 11: HISS and TOPSY experiments calculated with TRIPOLI4/JEF2.2. LDWL impact is evaluated with infinite medium calculations

The results are in agreement with a previous study [3] and demonstrate that the large overestimation of reactivity for hard spectrum system is strongly reduced using the LDWL evaluation.

The second investigated experiments set corresponds to highly enriched uranium solutions experiments from ICSBEP Handbook (UO_2F_2 and $UO_2(NO_3)_2$ solutions). Only light water moderated experiments have been selected. Gadolinium poisoned solutions were not chosen in order to avoid additional uncertainty linked to Gd content knowledge. Uranium concentration ranged from 20 gU/l to about 700 gU/l, covering a wide range of spectra.

Analysis of High-Sol-Therm experiments have been extensively performed in the framework of Safety-Criticality. In this study, calculations were not performed again, the results analysed here come from the JEFF-REPORT-17 [1] (TRIPOLI4 results). We calculated the differences between JEF2 and LDWL evaluations using infinite medium assumption.

Experiment	Solution	Conc gU/l	q_{inf}	uncert. σ	C-E (pcm) (JEF2.2)	C-E (pcm) (LDWL)
HST-012-1	$UO_2F_2 + H_2O$	22	0.9800	+400 pcm	+330(200)	+231
HST-011-2	$UO_2F_2 + H_2O$	52	0.9632	+400 pcm	+250(200)	+112
HST-011-1	$UO_2F_2 + H_2O$	53	0.9626	+400 pcm	+680(200)	+540
HST-010-1	$UO_2F_2 + H_2O$	102	0.9355	+400 pcm	+190(200)	-57
HST-001-7	$UO_2(NO_3)2 + HNO_3$	137	0.9134	+400 pcm	+400(200)	+79
HST-009-4	$UO_2F_2 + H_2O$	213	0.8779	+400 pcm	-90(200)	-531
HST-018-1	$UO_2(NO_3)2 + HNO_3$	300	0.8260	+400 pcm	-270(200)	-854
HST-001-2	$UO_2(NO_3)2 + HNO_3$	347	0.8013	+400 pcm	+320(200)	-355
HST-009-3	$UO_2F_2 + H_2O$	349	0.8151	+400 pcm	+420(200)	-219
HST-001-4	$UO_2(NO_3)2 + HNO_3$	358	0.7958	+400 pcm	+830(200)	+139
HST-001-9	$UO_2(NO_3)2 + HNO_3$	358	0.7958	+400 pcm	+290(200)	-401
HST-019-1	$UO_2(NO_3)2 + HNO_3$	400	0.7534	+400 pcm	+410(200)	-389
HST-009-2	$UO_2F_2 + H_2O$	543	0.7334	+400 pcm	+780(200)	-103
HST-009-1	$UO_2F_2 + H_2O$	696	0.6755	+400 pcm	+770(200)	-279

Table 12: Calculation-experiment discrepancies calculated with TRIPOLI4 for HST experiments. Only experiments without Gadolinium poison have been selected.

For selected experiments, LDWL reactivity effect is linear with q_{inf} (slowing down density calculated in infinite medium without leakage) and with uranium concentration. An average C-E equal to +330 pcm is obtained with JEF2.2, the use of LDWL evaluation gives a sligh underestimation of -140 pcm in average. The experiments corresponding to small uranium concentrations (20-50 gU/l) indicate a satisfactory value for thermal η_{U235} in both JEF2.2 and LDWL evaluation. Figure 1 points out a trend to overestimation for high U load with JEF2.2. on the other hand, the use of LDWL cross-sections induces a tendancy to keff underestimation in hardened spectra.

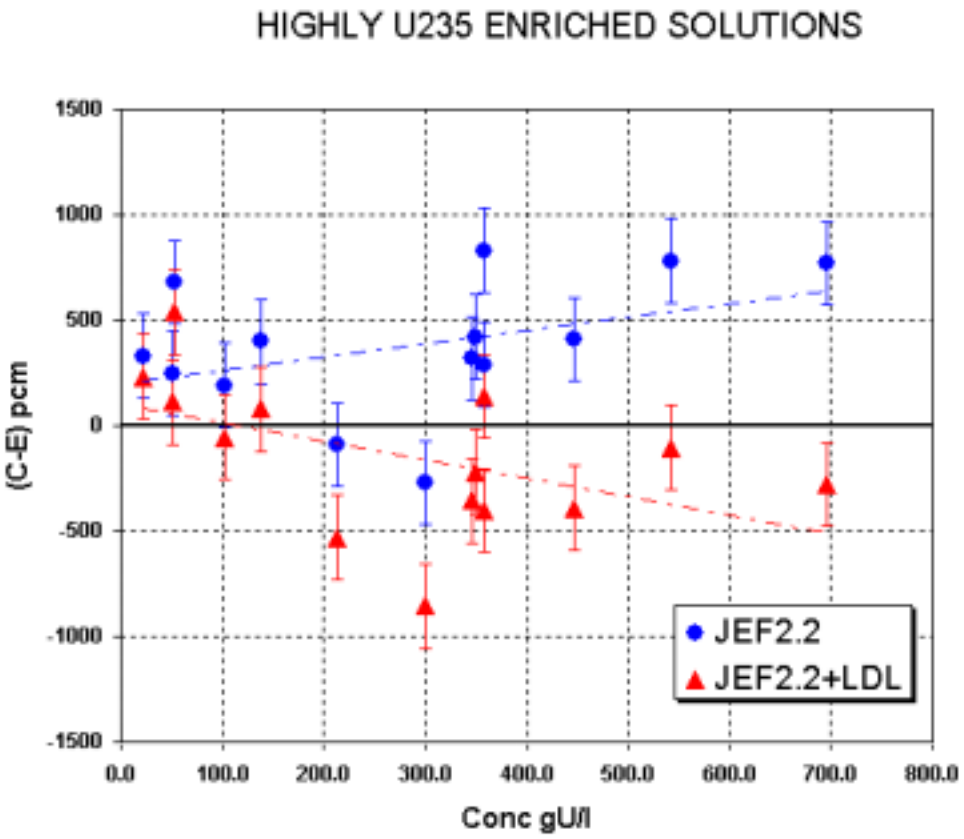

Figure 1: (C-E) in pcm for highly enriched uranium solution experiments using JEF2.2 anf LDWL evaluations.

We have also included in this analysis two HEU-SOL-THERM experiments with deuterium moderator. These systems have a very small q_{inf} and a large LDWL impact. The analysis was performed with CRISTAL/APOLLO2 SN calculations [12])

Experiment	Conc	qinf	σ	(C-E) pcm APOLLO2 SN U5 JEF2.2	(C-E) pcm APOLLO2 SN U5 LDWL
HST-004-1	679	0.1270	650	+1628	-18
HST-004-2	443	0.2280	710	+1058	-470

Table 13: (C-E) in pcm for HEU-SOL-THERM experiments with deuterium moderator.

We can conclude from this analysis that for high enriched uranium systems **LDL evaluation greatly improves results, the overprediction of reactivity observed with JEF2.2 cross-sections is corrected**

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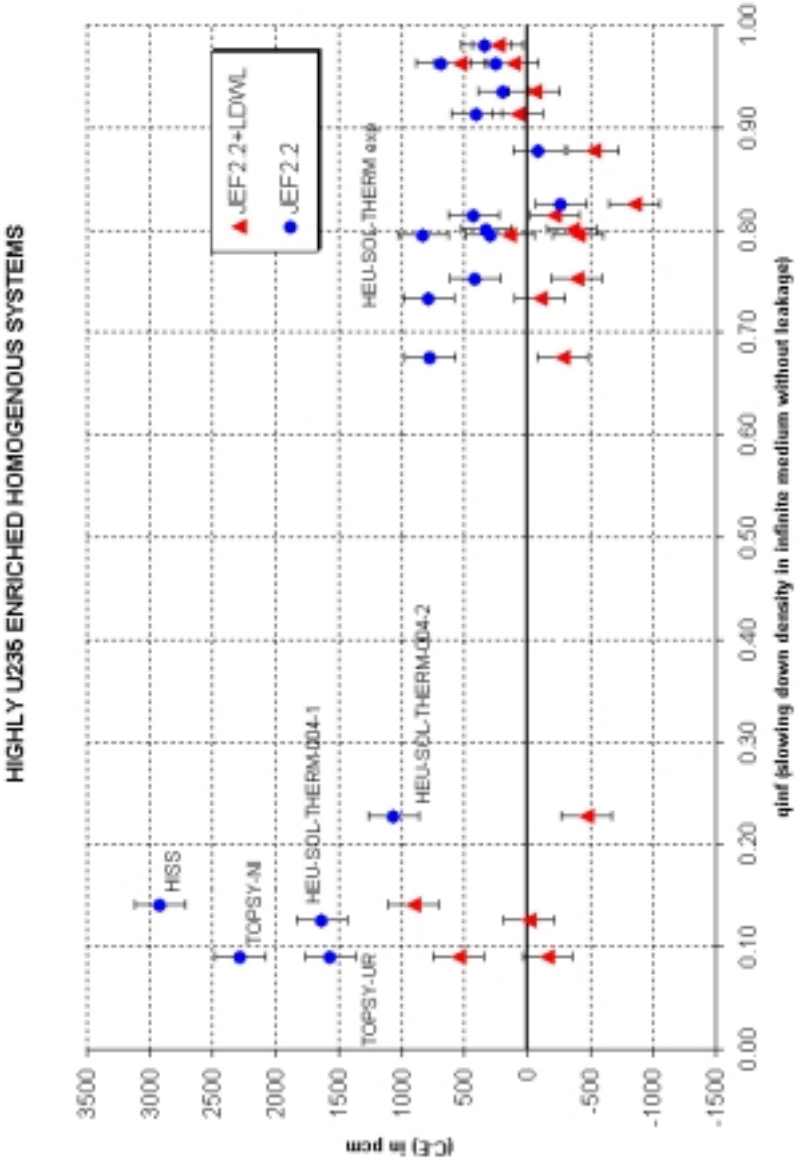
HIGHLY U235 ENRICHED HOMOGENOUS SYSTEMS
JEF2.2+LDWL
JEF2.2
HSS
TOPSY-NI
HEU-SOL-THERM-004-1
TOPSY-UR
HEU-SOL-THERM-004-2
HEU-SOL-THERM exp
(CE) in pcm
qinf (slowing down density in infinite medium without leakage)

5.3 Analysis of U_{235} sample reactivity worth measurements in Minerve

In the framework of the burnup-credit programme, the experimental reactor MINERVE [7], located at Cadarache is used to qualify actinides and fission-product cross-sections. Reactivity worth measurements are based on specific samples oscillations through the MINERVE core. A rotating control rod is automatically operated to maintain criticality level, the rotation amplitude (KUP units) is linear with the sample reactivity (pcm units).

Five Borated UO2 samples with increasing B_{nat} content supply the ρ_B reactivity worth and can be used to calibrate the measured reactivity worth. Moreover, several UO2 samples with increasing U235 enrichments (in the range 0.2%-5%) are used to provide the U235 reactivity worth ρ_{U235}. This analysis provides the calculation-experiment discrepancy on $\frac{\rho_{U235}}{\rho_B}$.

Three experiments has been investigated : R1-UO2 (in 1993 and 1995) which provides a PWR UOX spectrum and R1-MOX (closer to MOX spectrum where the LDWL effect is larger). Preliminary results are given in table 14. The experimental accuracy takes account on experimental statistical error, calibration process, uncertainty on the U235 composition and B_{10}(n,α) cross-section uncertainty.

	R1-UO2 1993	R1-UO2 1995	R1-MOX
ρ_{U235}/ρ_B JEF2.2	+0.8% ± 2%	+1.1% ± 2%	+4.7% ± 3%
ρ_{U235}/ρ_B LDWL	-1.4% ± 2%	-1.1% ± 2%	+1.8% ± 3%

Table 14: Calculation-experiment discrepancies on $\frac{\rho_{U235}}{\rho_B}$ in Minerve experiments.

In the two R1-UO2 experiments, considering the experimental accuracy, it is difficult to extract a clear tendency. In R1-MOX, the APOLLO2/CEA93 analysis indicates an overestimation of U235 reactivity worth using the JEF2.2 evaluation. this C/E disagreement is cancelled by the use of LDWL cross-section.
The new OSMOSE programme devoted to the qualification of actinides cross-sections is expected to start this year and should provide more accurate measurements.

6 η shape : Temperature effects

Calculations of reactivity temperature coefficient (RTC) in lattices has given significant information about the thermal cross-section curve shapes for U-235 and U-238 [15]. In particular, the analysis of thermal spectrum shift with temperature has led to a relevant η^{U235} adjustment in agreement with the differential experiment.

The CREOLE experimental program was conceived to supply accurate RTC differential information in the whole temperature range of interest in a large PWR (from room temperature up to 300C). The measurements were performed in the EOLE facility in 1978-1979.

In the CREOLE experiment, the impact of LDWL evaluation on RTC was evaluated with APOLLO2 core calculations in the UO2 clean lattice [14]. The temperature dependence of the calculation error on the RTC associated with JEF2.2 and (JEF2.2+LDWL) library is presented in Fig 2. As seen from this figure, there is no significant discrepancy between the two calculations. Hence, we can conclude that the **impact of LDWL U235 cross-section compared to JEF2 evaluation on the reactivity temperature coefficient is not important.**

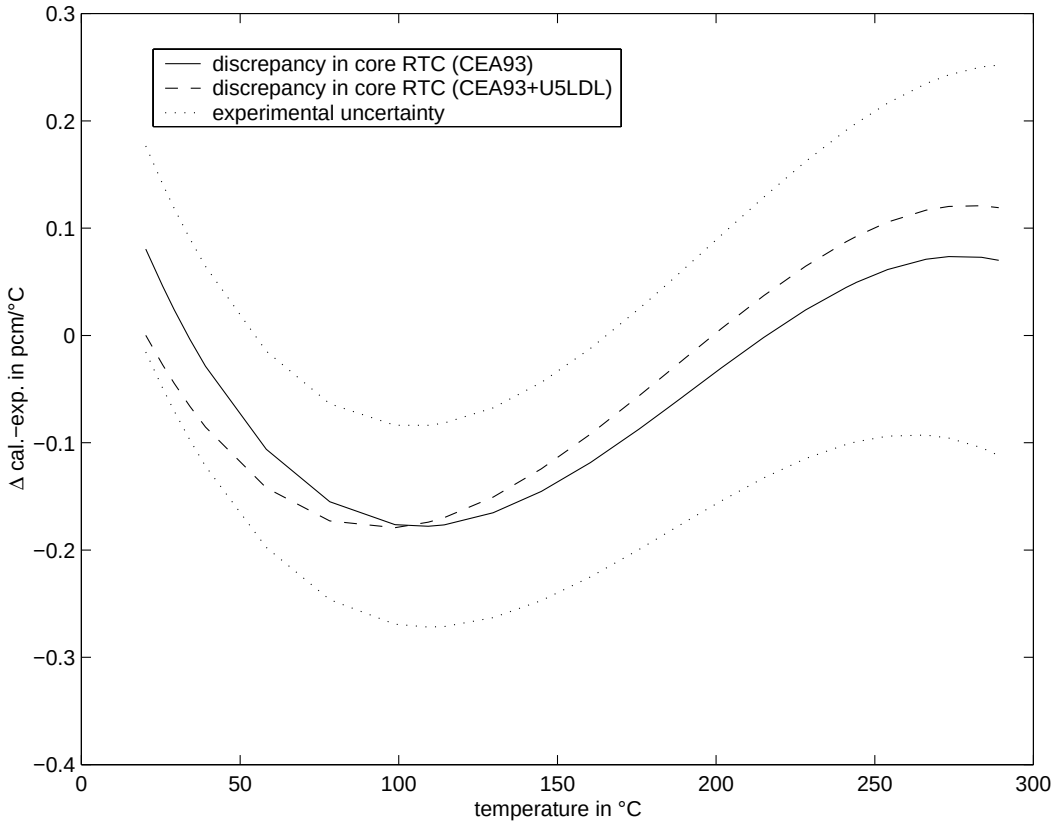

Figure 2: (C-E)/E in% for reactivity coefficient temperature in CREOLE experiment using JEF2.2 anf LDWL evaluations.

Furthermore, the good agreement observed in the temperature range below 100C provides a validation of η_{U235} shape in JEF2.2 and LDWL evaluation.

7 Conclusion

The french integral experiments (mainly spent fuel PIE) have pointed out that the increased $< \Gamma_\gamma >$ value of the LDWL evaluation is well suited to reproduce the U235 resonant capture rate. Concerning fission and total aborption, the adopted LDWL evaluation is consistent with integral measurements.
The $\eta_{U235} = \frac{\nu\sigma_f}{\sigma_a}$ value is deduced, on the one hand from U_{235} homogeneous system (highly enriched uranium solutions and homogeneous experiments) and on the other hand from U_{235} reactivity worth measurements in MINERVE. This integral information

- demonstrates that the thermal η_{U235} value, and consequently the thermal $\nu_{U235} = 2.437$ value is correct.
- points out that the average η_{LDWL} in U235 resolved resonances region is satisfactory (a slight trend to keff underestimation is observed which could be corrected by a slight modification of ν_{U235} in the resonance range). On the contrary, the JEF2 evaluation infers a keff overestimation in the considered intermediate spectrum systems.

The french UOX experiments (buckling and critical size) using low enriched fuel show a slight reactivity over-estimation in the undermoderated lattices. This keff overestimation in JEF2 calculations is cancelled using the U235 LDWL evaluation with a trend to keff underprediction. This slight underestimation could be mainly linked to a U_{238} resonance integral overestimation.

In summary, this qualification study allows us to recommend to maintain LDWL U235 evaluation in the final JEFF3.0 library

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