*Chapter 10*

# DELAYED NEUTRON VALIDATION STUDIES

Measurements of the effective delayed neutron fraction, $\beta_{eff}$, have been analysed by E. Fort, *et al*. (JEF/DOC-820 [1]). A series of 21 measurements have been calculated. They were made in 18 cores. Two of these (MISTRAL and SHE-8) were $^{235}$U fuelled thermal reactor cores and the remainder were fast reactor cores (two being the hard spectrum Los Alamos criticals, the $^{235}$U fuelled GODIVA core and the $^{239}$Pu fuelled JEZEBEL core, which have spectra approaching that of a fission spectrum). Of the 16 fast reactor cores, seven are uranium fuelled, two are fuelled with plutonium and the remainder with plutonium/uranium (with a significant contribution to $\beta_{eff}$ from $^{238}$U in most cases). The relative contributions of the different isotopes of uranium and plutonium are described in the thesis presented to the University of Aix-Marseille I by Véronique Zammit-Averlant [2].

The measured values of $\beta_{eff}$ are not obtained directly but involve calculated factors. These depend on such parameters as the calculated fission rate distributions over the reactor which are applied to the fission rates measured at the centres of the cores. The factors have been recalculated using adjusted JEF-2.2 data (the ERALIB1 library in the ERANOS system), and this has resulted in small modifications to the measured values. The uncertainties have also been reassessed. The calculated corrections and the reassessment of uncertainties are described in JEF/DOC-820.

The revised measured values, E, and the percentage differences from the JEF-2.2 calculated values, (E-C)/C %, are presented in Table 1. These include estimates of the uncertainties in the calculation, which are in the range ±3% to ±4.6%. All of the differences between the measured and calculated values are within 1 s.d. (combined measurement and calculational s.d.s) and all but two are within 1 s.d. of the measurement uncertainties. The JEF-2.2 total delayed neutron data are therefore seen to be consistent with the $\beta_{eff}$ measurements. Furthermore these calculated values of $\beta_{eff}$ are meeting the required target accuracy of ±3%.

It will be recalled that the time dependent data included in the files for $^{235}$U and $^{239}$Pu (the six group decay constants and relative abundances) were incorporated in the files from different sources and the decay constants are not consistent with the relative abundances. New recommendations concerning the time dependent data are being made by Subgroup 6 of the NEA Working Party on International Evaluation Co-operation.

An adjustment study has been carried out by E. Fort, *et al*. (JEF/DOC-820, and see also Part III) The adjusted values of $\nu_d$ result in a small overall improvement in the agreement with the $\beta_{eff}$ measurements. Adjustments have been made to both the fast reactor spectrum and thermal reactor spectrum averaged values of $\nu_d$. However, the values and uncertainties are to some extent dependent on assumptions about the accuracy of the energy dependence of $\nu_d$ in JEF-2.2.

## REFERENCES


[1] E. Fort, V. Zammit-Averlant, M. Salvatores and A. Filip, "Recommended values of the Delayed Neutron Yield for U-235, U-238 and Pu-239", JEF/DOC-820.

[2] Véronique Zammit-Averlant, Thesis, University of Aix-Marseille I, November 1998.


**Table 10.1. Results of the JEF-2.2 calculations**

| Core | Fuel | Technique | E (in pcm) | (E-C)/C (%) |
|---|---|---|---|---|
| **Fast spectrum** | | | | |
| *MASURCA* | | | | |
| R2 | U | Cf source | 755.0 ± 3.1% | 1.86 ± 4.3% |
| R2 | U | Frequency | 727.6 ± 2.0% | -1.84 ± 3.6% |
| R2 | U | Rossi-alpha | 745.0 ± 1.6% | 0.51 ± 3.4% |
| ZONA2 | U/Pu | Cf source | 359.1 ± 3.1% | 2.98 ± 4.9% |
| ZONA2 | U/Pu | Frequency | 350.0 ± 2.1% | 0.39 ± 4.3% |
| *SNEAK* | | | | |
| 7A | U/Pu | Cf source | 395.0 ± 2.8% | 1.94 ± 4.8% |
| 7B | U/Pu | Cf source | 429.0 ± 2.8% | -1.98 ± 5.0% |
| 9C1 | U | Cf source | 748.0 ± 4.2% | -0.06 ± 5.2% |
| 9C2 | U/Pu | Cf source | 416.0 ± 4.6% | 4.23 ± 5.9% |
| *ZPR* | | | | |
| C-Ref | U/Pu | Covariances | 383.6 ± 2.2% | 0.72 ± 4.8% |
| PuCSS | Pu | Covariances | 223.4 ± 2.3% | 0.72 ± 4.6% |
| RSR | U/Pu | Covariances | 337.3 ± 2.2% | 2.65 ± 4.4% |
| U9 | U | Covariances | 731.4 ± 2.1% | 0.81 ± 4.5% |
| UFe-Ref | $^{235}U$ | Covariances | 670.8 ± 2.1% | -0.53 ± 3.8% |
| UFe-Leak | $^{235}U$ | Covariances | 675.8 ± 2.1% | 0.22 ± 3.8% |
| *FCA* | | | | |
| XIX-1 | U | Frequency | 743.4 ± 3.1% | -2.61 ± 3.8% |
| XIX-3 | U/Pu | Frequency | 252.3 ± 3.5% | -0.50 ± 4.2% |
| **Thermal spectrum** | | | | |
| MISTRAL | U | Frequency | 789.7 ± 1.5% | -2.29 ± 3.3% |
| SHE-8 | $^{235}U$ | Kinetic | 696.0 ± 4.6% | 0.26 ± 5.6% |
| *Los Alamos criticals* | | | | |
| GODIVA | $^{235}U$ | Kinetic | 603.1 ± 4.6% | 0.17 ± 5.8% |
| JEZEBEL | $^{239}Pu$ | Kinetic | 143.1 ± 4.6% | 2.95 ± 6.5% |