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VERIFICATION OF THE LINEARITY OF THE IPR-R1 TRIGA REACTOR POWER CHANNELS

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ABSTRACT

The aim of this paper is to verify the linearity of the three power channels of the IPR-R1 TRIGA reactor. Located at Nuclear Technology Development Center – CDTN in Belo Horizonte, the IPR-R1 reactor is a typical 100 kW Mark I light-water reactor cooled by natural convection. When the experiments were performed, the reactor core had 59 fuel elements, containing 8% by weight of uranium enriched to 20% in ^{235}U. The core has cylindrical configuration with an annular graphite reflector. The responses of the detectors of the Linear, Log N and Percent Power channels were compared with the responses of detectors which only depend on the overall neutron flux within the reactor. Gold and cobalt foils were activated at low and high powers, respectively, and the specific count results were compared with measurements performed, simultaneously, with a fission chamber, and with the power registered by the three channels. The results show that the Linear channel responds linearly up to 100 kW, and the Log N channel responses are linear at low powers. In the range of high power, the Log N and the Percent Power channels exhibit linearity only from 10 kW to 50 kW.

1 INTRODUCTION

During the start up tests, after placing the aluminum tank in the TRIGA reactor well, it was observed that the responses of the power channels above 50 kW were not linear. In order to determine the possible causes of this nonlinearity, the responses of the Linear, Log N and Percent Power channels were compared with the responses of detectors which were independent of the reactor instrumentation, and only depend on the global neutron flux. As independent detectors were used a fission chamber, and also gold and cobalt foils, which were irradiated in the rotary specimen rack with the reactor operating at several powers up to 100 kW. This paper presents the results of a set of experiments that were conducted to provide data to explain the problems described above. Nothing was found in relation to the Start-up channel which operates only in the subcriticality region and early stages of criticality.

2 THE IPR-R1 TRIGA REACTOR

The IPR-R1 TRIGA reactor core consists of a lattice of cylindrical fuel-moderator elements, in which the zirconium-hydride moderator is homogeneously combined with 20 % enriched uranium [1, 2, 3, 4]. The elements are arranged in five concentric rings, and the spaces between the rods are filled with water that acts as coolant and moderator. In total there are 91 locations in the core, which can be filled by fuel elements, graphite elements and other components. The power level is controlled with three control rods: Regulating, Shim, and Safety. Four channels monitor the power of the reactor and their rate of change. One fission chamber feeds the Start-up channel, two compensated ionization chambers feed the Linear and Log N channels, and one uncompensated ionization chamber feeds the Percent Power channel.

3 EXPERIMENTAL PROCEDURE

Due to the high absorption cross section, gold foils were irradiated, at low power, in the rotary specimen rack of the TRIGA reactor. They were irradiated, one at a time, at 0.2, 0.4, 0.6, 0.8 and 1.0 kW for 10 minutes. In the range of high power cobalt foils were used, and they were irradiated, one at a time, from 10 kW to 100 kW, raised in steps of 10 kW. Simultaneously with the cobalt irradiations, it was taken counts with a fission chamber, which was placed in a dry tube inside the reactor, 3 meters below the top of the tank.

The Linear channel was taken as reference for setting the desired power, since it provides more accurate readings.

4 DATA PROCESSING

The ^{198}Au and ^{60}Co gamma-ray peaks were counted using a NaI (Tl) detector. The count rates were corrected by the dead time of the detector and the background. The specific count (SC) is given by [5]:

$$SC = \frac{N}{G(t)\, m}$$

where N is the corrected count rate, G (t) is the self-shielding factor, and m is the foil mass.

The standard deviation of the specific count is:

$$\sigma_{SC} = SC \sqrt{\left(\frac{\sigma_N}{N}\right)^2 + \left(\frac{\sigma_m}{m}\right)^2}$$

the mass foil standard deviation was estimated to be 0.05 mg.

5 RESULTS

This section presents the results obtained. Due to small standard deviations of the results, the points plotted on the graphs cover them. The lines drawn in the figures were obtained from least squares fit of the experimental data points.

5.1 Measurements at Low Powers

Figure 1 shows the values of the gold specific counts versus low powers recorded by the Linear and Log N channels. The behaviors of these two channels responses are linear.

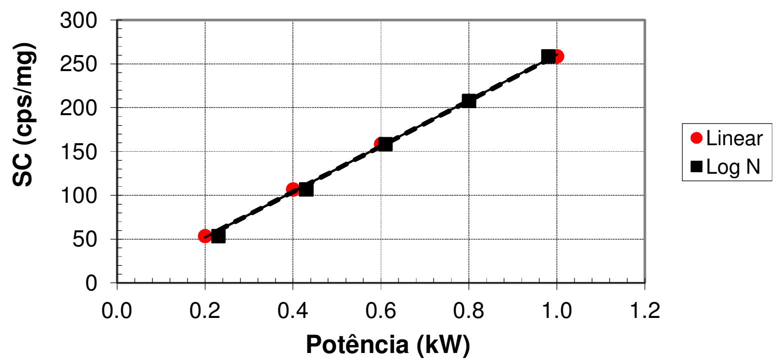

Figure 1: Gold specific count versus power.

5.2 Measurements at High Powers

In Figure 2 the cobalt specific counts are plotted as function of powers recorded by the Linear, Log N, and Percent Power channels. The observation of this figure shows that:

- Linear channel: the experimental points are well aligned from 10 to 100 kW;

- Log N channel: the power values recorded in this channel are smaller than the corresponding power in the Linear channel. The difference getting higher as the power increases. Up to 38 kW (equivalent to 50 kW in Linear channel) the experimental points are aligned. From 40 to 70 kW (60 to 100 kW in Linear channel) they are not aligned. From 50 kW to 60 kW (in the Linear channel) the Shim control rod was withdrawn and the Regulating rod was quite inserted. This caused a disturbance in the neutron flux recorded by the Log N channel detector, and the power recorded varied only from 40 to 45 kW.

- Percent Power channel: the values of the power readings are higher than their counterparts in the Linear channel. From 10 to 57 kW (10 to 50 kW in Linear channel) the points are well aligned. Above 66 kW (60 kW in Linear channel) the points deviate progressively from linearity.

Figure 3 shows the fission chamber count rates as function of the power values recorded by the three channels. The Linear channel response shows that the points are aligned up to 100 kW. The fission chamber responses as function of the power recorded by the Log N and Percent Power channels have the same behavior as the curves shown in Figure 2, only the first five points are aligned.

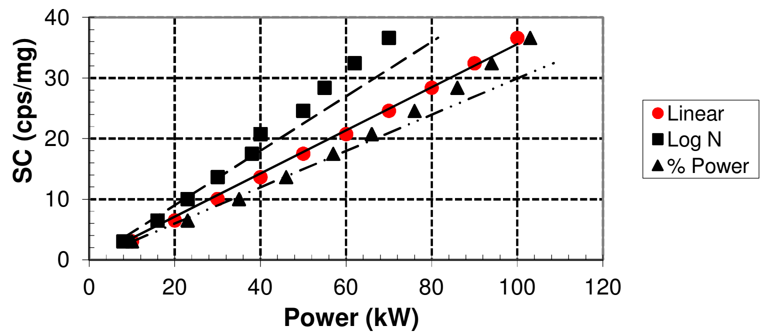

Figure 2: Cobalt specific count versus power recorded by the three channels.

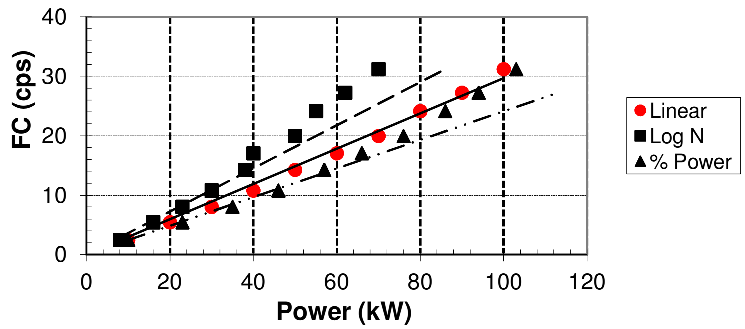

Figure 3: Fission chamber count rates versus power recorded by the three channels.

Figure 4 shows the fission chamber count rates versus the specific counts of the cobalt foils obtained in the irradiations from 10 to 100 kW. The points are aligned up to 100 kW.

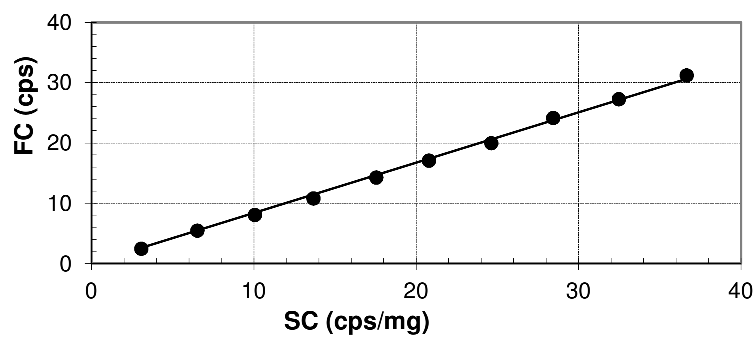

Figure 4: Fission chamber count rates versus cobalt specific counts.

In order to verify the behavior of the fission chamber and the three power channel responses associated with the control rod positions, measurements were performed with the fission chamber placed at three axial positions, and with the Regulating control rod in two extreme positions: fully inserted (IN) and withdrawn (OUT) from the reactor core.

Figures 5 and 6 show the results obtained with the fission chamber at Z = 2.0 m and 2.5 m axial positions, respectively versus the powers recorded by the Linear channel, with the Regulating rod inserted and withdrawn.

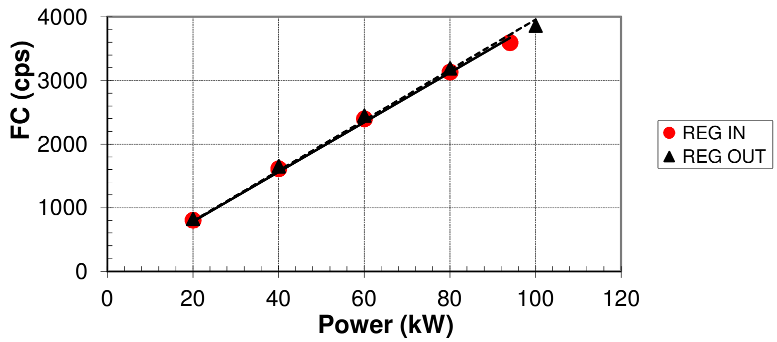

Figure 5: Influence of the control rod position in the fission chamber (at Z= 2.0 m) and Linear channel responses.

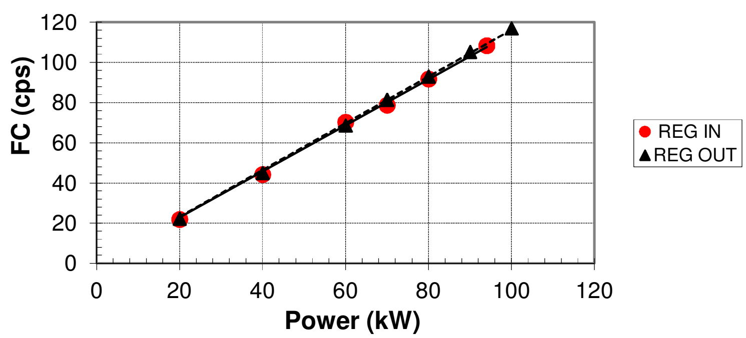

Figure 6: Influence of the control rod position in the fission chamber (at Z= 2.5 m) and Linear channel responses.

Figures 7, 8 and 9 show the results of the fission chamber at Z = 3.0 m as function of powers recorded by the three channels, with the Regulating rod inserted and withdrawn.

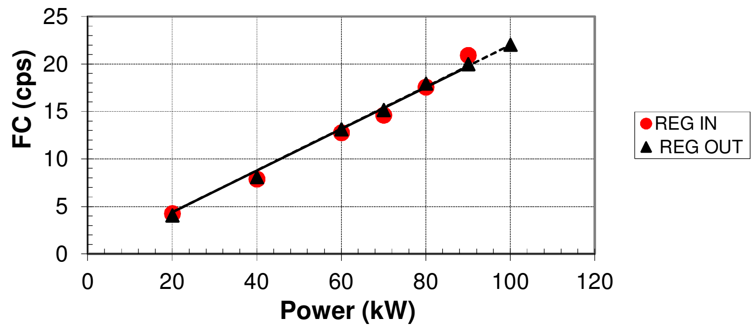

Figure 7: Influence of the control rod position in the fission chamber (at Z= 3.0 m) and Linear channel responses.

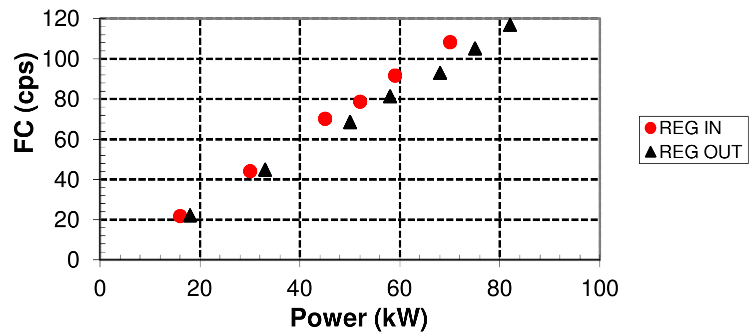

Figure 8: Influence of the control rod positions in the fission chamber (at Z= 3.0 m) and Log N channel responses.

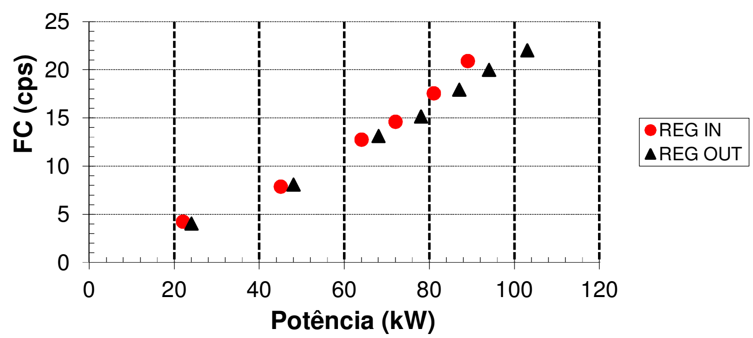

Figure 9: Influence of the control rod positions in the fission chamber (at Z=3.0 m) and Percent Power channel responses.

As expected, we see that the responses of the fission chamber are not influenced by the control rod movements (Figures 5 to 9). The losses due to detector dead time (τ = 3 μs [6]) are negligible.

The Linear channel response is not influenced by the control rod position (Figures 5, 6 and 7), while Figures 8 and 9 show that the power responses recorded by Log N and Percent Power depend on the position of the control rods.

It was calculated the average values of the fission chamber count rates from the results obtained with the Regulating rod at IN and OUT positions, for each particular power and position of the chamber. These data were then normalized for the point obtained at 20 kW and Z = 3.0 m. Figure 10 shows the average values as function of cobalt specific counts. For Z = 2.0 m the points are only aligned up to 60 kW. After this power, it seems to be lost in the fission chamber count. With the detector at Z = 2.5 m and 3.0 m, the results obtained are aligned for all powers.

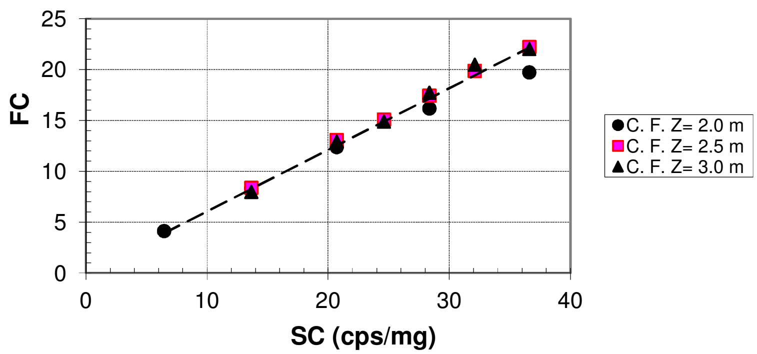

Figure 10: Average values of the fission chamber count rates versus cobalt specific counts.

6 CONCLUSIONS

The responses of Linear and Log N channels at low powers (from 0.2 kW to 1.0 kW) are linear, but there are small discrepancies between the readings of the two channels.

At high powers the three channels have the following behavior:

- The Linear channel responds linearly from 10 to 100 kW, and it is not influenced by the Regulating control rod position.

To verify if the power values reported by the Linear channel are actually correct, thermal power calibrations must be performed at least for two power values, for example 20 kW and 100 kW [4].

- The Log N and Percent Power channel responses are linear only from 10 to 50 kW (values in Linear channel). If the power values recorded by the Log N and Percent Power channels are compared with the powers recorded in the Linear channel, it is observed that the difference increases with increasing reactor power.

At high powers, the responses of the Log N and Percent Power channels are influenced by the positions of the control rods, especially the Regulating rod, but this fact is not solely responsible for the differences in power readings in these channels. Possible causes of the discrepancies such as the operation of the compensated and uncompensated ionization chambers and their associated electronics, the position of these detectors in the core, etc. should be checked.

These discrepancies in the power values have accompanied the TRIGA for a long time, and do not cause major problems for operation at 100 kW, but for safety reasons this matter should be examined, especially considering the reactor power increasing to 250 kW. It should be noted that the lack of linearity of the chambers has changed in the last years.

7 ACKNOWLEDGMENTS

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