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ABSOLUTE MEASUREMENT OF β_{eff} BASED ON ROSSI-α EXPERIMENTS AND THE TWO-REGION MODEL IN THE IPEN/MB-01 RESEARCH REACTOR

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ABSTRACT

A new method for absolute measurement of the effective delayed neutron fraction, β_{eff}, based on Rossi-α experiments and the Two-Region Model was developed at the IPEN/MB-01 Research Reactor facility. In contrast with other techniques like the Slope Method, Nelson-Number Method and ^{252}Cf-Source Method, the main advantage of this new methodology is to obtain the effective delayed neutron parameters in a purely experimental way, eliminating all parameters that are difficult to measure or calculate. In this way, Rossi-α experiments for validation of this method were performed at the IPEN/MB-01 facility, and adopting the present approach, β_{eff} was measured with a 1.46% uncertainty. In addition, the prompt neutron generation time, Λ, and other parameters, was also obtained in an absolute experimental way. In general, the final results agree well with values from frequency analysis experiments. The theory-experiment comparison reveals that JENDL-3.3 shows deviation for β_{eff} lower than 1% which meets the desired accuracy for the theoretical determination of this parameter. This work supports the reduction of the ^{235}U thermal yield as proposed by Okajima and Sakurai.

1. INTRODUCTION

Among the different parameters influencing the dynamic behavior of a nuclear reactor, the effective delayed neutron fraction, β_{eff}, play the most important role. Current calculation/experiment discrepancies on measurements of β_{eff} are undesirable in design and operation of reactor control systems. More precisely, a target accuracy of ±3%(1 s.d.) has been requested for the experimental β_{eff}[1]. For β_{eff} calculations, the target accuracy which has been proposed is also ±3%(1 s.d.)[2]. Concerning thermal reactors fueled with slightly enriched uranium, a literature survey shows that only TCA[3], MISTRAL-1[4] and IPEN/MB-01[5] experiments, reported measured values of β_{eff} that satisfies the proposed target accuracy. In such a way, a collaborative effort to improve the β_{eff} measurements in thermal systems has been recommended.

Nowadays, the measured values of β_{eff} are not obtained directly but involve other parameters. The derivation of the β_{eff} value from all the known techniques involves calculated parameters and/or results from other experiments. These calculated and measured parameters are sources of error common to all techniques.

For these reasons, a new technique was developed in order to obtain β_{eff} in a purely experimental way, eliminating all parameters that are difficult to measure or calculate. Consequently, the uncertainties associated to these parameters are eliminated and the accuracy in β_{eff} is improved. In summary, several Rossi-α measurements were performed in the IPEN/MB-01 facility. The Rossi-α distributions were acquired in a very large subcritical interval, spanning from -500pcm to -25000pcm approximately. At subcritical levels under -3000pcm, it was observed that prompt neutrons in the IPEN/MB-01 core die out with two decay constants rather than one, in agreement with the Two-Region Model. Moreover, using the Two-Region Model the α versus reactivity curve was fitted by means of a least-square approach in order to extract β_{eff}

2. THE REFLECTED CORE ROSSI-α DISTRIBUTION

The Two-Region Model formalism presented here is a simplified methodology proposed by Spriggs et al.[6]. In this model, the reactor is represented by two regions: the core and the reflector. These two regions are then coupled together using coupling parameters that represent the probability that a neutron lost from one region will appear in the other region.

If six groups of delayed neutrons are assumed the inhour equation derived from the Two-Region Model will have eight roots with an additional asymptote at $-1/\tau_r$, where τ_r is the adjoint-weighted neutron lifetime in the reflector region. The ω_7 and ω_8 roots can be obtained from the reflected core inhour equation neglecting delayed neutrons ($\omega \gg \lambda_I$)[7]:

$$\omega_{7,8} = \frac{1}{2\Lambda_c \Lambda_r (1-f)} \left\{ \begin{array}{l} -\left[(1-\rho)(\Lambda_c + f\Lambda_r) + \Lambda_r(1-f)(\beta_{eff}-\rho)\right] \pm \\ \pm\sqrt{\left\{(1-\rho)(\Lambda_c + f\Lambda_r) + \Lambda_r(1-f)(\beta_{eff}-\rho)\right\}^2 - 4\Lambda_c\Lambda_r(1-f)(1-\rho)(\beta_{eff}-\rho)} \end{array} \right\} \quad (1)$$

where the positive and negative signs go with ω_7 and ω_8 respectively. This equation shows clearly that the relationship between the roots ω_7 and ω_8, and reactivity is not linear. The ω_7 root is obtained in conventional one-region Rossi-α experiments and is designated as prompt neutron decay constant, α. The ω_8 root is related to the reflector effect and introduces an additional decay mode in the Rossi-α distributions. In such a way the reflected core Rossi-α distribution may be written as[8]:

$$p_{Rossi}(\tau) = A_7 e^{\omega_7 \tau} + A_8 e^{\omega_8 \tau} + BG \quad (2)$$

where the amplitudes A_7 and A_8, and the background term BG, are fitting parameters.

3. THE IPEN/MB-01 RESEARCH REACTOR AND CORE CONFIGURATIONS

The IPEN/MB-01 reactor[7] is a zero-power critical facility and consists of a 28x26 square array of UO_2 fuel rods, 4.3% enriched and clad by stainless steel (type 304) inside a light water tank. The reactivity is controlled by control and safety rods. The control banks are composed of 12 Ag-In-Cd rods and the safety banks of 12 B_4C rods. The pitch of the rods is 15.0 mm, which is close to the optimal pitch (maximum k_∞). This feature favors the neutron thermal energy region events. The maximum operating power of the facility is limited to 100W.

For the Rossi-α measurements, two different core configurations were loaded as showed in Fig. 2. The core configuration given in Fig. 2a was used to perform Rossi-α measurements at subcritical levels near the critical state in order to obtain the β_{eff}/Λ value. In this configuration a small BF_3 neutron detector was placed in the center of the active core. Moreover, in order to reduce the count rate of the BF_3 detector near the critical state, the startup source (Am-Be, 1*Ci*) was removed from the bottom of the core and the reactor was driven by its own intrinsic source.

The core configuration given in Fig. 2b, was implemented to perform Rossi-α measurements in a very large range of reactivity (nearly from -500pcm to -25000pcm). This large subcritical level is achieved employing eight burnable poison rods in order to reduce the reactivity excess of the core to nearly zero (see Fig. 2b). Each rod is filled with 52 pellets of Al_2O_3-B_4C with 40.53 mg/cm^3. Uncertainty reduction of the α value evaluation and reduction of measurement time was attained by the high sensitivity of a detector for large subcritical levels. Thus, a ^{3}He detector, whose sensitivity was 54.3 *cps/nv*, was employed. To increase the count rate of the detector to a more reasonable value, the start up source was inserted to drive the system during the measurements. For measurements at near critical conditions, a less sensitive (12.9 *cps/nv*) boron-lined detector was used to avoid dead time effects.

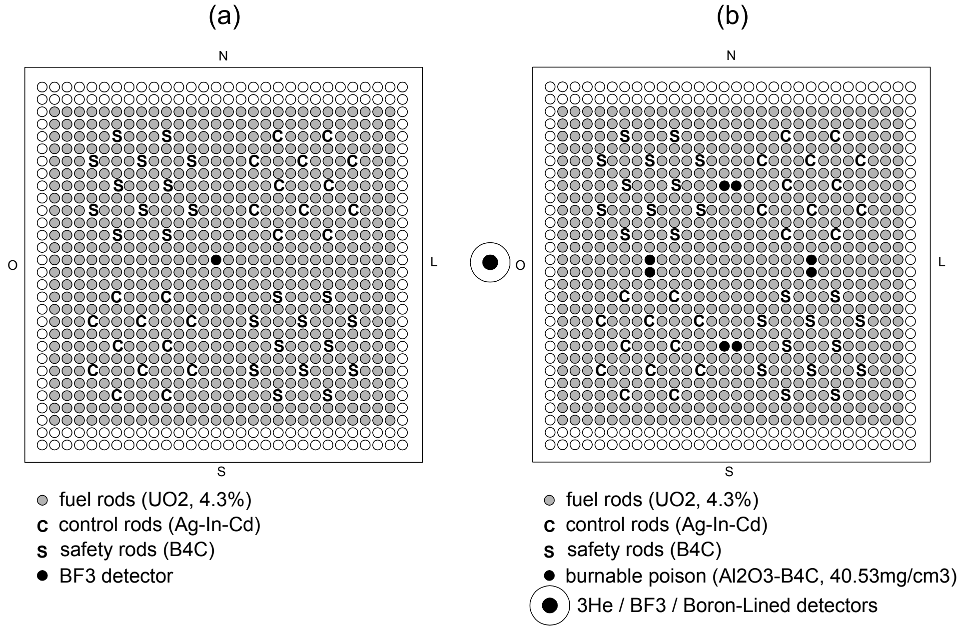

Figure 1. IPEN/MB-01 core configurations. (a) BF_3 detector positioned in the center of the active core. (b) Eight burnable poison rods positioned in the active core and three different detectors in the reflector region.

In order to perform the Rossi-α measurements, it was developed a data acquisition system for microscopic noise analysis called IPEN/MB-01 Correlator[7,8], which is a Virtual Instrument coded on the LabVIEW^{TM}, that records the timing of all neutrons events, allowing on-line and real-time data analysis.

4. MEASUREMENTS RESULTS

In the first approach illustrated in Fig. 1(a), the measurements were performed with the reactor driven by its own intrinsic source at levels near the critical state. In total, three different measurements were performed with different control rods positions. In agreement with theoretical prediction, only one decay mode was observed. Thus, α values were obtained from these three subcritical levels via a least-square fit procedure using only one exponential term. The determination of relative changes in reactivity due to changes in control rods positions was carried out by the inverse count rate in the detector[7,8]. Figure 2 shows a plot of the adjusted α vs. the inverse count rate of the BF_3 detector. A linear extrapolation to ρ=0, which is equivalent to $1/C$=0, gave α_0 of the system as 235.28 ±1.70s^{-1}.

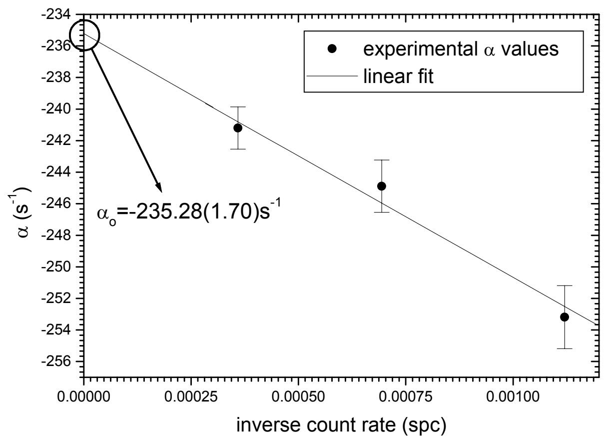

Figure 2. Plot of the α values versus the inverse count rate.

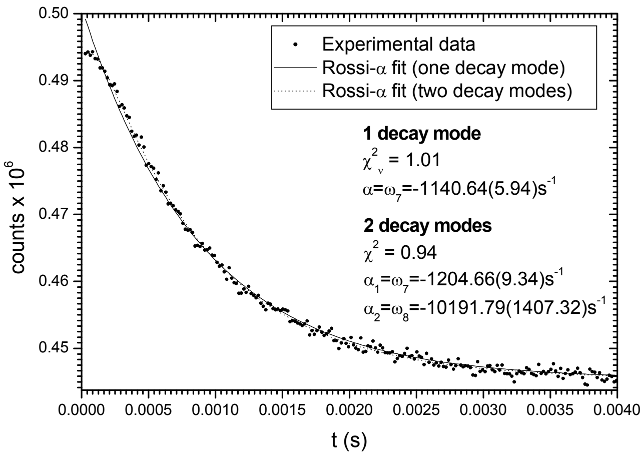

Figure 3. Rossi-α distribution for a subcritical level of -3363.76pcm.

In the second approach (Fig. 1b) different subcritical states were achieved through the simultaneous introduction of all control and safety rods of the reactor in steps of 5% insertion. Above -3000pcm approximately, only one decay mode was identified in Rossi-α distributions. On the other hand, below -3000pcm two decay modes were considered to fit the distributions. This behavior is in agreement with theoretical predictions based on the Two-Region Model. A Rossi-α distribution fitted with two decay modes is illustrated in Figs. 3.

Fig. 4 shows the measured α values vs. the inverse count rate. We recognized that the variation of α with reactivity shows a behavior described by Eq. (16). The parameters α_o, τ_c, τ_r, f and β_{eff} can be obtained by fitting this data using Eq. (16). This fitting procedure is indicated by the solid-line in Fig. 4, and the fitted parameters are listed in Table 1. As observed in this table, the measured parameters are well in accordance with a previous results from frequency analysis methods[5,7].

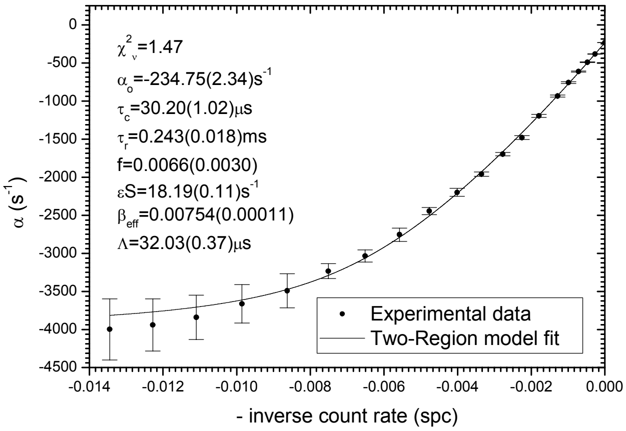

Figure 4. The α values vs. reactivity plot. The parameters were obtained via least-square fit using Eq. 1.

Table 1. Measured results.

parameter	**Rossi-α (core measurements)**	**Rossi-α (reflector measurements)**	**Frequency Analysis[a]**	**Frequency Analysis[b]**
α_o	-235.28(1.70)s^{-1}	-234.75(2.34)s^{-1}	-234.61(3.26)s^{-1}	-231.00(0.94)s^{-1}
τ_c	-	30.20(1.02)μs	-	-
τ_r	-	0.243(0.018)ms	-	-
f	-	0.0066(0.0030)	-	-
β_{eff}	-	7.54(0.11)x10^{-3}	7.47(0.11)x10^{-3}	7.39(0.07)x10^{-3}
Λ	-	32.03(0.37)μs	32μs	31.99(0.33)μs

[a] With delayed neutron[41]
[b] Without delayed neutron[42]

The fitted quantities τ_c, τ_r and f, can be combined to yield the prompt neutron generation time, Λ, by the following equation[6]:

$$\Lambda = \frac{1}{1-f}\left(\tau_c + f\tau_r\right) \tag{3}$$

and the final value is Λ=32.03(0.37)μs.

The theory/experiment comparisons listed in Table 2 shows that the JENDL3.3 has the best performance and meets the desired accuracy for the calculation of this parameter. This is a direct consequence of an adoption of a smaller ^{235}U thermal yield as proposed by Okajima and Sakurai[7].

Table 2. Comparison of the calculated β_{eff} with the experimental value.

		ENDF/B-VI.8[(a)]	JEFF-3.1	JENDL 3.3
β_{eff} (C/E)	TORT	1.0509	1.0270	1.0028
	MCNP-4C3	1.0366	1.0234	1.0021

(a) LANL review

5. CONCLUSIONS

Measurements for the determination of β_{eff} were successfully performed at the IPEN/MB-01 Research Reactor. Firstly, the observation of two decay modes in Rossi-α distributions recorded in reflector region and the non-linear behavior between α and inverse count rate, demonstrated that the kinetic behavior of this core is governed by the Two-Region Model. To assure a correct validation of nuclear data library and neutron transport codes, a new methodology for absolute measurement of β_{eff} based on Two-Region Model predictions and Rossi-α measurements was developed. By adopting this approach, an experimental value for β_{eff} could be derived without any calculations or other experiments results. Furthermore, the prompt neutron generation time Λ and other parameters, were also measured in a purely experimental way. The final measured results agree well with values from frequency analysis experiments. In particular, an uncertainty of 1.46% on β_{eff} was achieved, and a precise absolute measurement using this new technique could be obtained. In fact, this uncertainty is smaller than the requested target accuracy of ±3%(1 s.d.). The theory/experiment comparison of β_{eff} shows that among the available nuclear data libraries JENDL3.3 has the best performance. The reduction of the ^{235}U thermal yield as proposed by Okajima and Sakurai is completely justified according to the β_{eff} measurements performed in this work.

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REFERENCES

1. T. Sakurai et al., "Experimental Cores for Benchmark Experiments of Effective Delayed Neutron Fraction β_{eff} at FCA," *Prog. Nucl. Energy*, **35**, 2, pp.131 (1999).
2. G. Rudstan et al., "Delayed neutron data for major actinides", *NEA/WPEC-6 Report* (2002).
3. K. Nakajima, "Re-evaluation of the effective delayed neutron fraction measured by the substitution technique for a light water moderated low-enriched uranium core," *J. Nucl. Sci. Technol.*, **38**, 1120 (2001).
4. O. Litaize and A. SANTAMARINA., "Experimental Validation of the Effective Delayed Neutron Fraction in the MISTRAL1-UOX and MISTRAL2-MOX Homogeneous Core," *JEFDOC-872* (2001).
5. A. Dos Santos et al., "A proposal of a benchmark for β_{eff}, β_{eff}/Λ and Λ of thermal reactors fueled with slight enriched uranium," *Ann. Nucl. Energy*, **33**, 848 (2006).
6. G. D. Spriggs et al., "Two-Region Kinetic Model for Reflected Reactors," *Ann. Nucl. Energy*, **24**, 3, 205 (1997).
7. R. Y. R. Kuramoto et al., "Absolute Measurement of β_{eff} based on Feynman-α experiments and the Two-Region Model in the IPEN/MB-01 Research Reactor," *Ann. Nucl. Energy*, **34**, 6, pp.433-442 (2006).
8. R. Y. R. Kuramoto et al., "Absolute Measurement of β_{eff} based on Rossi-α experiments and the Two-Region Model in the IPEN/MB-01 Research Reactor," *Nucl. Sci. and Engr.* (submitted for publication) (2007).