



## OPERATIONAL PARAMETERS STUDY OF IPR-R1 TRIGA RESEARCH REACTOR USING VIRTUAL INSTRUMENTS

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**Abstract.** *The instrumentation of nuclear reactors is designed with the principle of reliability, redundancy and diversification of control systems. Reliable monitoring of the parameters involved in the chain reaction is of crucial importance with regard to efficiency and operational safety of the installation. The main goal of the simulation system in developing proposed is to provide the study and improvement the understanding of how these operational variables are interrelated and their behavior, especially those related to neutronic and thermohydraulics. The work will be developed using the software LabVIEW® (Laboratory Virtual Instruments Engineering Workbench). The program will enable the study of the variables involved in the operation of the installation throughout its operating range, i.e. a few mW up to 250 kW. The IPR-R1 TRIGA is a research nuclear reactor placed in a pool open and cooled by light water natural circulation. Is located in the Nuclear Technology Development Center (CDTN), in Belo Horizonte Brasil. The developing system employs the modern concept of virtual instruments (VIs), using microprocessors and visual interface on video monitors. LabVIEW® breaks the paradigm of text-based programming language, for programming based on icons. The system will enable the use of this reactor in training and personnel training in the nuclear field. The work meets the recommendations of the International Atomic Energy Agency (IAEA), which has encouraged its members to develop strategic plans for the use of their research reactors.*

**Keywords:** *Instrumentation, TRIGA Nuclear Research Reactor, LabVIEW®, Neutronics Parameters, Simulation.*

### 1. INTRODUCTION

In the IPR-R1 TRIGA reactor the operational variables are shown by analog indicators located on the console. The operators register the most important operation parameters manually. The console uses discrete electronic components and the logic of operation is carried out by electromagnetic relays. The CDTN intends to adopt in its laboratories the ISO standards, for example, the standard ISO IEC 17025 (2005) to show reliability in their results. In accordance with ISO 9000, an institution must meet certain requirements to be certified. Among these, we can cite: measure and monitor the processes to ensure the quality of the product service through performance indicators and standard deviations; implement and maintain appropriate records and to ensure the traceability of the process and carry out systematic reviews of the processes and of the quality system to ensure its effectiveness.

This article presents a system, in developing, in order to simulate the IPR-R1 operation, through virtual instruments, aiding in the understanding of the behavior of the operating variables. This work will contribute to the use of IPR-R1 in research and training, in addition to attend the recommendations of the International Atomic Energy Agency (IAEA), which has encouraged its members to draw up strategic plans for the use of their research reactors (IAEA, 2001).

## 1.1 Kinetics and control of nuclear reactors

It will be described below in summary mode, some basic principles concerning operation of nuclear reactors that will be simulated by the system in development

The importance of nuclear fission, from the point of view of their use in power generation, is due to three factors. First, the process is associated with the release of a large amount of energy per unit mass of fuel. Second, the fission reactions, which are initiated by neutrons, are followed by the release of an average of 2.5 new neutrons (fission of  $^{235}\text{U}$ ). Third, the fact that some neutrons generated in fission only appear with certain delay after fission, causing the rate of growth has a great reduction, enables the control of the reaction. The combination of these factors led to the design of nuclear reactors, in which the sustainable chain reaction occurs with the continuous and controlled release of energy (Lamarsh and Baratta, 2001).

For the delayed neutron fraction is used the symbol  $\beta$  and for the effective amount of delayed neutron fraction is used the symbol  $\beta_{\text{eff}}$ . The value of  $\beta_{\text{eff}}$  for a given reactor varies with the average energy of the neutrons that produce fission. For the TRIGA reactor IPR-R1 the  $\beta_{\text{eff}}$  is 0.0079. The chain reaction can be described quantitatively in terms of the multiplication factor  $k$ , which is defined as the reason of the number of fissions of a generation divided by the number of fissions of the previous generation.

The basic purpose for nuclear reactor control system is to provide means of starting the reactor, raise the power up to a certain level, maintain this level and turn it off in the context of routine operations. In normal working conditions the core operates too close to criticality ( $k \approx 1.0$ ). Minor deviations of  $k$  above or below 1, will result in negligible changes in reactor power. In practice the term reactivity ( $\rho$ ) is used to indicate how much the reactor is away from criticality ( $k=1$ ) or, as in fraction multiplication factor, system clearance of critical position. This is the most important operating parameter of a nuclear reactor. The expression that relates the reactivity ( $\rho$ ) with the addition multiplication factor ( $\delta k$ ) that is given by Eq. (1) (Mayo, 2001).

$$\rho = \frac{\delta k}{1 + \delta k} \quad \rho = \frac{k - 1}{k} \quad (1)$$

The normal operations of a reactor involve small changes of  $k$  (around 1), for example  $k = 1.003$  means a  $\delta k = 0.003$ . The TRIGA reactor routine departure IPR-R1 is held by the total withdrawal of the safety rod, which is available for the fast reactor shutdown. Then the control rod is built in small steps and then does the same with the a regulation rod. Every step ( $\delta k$ ) in the movement of the control bars is followed by neutronic growth. Is defined as period ( $T$ ) s for the time that this growth change by a factor equal to the number "e" (2, 718 ...). From the definition of the period is found the expression for the neutronic growth, which is directly proportional to the power of the reactor, given by Eq. (2), (Böck, and Villa, 2004).

$$N(t) = N_0 * e^{t/T} \quad (2)$$

Where:

$N$  = neutron flow at any given time.

$N_0$  = initial neutron flow.

$T$  = reactor period (s)

$t$  = time (s).

The equation known as the inhour equation, which relates the reactivity  $\rho$  and a stable period ( $T$ ), with  $k \approx 1$  is given by Eq. (3) (CDTNCNEN, 1997) (CDTNCNEN, 2007)

$$\rho = \frac{\ell}{T(1 + \delta k)} + \sum_{i=1}^6 \frac{\beta_i}{1 + \lambda_i T} \quad (3)$$

Where:

$\ell$  = average life time of neutron (neutron generation time) in (s), that for the IPR-R1 TRIGA  $\approx 100 \mu\text{s}$ ;

- $T$  = reactor period (s);  
 $\delta k$  = multiplication factor addition;  
 $\beta_i$  = delayed neutron fraction of group  $i$ ;  
 $\lambda_i$  = decay constant of delayed neutron group  $i$  ( $s^{-1}$ ).

## 2. NUCLEAR RESEARCH REACTOR TRIGA IPR-R1

TRIGA reactors (*Training Research Isotope General Atomics*) are the most widely used research reactors in the world. There are currently 65 reactors of this type in operation installed in 25 countries. The company General Atomics (GA), manufacturer of TRIGA reactors, since the late 1950, continues to design and install these reactors. They are built in various configurations and powers ranging from 100 kW to 16 MW. (General Atomic, 2013).

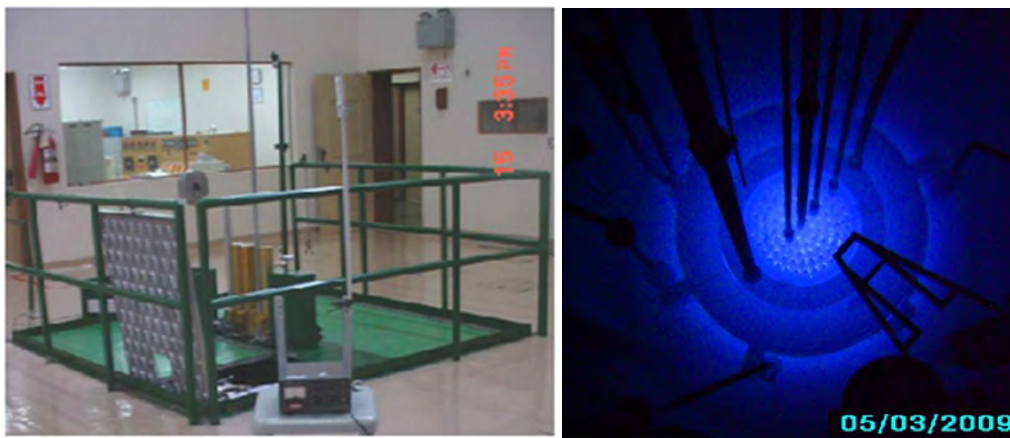


Figure 1. Pool and core of IPR-R1 TRIGA nuclear reactor

Figure 1 shows two photographs of the pool and the core of IPR-R1 TRIGA. In the figure it can see the radiation of Cerenkov when the reactor is in operation.

The initial maximum power of the IPR-R1 reactor was 30 kWt. Additional fuel elements inserted in the reactor core allowed the increase of power to 100 kWt, which is the reactor's maximum licensed power. In 2004 the reactor's core underwent modifications and new fuel elements were added, allowing a maximum power of 250 kW level.

A TRIGA (Training, Research, Isotopes, General Atomics) reactor remarkable characteristic is its inherent safety, which explains why it is normally installed in universities, hospitals, industries and research centers in several countries and why its main application is training, as hinted by its acronym.

The IPR-R1 reactor is a demineralized light water research reactor using uranium metallic alloy fuel with Zirconium hydrate (U-ZrH) moderator, containing 8% to 8.5%  $^{235}\text{U}$  enriched uranium (in weight). The reactor's core has a cylindrical arrangement with 63 fuel elements, 59 of them being original elements with aluminum cladding and four newly inserted having inox cladding. The fuel elements also serve as the reactor's moderator. (Souza et al, 2002) (Dalle, 2005).

The power of the reactor is controlled by three independent neutron absorber bars. The two main power measurement channels are the Linear and Logarithmic Channel, which are made up of ionization chambers sensitive to neutron flow, installed around the core. The two channels are designed in order to monitor the development of the neutron flow, with the same precision, from a few mW up to the maximum power of 250 kW.

## 3. VIRTUAL INSTRUMENTS (VI)

The proposed system will be developed using the software LabVIEW<sup>®</sup> (*Laboratory Virtual Instruments Engineering Workbench*) (National Instruments Co., 2007). This program uses the modern concept of virtual instruments (VI's), using microprocessors and visual interface on video monitors. The icons in the LabVIEW<sup>®</sup> represent controls and available functions in the software menus, called visual programming. LabVIEW<sup>®</sup> breaks the paradigm of text-based

A.J. Pinto, A.Z. Mesquita, F. S. Lameiras  
 Operational Parameters Study of IPR-R1 TRIGA Research Reactor using Virtual Instruments

programming language, for programming based on icons. The user interface consists of two parts, which are: the front panel and block diagram, similar to traditional instruments that have a front panel and the printed circuit board on which the electronic circuit. On the front panel of LabVIEW® can be created the control buttons, keys, leds and displays graphics to display the data, as shown in Figure 2. While in the block diagram there are blocks that, properly interconnected, constitute the electronic circuit, as in the example shown in Figure 3.

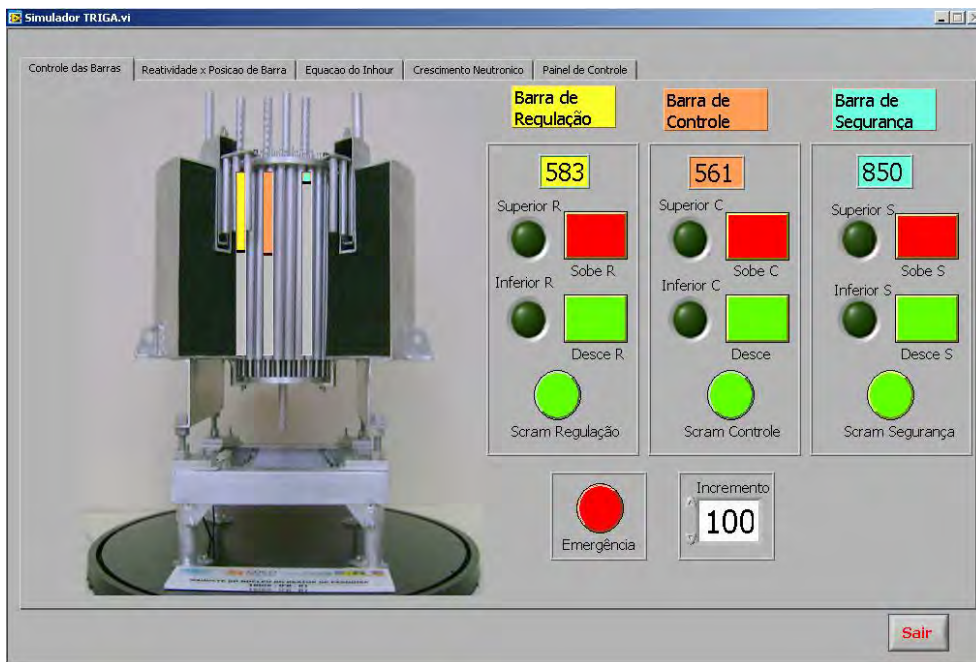


Figure 2. Example of a front panel developed in LabVIEW

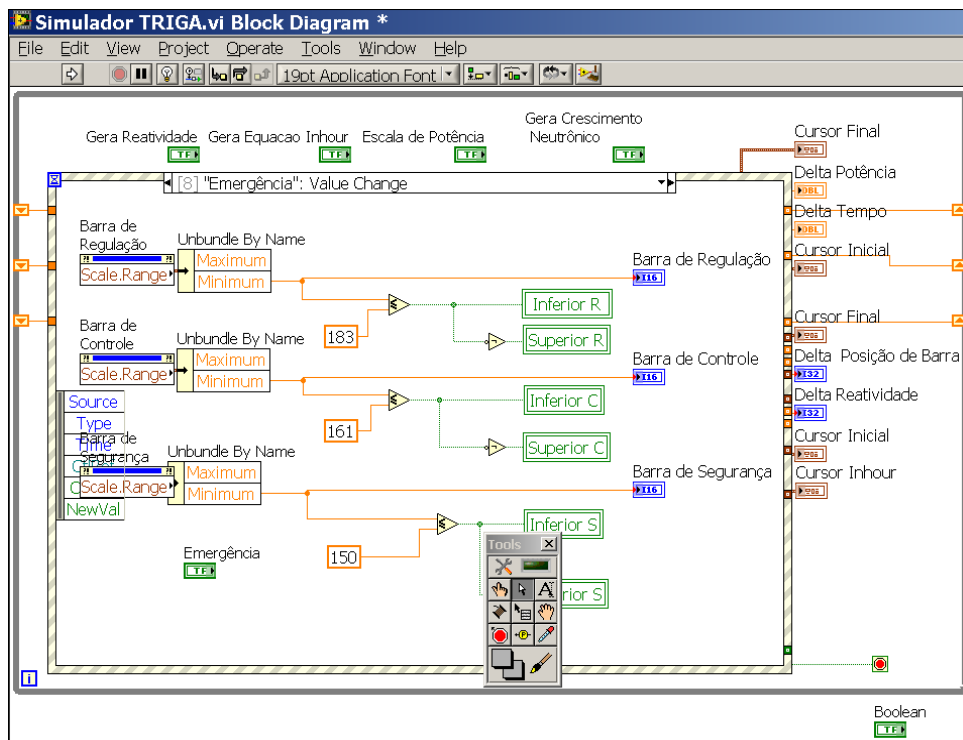


Figure 3. Example of a block diagram developed in LabVIEW

#### 4. JUSTIFICATION

The instrumentation of nuclear reactors is designed with the principles of reliability, redundancy and diversification of control systems. Monitoring of the parameters is of crucial importance with regard to efficiency and operational safety of the installation. Since the first criticality of a nuclear reactor, achieved by Fermi and collaborators in 1942, has been concerned with the study and reliable monitoring of the parameters involved in the chain reaction. As, for example, is shown in Figure 4, the actual curve that relates the adjustment bar position with the reactivity in the core by the insertion of the same. Studied and developed innovations in research reactors are commonly used in power reactors, and the relative low costs allow research reactors to be an excellent laboratory for technical development for future power reactors (Mesquita et al, 2010).

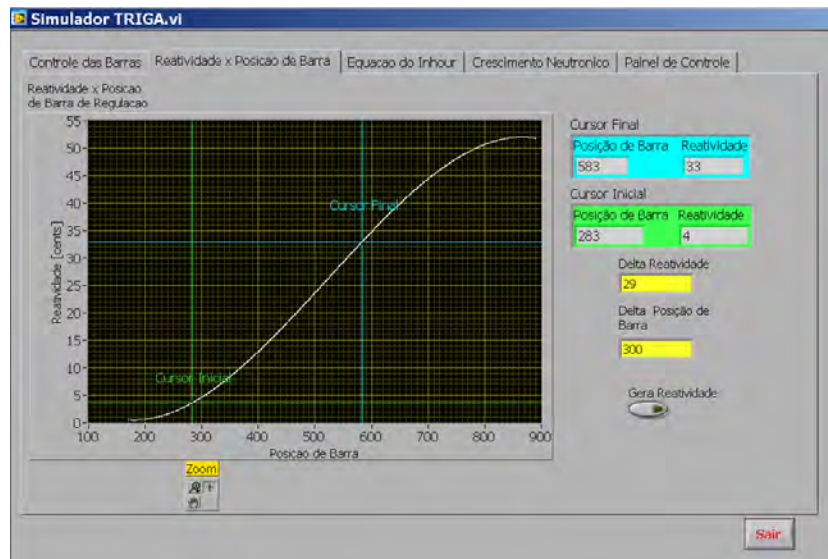


Figure 4. Curve that relates the adjustment bar position with inserted reactivity

The operation of nuclear reactors involves, mainly, the neutron (Neutron Physics) and thermohydraulics (heat transfer and fluid dynamics). The reactors dynamic behavior is associated with an important property known as reactivity. This property varies with the change of the temperature of fuel (Mesquita, 2005) (Hetrick, 1993).

The system to intend provide the nuclear research reactor TRIGA of a modern and reliable system for study of its operational parameters, without the need to use the installation by minimizing costs and time of operation.

#### 5. GOAL

The main goal of the simulation system in developing proposed is to provide the study and improvement the understanding of how these operational variables are interrelated and their behavior, especially those related to neutronic and thermohydraulics, analyzing the evolution of neutron flux and their interaction on the other neutronic parameters. Specific objectives of the work may be mentioned:

- Development of a program to the study of the behavior of the reactor operating variables, covering their entire operating range a few mW up to 250 kW.
- Implementation of heat transfer experiments and physics of reactors for the validation of studies comparing actual operating data.

#### 6. METHODOLOGY

Using LabVIEW software, of the National Instruments, for development of these application are being developed didactic resources to show how these operational variables are interrelated and behave. The following is shown the study and the relationships among operational parameters in examples.

##### 6.1 Exemples of using the simulation system

• **Example 1 - Generation of neutronic growth in function of the toolbar position**

a) Starting from a shift or a repositioning of the control rod by cursors shift, the chart "rod position X Reactivity" the reactor reactivity is obtained.

b) Through a shift or repositioning of the "regulation rod" simulated by the cursor shift on the chart "Reactivity x Rod Position", one can get the "real" reactivity inserted into the reactor, whose result is presented on the display "Delta Reactivity". The regulating rod is moved from the initial position 283 to 300, which causes a positive reactivity insertion of 29 cents. This is shown in Fig.5.

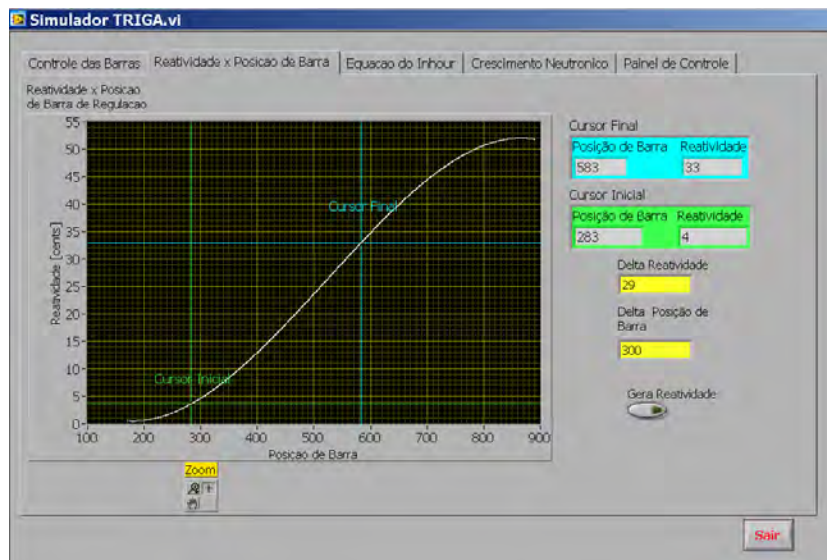


Figure 5. Obtaining the Reactivity through adjusting bar position

c) With the value found of the reactivity (29 cents), must position the cursor at 29 cents in the "Inhour" curve to obtain the period value of the 20 seconds, as can be analyzed in Figure 6.

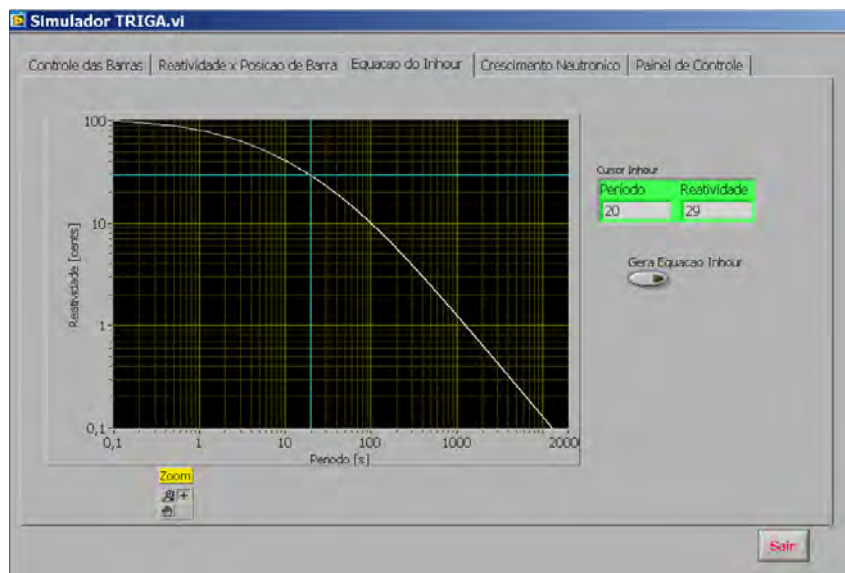


Figure 6. Obtaining the period through the known reactivity

d) insert in the tab "Neutronics Growth", values "period" found in the previous step, 20 s, the "initial power", of 10 mW, for example, the user clicks the button control "Generates Neutrônicos Growth" to create the neutronics growth curve or reactor power, from which can be done the analysis and observation of the trend of the process for these conditions, as may be accompanied in Figure 7.

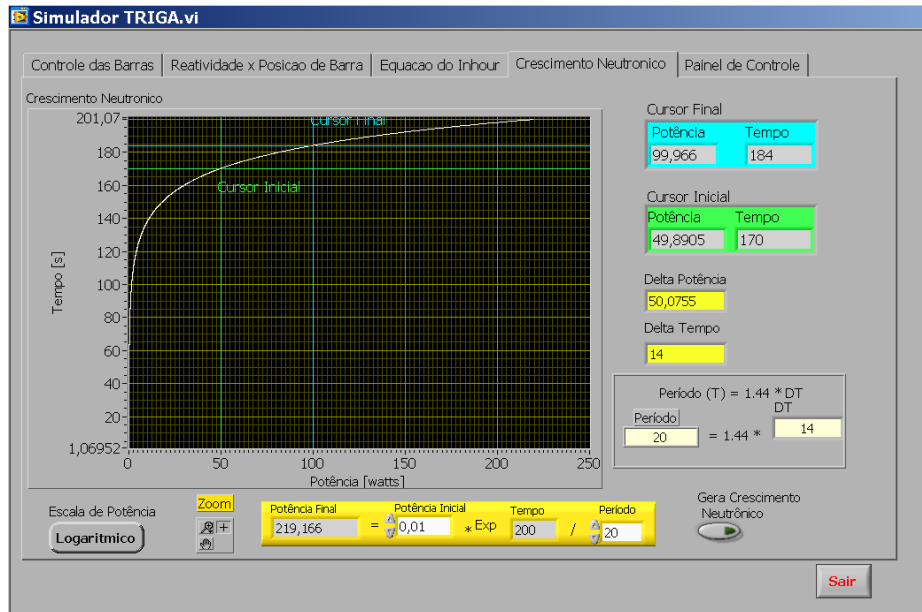


Figure 7. Presentation of neutrônicos growth

- **Example 2 - Repositioning rod according to the period of the process**

- Whereas if you want to simulate the start of the reactor with a predetermined "period". For example, you want to start the reactor or change the power level, in which he finds himself, with a "period" of 25 seconds.
- In the tab " Inhour equation", from the repositioning of the cursor in the position 25 s, note that the value of the corresponding reactivity is, according to the "equation of Inhour", of 26 cents. As can be seen in Figure 8.

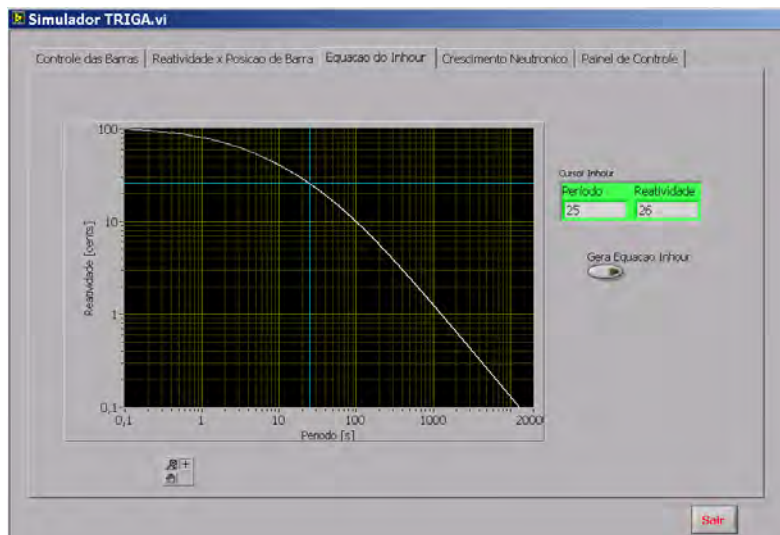


Figure 8. Obtaining the Reactivity as a function of the period known

- Using the tab "Reactivity x Position rod ", and considering that the regulating rod is, for example, in 346 position, make increments in the cursor "final cursor" until the "Reactivity" shown in the display "Delta Reactivity" be of 26 cents. Note that the new position of the regulating rod 591, simulating a reactivity of 26 cents, as shown in Figure 9.

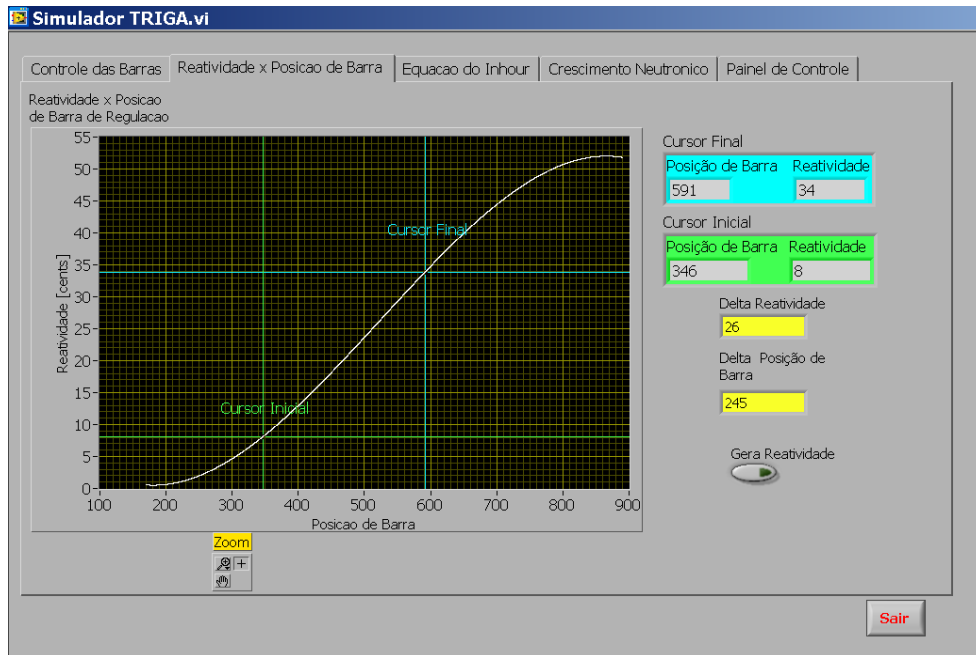


Figure 9. Obtainment of the new position adjustment bar depending on the Reactivity

- d) As a result, it turns out, through this exercise, that the shift of the regulating rod required to insert this reactivity of 26 cents, is of 245 positions. in order to achieve the ultimate goal, that is, to obtain power growth with a "period" known of 25 seconds.
- e) Optionally, by accessing or clicking on the tab "Neutronics Growth", the user can insert of the "period" value (25 s) choosing the "initial power", (for example, 100 mW) and obtain the process trend chart for these conditions, for the Linear Channel as you can see in Figure 10, or for the Logarithmic Channel.

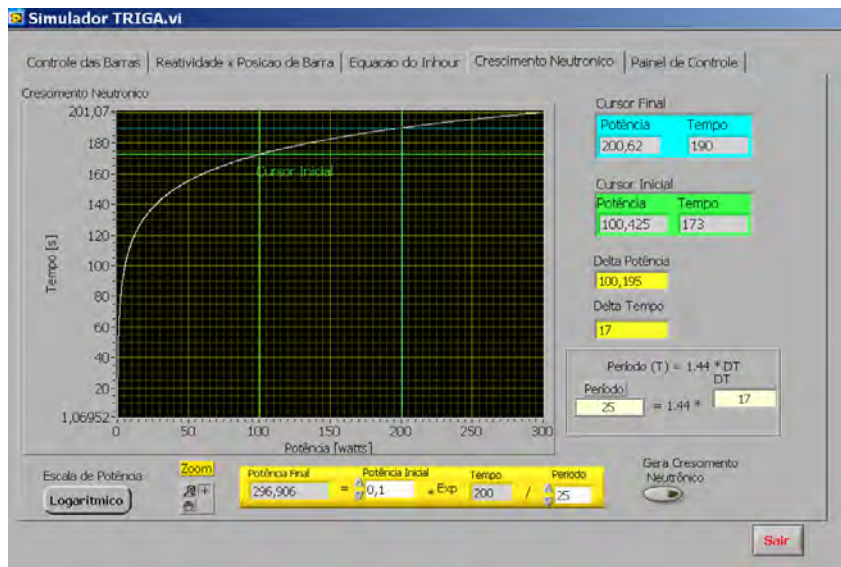


Figure 10. Obtaining the power growth



**Example 3 - Insufficient reactivity inserted**

- a) You want to, for example, insert in the reactor a positive reactivity (withdrawal of rod), that enables a working period of 18 seconds, remembering that with a period of 10 seconds occurs the "Scram", that is IPR-R1 reactor shutdown by protection system.
- b) By positioning the cursor on "Inhour curve" note that to work with a "period" of 18 s, you must enter positive reactivity (removed rod) of 31 cents, as highlighted in Fig 11..

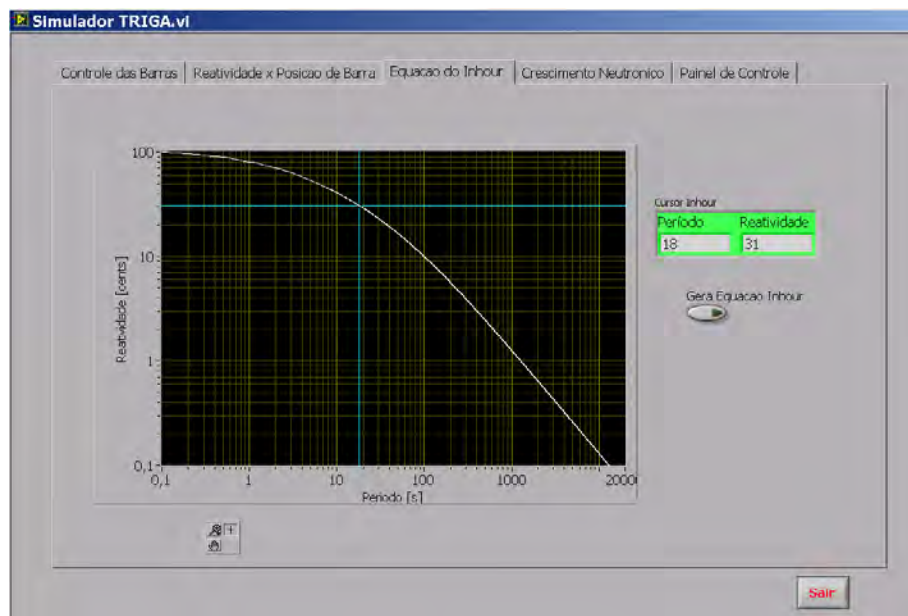


Figure 11. Obtaining the reactivity as a function of the period known

- c) For insert the reactivity of 31 cents, consider that the regulating rod is, for example, in the position 550. Using the tab "Reactivity x Position Rod", to simulate the repositioning regulating rod, the user sets the "Initial Cursor" in 550 which is where the rod is located (origin), and moves the "Final Cursor" until the display "reactivity" show the value 31 cents.

- d) In this case the User note that even removing all the regulating rod, until position 888, is not possible to insert the desired reactivity of 31 cents. But only 23 cents, as shown in Figure 12.

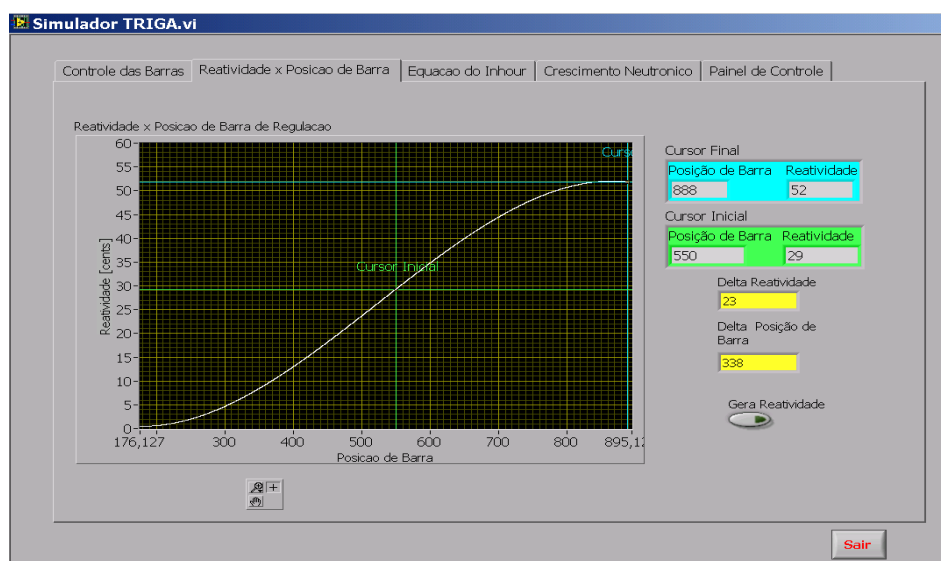


Figure 12. Obtaining the reactivity as a function of position adjustment bar

A.J. Pinto, A.Z. Mesquita, F. S. Lameiras  
Operational Parameters Study of IPR-R1 TRIGA Research Reactor using Virtual Instruments

e) In this way, using the developed simulation system for study, the operator finds the need to act in another control rod to insert the desired positive reactivity of 31 cents.

## 7. PROGRESS OF THE PROJECT

This work presented here is continuation of the master degree defended at post graduate program CDTN (Pinto, 2010) and that generated a patent registered in the INPI (Pinto et al, 2011). The work is highly experimental and is being developed now as a doctoral thesis in this same course. The study will cover the entire range of IPR-R1 reactor power, namely a few mW up to the maximum power of 250 kW. Among the innovations can be cited the inclusion of thermohydraulics operational parameters and the influence of the core temperature effect on the variables neutronics, Innovations these will be still implemented in this work.

## 8. CONCLUSION

The resumption of nuclear power projects in Brazil can be noted in actions such as the National Energy 2030 Plan, which in addition to the completion of the Angra 3 nuclear power plant, also contemplates the construction of at least four more units. The design of Multipurpose Research Reactor (RMB in Portuguese) is also in progress. Therefore, the current scenario indicates the need for staff training in reactor technology and the CDTN can provide it though its IPR-R1 TRIGA.

The system described here to study the behavior of the TRIGA reactor operating variables IPR-R1, will contribute to the security, reliability, quality and reliability in operation, providing the understanding of how these parameters are interrelated, in nuclear reactors. The use of virtual instruments with visual interface in video monitors will enable the use of this reactor in training personnel in the nuclear area. In the development of this paper, experimental and analytical results not previously investigated for this reactor will be covered, giving it originality.

It is important to emphasize that this system, when ready, it can be used for training in other rooms, e.g., classrooms and will not affect the IPR-R1 operation.

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