EXPERIMENTAL VALIDATION OF U_{238} CROSS-SECTIONS RECOMMENDATIONS FOR JEFF3

JEFF Meeting

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1 Background

The new U_{235} evaluation proposed by Leal, Derrien, Wright and Larson (LDWL) [1] has been adopted in the JEFF3.0 file and in the Release 5 of ENDF/B-VI. An extensive validation work have demonstrated that this new evaluation significantly improves many aspects of the neutronic calculations and reduces the discrepancies observed with JEF2.2 [2] :

- The over-estimation of U236 build-up observed with JEF2.2 in the P.I.E of French PWR assemblies (UOX and MOX fuel cuts) is strongly reduced with the new U235 evaluation.
- The strong reactivity over-estimation in highly enriched uranium homogeneous systems is well corrected with LDWL.

However, the Keff prediction for Light Water Reactors and thermalized UOX lattices seems to be less satisfactory with JEF2.2 plus the U235 LDWL evaluation. A trend to under-prediction is demonstrated, requiring to improve other nuclear data involved in the UOX lattices calculation such as U238, H2O or oxygen cross-sections.
A Web forum was created at the NEA (*http ://www.nea.fr/lists/ueval.html*) to solve the low-reactivity problem and to propose better nuclear data.
This document presents the experimental validation of U238 reaction rates through the french integral experiments particularly, irradiated fuel analysis and spectral indices. In this study, a trend to a slight over-estimation of U238 capture rate is observed. Recommendations are given to reduce this U238 capture rate over-estimation through specific nuclear data modifications. This modifications are in agreement with differential measurements results and will improve Pu239 build-up, Np237 and Pu238 formation in reactor [3] as well as UOX reactivity prediction.

2 Calculation methods

Deterministic calculations were performed with the French multigroup transport code APOLLO2 [4]. 2D lattice and assembly calculational schemes were defined to avoid significant biases. A lot of attention was paid to calculate accurately the U238 resonant capture rate :

- 172 energy group structure XMAS (CEA93 library based on JEF2.2) ;
- Accurate space dependent self-shielding formalism based on the background matrix theory (4 rings per fuel pins in order to take account accurately for the "rim effect") ;
- The solid state effect in the Doppler broadening of the U238 resonances in UO_2 lattices has been studied in detail. To take account of this effect in the APOLLO2 code (only gas model for doppler broadening), the fuel temperature is adjusted to the following effective temperature T_{eff} which preserves the U238 reaction rate [6] :

$$T_{eff} = T_{fuel} + 8.6 + \frac{3100}{T_{fuel} + 273}$$

  where T_{fuel} is the real fuel temperature in Celsius. This formula has been derived from resonant reaction rate calculations performed on the actual cross-section shape measured on UO_2 samples at GELINA facility [5] ;
- Collision probability methods (Pij) for the flux calculation. Calculations of Pij can be performed in the 2D exact geometry. Several module using interface currents methods have also been introduced allowing the use of the UP1 approximation (interface angular fluxes are linearly anisotropic).

To check these models, the integral experiments were also analysed through reference calculations using the TRIPOLI4 continuous-energy Monte Carlo code [7]. The probability table method is used to handle the U238 self-shielding in the unresolved resonance range.

3 Trends given by integral information

3.1 Spectral index

The modified Conversion Ratio C^{U238}/F^{tot} or the spectral index $\sigma_c^{U238}/\sigma_f^{U235}$ were measured in the various experiments performed in the EOLE facility at CEA Cadarache. Two important experimental programs were chosen. The program called MISTRAL [8] (MOX : Investigation of Systems which are Technically Relevant of Advanced Light water reactors), was devoted to advanced LWR loaded with 100% of MOX fuel. The program called ERASME [9] was performed in 1985-1987 to study Light Water High Conversion Reactors loaded with mixed oxide fuel.

Four experimental configurations were investigated :

- **MISTRAL-1 :** Regular enriched UO_2 lattice (3.7% U235 enrichment) involving about 750 fuel pins in a square pitch of 1.32 cm (moderation ratio equal to 1.76, H/HM=5.1). The criticality is achieved by adjusting the soluble boron concentration.
- **MISTRAL-2 :** Regular 100% MOX lattice (7% Pu content) involving about 1600 fuel pins in a square pitch of 1.32 cm. Contrary to the previous experiment, no boron was added to the moderator. The criticality was obtained by adjustment of the radial critical size.
- **ERASME-S :** Tight hexagonal MOX lattice (11% Pu content, about 1500 MOX fuel pins) with a moderation ratio of 0.5
- **ERASME-R :** Realistic HCR hexagonal MOX lattice (11% Pu enrichment, about 1200 MOX fuel pins), with a moderation ratio equal to 0.9

Experiment name	Spectral index	C/E TRIPOLI4	exp. uncert.
MISTRAL1 UOX 3.7%	C^{U238}/F^{tot}	+2.2 %	± 2.0 %
MISTRAL2 MOX 7.0%	C^{U238}/F^{tot}	+2.3 %	± 1.5 %
ERASME-S	$\sigma_c^{U238}/\sigma_f^{U235}$	+1.6 %	± 2.3 %
ERASME-R	$\sigma_c^{U238}/\sigma_f^{U235}$	-0.2 %	± 2.1 %

TAB. 1: C/E in % on spectral index

A previous study of ERASME experiments (JEFDOC-428) gave an higher U238 capture rate overestimation (+ 4.1% for ERASME/S and +2.1% for ERASME/L). The measurements were interpreted with the deterministic code APOLLO2 using rough calculation route. The over-estimation is explained by the multicell calculation scheme using simple isotropic assumption for the interface angular fluxes. The present ERASME experiments calculations with both APOLLO2 using current recommended route and monte-carlo code TRIPOLI4 point out a slighter over-estimation for ERASME experiments.

From these independent U_{238} capture rate measurements, we can conclude that the average overestimation is :

$$(C-E)/E = +1.5\% \pm 1.0\%(1\sigma) \quad (1)$$

3.2 Irradiated fuel analysis

Analysis of the Pu239 build-up from PWR spent fuel experiments provides a direct validation of U238 capture rate in the large resonances and in the thermal range (20% of the U238 capture rate). Three P.I.E experiments have been investigated : 17*17 assemblies irradiated in BUGEY3, FESSENHEIM2 and GRAVELINES commercial reactors. In these experiments, removable pins are extracted from two assemblies at each inter-cycle shut-down, up to 5 irradiation cycles. The chemical assays are carried out on several rod cuts, at various heights in order to stress the axial variation effect of the water temperature.

NAME	cycle	U_{235} enrichment	maximum burn-up
Bugey3	3	3.1%	38 GWd/t
Fessenheim	5	3.1%	58 GWd/t
Gravelines	5	4.5%	60 GWd/t

TAB. 2: Characteristics of UOX spent fuel experiments

An accurate modelling for depletion calculations has been defined [10]. The influence of sensitive physical parameters has been studied in detail such as, 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.
At every burn-up step, the APOLLO2 flux calculations were validated against reference continuous-energy TRIPOLI4 calculations : the U238 capture rate is calculated in the deterministic APOLLO2 route with an accuracy of $-0.1\% \pm 0.1\%$ 1σ (TRIPOLI4 statistical uncertainty) and the Pu239 absorption rate is calculated with a negligible bias $+0.2\% \pm 0.1\%$ at any burn-up.
Burnup of PIE 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, experimental uncertainties have been evaluated from a detailed sensitivity study.

Experiment	20 GWj/t	40 GWj/t	50 GWj/t	60 GWj/t
Bugey	0.6	2.1		
Fessenheim			0.5	2.6
Gravelines	-0.7	0.4	1.0	1.4
exp. uncert. 1σ	$\pm 1.0\%$	$\pm 1.1\%$	$\pm 1.2\%$	$\pm 1.3\%$

TAB. 3: C/E-1 in % on $\frac{PU_{239}}{U_{238}}$ using JEF2.2 cross-sections for UOX spent-fuel experiments [3].

The analysis results of the various $\frac{PU_{239}}{U_{238}}$ chemical assays show that the U238 capture rate is overestimated in JEF2.2 based calculations by $+1\% \pm 1\%(1\sigma)$.
This trend is confirmed by the PIE experiments performed in MOX fuels : chemicals assays in the central zone (5-6% Pu content) of a MOX assembly irradiated in the SLB1 PWR reactor have shown a Pu239 buid-up overestimation reaching $+3\% \pm 2\%$ after 3 irradiation cycles (BU = 45 GWd/t) [11].

3.3 UOX system reactivity

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 Monte-carlo code 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 programme. Calculations were carried out both with APOLLO2 Sn and TRIPOLI4. To enlarge the experimental validation of well thermalised UOX lattices, the buckling measurements in various EOLE experiments (CRISTO1, CRISTO2) are also reported in Table 4.

A 3D monte-carlo calculation (with TRIPOLI4 code) of the N4 PWR (CHOOZ-B1) start-up configuration is also analysed [12]. 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 programme 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. The results shown in Table 4 represent the C/E value averaged over the various configurations.

To extend the experimental validation of the reactivity in LWR lattices, relevant LEU benchmarks from the ICSBEP handbook have been analysed. The TRIPOLI4-JEF2.2 results from HiC (High Conversion tight lattices), KRITZ2 :1 and VVER experiments are summarised in Table 4.

Experiment name	Lattice Pitch (cm)	V_{H2O}/V_{UO2}	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	569	200	+347(70)	-113
N4	1.26	1.4	1214	300	+397(15)	-188
MISTRAL1	1.32	1.75	294	200	+147(80)	-264
CAMELEON	1.26	1.80	610	300	+801	+378
VALDUC1	1.26	1.82	0	300	-326(50)	-619
VALDUC2	1.60	3.81	0	300	-143(50)	-236
VALDUC3	2.10	7.58	0	300	-379(50)	-384
CRISTO2	1.58	3.56	832	300	-161	-351
CRISTO2L	1.71	4.40	672	300	-4	-226
CRISTO1	1.86	5.46	750	300	+217	+94
ZPR-HiC10	1.24	0.96	0	400	-180(70)	-572
ZPR-HiC13	1.16	0.60	0	600	-310(70)	-980
VVER11.0	1.10	0.89	0	370	-50(40)	-550
VVER12.7	1.27	1.66	0	300	+250(50)	-60
KRITZ2 :1	1.48	1.17	218	380	-460(50)	-730
KRITZ2 :13	1.63	1.70	452	250	-310(50)	-470

TAB. 4: C/E discrepancies on Keff for french UOX regular cores and LEU benchmarks

From the results presented in table 4, the following conclusions can be drawn :

- In the Eole regular UOX cores UH1.2, MISTRAL1 and CAMELEON, the reactivity is well predicted using the U235 LDWL evaluation : -100 pcm ± 150 pcm (on the other hand the previous calculations based on JEF2.2 gave a Keff overestimation by +330 pcm).
- On the contrary, in VALDUC, the Keff calculations performed with TRIPOLI4/JEF2.2 are in good agreement with the experimental results. When the new U235 evaluation is used, the multiplication factors are underestimated by about -500 pcm ± 300 pcm for typical PWR spectra.

– Concerning the PWR-type international ICSBEP benchmark experiments (ZPR-HiC, VVER, KRITZ2), we notice a good reactivity prediction by TRIPOLI4/JEF2.2 : -150 pcm ± 150 pcm. The use of LDWL evaluation for U235 cross-section raises a clear underestimation of the multiplication factor of these undermoderated LWR small cores : -420 pcm ± 200 pcm.

To conclude, the analysis of the LWR UOX experiments with JEF2 shows 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 underestimation amounts to -250 pcm ± 110 pcm (average C/E values between EOLE results and other critical experiments)

3.4 Conclusions from integral experiments

The LWR mock-up experiments have pointed out that the JEF3.T evaluations (U238 from JEF2.2 and LDWL U235 evaluation) induce an underestimation by $-250\ pcm \pm 110\ pcm\ (1\sigma)$ of these UOX lattices From the irradiated fuel PIE experiments and the direct U238 capture measurements, we can conclude that the U238 capture rate is slightly over-estimated in UOX and MOX lattices : $1.0 \pm 0.7\%\ (1\sigma)$

Thus, the reduction of the U238 resonance capture should be the main objective in nuclear data analysis : this reduction will also cancel the current disagreement in Keff prediction for LWR UOX lattices.

4 Reduction of U238 capture rate through nuclear data modification

4.1 Resonance parameters

The low energy part of the U238 evaluations (below 10 keV) is identical for JEF2.2, ENDFB6 and JENDL3.2 library. The evaluation of the resonance region was revised by the NEANDC task force [13]. In BROND2.2, the U238 evaluation in the resolved resonance range is different from JEF2.2. The comparison between JEF2.2 and BROND2.2 resonance parameters for the first large resonances is presented in Table 5.

JEF2.2			BROND2.2		
E_0 eV	Γ_n meV	Γ_g meV	E_0 eV	Γ_n meV	Γ_g meV
6.674	1.493	23.00	6.670	1.500	23.00
20.87	10.26	22.91	21.00	9.890	22.97
36.68	34.13	22.89	36.70	33.30	22.55
66.03	24.60	23.36	66.20	24.30	24.20
80.75	1.865	23.00	81.00	2.000	21.10
102.6	71.70	23.42	102.4	71.30	25.72
116.9	25.49	22.99	116.9	28.00	21.40

TAB. 5: U238 resonance parameters from JEF2.2 and BROND2.2

In order to have the effect of these parameters on the U238 reaction rate we have calculated for each resonance the effective resonance integral using very simple assumption (T = 0K, Single Level Breit Wigner formalism, Wide Resonance assumption, dilution $\sigma_d = 50\ b$).

$$I_{WR} = \frac{\pi \sigma_m \Gamma_\gamma}{2E_0} \sqrt{\frac{\sigma_d}{\sigma_d + \sigma_m \Gamma_\gamma / \Gamma}} \tag{2}$$

with σ_m the maximum cross-section value $\sigma_m = 4\pi\lambda^2 g \Gamma_n \Gamma_\gamma / \Gamma^2$.
From this crude resonance integral model, it can be shown that the BROND2.2 resonance parameters for the 20.9 eV and 36.7 eV resonances lead to a significant reduction of the effective integral (-2.0 % for 20.8 eV resonance and -1.7 % for 36.7 eV) in the range of LWR lattices.
An important issue concerning these evaluations is the assessment of the resonance parameters uncertainties. Table 6 shows the uncertainties quoted in the NEANDC report and in the BNL-325. The NEANDC uncertainty assessment do not account for sytematic errors such as crystalline binding effects. These effects are not well reproduced within the Lamb assumption for this low-energy resonances [6] in the code used to extract R-matrix nuclear parameters such as SAMMY or REFIT. If we use the more realistic BNL-325 uncertainties, the JEF2.2 and BROND2.2 resonance parameters are consistent. Therefore we propose to adopt in JEFF3.0 the Russian evaluation for the large resonances (the second and the third one).

	NEANDC		BNL-325	
E_0 eV	Γ_n meV	Γ_g meV	Γ_n meV	Γ_g meV
6.674	0.0023	0.042	0.02	0.3
20.87	0.0093	0.040	0.2	0.8
36.68	0.0230	0.048	0.2	0.3

TAB. 6: U238 resonance parameter uncertainties quoted in NEANDC report and in BNL-325

4.2 Thermal capture cross-section

In the JEF2.2 evaluation, the thermal capture cross-section is set to 2.717 barns. This value is higher than the recommended value of the BNL-325 which is equal to 2.680 ± 0.019 b. Therefore, it was suggested to decrease by 0.5% the thermal value.
A sensitivity study has been performed to assess the influence of this modification on reactivity. The calculations are performed on the cell geometry of the UH1.2 configuration. The UH1.2 experiment was performed in the EOLE facility located at CEA Cadarache. It is a regular enriched UO_2 core (3.7 wt% U_{235}) involving 1400 fuel pins in a square pitch of 1.26 cm (moderation ratio equal to 1.27).

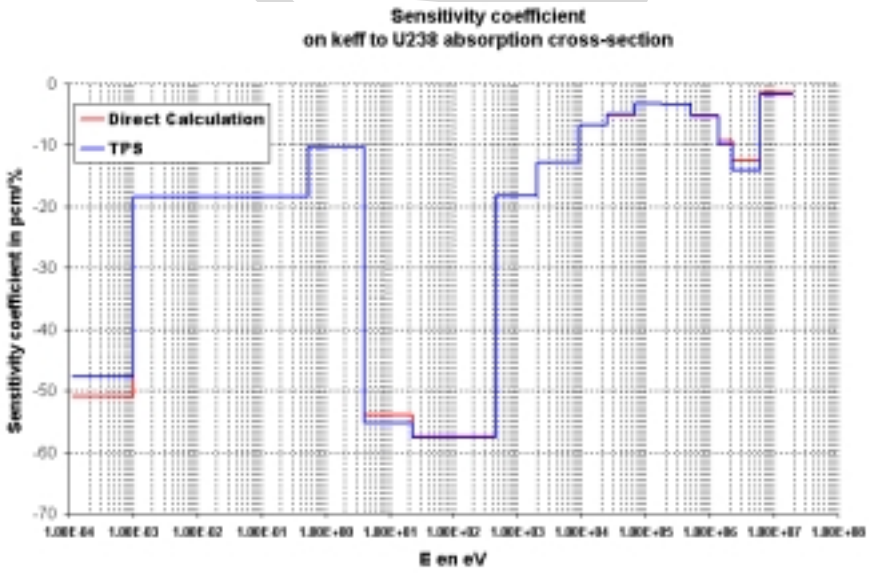

FIG. 1: Group integrated sensitivity of Keff to U238 cross-section in the JEF 15 energy-group structure for the UH1.2 configuration

The sensitivity profile plotted in Figure 1 shows that a reduction by 0.5% of the thermal value lead to an increase of reactivity on the UH1.2 configuration by about 35 pcm. In well thermalized systems with lower U235 enrichment encountered in critical experiments, the modification of the capture thermal value could have a stronger effect (up to 100 pcm).

4.3 U_{238} Inelastic data

In previous studies, it was suggested to modify inelastic data of U238 (inelastic cross-section and secondary neutron emission spectra for the discrete level and the continuum). The inelastic cross-section are not the same in the different libraries, as shown in Figure 2. Nevertheless the cross-section values proposed by the different evaluations are in agreement within 10% below 4 MeV, energy range which is relevant for fission reactors.
The impact of inelastic data modification on U238 capture rate is negligible in a LWR lattices due to the small changes of the neutron slowing-down density below 10 keV. Furthermore, inelastic data modification induces a small inpact on reactivity prediction of large PWRs and LWR mock-ups (the migration area effect will affect only small-size critical experiments such as VALDUC).
Figure 3 shows that the known underestimation by ENDF/B6.4 of the inelastic scattering above 1 MeV is already corrected in the JEF2.2 evaluation (in agreement with the JENDL3.2 evaluation).

Nevertheless, in order to put in JEF2.2 the most reliable nuclear data using improved nuclear model, the recent evaluation performed by Maslov et al. and adopted in the JENDL3.3 library could be proposed for JEFF3.0, provided that integral benchmarking on FBR spectra gives satisfactory results.

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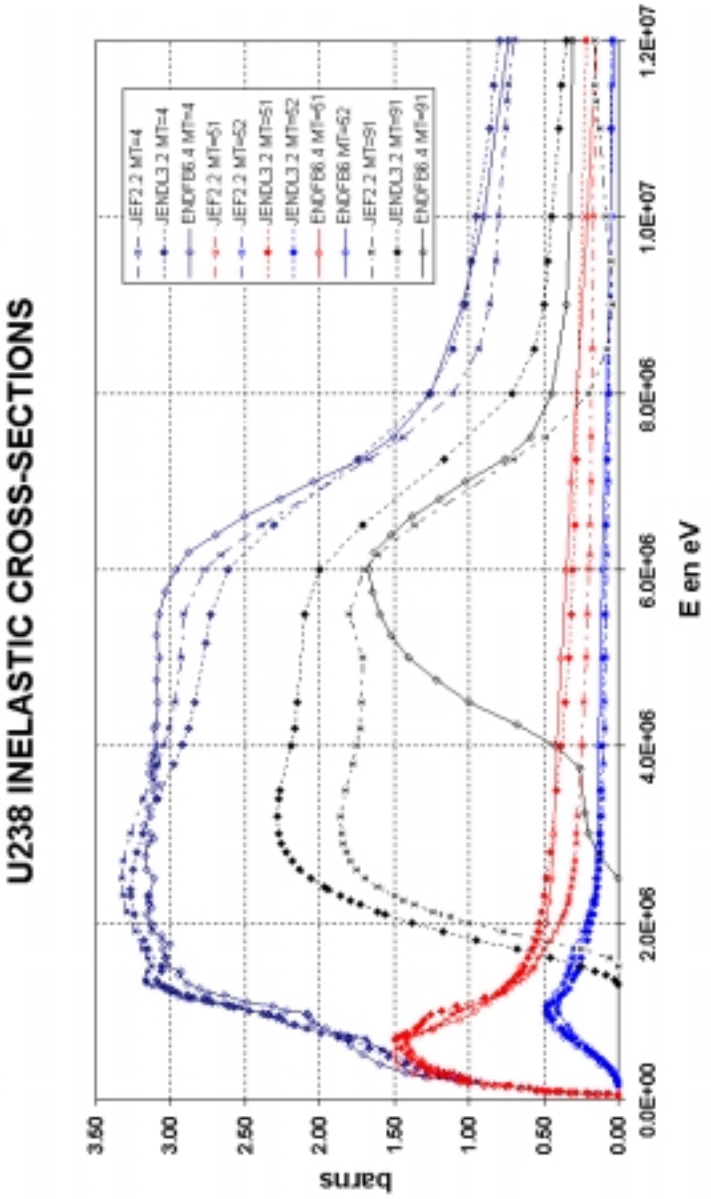

FIG. 2: Inelastic cross-section from the different evaluations

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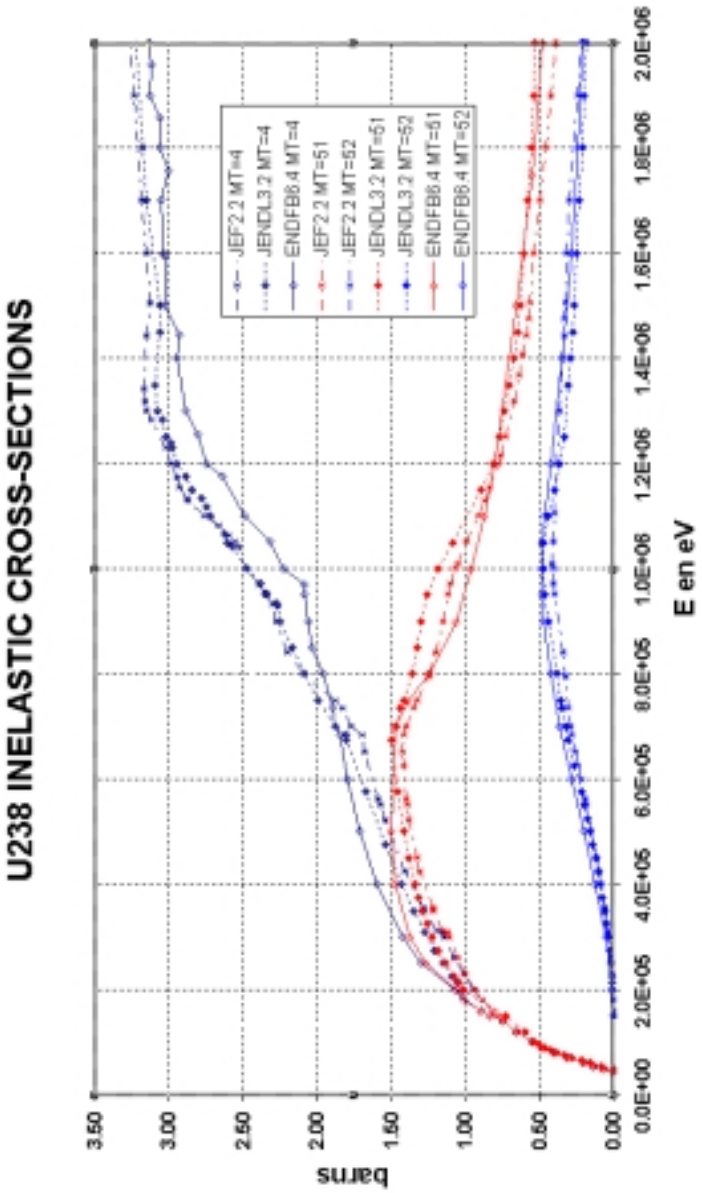

FIG. 3: Inelastic cross-section from the different evaluations

4.4 H2O elastic scattering cross-section

H2O elastic scattering cross-section can significantly influence the U238 capture rate in a water moderated reactor. The increase of this cross-section will affect the neutron slowing down and will decrease the U238 resonant capture rate.
A sensitivity study on the UH1.2 experimental configuration shows that in the 4 eV - 25 keV energy range, where the H(n,n) cross-section is constant, the increase of this scattering cross-section by an amount of 1%, decreases U238 capture rate by about 0.6% (see fig 4). Concerning the multiplication factor, those 1% modification would increase reactivity by about 230 pcm in the UH1.2 configuration. As Hydrogen Scattering cross-section is a standard, known probably within 0.5% accuracy. We can conclude that hydrogen scattering is not the suited parameter to modify U238 capture rate prediction.

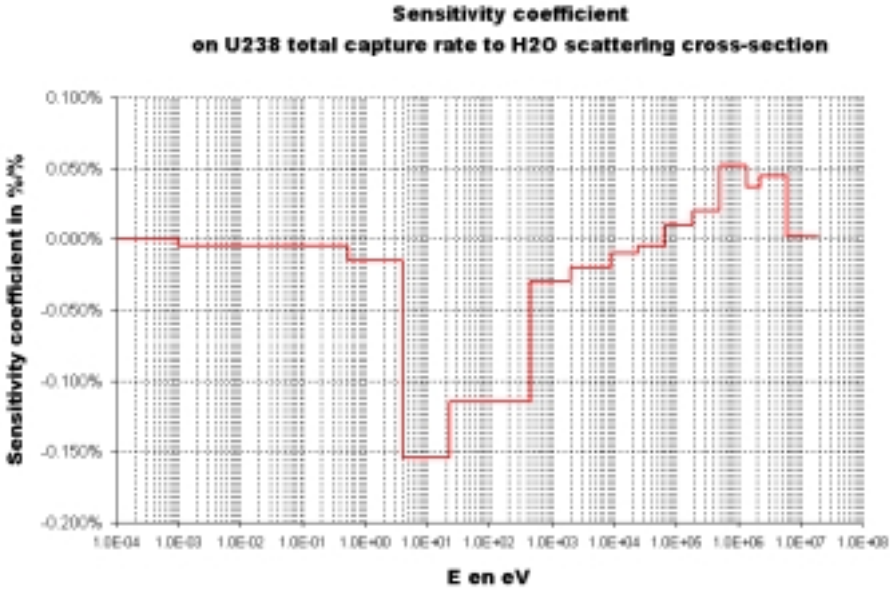

FIG. 4: Group-integrated Sensitivity of U238 capture rate to H2O scattering cross-section in the 15 energy group scheme for the UH1.2 configuration

4.5 Oxygen data

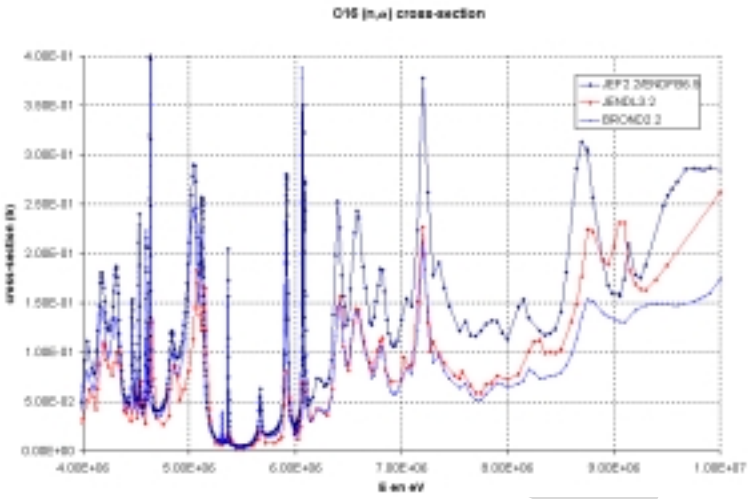

FIG. 5: (n,α) O16 cross-section in the different evaluations

In agreement with the remarks of C. Lubitz and H. Huria [14], Figure 5 and Table 7 point out that the JEF2 (n,α) cross-section is significantly higher than JENDL3.2 and BROND2.2 :

Energy range	JEF2/ENDFB6	JENDL3.2
3.7 MeV - 6 MeV	0.0712 b	0.0435 b
6 MeV - 10 MeV	0.156 b	0.101 b

TAB. 7: O16 (n,α) cross-section (average value)

Hence, the reduction of the (n, α) cross-section in the future JEFF3.0 evaluation (JENDL3.2 file could be used) would increase the LWR-UOX reactivity by about 100 pcm.

5 U_{238} fission cross-section

The spectum index $\sigma_f^{U238}/\sigma_f^{U235}$ was measured in EOLE for two 100% MOX LWR regular cores : the MISTRAL2 and ERASME/L experiments. The analysis was performed with APOLLO2/CEA93 and confirmed by TRIPOLI4 calculations. These results demonstrate that the current U_{238} fission cross-section in JEF2.2 is satisfactory.

Experiment name	Spectral index	C/E APOLLO2	exp. uncert.
MISTRAL2 MOX 7.0%	$\sigma_f^{U238}/\sigma_f^{U235}$	-2 %	$\pm$ 5 %
ERASME/L MOX 11.0%	$\sigma_f^{U238}/\sigma_f^{U235}$	+6 %	$\pm$ 3 %

TAB. 8: C/E in % on $\sigma_f^{U238}/\sigma_f^{U235}$ spectral index

6 U_{238} (n,2n) cross-section

The U_{238} (n,2n) cross-section is important in the depletion calculation because it influences greatly the formation of Np237 and Pu238 in LWR.

Np237 formation : Table 9 shows that in French PWR assemblies, the Np237 build-up is underestimated. The formation of Np237 in UOX fuel is mainly governed by two mecanisms :

- the U_{235} capture : $U235 \xrightarrow{n,\gamma} U236 \xrightarrow{n,\gamma} U237 \xrightarrow{\beta^-} Np237$
- the U_{238} (n,2n) reaction : $U238 \xrightarrow{n,2n} U237 \xrightarrow{\beta^-} Np237$

The new U_{235} evaluation has led to a reduction of this discrepancy, but there is still an underestimation which can be explained by the underestimation of (n,2n) U_{238} cross-section.

Experiment	20 GWj/t	40 GWj/t	50 GWj/t	60 GWj/t
e=3.1%	-9.1	-1.9	-4.6	-0.6
e=4.5%	-2.3	-3.7	-5.3	-6.5
exp. uncert. 1σ	$\pm$3.4%	$\pm$3.4%	$\pm$3.4%	$\pm$3.2%

TAB. 9: C/E-1 in % on $\frac{Np_{237}}{U_{238}}$ using JEF2.2 cross-sections for UOX spent-fuel experiments.

Pu238 formation : In a UOX spectrum, the Pu238 comes from three main processes :

- the U_{235} capture : $U235 \xrightarrow{n,\gamma} U236 \xrightarrow{n,\gamma} U237 \xrightarrow{\beta^-} Np237 \xrightarrow{n,\gamma} Np238 \xrightarrow{\beta^-} Pu238$
- the U_{238} (n,2n) reaction : $U238 \xrightarrow{n,2n} U237 \xrightarrow{\beta^-} Np237 \xrightarrow{n,\gamma} Np238 \xrightarrow{\beta^-} Pu238$
- the U_{238} (n,γ) through a complex chain of reactions can participate to the Pu238 formation (Cm242 decay)

At low burn-up, the U_{235} capture and U_{238} (n,2n) reaction contribute the most to the Pu238 build-up. The increase of the U_{235} capture in the resolved resonance range with the new LDWL evaluation improves the prediction but it does not correct entirely the discrepancies (the effect of the new evaluation is to reduce the $\frac{Np_{237}}{U_{238}}$ by 2-3% at low burn-up in a UOX spectrum).

Experiment	20 GWj/t	40 GWj/t	50 GWj/t	60 GWj/t
e=3.1%	-8.7	-5.3	-4.0	-4.7
e=4.5%	-12.2	-10.6	-10.2	-10.2
exp. uncert. 1σ	$\pm$4.0%	$\pm$3.9%	$\pm$3.8%	$\pm$3.7%

TAB. 10: C/E-1 in % on $\frac{PU_{238}}{U_{238}}$ using JEF2.2 cross-sections for UOX spent-fuel experiments.

Figure 6 summarised the comparison of U_{238} (n,2n) cross-section between JEF2.2, ENDFB6.4 and BROND2.2. (JEF2.2 and JENDL3.2 (n,2n) cross-section are the same). The JEF2.2 evaluation is significantly lower than the other evaluations. Moreover, the comparison with the differential experimental data shows that the JEF2.2 evaluation is mainly based on only one measurement [15]. The other U238 (n,2n) differential measurements are significantly higher and more in agreement with ENDFB6 or BROND2.2 evaluation.
Consequently, we propose to adopt the ENDFB6 evaluation for the U238 (n,2n) cross-section.

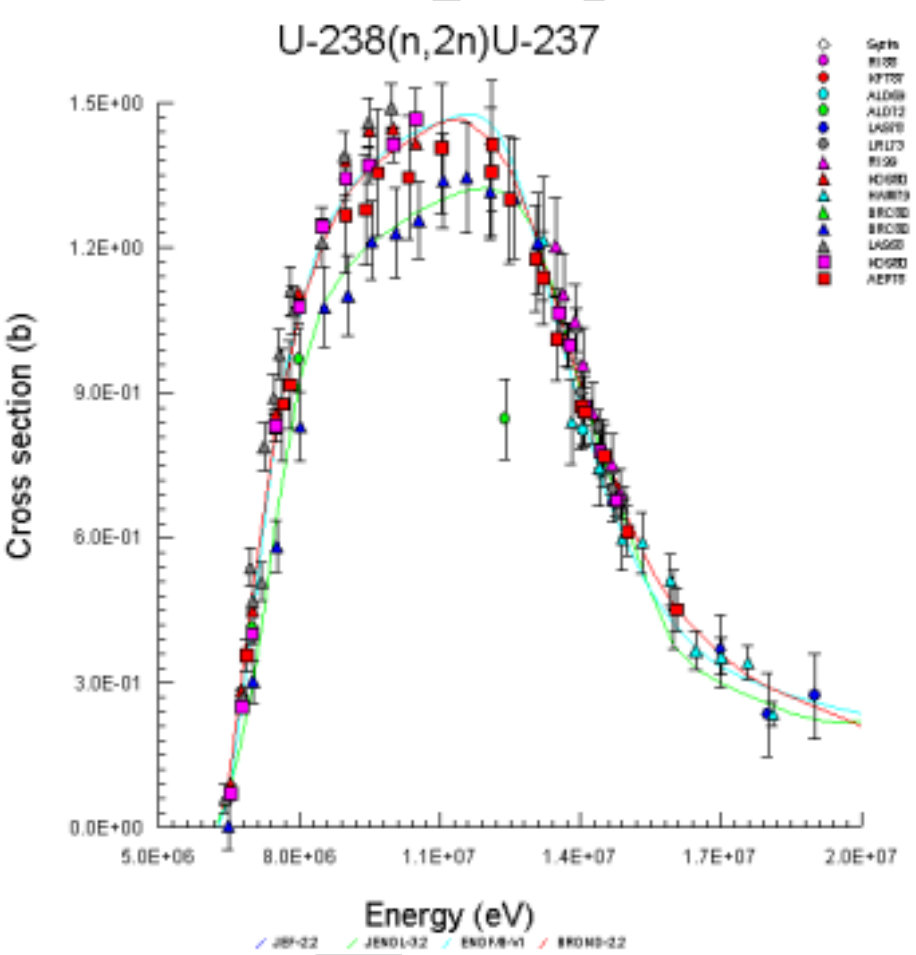

FIG. 6: (n,2n) U_{238} cross-section in the different evaluations and comparison with experimental data from EXFOR

7 Conclusions and recommendations

The analysis of French integral experiments using JEFF3.T has pointed out some improvements compared to the JEF2.2 calculations. However, it remains some C/E disagreements, compared to the target accuracy on PWR design parameters and fuel cycle requirements :

- the Keff value of LWR cores is underestimated by -250 pcm $\pm$ 110 pcm (1σ)
- the U238 capture rate and the Pu239 buid-up is overestimated by $1\% \pm 0.7\%(1\sigma)$.
- the Pu238 build-up is still underestimated by 7% during the first irradiation cycles.

The main potential contribution to these C/E disagreements is U238. We can conclude from this work that the current evaluation is satisfactory except :

- The resonant capture which must be decreased : we recommend to adopt the BROND2.2 resonance parameters for the large resonances
- The (n,2n) cross-section which is too low, we recommend to adopt the ENDFB6 values
- Furthermore, the current H1 evaluation can be maintained in JEFF3.0, contrarly to the O16 evaluation where the (n, α) cross-section must be strongly decreased.

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