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ABSTRACT

The characteristics of any nuclear power plant should be determined according to well-defined calculation conditions and accuracies. The neutronic tools should go under a series of verification, validation and uncertainty quantification processes.

The proof of the best estimate values plus uncertainties of the neutronic tools should be achieved using measurements in critical facilities.

Concerning the sodium void reactivity worths in sodium fast reactor cores (SFR), measurements can take the usual form of successive substitutions of different materials (voided rodlets replacing Na rodlets for instance) and different sizes in order to vary the relative importance of central and leakage components.

The reactivity variations induced by these changes are compensated by a change in the position of the shim rod if the reactivity variation is smaller than half a β_{eff} and if larger by the addition or the removal of peripheral sub-assemblies.

The calibration of the shim rod is performed by measuring a fission chamber response when dropping a control rod and solving the Nordheim equation. This gives a S curve where the position of a control rod is associated to a reactivity expressed in \$. In this study, the uncertainties associated to this calibration are revisited, not only due to β_{eff} value (~2%) but also to decay time constants associated to each family (~6%), these being quite different from one nuclear data evaluation to another.

1 INTRODUCTION

In critical facilities, reactivity worths are usually measured by moving the position of the shim rod if the reactivity variation is smaller than half a β_{eff} and if larger by the addition or the removal of peripheral sub-assemblies.

The calibration of the shim rod is performed by measuring a fission chamber response when dropping a control rod and solving the Nordheim equation. This gives a S curve where the position of a control rod is associated to a reactivity expressed in \$. The purpose of this study is to revisit the uncertainties associated to this calibration, not only of the β_{eff} value but also of the decay time constants associated to each families, these being quite different from one nuclear data evaluation to another.

The work has been done on the ZONA2 core of the BERENICE experimental programme whose analyses are summarised in chapter 2. Incidentally, this core is also part of the CIRANO programme which had the purpose of studying Plutonium burning cores.

Using different sets of delayed neutron constants, KEEPIN, ENDF/B-VII.1 and JEFF3.1.1 the work conducted at first was to calculate kinetic values for the same ZONA2 core. This is presented in chapter 3.

With the use of results presented in chapters 2 and 3, it was possible to solve the Nordheim equation and derive reactivity as a function of time. The use of the different kinetic sets led to a significant change in the reactivity scale.

2 BERENICE EXPERIMENTAL ANALYSES

The effective delayed neutron fraction (β_{eff}) is an important neutronic characteristic which deserves attention. The BERENICE measurements campaign which took place in the experimental facility MASURCA at CEA Cadarache was devoted to the experimental validation of the βeff with the two cores R2 reference and R2 experimental using enriched uranium fuel and one core ZONA2 using MOX fuel [1]. The progresses in neutronic codes and nuclear data have enable to revisit these experiments with modern tools such as the Iterated Fission Probability method [3] implemented in the Monte Carlo code TRIPOLI4® [2]. This code gives credit to deterministic codes such as ERANOS [4] for calculating β_{eff}. However, the asset of TRIPOLI4® is the possibility to get a better representation of experimental cores. It is also important for calculating parameters entering in the determination of the experimental values.

For JEFF3.1.1 [5] , the revised C/E discrepancies are of 1.2% ± 3.6% for the ZONA2 core and -1.2% ± 3.7 % for the R2 experimental core when using the Noise measurement technique [1].

The nuclear data uncertainty propagation [6, 7] has been leading to a 2.6% uncertainty for U-Pu core and 2.8% for enriched uranium cores with main contributors being the delayed neutron fission yield and the fission cross section of U238 values consistent with the Noise Technique re-analyses [8, 9].

3 ZONA2 DELAYED NEUTRON CONSTANTS

The effective delayed neutron fraction (β_{eff}) has been calculated with the ERANOS code for the ZONA2 core using the same nuclear data, i.e. JEFF3.1.1 with the exception of delayed neutron constants which can be KEEPIN [10], ENDF/B-VII.1 [11] and JEFF3.1.1 [12]. The values for β_{eff} differ significantly with KEEPIN giving 325 pcm, ENDF/B-VII.1 339 pcm and JEFF3.1.1 357 pcm. Compared to BERENICE measurements, the discrepancies are respectively of -7.8%, -3.9% and 1.2% to which a 3.6% experimental uncertainty should be associated. KEEPIN constant which have been often used at the time looks highly discrepant.

The delayed neutron constants are for KEEPIN and ENDF/B-VII.1 given in 6 families while JEFF3.1.1 is using 8 group. The same set of eight-group half-lives for all fissioning systems in the JEFF3.1.1 data set, with the half-lives adopted for the three longest-lived groups corresponding to the three dominant long-lived precursors: ^{87}Br, ^{137}I and ^{88}Br. Two main reasons for adopting this new delayed neutron group data structure can be briefly mentioned here [13]:

1. the need for a more consistent description of the delayed neutron emission from the longest-lived precursors to avoid distortions in the reactivity measurement analysis (today it is recognised that the half-lives used in Keepin's six-group structure do not accurately reproduce the asymptotic die-away time constants associated with the three longest-lived dominant precursors);
2. the advantage of using a single set of precursor half-lives (for all fissile isotopes and incident neutron energies) in calculations of reactor kinetics.

Values of delayed neutron constants calculated with ERANOS using KEEPIN, ENDF/B-VII.1 and JEFF3.1.1 for the ZONA2 core of the BERENICE experimental programme are presented in tables 1, 2a and 3 respectively. Values for ENDF/B-VII.1 have been also calculated with SUSD3D (table 2b) and confirm those of ERANOS (Table 2a).

Table 1. Values of delayed neutron constants calculated with ERANOS & KEEPIN

Family number	1	2	3	4	5	6
beta i	8.4	69.3	60.6	116.8	52.7	17.4
lambda i	0.0127	0.0317	0.116	0.311	1.4	3.87

Table 2a. Values of delayed neutron constants calculated with ERANOS & ENDF/B-VII.1

Family number	1	2	3	4	5	6
beta i	8.6	60.5	52.4	120.9	70.7	25.9
lambda i	0.0133	0.0309	0.113	0.293	0.857	2.73

Table 2b. Values of delayed neutron constants calculated with SUSD3D & ENDF/B-VII.1

Family number	1	2	3	4	5	6
beta i	8.4	60.7	52.1	122.7	72.2	26.5

Table 3. Values of delayed neutron constants calculated with ERANOS & JEFF3.1.1

Family number	1	2	3	4	5	6	7	8
beta i	6.3	59.0	22.7	51.4	114.1	43.6	40.1	19.9
lambda i	0.01247	0.0283	0.0425	0.133	0.292467	0.666488	1.63478	3.5546

With these values, one can calculate τ = sum ($beta_i/lambda_i$) for ZONA2 using different nuclear data constants (Table 4).

Table 4. Average lifetimes of delayed neutrons τ for ZONA2 using different nuclear data constants

Nuclear Data	KEEPIN	ENDFBVII	JEFF3.1.1
τ (s)	11.64	10.54	11.18
deviation % JEFF3.1.1	4.0%	-5.8%	-

One can notice a significant difference (10% between the extreme values) between the 3 sets.

4 SOLUTIONS OF THE NORDHEIM EQUATION

With the use of results presented in chapters 2 and 3, it was possible to solve the Nordheim equation and derive reactivity as a function of time.

Variations of the neutron population in the core are described by the point kinetics equations:

$$\frac{dn(t)}{dt} = \frac{\rho(t) - \beta_{eff}}{\Lambda} n(t) + \sum_i \lambda_i C_i(t) + S(t)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_{eff,i}}{\Lambda} n(t) - \lambda_i C_i(t)$$

After the cancellation of transients, the doubling time can be measured and the reactivity can be derived by the following kinetics relationship:

$$\rho = \frac{\ln 2}{T_d} \left(\Lambda + \sum_{i=1}^{n} \frac{\beta_{\mathrm{eff},i}}{\frac{Ln2}{T_d} + \lambda_i} \right)$$

For instance, for a 100 pcm reactivity insertion at the initial of the transient, we obtain the following curve presented in Figure 1.

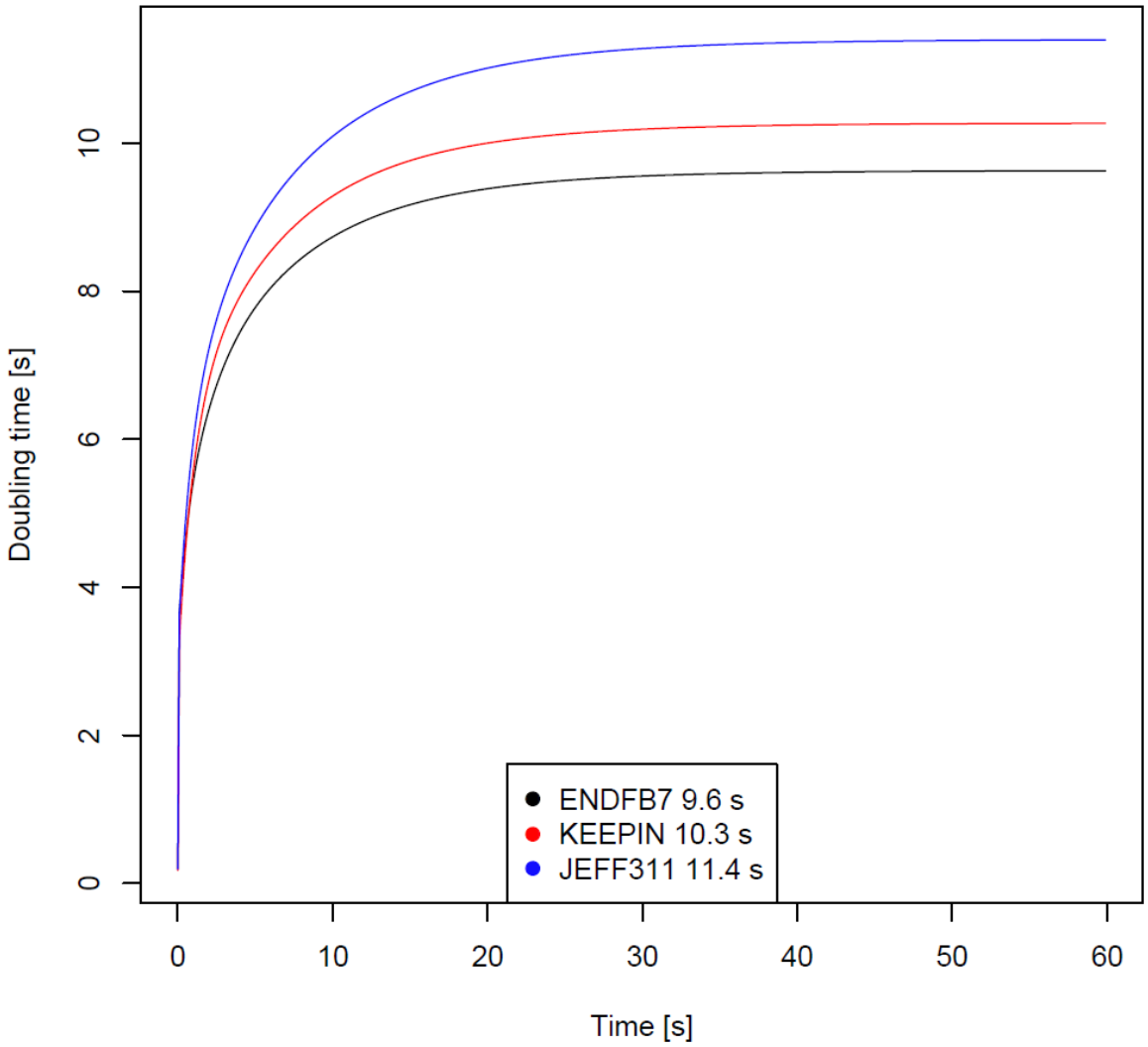

Figure 1. Doubling time T_d [s] as a function of time [s] for ρ = 100 pcm

The use of different kinetic sets leads to a significant change in the doubling time. In the current work, the reactivity is set to 100 pcm and the doubling time is derived. The difference on the doubling times using different kinetic sets is significant. This has also been shown for thermal systems [14] but is also true for SFR. Now if we use the same measured doubling time (for instance the one of JEFF3.1.1) to set up the reactivity scale, we get a deviation of -5.1% for KEEPIN and -8.4% for ENDF/B-VII.1. This means that a significant deviation is existing when analysing past experiments and they should be revisited with the most recent nuclear data.

5 CONCLUSIONS

The calibration of the shim rod is performed by measuring a fission chamber response when dropping a control rod and solving the Nordheim equation. This gives a S curve where the position of a control rod is associated to a reactivity expressed in \$.

Revisiting the uncertainties associated to this calibration, we use the experimental results of the BERENICE programme and we found a discrepancy of 1.2% with an experimental uncertainty of 3.6%. Uncertainty due to nuclear data on β_{eff} value is of 2.6%. However, the

decay time constants associated to each family are quite different from one nuclear data evaluation to another. Solving the Nordheim equation with different sets lead to a deviation on reactivity of -5.1% for KEEPIN and -8.4% for ENDF/B-VII.1 when using JEFF3.1.1 as a reference. The reactivity scale can be seriously impacted by such deviations. Analysing past experiments require hence to change the scale with which reactivity worths were measured. The uncertainty on the reactivity due to delayed neutron data amounts to 6% mainly linked to the neutron data average lifetime τ.

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