2013 International Nuclear Atlantic Conference - INAC 2013
Recife, PE, Brazil, November 24-29, 2013
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: **978-85-99141-05-2**

Determination of Buckling in the IPEN/MB-01 Reactor in Cylindrical Configuration

Rafael Turrini Purgato[1], Ulysses d´Utra Bitelli[1], Vitor Ottoni Aredes[1], Alexandre F. Póvoa da Silva[1], Diogo Feliciano dos Santos[1], Luís Felipe L. Mura[1] and Rogério Jerez[1]

[1] Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
rtpurgato@ipen.br
ubitelli@ipen.br

ABSTRACT

One of the key parameters in reactor physics is the buckling of a reactor core. It is related to important parameters such as reaction rates, nuclear power operation, fuel burning, among others. In a critical reactor, the buckling depends on the geometric and material characteristics of the reactor core.

This paper presents the results of experimental buckling in the reactor IPEN/MB-01 nuclear reactor in its cylindrical configuration with 28 fuel rods along its diameter. The IPEN/MB-01 is a zero power reactor designed to operate at a maximum power of 100 watts, it is a versatile nuclear facility which allows the simulation of all the characteristics of a large nuclear power reactor and ideal for this type of measurement.

We conducted a mapping of neutron flux inside the reactor and thereby determined the total buckling of the cylindrical configuration. The reactor was operated for an hour. Then, the activation of the fuel rods was measured by gamma spectrometry on a rod scanner HPGe detector. We analyzed the gamma photons of the ^{239}Np (276,6 keV) for neutron capture and the ^{143}Ce (293,3 keV) for fission on both ^{238}U and ^{235}U, respectively. We analyzed the axial and radial directions. Other measurements were performed using wires and gold foils in the radial and axial directions of the reactor core.

The results showed that the cylindrical configuration compared to standard rectangular configuration of the IPEN/MB-01 reactor has a higher neutron economy, since in this configuration there is less leakage of neutrons. The Buckling Total obtained from the three methods was **95.84 ± 2.67 m^{-2}**.

1. INTRODUCTION

The nuclear reactor is a zero power reactor IPEN/MB-01 designed to operate at a maximum power of 100 watts, is a nuclear facility that allows the simulation of all the characteristics of a nuclear reactor for large-scale, without the need to build a complex heat removal system. These reactors represent a basic tool that allows researchers to study not only by theoretical calculations, but also with experimental measurements, the performance and characteristics of the core of a power reactor, prior to its effective installation, simulating the conditions of the project itself installation.

Given the flexibility of IPEN/MB-01 reactor, one of the possible configurations of the core is cylindrical, used in this work, with 28 diameter fuel rods and 48 guide tubes, designed for neutron absorbing rods (control rods and safety), see figure 1. This configuration was chosen because among those critical cylindrical configurations have the lowest excess reactivity, only 300 pcm. This ensures that the operation of the reactor control rods are withdrawn well thereby minimizing disturbance to the neutron flux within the reactor core, thereby increasing the length of the asymptotic region neutron flux.

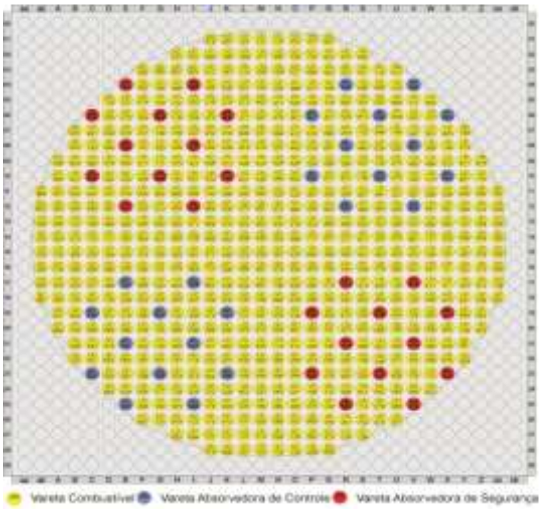


Figure 1: cylindrical reactor configuration IPEN/MB-01

Many of the nuclear parameters are obtained from gamma spectrometry of a target irradiated in a reactor core of research. [1] This irradiation causes activation of the target material can be, for example, gold foil, indium and nickel, which enables through measurement of the activity induced obtain relevant parameters, such as irradiation time, the timing the delay time for the count (decomposition), the counting efficiency of the cross-section for the nuclear reaction, to determine the neutron flux in the place where they were irradiated. The values obtained allow to know the extent of the asymptotic region of the reactor core (free from disturbance of the core interfaces), and the curvature of the neutron flux [2].

Knowledge of the neutron leakage from the reactor core is a fundamental problem of Reactor Physics, known as the balance of neutrons in the reactor core (absorption and leakage) can accurately estimate very important parameters, such as nuclear reaction rates, power operation, fuel burning, among others [3]. The escape probability of neutrons is a parameter that is directly related to the curvature of neutron flux inside the reactor core, this parameter known as "Buckling" [4].

There are two types of buckling: geometric and material. The material depends on the composition of the constituent materials of the reactor core and is given in the construction project. The geometric depends on the geometry and dimensions of the core and therefore may be changed according to the assembled configuration. In a critical system Buckling the geometric and material have the same value.

Thus, the determination of Buckling may be considered by the geometry of the reactor core. One of the possible configurations of the nuclear reactor is IPEN/MB-01 cylindrical configuration, studied in this work. The Buckling [5] in this case is given by equation 1:

$$B_g^2 = \left(\frac{2{,}405}{R_{eff}}\right)^2 + \left(\frac{\pi}{H_{eff}}\right)^2 \qquad (1)$$

where:

B_g is the geometric Buckling;

R_{eff} is the effective radius obtained in the radial direction.
He_{ff} is the effective height with measurements obtained in the axial direction.

The values of effective radius and height are obtained experimentally from detection range and computational calculations, hence the Buckling of cylindrical reactor core is determined.

2. METHODOLOGY

For the experimental data were irradiated fuel rods, gold thread and gold foil. For the fuel rods, the reactor was critical at 30 watts for 1 hour. A new fuel rod was used to acquire data for mapping axial flow, located in the central region of the reactor core.

Spectrometry was performed range from fuel rods irradiated using a hyperpure germanium detector (HPGe). To measure the neutron flux profile was analyzed epithermal of 276.6 keV gamma photon emission with probability 14.28% of ^{239}Np.

To measure the relative profile of thermal neutron flux was analyzed the photon gamma of ^{143}Ce 293.3 keV with the emission probability of 42.8%. The ^{143}Ce is a product of fission ^{235}U by thermal neutrons and has the advantages of having a reasonable fission yield (~ 6%) and a sufficiently long half-life (33 hours) for a spectral analysis of gamma rays.

The radial flow was obtained for the directions north-south and east-west. The count (C_{net}) obtained with the detector was held at 364mm axial dimension which corresponds to half the active length of the core. The Real Time used was 1800 seconds.

In counting Axial counts (C_{net}) were made of the photopic range for emission energies of ^{239}Np and ^{143}Ce in 29 regions 20mm axial separate from one another, lasting 30 minutes each region. The rod used was withdrawn in position M14 central core of the reactor.

The counts were corrected due to decay (2) and deviations in the rates of corrected counts were considered (3) using the decay constants of ^{239}Np (λ = 3.41 x10^{-6} s^{-1}) and ^{143}Ce (λ = 5,83x10^{-6} s^{-1}).

$$C_{corrigido} = \frac{C_{Net}}{LT}\, e^{\lambda TE} \qquad (2)$$

$$\sigma^2_{C_{cor}} = \left(\frac{C_{cor}}{C_{Net}}\right)^2 \sigma^2_{C_{Net}} \qquad (3)$$

Still, to obtain the corrected counts, was essential to record the waiting time between the end of irradiation and the time of measurement (TE).
Similarly, 02 irradiations were performed for the gold wires on one another in the axial direction and radial, both at central locations in the reactor core. The irradiation was carried out at full power operation of the reactor IPEN/MB-01, that is, 100 W, the irradiation times were 2 hours in the axial direction and the radial 01 hours. The same data and equations (2) and (3) used for the rods were used for the wires. However, scores were recorded every 20

mm along the wire for a one hour time in each of these positions. The decay constant for gold is $\lambda = 2.97$ x10-6 s^{-1}.

Irradiation and for positioning the center of the reactor core, the gold foils were placed on a acrylic plate and the system was irradiated with a 100 Watt 1 hour.

Data were entered into the Origin software and settings for the values of effective radius and height, radial and axial directions, respectively, were determined with cosine adjustments for axial and Bessel functions for radial.

3. RESULTS

The values for the corrected counts as a function of the position of the fuel rods are shown below.

In figure 2 is shown the distribution profile of the epithermal neutron flux in the radial direction East - West and also the adjustment made to determine the effective radius.

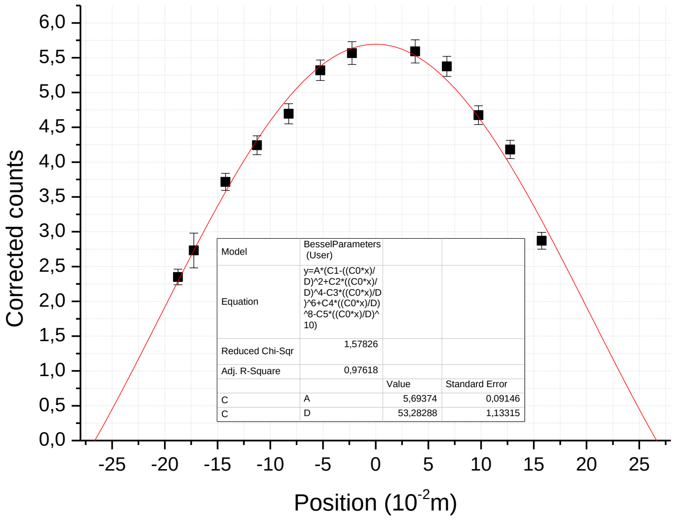
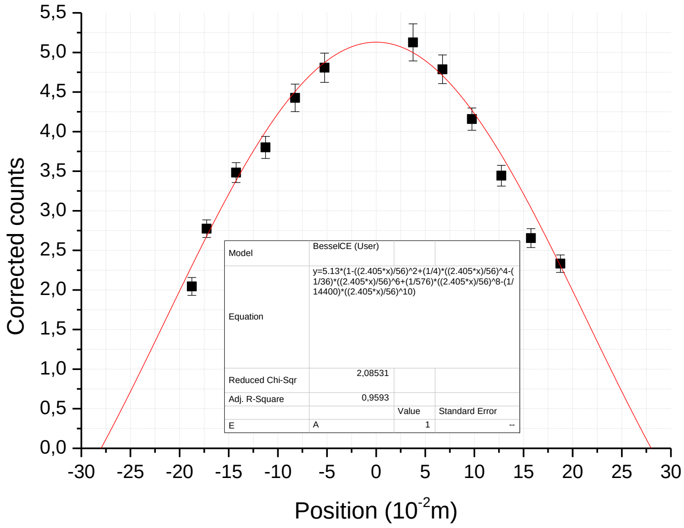


Figure 2: Chart Position Counts by East-West direction - Np-239

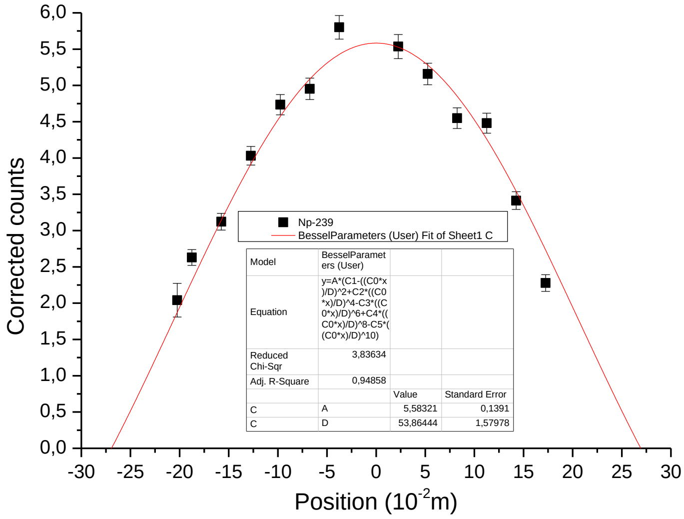
Figure 3 shows the profile of the distribution of the thermal neutron flux in the radial direction East-West and the adjustment made to determine the effective radius.



Model	BesselCE (User)		
Equation	y=5.13*(1-((2.405*x)/56)^2+(1/4)*((2.405*x)/56)^4-(1/36)*((2.405*x)/56)^6+(1/576)*((2.405*x)/56)^8-(1/14400)*((2.405*x)/56)^10)		
Reduced Chi-Sqr	2,08531		
Adj. R-Square	0,9593		
		Value	Standard Error
E	A	1	--

Figure 3: Chart Position Counts by East-West direction - Ce-143

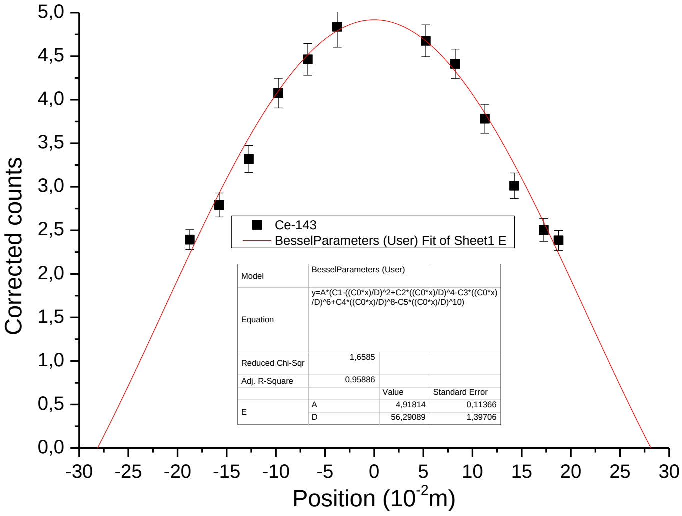
In figure 4 is shown the distribution profile of the epithermal neutron flux in the radial direction North-South and also the adjustment made to determine the effective radius.



Model	BesselParameters (User)		
Equation	y=A*(C1-((C0*x)/D)^2+C2*((C0*x)/D)^4-C3*((C0*x)/D)^6+C4*((C0*x)/D)^8-C5*((C0*x)/D)^10)		
Reduced Chi-Sqr	3,83634		
Adj. R-Square	0,94858		
		Value	Standard Error
C	A	5,58321	0,1391
C	D	53,86444	1,57978

Figure 4: Chart Position Counts by North-South direction - Np-239

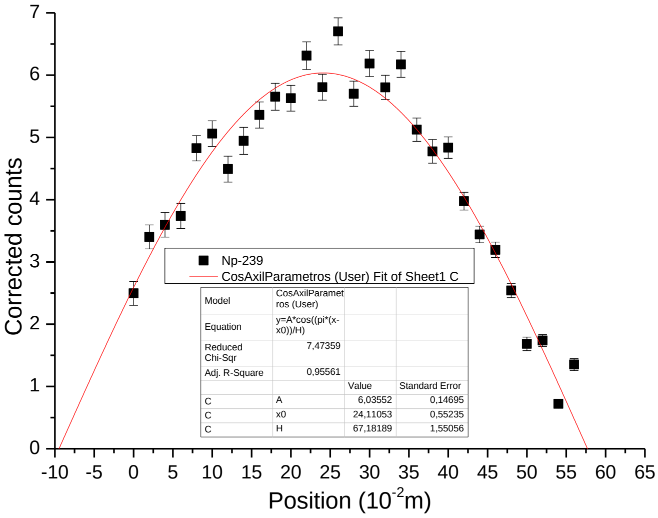
In figure 5 is shown the distribution profile of the thermal neutron flux in the radial direction North-South and also the adjustment made to determine the effective radius.



Model	BesselParameters (User)		
Equation	y=A*(C1-((C0*x)/D)^2+C2*((C0*x)/D)^4-C3*((C0*x)/D)^6+C4*((C0*x)/D)^8-C5*((C0*x)/D)^10)		
Reduced Chi-Sqr	1,6585		
Adj. R-Square	0,95886		
		Value	Standard Error
E	A	4,91814	0,11366
	D	56,29089	1,39706

Figure 5: Chart Position Counts by North-South direction - Ce-143

The graphics with adjustments in the axial direction of the measures for the central core rod of the rods are shown in Figures 6 and 7.



Model	CosAxilParametros (User)		
Equation	y=A*cos((pi*(x-x0))/H)		
Reduced Chi-Sqr	7,47359		
Adj. R-Square	0,95561		
		Value	Standard Error
C	A	6,03552	0,14695
C	x0	24,11053	0,55235
C	H	67,18189	1,55056

Figure 6: Adjust the counts in the axial direction for epithermal neutrons.

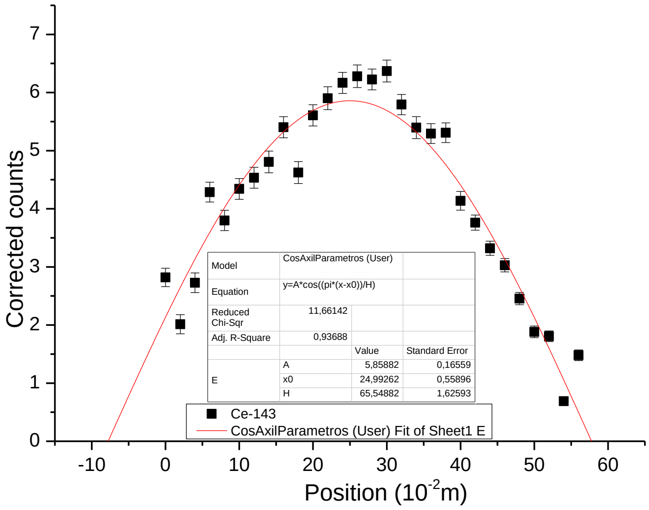


Figure 7: Adjust the counts in the axial direction for thermal neutrons.

Based on the graphs of Figures adjustments from 2 to 7 were obtained ray effective height and the total Buckling and from the reactor fuel rods for thermal and epithermal neutrons. Table 1 shows these results.

Table 1: Total Buckling of Fuel Rods

	Np^{239}(epithermal)	Ce^{143}(thermal)
R_{eff}	26.93 ± 1.58 cm	28.15 ± 1.40 cm
H_{eff}	67.18 ± 1.55 cm	65.55 ± 1.63 cm
B^2_{total}	**101.61 ± 6.10 m^{-2}**	**95.98 ± 4.80 m^{-2}**

The following are graphs with the flow profiles obtained for the gold wires in the radial and axial Figures 8 and 9.

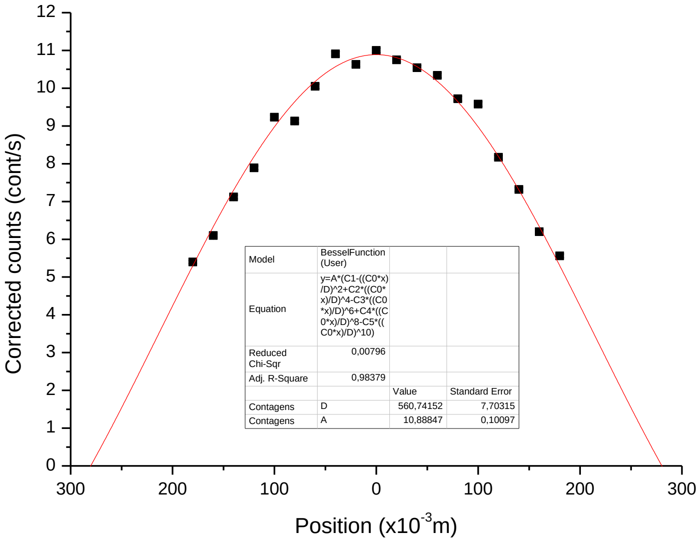


Figure 8: Radial adjustment for the gold wire

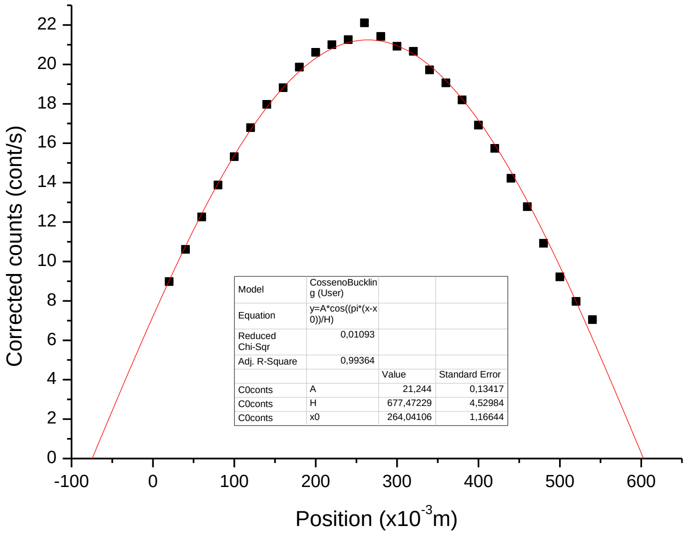


Figure 9: Axial adjustment for the gold wire

The settings for the gold wire possible to obtain the effective radius and height of the reactor core and thereby obtaining the full Buckling (1) to the cylindrical configuration. Table 2 shows these results.

Table 2: Total Buckling gold wires

	Results Obtained
R_{eff}	28.04 ± 0.77 cm
H_{eff}	67.75 ± 0.45 cm
$B^2{}_{total}$	**95.08 ± 2.85 m^{-2}**

The following are the charts with the flow profiles obtained for the gold foils in the radial and axial directions, respectively, Figures 10 and 11.

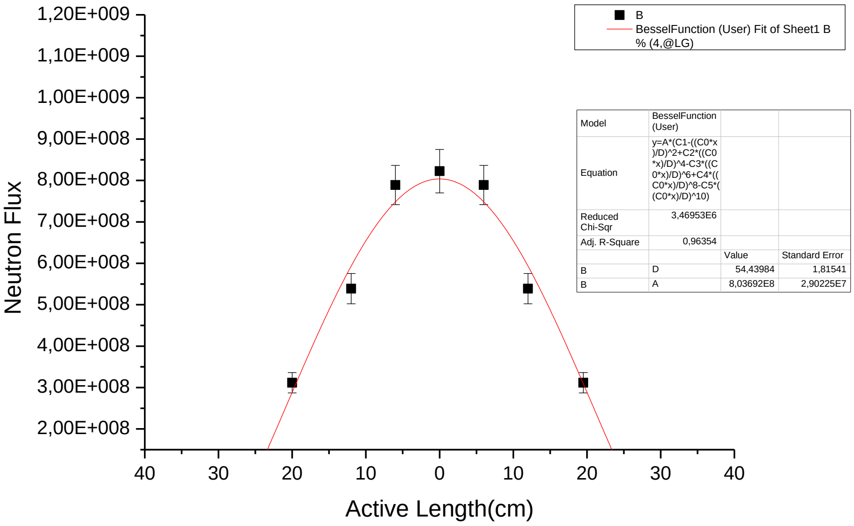


Figure 8: Radial adjustment for the gold foils

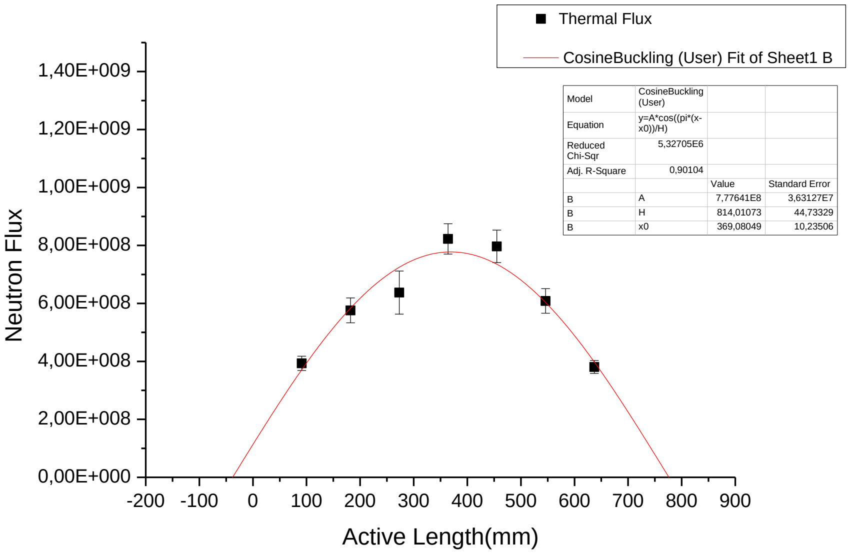


Figure 11: Axial adjustment for the gold foils

With the adjustments made for gold foils, there was obtained the effective radius and height of the reactor core IPEN/MB-01 and thus its overall buckling. Table 3 shows the results.

Table 3: Total Buckling gold foils

	Results Obtained
R_{eff}	27.22 ± 1.82 cm
H_{eff}	81.40 ± 4.47 cm
B^2_{total}	**92.96 ± 6.51 m^{-2}**

Based on the data obtained in the four calculations performed for the measurement of Buckling was determined buckling total reactor from obtaining the weighted average of the four measures, as well as the uncertainty associated with the calculation [6].

4. CONCLUSIONS

The results obtained in this work can be stated that the Buckling is a measure of the leakage neutrons in the reactor and the smaller the size of a nucleus, the greater the buckling, ie, the greater the curvature of the flow with higher leakage neutrons.

The larger curvatures were observed for epithermal neutrons in the case of rods, and indicate higher values of Buckling and therefore leaky, which is already expected due to its higher energy compared to thermal neutrons.

For the radial directions of highest values were observed Buckling since that direction has the smaller core causing higher leakage.

It is also verified that the Buckling is independent of power level, since when the output changes, the neutron flux changes in all dimensions proportionally core, ie the shape of the neutron flux distribution is unchanged.

The weighted average of the four results allowed the determination of Buckling Total reactor IPEN/MB-01 for its cylindrical configuration studied in this work and this value was **95.84 ± 2.67 $\mathbf{m^{-2}}$**.

ACKNOWLEDGMENTS

My acknowledgments to all the staff of the Centre for Nuclear Engineering (CEN) Institute of Nuclear and Energy Research, for their support, assistance and knowledge sharing during the experiments.

REFERENCES

1. Profio, A.E. *Experimental Reactor Physics*. New York, Wiley, 1976.

2. Bitelli, Ulysses d' U. et alli. *Medida do Buckling na Unidade Critica IPEN/MB-01. X ENFIR,7-11 Agosto de 1995, Aguas de lindóia, SP, Brasil.*

3. Lamarsh, J.R., Baratta A.J, *Introduction to Nuclear Engineering*, Third Edition, Prentice Hall, Inc (2001).

4. Zamboni, C. B. and others, *Fundamentals of Physics Neutron*, Publisher of the Physical Bookstore (2007).

5. LAMARSH - *Theory of Nuclear Reactors*, New York University, EUA.

6. Zijp, W. L., *Treatment of Measurement Uncertainties*, ECN-194, January (1987).