A Simple Way to Overcome the Shortage of ^{3}He Detectors in the IPEN/MB-01 Nuclear Reactor

E. Gonnelli, R. Diniz, A. dos Santos, R. Jerez, L. N. Pinto and H. R. Landim

***Abstract*– To overcome the shortage of ^{3}He detectors for subcritical experiments in the IPEN/MB-01 reactor, some experiments were performed using less sensitive detectors, such as BF_3, and a logic input module, which sum the counts from different detectors. Through macroscopic neutron noise technique, the Auto Power Spectral Densities (APSD) were obtained for each detector configuration and various subcritical levels, and the prompt neutron decay constant (α) was extracted through a least squares procedure. The α parameter was used as an indicator for the comparison of the results and the quality of the experimental data. The values obtained show that the sum of counts technique presents no loss of information (correlated neutrons) even for different models and types of detectors, suggesting that the technique can be employed in neutron noise measurements.**

I. INTRODUCTION

The increasing demand for neutron detection systems based on ^{3}He is generating a huge problem in its production and supply worldwide [1]-[3], mainly in the last decade [4]-[7]. Considering this context, alternative solutions must be thought and developed [8], [9], since the ^{3}He neutron detector is extensively used in strategic fields as scientific research [6], public security (airport and seaport monitoring) [10] and industry applications [6] and mainly in nuclear reactors experiments [11].

The nuclear reactor physics program developed at the Nuclear and Energy Research Institute (IPEN/CNEN – Brazil) performs a series of experiments in which the employment of the neutron detectors is crucial [12]-[18]. The experiments carried out at the nuclear reactor facility IPEN/MB-01 use several types of thermal neutron detectors – boron lined, boron trifluoride (BF_3) and helium-3 (^{3}He) proportional detectors – for the traditional nuclear reactor physics experiments, including important benchmark works for ICSBEP (International Criticality Safety Benchmark Evaluation Project) [19]-[23] and IRPhEP (International Reactor Physics Evaluation Project) [24] which validate essential parameters.

Subcriticality has been of great experimental and theoretical relevance with the development of Accelerator Driven Systems (ADS) [25]-[29]. Regarding subcritical systems, the IPEN/MB-01 reactor can provide useful results through a series of experiments where new subcritical arrangements for the reactor core are being proposed [23]. In these new configurations, where subcriticality ranges from -3000 to -6000 pcm, BF_3 and Boron Lined counters have no enough sensitivity to give reliable results, and ^{3}He detectors must be employed due to the higher neutron sensitivity.

The aim of this work is the use of a logic input module (ORTEC® Quad 4-Input Logic Unit) [30] to sum the counts from 2 or more BF_3 detectors and to verify if the results of macroscopic noise analysis are reliable in comparison to the ^{3}He results. For this end, the APSD's of one detector and the combination of two and three detectors were used to obtain the prompt neutron decay constant, α, for 13 subcritical levels, ranging from near critical up to -4000 pcm. The α parameter for each subcritical level and for each BF_3 detector arrangement, and also for the ^{3}He detector, is obtained by a least squares approach in a purely experimental way. It should be noted that the α parameter is the only parameter that can be used for the comparison of the "detectors performance", since it depends only on the experimental data. The results for ^{3}He detectors presented here are supposed correct for all subcritical levels based on earlier experiments [13]-[14]

This data acquisition technique, where the signals of detectors are summed, could allow the possibility to overcome the ^{3}He detectors shortage by using less sensitive, less expensive and more accessible neutron detectors, as BF_3.

II. EXPERIMENTAL PROCEDURE

Thirteen subcriticality levels were considered in this work where the movement of control banks BC#1 and BC#2 occurs in steps of 2.50% of insertion. Both control banks initiated its position in 55.00% withdrawn (near critical state) and finished in the 25.00% withdrawn (-4000 pcm subcritical).

The experiment employed BF_3 and ^{3}He detectors, each one having its own set of electronic equipment (standard equipment for pulse mode detectors). Hereafter, the superscripts (a) and (b) will be used for different detectors of the same type (or the same gas), as BF_3^{a}, BF_3^{b}, $^{3}He^{a}$ and $^{3}He^{b}$.

The main properties of these detectors are as follow:

BF_3^{a}: Reuter Stokes, model RS-P1-0820-201.
Gas pressure: 40 cm Hg
Thermal neutron sensitivity: ~13 cps/nv

BF_3^{b}: Reuter-Stokes, model RS-P1-0836-201
Gas pressure: 40 cm Hg
Thermal neutron sensitivity: ~ 11 cps/nv

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This work was supported by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) under the grant number 13/14908-4 and by the Nuclear and Energy Research Institute (IPEN/CNEN-SP).

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^{3}He^a: Centronic, model 31-He3-380/25
Gas pressure: 380 cm Hg
Thermal neutron sensitivity: ~ 54 cps/nv

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

The Fig. 1 illustrates the core configuration and the detectors position for the case where three detectors are employed. For the configurations employing two detectors, the central position was used.

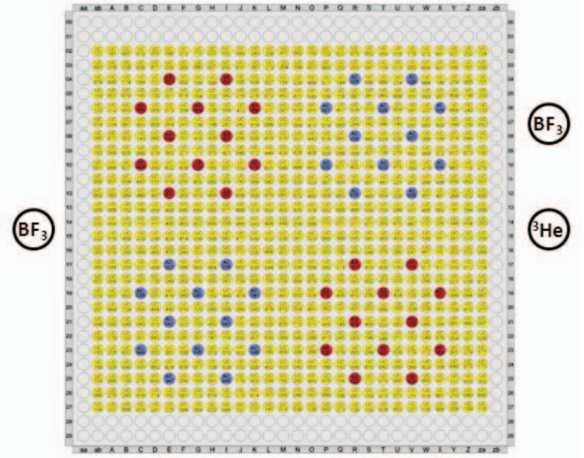

Fig. 1 – The standard core configuration of the IPEN/MB-01 nuclear reactor. This upper view shows the fuel rods in yellow, the control rod banks (BC#1 and BC#2) in blue and the safety rod banks in red. The black circles in the left and right side represents the detector location in the reflector region.

The standard core configuration with 28x26 fuel rods was used for the whole set of experiments. In this way it was possible to achieve a large range of subcriticality levels and, for this particular experiment, the reactivity ranged about -70 up to -4000 pcm, which corresponds to 55% and 25% of control banks withdrawn, respectively.

Through the acquired neutron signals the Auto Power Spectral Densities were obtained using a Multichannel Scaler (MCS-PCI board) attached in a desktop computer by a PCI Local Bus standard. The MCS board, which has no dead time between adjacent channels, records the counting rate of events in a given time bin (dwell time), and the APSD is obtained by a Fast Fourier Transform (FFT) algorithm using the LabView^{TM} software. In all cases, the APSD´s were obtained with 500 averages.

The prompt neutron decay constant (α) is then derived by a least squares fitting of the experimental APSD's through the theoretical model based on the standard point kinetic equations [22].

A. Nuclear Module

The ORTEC Model CO4020 Quad 4-Input Logic Unit [30] can provide several logic functions without the necessity of other logic modules in the electronic system acquisition. The function selected that is more useful to this work is the *Fan-in* and represents the *OR* logic operation. The selected function sums the neutron NIM fast negative logic pulses from the amplifier module. In a simplified mode the equation below represents the logic operation *OR*:

$$X = A + B + C + D \qquad (1)$$

X is the fast-NIM logic output signal and A, B, C and D are the input fast-NIM logic signals

The Fig. 2 represents the block diagram of the Model CO4020 Logic Unit and it shows the various combinations of logic functions that can be implemented[30].

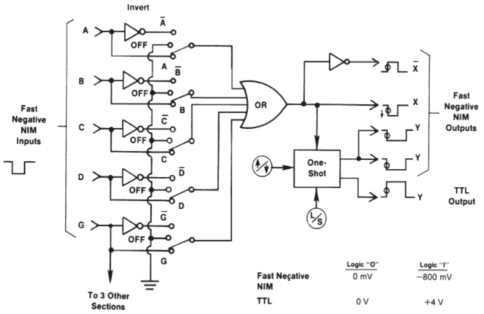

Fig. 2 – Block Diagram of the Model CO4020 Logic Unit

III. RESULTS

The results for the α parameter obtained from single detectors and pair combinations are shown in Fig. 3.

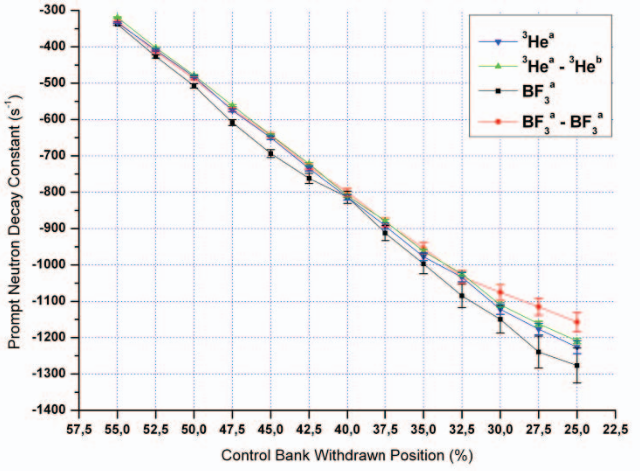

Fig. 3 – α results obtained through the ORTEC 4020 Quad 4-Input Logic Unit for single and detectors pair combination.

As can be seen from Fig. 3, the agreement of only one BF$_3$ detector (black line) with the ^{3}He detectors (blue and green lines) is not good, but there is an improvement when one more BF$_3$ detector is added (red line). However, the agreement is still not good for 30%, 27.5% and 25% of banks withdrawn, which represent more subcritical states. This means that the sum of the counts from two BF$_3$ detectors is not enough to give reliable results for these three subcritical states.

Fig. 3 also shows that the results for one ^{3}He detector and for the sum of two ^{3}He detector are almost the same, indicating that the individual ^{3}He detectors (a) and (b) already have enough sensitivity to give reliable results up to -4000 pcm, as expected [13]-[14].

Now, Fig. 4 shows the results for α obtained with one ^{3}He detector and the sum of three BF_3 detectors. As can be seen, there was a good improvement when three BF_3 detectors are used. For the last two bank positions there is still some disagreement, but to a lesser extent than the earlier case. Even so, the tendency for reach the ^{3}He detector results are clear.

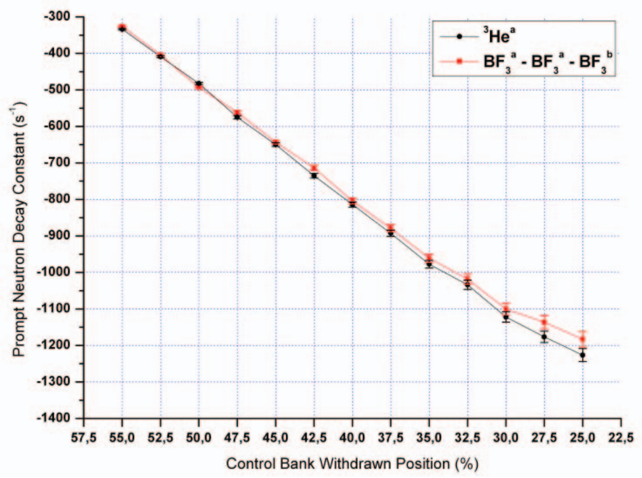

Fig. 4 - α results from a set of three BF_3 detectors and one single ^{3}He detector.

The uncertainty of the α parameter, obtained from the fitting procedure, also decreases as more detectors are employed. The decrease in the uncertainty of the α parameter can be seen in Table I.

TABLE I – COMPARISON IN PERCENTAGE OF THE PROMPT NEUTRON DECAY CONSTANT STANDARD ERROR.

Control Banks Position (%)	**Standard Error (S.E.)** BF_3^a A	 BF_3^a - BF_3^{-a} B	 BF_3^a - BF_3^{-a} BF_3^b C	**Decrease in percentage of Standard Error (%)** A - B	 B - C
55.00	3.13	2.36	2.04	24.69	13.56
52.50	4.45	3.11	2.66	30.08	14.47
50.00	6.06	4.01	3.46	33.79	13.72
47.5.	8.28	5.23	4.26	36.88	18.55
45.00	11.06	6.57	5.36	40.56	18.42
42.50	14.04	8.29	6.60	40.96	20.39
40.00	16.79	10.33	8.01	38.46	22.46
37.50	20.71	12.56	9.72	39.36	22.61
35..00	27.22	14.96	11.38	45.05	23.93
32.50	32.79	17.71	13.84	46.00	21.85
30.00	37.35	20.63	15.50	44.76	24.87
27.50	43.88	23.07	18.03	47.41	21.85
25.00	47.97	26.15	20.35	45.49	22.18

For a given state of the reactor, a low sensitivity detector also has low efficiency (in detected neutrons per all neutrons in the reactor) and this efficiency is a limiting factor for the discrimination of correlated neutrons to uncorrelated neutrons, i.e. the first plateau to the second plateau of the APSD's. The relative proportion of correlated noise to uncorrelated noise is crucial for the determination of any parameter from spectral densities [31]. Thus, the addition of more detectors is equivalent to increase the sensitivity and the efficiency of a single detector, and so increasing the correlated noise to uncorrelated noise ratio.

The increase of correlated to uncorrelated ratio can be seen in Fig. 5 which shows the APSD's for the more subcritical state (banks 25% withdrawn) obtained from two individual BF_3 detectors (in red and black) and for the sum of the two (in blue). The data that originated the APSD's are shown in Fig. 6 only for illustrative purposes.

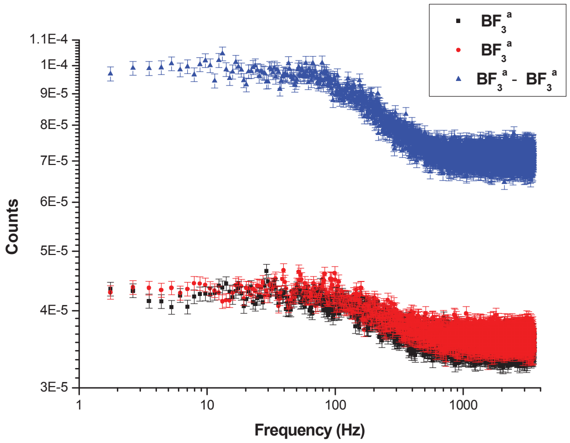

Fig. 5 – APSD obtained with two individual detectors and the sum of the two (banks position in 25%). Each point has an error bar, in %, given by [SQRT(500)]-1, were 500 is the number of averages.

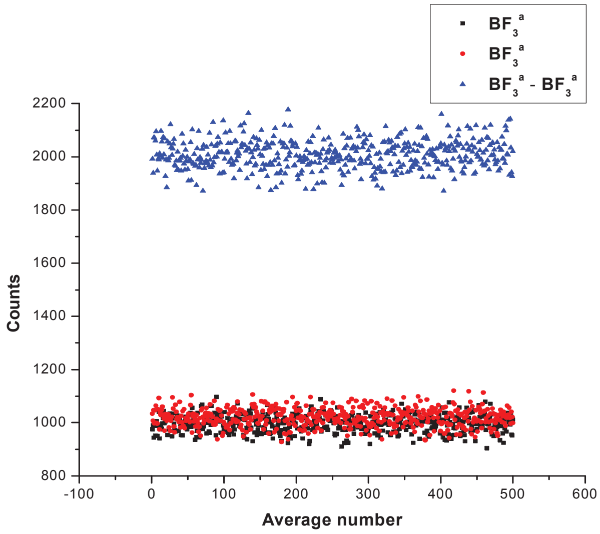

Fig. 6 – Raw data for obtaining the APSD's of Fig. 5.

IV. CONCLUSIONS

The logic pulse module was employed to the experimental determination of the prompt neutron decay constant (α) for all proposed subcritical states in the IPEN/MB-01. The experimental data were statistically improved because of the neutron counts were enhanced through this method. It impacts directly on the decrease of the standard error of the α parameter. In addition, it should be emphasized that in deeply subcritical states, where the macroscopic neutron noise technique tends to fail, the sum of the neutron counts contributed positively over the plateaus difference of the auto power spectral densities. The greater the difference between the plateaus, more reliable the α parameter result will be. It can be seen for the employment of three BF_3 detectors. The results are in agreement with one ^{3}He detector, though the last three subcritical states have coincided with 2σ.

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.

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