

## Rossi- $\alpha$ Experiment in the IPEN/MB-01 Research Reactor

R. Kuramoto, Adimir dos Santos, Rogério Jerez, Ulysses D'Utra Bitelli, Ricardo Diniz, Tufic Madi Filho, and Samuel C. Santos  
*Instituto de Pesquisas Energéticas e Nucleares - IPEN/CNEN*

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One major objective of this work is to experimentally estimate the following kinetic parameters on the IPEN/MB-01 research reactor at São Paulo: the effective neutron delayed fraction,  $\beta_{eff}$ , the prompt neutron generation time,  $\Lambda$ , and the ratio  $\beta_{eff}/\Lambda$ . In order to achieve our goal, we will use a microscopic noise technique called Rossi- $\alpha$  method. This method is based on the statistical nature of the fission-chain process. Using a coincidence acquisition system, the rationale is to experimentally determine the probability distribution of detecting neutrons from the same chain. Through a least-squares fit of this distribution we estimate the prompt neutron decay constant  $\alpha = (\beta_{eff} - \rho)/\Lambda$ . The  $\alpha$  parameter will be measured for three sub-critical levels using three different source configurations, and the ratio  $\beta_{eff}/\Lambda$  is obtained via a extrapolation to  $\rho = 0$ . A specific acquisition system for Rossi- $\alpha$  measurements has been developed in order to achieve our objective. This system is based on a multichannel scaler controlled by virtual instruments that records the timing of all neutron events, allowing data analysis during the acquisition. The first measurements were performed using two  $BF_3$  detectors positioned at the center of IPEN/MB-01 reactor core. In the future the same measurements described above will be performed using  $^3He$  and photodiode detectors. The photodiode detectors have been developed by the Reactor Physics Division of IPEN. In this work we will present a preliminary set of Rossi- $\alpha$  measurements performed on the IPEN/MB-01 research reactor at São Paulo.

### I. INTRODUCTION

The Rossi- $\alpha$  experiment, the first of the neutron counting techniques [1–3], was introduced by Rossi, who suggested that nuclear assemblies were self-modulating because of the presence of long chains and that prompt-neutron lifetime could be obtained by measuring the time average distribution of neutrons associated with a common ancestor. Nowadays, the Rossi- $\alpha$  experiment is one of the standard techniques of reactor noise analysis, and has been used currently for determining the prompt neutron decay constant  $\alpha = (\beta_{eff} - \rho)/\Lambda$ .

This technique is based on the fact that the occurrence of a fission in an assembly is nonrandom because the time correlation between neutrons that have a common ancestry. Using a coincidence acquisition system, the rationale is to experimentally determine the probability distribution of detecting neutrons from the same chain. To ensure that the time-correlated counts are not lost in the random background, the fission rate must be kept low enough to prevent any significant overlapping of chains in the assembly. The Rossi- $\alpha$  distribution, related to the correlation function of neutrons detection time series, can be derived theoretically through a birth-to-death probability balance equation. In this work we only consider the following Rossi distribution  $p_{rossi}$  for a point kinetic model without delayed neutrons[4]:

$$p_{rossi}(\tau) dt_g dt_c = \epsilon_g F_o dt_g \times \left( \epsilon_c F_o dt_c + \frac{\epsilon_c D}{2\alpha\Lambda^2} dt_c e^{-\alpha\tau} \right) \quad (1)$$

where:  $\tau = t_c - t_g$ .

The above expression can be heuristically derived.

The Rossi- $\alpha$  experiment is as follows. There are two input channels: a trigger channel with detection efficiency  $\epsilon_g$  and counting channel with efficiency  $\epsilon_c$ . Those two channels can be provided by either a single detector (auto-correlation) or

two separated detectors (cross-correlation). A time gate  $\Delta T$  divided in bins of width  $\delta t_c$  is opened at a certain time  $t_g$  by a pulse from the trigger channel. Some bins  $\delta t_c$  corresponding to the elapsed time between the occurrence of a pulse from the counting channel at  $t_g$  and this of the original trigger pulse are then incremented. Since a timemarking acquisition system is capable of recording all events of any detector and thus makes possible an offline data reduction, a time gate of width  $\Delta T$  is opened for each trigger pulse. This data processing is referred as to the Rossi- $\alpha$  type I in the literature.

According to Eq. (1), the number of coincidences counts  $n_{rossi}$  in a bin  $i$  corresponding to the lag  $\tau = i\delta t_c$  is given by:

$$n_{rossi}(\tau) = n_{rand} + n_{corr} e^{-\alpha\tau} \quad (2)$$

The uncorrelated or random component  $n_{rand}$  is:

$$n_{rand} = N_g \epsilon_c F_o \delta t_c \quad (3)$$

where  $N_g = \epsilon_g F_o T$ , the number of time gates, is proportional to the acquisition duration  $T$ . The correlated component  $n_{corr}$  is:

$$n_{corr} = N_g \epsilon_c \frac{D}{2\alpha\Lambda^2} \delta t_c \quad (4)$$

Assuming that the number of coincidences counts  $n_{rossi}$  approximately follows a Poisson distribution, its standard deviation  $\sigma_n$  is:

$$\sigma_n(\tau) = \sqrt{n_{rossi}(\tau)} \quad (5)$$

### II. PROPERTIES OF ROSSI- $\alpha$ DISTRIBUTION

The Rossi- $\alpha$  distribution is obtained by starting a clock at  $t = 0$ , with the arrival of each pulse. Each clock register the

arrival times of all following pulse and these times are registered in time bins ranging from 0 to a predefined value corresponding to a fixed observation window  $OW$ , chosen long enough to allow proper fitting of the Rossi- $\alpha$  distribution. Typical lengths for  $OW$  are several times the die-away time  $(1/\alpha)$ [5]. The distribution of the tallies among the different time bins provides the Rossi- $\alpha$  distribution  $n_{rossi}$  triggered by pulse pairs, e.g., a tally is only made when at least a pulse pair lays within the  $OW$ . The way the Rossi- $\alpha$  distribution is constructed is shown in Fig. 1.

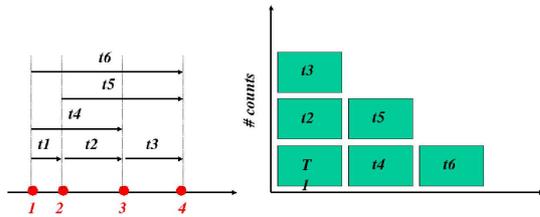


FIG. 1: The response of a quadruplet to the Rossi- $\alpha$  distribution.

### III. THE IPEN/MB-01 RESEARCH REACTOR - EXPERIMENTAL SETUP

The IPEN/MB-01 reactor[6] is a zero-power critical facility especially designed for measurements of a wide variety of reactor physics parameters to be used as benchmark experimental data for checking the calculational methodologies and related nuclear data libraries commonly used in the field of reactor physics. The IPEN/MB-01 reactor reached its first criticality on November 9, 1988, and since then it has been utilized for basic reactor physics research and as an instructional laboratory system. This facility consists of a  $28 \times 26$  square array of  $UO_2$  fuel rods, 4.3% enriched and clad by stainless steel (type 304) inside a light water tank. The control banks are composed of 12  $Ag - In - Cd$  rods and the safety banks of 12  $B_4C$  rods. The pitch of the IPEN/MB-01 reactor was chosen to be close to the optimum moderator ratio (maximum  $k_\infty$ ). This feature favors the neutron thermal energy region events. Fig. 2 shows the cross-section view of the IPEN/MB-01 reactor core.

During the execution of the experiment, both of the safety banks were kept completely far away from the 100% withdrawn position. In order to achieve the different subcriticality levels, the system is perturbed with the insertion of control rods. Different subcriticality levels have been measured depending on the position of these rods. The preliminary Rossi- $\alpha$  measurements were performed with the reactor being driven by the intrinsic source, for reactivities ranging from  $-30pcm$  to  $-10pcm$ . Two  $BF_3$  detectors were placed in the core (see Fig. 2). The two  $BF_3$  detectors were cross correlated with each other and electronically summed together and then auto-correlated as a single input signal.

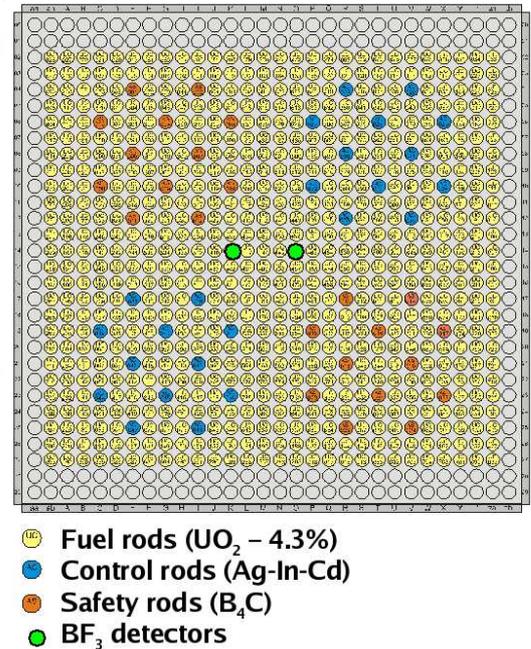


FIG. 2: Schematic view of the IPEN/MB-01 core.

### IV. ACQUISITION SYSTEM - VIRTUAL INSTRUMENTS

We have developed a new data acquisition system for Rossi- $\alpha$  measurements called IPEN/MB-01 Correlator (see Fig. 3), which is a Virtual Instrument (VI) that records the timing of all neutrons events, allowing on-line data analysis. The main part of our timemarking system is a Multi-Channel Scaler PCI card. The LabVIEW software is used to program the Multi-Channel Scaler. With dwell times from  $100ns$  to  $1300s$ , a memory length of 65536 channels, and input counting rates up to  $150MHz$ , the IPEN/MB-01 Correlator provide us a high time resolution.

### V. PRELIMINARY RESULTS

Fig. 4 shows one of the recorded Rossi- $\alpha$  distributions for a subcritical level of  $-13pcm$  together with the fitted curve according to the model given by Eq. (2). This curve was obtained with the reactor driven by the intrinsic source, and only one  $BF_3$  detector. The nonlinear regression method used to fit the curve is based on the Levenberg-Marquardt algorithm. For evaluating the goodness of fit, one uses graphical and numerical indicators ( $\chi^2_\nu$ ). The domain of fit range from 0 to  $50ms$ .

The signal-to-noise ratio for this configuration was 21.89%.

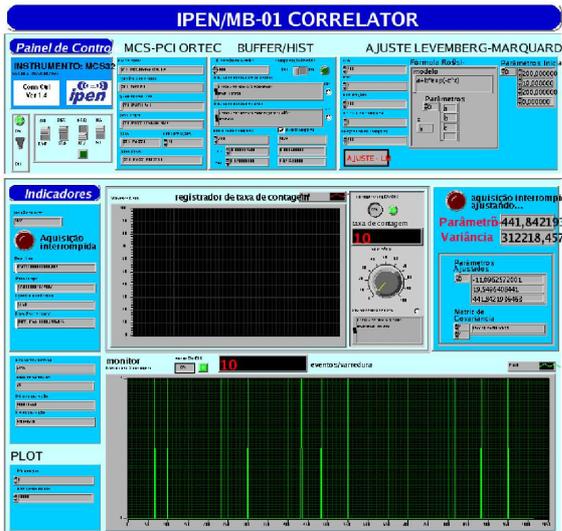


FIG. 3: The IPEN/MB-01 Correlator front panel.

Assuming an effective delayed neutron fraction of  $(7.42 \pm 0.07) \times 10^{-3}$  and a neutron generation time of  $(32.12 \pm 0.33) \times 10^{-6}s$ , which were calculated and measured previously, the  $\alpha$ -value of  $-250.38 \pm 4.55s^{-1}$  provide us a reactivity of:

$$\alpha = \frac{\rho - \beta_{eff}}{\Lambda} \rightarrow \rho = \Lambda\alpha + \beta_{eff} = -62.22 \pm 18.19pcm \quad (6)$$

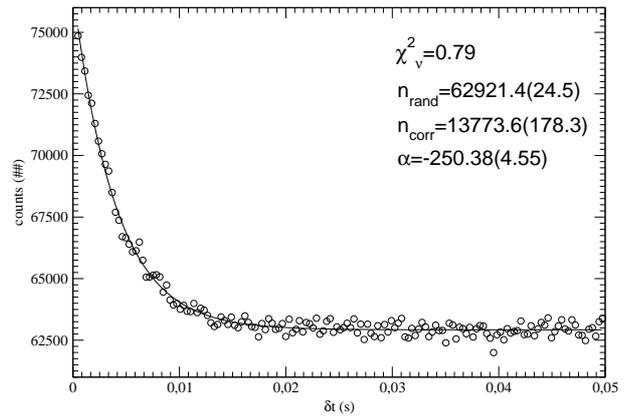


FIG. 4: Fit of the Rossi- $\alpha$  distribution for a subcriticality level of -13pcm.

This corresponds reasonable well with the estimated value by the control rods calibration.

**Acknowledgments**

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[1] R.E.Uhrig, *Random Noise Techiques in Nuclear Reactor Systems*, The Ronald Press Company (1970)  
 [2] M.M.R.Williams, *Random Processes in Nuclear Reactor*, Pergamon (1974)  
 [3] J.A.Thie, *Reactor Noise*, Rowman and Littlefield, Inc. (1963)  
 [4] C.James and G.Perret and G.Imel, *First MUSE-4 Experimental Results Based on Time Series Analysis*, PHYSOR (2002)  
 [5] M.Bruggeman, P.Baeten, W. De Boeck and R.Carchon, *Neu-*

*tron Coincidence counting based on time interval analysis with one- and two-dimensional Rossi-alpha distributions: an application for passive neutron waste assay*, Nucl. Instr. and Meth. 382(1996)511-518  
 [6] U.D.Bitelli, *Medida de Parâmetros Integrais no Reator IPEN/MB-01*, Master Thesis, IPEN (2001)