2017 International Seminar on Sensor, Instrumentation, Measurement and Metrology (ISSIMM)
Surabaya, Indonesia, August 25th - 26th, 2017

Characterization of Neutron Detectors at the IPEN/MB-01 Nuclear Reactor

Eduardo Gonnelli
Nuclear and Energy Research Institute
IPEN/CNEN
São Paulo, Brazil
egonnelli@gmail.com

Letícia Negrão Pinto
Nuclear and Energy Research Institute
IPEN/CNEN
São Paulo, Brazil

Ricardo Diniz
Nuclear and Energy Research Institute
IPEN/CNEN
São Paulo, Brazil

Adimir dos Santos
Nuclear and Energy Research Institute
IPEN/CNEN
São Paulo, Brazil

***Abstract*— A huge Brazilian nuclear project, the Brazilian Multipurpose Research Reactor (RMB), is being carried out and one of the project steps is to verify experimentally the physical quantities related to the operational performance of the new fuel elements. In this context, the aim of this work is to characterize the neutron detectors due to its crucial role during the nuclear reactor criticalization. A series of experiments was performed at the IPEN/MB-01 nuclear reactor in order to characterize a set of new helium-3-filled gas proportional counters. The detectors characterization procedure takes into account the operating voltage curve and the detectors dead time. The Rossi-α method was employed in order to acquire the time difference between a detected neutron pair. The dead time determination through the Rossi-α method is very important to discriminate the reflector effect over the neutron lifetimes in subcritical reactivity levels. Furthermore, the Auto Power Spectral Densities (APSD) for those new detectors were experimentally acquired and those results were compared among some well-known detectors and with theoretical simulation results using the MCNP5 code with the ENDF/B-VII.0 library neutron data.**

Keywords—Dead Time, IPEN/MB-01, Neutron Detectors, Neutron Noise Technique, Rossi-α.

I. INTRODUCTION

A huge Brazilian nuclear project, the Brazilian Multipurpose Research Reactor (RMB), is being carried out and one of the project steps is to verify experimentally the physical quantities related to the operational performance of the new fuel elements. The IPEN/MB-01 reactor facility was chosen to receive a similar core as the RMB and the plate-type fuel was projected to be manufactured at the Nuclear and Energy Research Institute (IPEN/CNEN-SP) in order to perform the necessary measurements. Due to this fact, plenty of modifications must be done in the IPEN/MB-01 reactor. After all of the implementations of new instrumentation, fuel matrix, control and safety rods mechanism, and detectors, one of the first experimental procedures, as known, is the achievement of the criticality (start up procedure). In this context, the aim of this work is to characterize the neutron detectors due to its crucial role during the nuclear reactor criticalization.

II. EXPERIMENTAL PROCEDURE

The operating voltage curve was obtained using a 100mCi Am-Be neutron source where the detectors were positioned 10cm from the source. The counts for each detector were acquired using the Nuclear Instrumentation Modules (NIM) from Ortec™ and the software MAESTRO™. The neutron counts must be discriminated from the gamma radiation and, for this purpose, the detectors' energy spectra was acquired.

The detector's dead time was obtained based on the Rossi-α method. Due to the fact that the radioactive decay process of the neutron source of Am-Be follows the Poisson Statistical Distribution, the detection of independent events originated through this method will generate a curve which the experimental data will be around a medium value as a white noise, i.e., these events occur with a known average rate and independently of the time since the last event [1][2].

A set of experiments was performed at the IPEN/MB-01 nuclear reactor in which control banks were responsible for the negative reactivity insertion. The step range started at 55.0% of control bank withdrawal and finished at 0.0% (totally inserted). The standard core configuration for 28x26 fuel rods was employed for the whole set of experiments. For this arrangement, the criticality can be achieved at 58.08% of control banks simultaneously withdrawn. Because of that, the initial step was 55% for both control bank withdrawal.

The detectors employed for this work were the neutron proportional counter filled with helium-3 and BF_3 gas, manufactured by CENTRONIC™.

This work was supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) under the grant number of 2013/14908-4, CAPES, ELETRONUCLEAR and by the Nuclear and Energy Research Institute (IPEN/CNEN-Brazil).

The characteristics of the detectors employed in this work are shown below. The detector denoted by A was used as a reference.

A. **^{3}He**: Centronic, model 50He3-760/38E
Gas pressure: 760 cm Hg
Thermal neutron sensitivity: ~186 cps/nv

B. **^{3}He**: Centronic, model 100He3-152/38HS
Gas pressure: 152 cm Hg
Thermal neutron sensitivity: ~202 cps/nv

C. **BF$_3$**: Centronic, model 107EB70-50HS
Gas pressure: 70 cm Hg
Thermal neutron sensitivity: ~150 cps/nv

This paper presents results for the characterization of the detectors denoted by B and C.

III. NEUTRON NOISE MEASUREMENT METHOD

The Auto Power Spectral Densities (APSD) and the Rossi-α method employed in this work used the following electronic system. Fig. 1 shows the electronic equipment assembly scheme for the neutron data acquisition, besides the processing system of the information. As can be seen, firstly, the detected neutron pulses are formatted by the pre amplifier module and its amplification occurs after this procedure due to the employment of the amplifier module. Secondly, the discrimination of the neutron pulses from the gamma radiation is done and, for this purpose, the specific module Single Channel Analyzer (SCA) [3] was implemented using the windowing energy options Lower and Upper Level Discriminator. Thirdly, regarding the negative logical pulses, those are generated from the output of the SCA for acquirement and are standard NIM fast negative [4]. Some characteristics must be emphasized: the width is 25ηs, the amplitude in voltage is - 5 V and the impedance is 50 ohms. Finally, at the computational acquisition, the board that registers the logical pulses is known as Multi Channel Scaler [5] and the time interval in which the logical pulses are registered is the dwell time [6] [7].

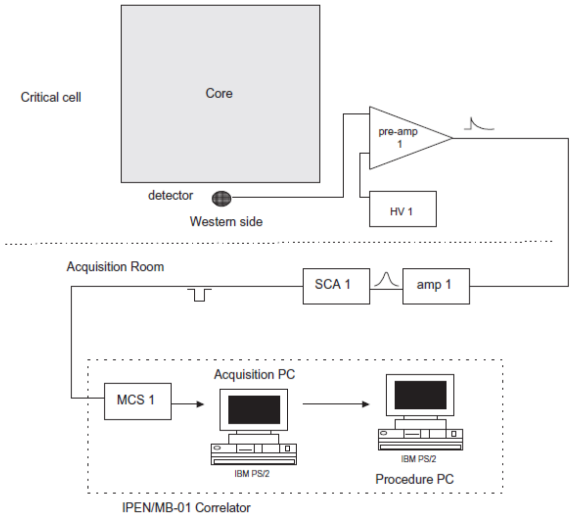

Fig. 1. Electronic data acquisition system.

The physical principle of the Rossi-α method is the difference of time between a detected neutron pair. For this reason, only a neutron must be detected in the channel illustrated by the Fig. 2. It guarantees that only the correlated neutron events are being detected [8].

The flow chart representing the time domain data, the counts per dwell time and the power spectral density are shown in Fig. 2. The Fast Fourier Transform (FFT) algorithm is employed for the PSD acquisition. The MCS board channels are also represented in Fig. 2.

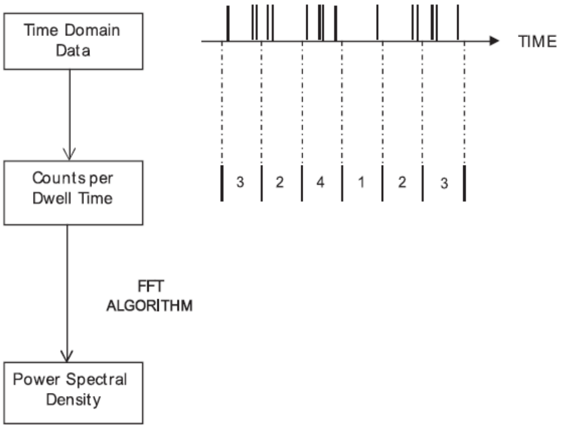

Fig. 2. Data processing flow chart spectral densities acquiriment.

The reactivity for all of the bank control steps was obtained using the least square method. The equation employed to fit the APSD's curves was based on the point kinetics equations.

$$\Phi_{xx}(f) = \frac{A}{B^2 + (2\pi f)^2} + C \tag{1}$$

where Φ_{xx} represents the Auto Power Spectral Density, f is the frequency domain, A and C are constants determined through the least square method. The parameter B is the prompt neutron decay constant [9], detonated as α, and defined by the following equation.

$$B = \alpha = \frac{\rho - \beta_{eff}}{\Lambda} \tag{2}$$

where ρ is the reactivity, β_{eff} effective delayed neutron fraction and Λ is the prompt neutron generation time [9].

IV. RESULTS

The operating voltage curves for the BF$_3$ and ^{3}He detectors were obtained and are shown in Fig. 3 and Fig. 4, respectively.

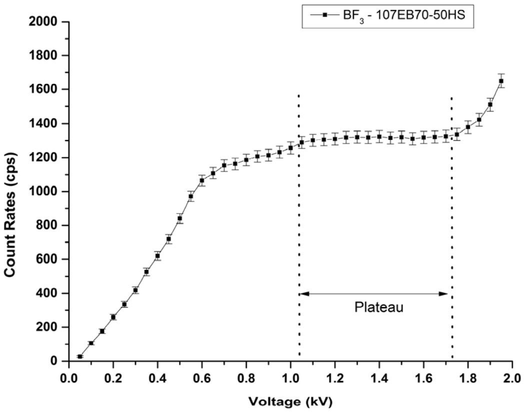

Fig. 3. BF_3 detector operating voltage curve

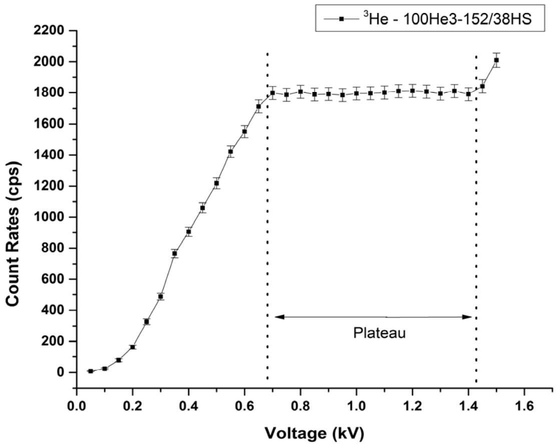

Fig. 4. ^{3}He detector operating voltage curve

The operating voltages for the detectors were based on the voltage average value of the plateau. This region represents that the detectors are operation in proportional region in which the applied voltage between the anode wire and the cathode wall provides enough electric field to create gas multiplication.

Through the plateau voltage average values, the energy spectra of the detectors was acquired employing the 100mCi Am-Be neutron source. The energy spectra of the BF_3 and ^{3}He detectors are shown in Fig. 5 and Fig. 6, as follows:

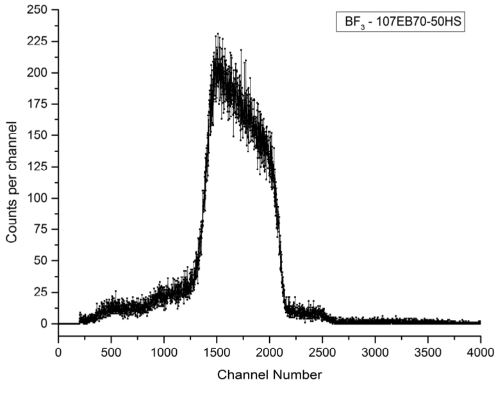

Fig. 5. BF_3 detector energy spectra

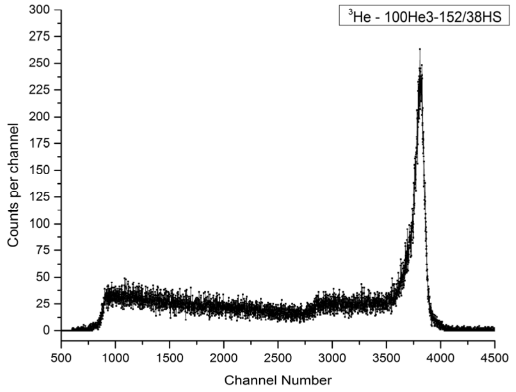

Fig. 6. ^{3}He detector energy spectra

The Fig. 7 and Fig. 8 show the dead time determination through the Rossi-α method for the BF_3 (107EB70-50HS) and ^{3}He (100He3-152/38HS) detectors, respectively. Differences between the neutrons pulse pair interval are on the axis "y" as the counts and the time for each correlated event are denoted on axis "x". Furthermore, it is possible to notice that the dead time for the helium-3 is approximately 5.8 times higher than the BF_3 dead time.

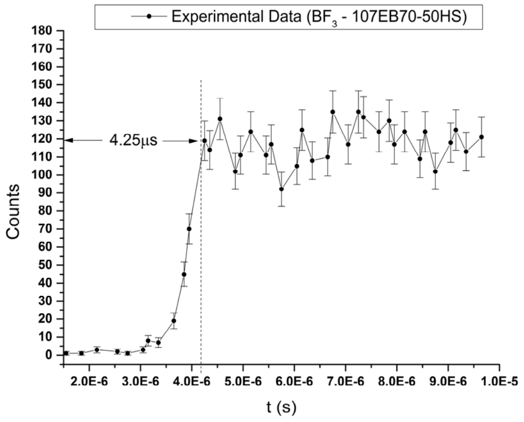

Fig. 7. BF_3 (107EB70-50HS) neutron detector dead time obtained through the Rossi-alpha method

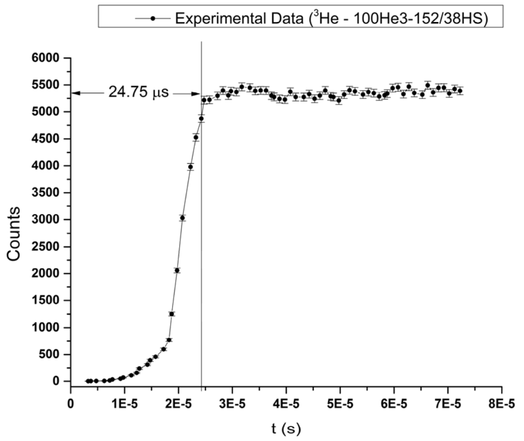

Fig. 8. ^{3}He (100He3-152/38HS) neutron detector dead time obtained through the Rossi-alpha method

The Table I shows the results for the prompt neutron decay constant (α) obtained through the Auto Power Spectral Densities for each step of control bank position.

TABLE I. THE PROMPT NEUTRON DECAY CONSTANT RESULTS

Control Bank Position (%withdrawal)	**^{3}He 50He3-760/38E**	**BF$_3$ 107EB70-50HS**	**^{3}He 100He3-152/38HS**
55	-341.13(3.42)	-325.82 (2.50)	-318.96 (3.26)
50	-519.18(4.00)	-498.46 (3.20)	-501.31 (3.47)
40	-868.85(6.26)	-844.11 (6.43)	-832.23 (6.41)
30	-1192.44(10.05)	-1135.14 (10.97)	-1125.55 (10.47)
25	-1287.83(11.63)	-1273.23 (13.87)	-1245.41 (22.92)
20	-1422.04(13.45)	-1397.16 (16.53)	-1353.57 (13.07)
15	-1470.90(13.66)	-1474.61 (18.95)	-1438.84 (15.16)
10	-1551.58(14.95)	-1466.66 (19.41)	-1514.85 (16.39)
5	-1595.60(15.53)	-1490.61 (20.31)	-1504.15 (17.56)
0	-1596.41(15.91)	-1461.72 (20.01)	-1526.84 (16.16)

The Fig. 9 shows the reactivity value for all of the steps of this experiment.

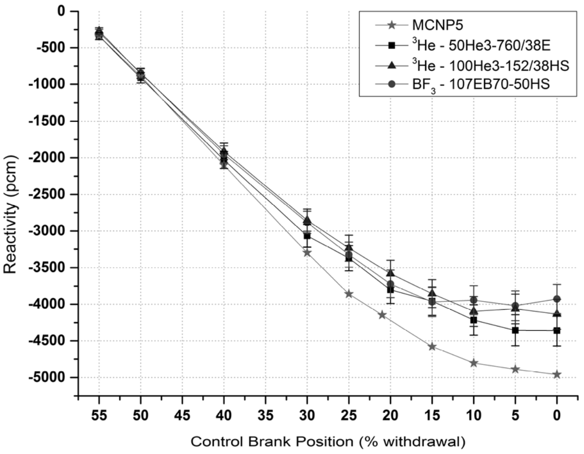

Fig. 9. Reactivity results for all steps of this experiment

The prompt neutron generation time (Λ) and the effective delayed neutron fraction (β_{eff}) were maintained constant during the least square fitting method, and their values are (31.96 ± 1.06) μs and (750 ± 19) pcm, respectively. The values of those nuclear reactor kinetic parameters were obtained from IRPhE Handbook [10].

V. DISCUSSION AND CONCLUSIONS

The BF$_3$ and ^{3}He detector operating voltages were obtained through the average value of the proportional region plateau of the Fig. 3 and Fig. 4. The operating high voltages obtained are 1375 V and 1050 V for BF$_3$ and ^{3}He, respectively. In addition, the energy spectra for both detectors were obtained employing those voltages. It can be seen in the Fig. 5 and Fig. 6.

The dead time determination for the detectors employed in this work was achieved experimentally through the Rossi-α method.

Due to the high sensitivity of the helium-3 detector, the dead time of those detectors are higher than the BF$_3$ detectors. The dead time obtained for the ^{3}He (100He3-152/38HS) and BF$_3$ (107EB70-50HS) were 24.75μs and 4.25μs, respectively. The inter chain dead time effects and the transition zone behaviors for the analyzed detectors are in agreement with the literature [11], and this phenomenon could be noticed in the Fig. 7 and Fig. 8.

One aspect that must be highlighted regarding the detector dead time is the data board processing PCI Multichannel Scaler. It has no dead time between the adjacent channels [5] which does not contribute for any interference in the detector dead time determination.

The reactivity results obtained experimentally through the APSD fitting curve are in qualitative and quantitative agreement among the detectors employed in this work. It can be noticed in the Fig. 9 for square, triangle, and circle symbols which represent the results for the ^{3}He and BF$_3$ detectors.

The experimental results are in 1σ concordance for all control bank positions despite the fact that there are differences between the gas detector properties (^{3}He and BF$_3$), geometry, and operation voltage. It is a very good result because it shows the consistency of the method employed and it suggests that the detectors are measuring the same physical phenomenon.

The MCNP5 calculated results are in agreement with the experimental APSD results for a specific range of subcritical reactivity. The Fig. 9 shows the agreement among the results from 55% up to 40% of control bank position withdrawal. It could be represented approximately from -350 pcm up to -2500 pcm. For more subcritical reactivity levels, the difference between MCNP5 and experimental results tends to increase. It was already predicted in other works related to subcriticality reactivity studies [7].

The method developed in this work will be very useful for the subcritical experiments employing the neutron noise techniques, especially for the Rossi-α and Feynman-α. Furthermore, the dead time determination is very important to discriminate the reflector effect over the neutron lifetimes in subcritical level of reactivity [8][12][13].

ACKNOWLEDGMENT

The authors would like to thank the operational staff of the IPEN/MB-01 reactor for their professionalism and efficient operation during the course of the experiment.

REFERENCES

[1] F. A. Haight, Handbook of the Poisson Distribution. New York: John Wiley & Sons, 1967.

[2] J. F. C. Kingman, Poisson Processes. New York: Oxford University Press, 1993.

[3] ORTEC® manual users guide, "550A Single Channel Analyzer User's Manual," Oak Ridge, TN, U.S.A.

[4] U.S Department of Energy, U.S NIM COMMITTEE, "Standard NIM Instrumentation System," DOE/ER-0457T, May, 1990.

[5] ORTEC® manual users guide, "MCS-pci™ (A73-B32) Hardware and Software User's Manual," Oak Ridge, TN, U.S.A.

[6] Y. Kitamura, M. Matoba, T. Misawa, H. Unesaki, and S. Shiroya, "Reactor noise experiments by using acquisition system for time series data of pulse train," Journal of Nuclear Science and Engineering, vol. 36, no 8, pp. 653–660, 1999.

[7] A. dos Santos, S. M. Lee, R. Diniz, and R. Jerez,. "A new experimental approach for subcritical reactivity determination of multiplying systems," Annals of Nuclear Energy, vol. 59, pp. 243-254, 2013.

[8] R. Y. Kuramoto, A. dos Santos, R. Jerez, and R. Diniz, "Absolute Measurement of Beta Effective Based on Rossi-alfa Experiments and the Two-Region Model in the IPEN/MB-01 Research Reactor," Nuclear Science and Engineering, vol. 158, no 3, pp. 272-283, 2008.

[9] G.I. Bell and S. Glasstone, Nuclear Reactor Theory, Van Nostrand Reinhold Company, 1970.

[10] A. dos Santos *et al.*, IPEN (MB01)-LWR-COEF-KIN-RESR-001: reactor physics experiments in the IPEN/MB-01 research reactor facility. In: International Handbook of Evaluated Reactor Physics Benchmark Experiments. NEA/NSC, Paris, pp. 1–142, 2009.

[11] P. Baeten, M. Bruggeman and R. Carchon, "Single- and multi-deadtime parameter corrections of one- and two-dimensional Rossi-alpha distributions for time interval analysis in neutron coincidence counting," Nuclear Instruments and Methods in Physics Research A vol. 390, pp. 345-358, 1997.

[12] E. Gonnelli, L. N. Pinto, A. dos Santos, and R. Diniz, "The Determination of Reflector Kinetic Parameters through ROSSI-α Experiments in the IPEN/MB-01 Reactor," In: Physics of Reactors Conference - PHYSOR 2016, Sun Valley. La Grange Park: American Nuclear Society, pp. 2692-2697, ISBN: 978-1-5108-2573-4, 2016.

[13] E. Gonnelli, S. M. Lee, L. N. Pinto, H. R. Landim, R. Diniz, R. Jerez, and A. dos Santos, "An alternative experimental approach for subcritical configurations of the IPEN/MB-01 nuclear reactor," Journal of Physics, Conference Series (Online), vol. 630, 2015.