Research Article

Digital system project for graphic simulation of operational parameters of the IPR-R1 Triga nuclear research reactor

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Abstract
The instrumentation of nuclear reactors is designed based on the reliability, redundancy and diversification of control systems. The monitoring of the parameters is critically important to the operational efficiency and safety of the installation. Since the first criticality of a nuclear reactor, achieved by Enrico Fermi in 1942, there has been concern regarding the reliability of monitoring of the parameters involved in chain reactions. This paper presents the current stage of simulation systems that are under development at the nuclear technology development center (CDTN), intending to simulate the operation of the IPR-R1 Triga nuclear reactor, involving the evolution of neutron flux and reactor power-related events. The system will be developed using LabVIEW® software, using the modern concept of virtual instruments (VIs) that are visualized on a video monitor. For the implementation of this model, computational tools and systems analysis are necessary, facilitating the implementation of the simulator. This article demonstrated some of these techniques and the initial design of the model to be implemented. The design of a computational system is critically important, because it guides the implementation stages and generates the documentation for later maintenance and updating of the computational systems. It is noteworthy that the innovations developed in research reactors are normally used in power reactors. The relatively low costs enable research reactors to serve as excellent laboratories for developing techniques for future reactors.

Keywords
Simulation, Modelling, Nuclear reactor, Virtual instruments, Visual interface.

1.Introduction
The training, research, isotopes, general atomics (Triga) research reactor of the nuclear technology development center (CDTN) is used in research and training of nuclear reactor operators. Operational variables are shown in analogue and digital indicators on the control console. Operators manually register the most important parameters of the operation. The control console uses discrete electronic components and the logic of operation is performed by relays. The CDTN is in the process of adopting international organization for standardization (ISO) standards in their laboratories to show reliability of their results [1].

According to the ISO 9000 standard, an institution must meet certain requirements in order to be certified.

These include: measuring and monitoring processes to ensure the quality of the product/service through performance indicators and deviations; implementation and maintenance of adequate and necessary records to ensure process traceability; and systematic reviews of processes and the quality system to ensure their effectiveness.

A graphic simulator using virtual instruments (VIs) is under development at the CDTN research institute. It will meet the demand of operators as well as undergraduate and graduate students in the operational understanding of a nuclear reactor. In this article, the project of the Triga IPR-R1 reactor simulator is presented. This project is the result of a study of the techniques of analysis of computational systems.

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The implementation in LabVIEW®, where the virtual instruments (Vis) are programmed by block diagrams and front panels, is also observed.

2. Materials and methods
2.1 Design of simulation of the IPR-R1 Triga reactor

The IPR-R1 Triga nuclear research reactor was acquired from general atomics by the government of the State of Minas Gerais in 1960, through the United States Government's "Atoms for Peace" program. It was installed in the former institute of radioactive research (IPR), currently the nuclear technology development center (CDTN), one of the institutes of the Brazilian Nuclear Energy Commission (Cnen). The IPR-R1 Triga reactor was the second nuclear reactor installed in the country. Even with the long operating time, only small amounts of its fuel was burned, about 4% on average [2]. It can operate for several years for research and analysis, radioisotope production and training [3]. *Figure 1* shows two photographs of the reactor pool, and the core of the IPR-R1 Triga reactor, in which Cherenkov radiation can be observed when the reactor is critical and at high power.
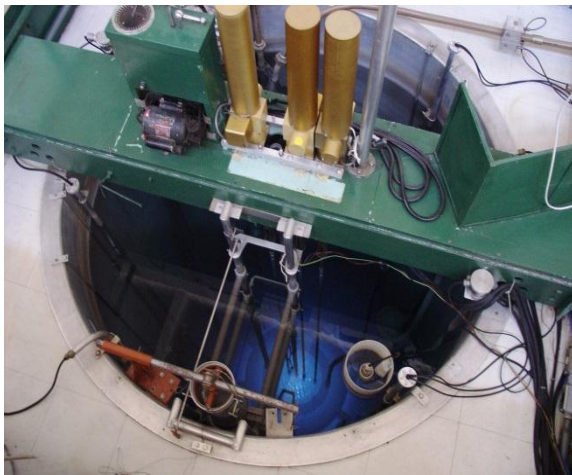
Figure 1 Triga IPR-R1 reactor-Details of the pool

Figure 2 shows the operating console of the IPR-R1 Triga reactor, where:

- On the left panel are the meters and temperature controllers, pool water level indicator, water conductivity meters and flow controller;
- In the middle of the console are the control rod drives, registers and power indicators, period indicator, reactivity indicator and neutron counter rate indicator;

- Radiation indicators and the alarm panel appear on the right panel.

Figure 2 Control panel for the IPR-R1 Triga reactor

2.2 IPR-R1 Triga reactor operation

In order to place the Triga reactor in operation, the operator must follow pre-operational and operational procedures [4].

The operation of the reactor can only be started after the following pre-operational conditions and/or procedures have been achieved:

a) Inspection of the operation of the control, safety and monitoring systems of the IPR-R1 Triga reactor;
b) Filling in of the daily checklist and the weekly checklist for the first operation of the week, observing the operating conditions for the control of the reactor specified in the list.

The operational procedures for start-up are as follows:
a) Recording of the start time of operation in the reactor log book;
b) Switching on the cooling system;
c) Turning on the movement of the registers;
d) Completely removal of the safety rods;
e) Starting of the subcritical approximation by partially extraction of the shim rod to a position close to the criticality;
f) After the reactor is close to criticality, stopping the extraction of the shim rod and initiating the extraction of the regulating rod;
g) Stabilization of the desired power level;
h) The start operation is considered finished when the desired power level remains stationary on the linear power channel.

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Recording of the time, position of the rods, and power level in the linear, logarithmic and percentage power channels in the reactor data log.

The operating procedure above is the model that will be used to develop the Triga reactor simulator project, and this project will be used to implement the simulator in the VIs programming language. In the sections that follow, the proposed project for the simulator will be shown in diagrams.

2.3 Structured system analysis techniques applied to the simulator

The use of system analysis techniques will aid the development process of the system to be modelled [5]. Historically, the first technique approached was the traditional analysis. This technique had only a functional approach making use of tools of texts and flowcharts. With the evolution of computer systems and equipment, a structured analysis technique emerged, which, in addition to the functional approach, has an approach to the data of the system, using the following as tools: context diagram; data flow diagrams (DFD); data structure diagrams (DSD); standardization and process specifications. These techniques and tools will be described below.

2.4 LabVIEW® Language

Once the simulator project is completed, implementation will be carried out, that is, simulator programming. In this step, the LabVIEW® programming language that is based on programming oriented to VI's will be used. The VIs are divided into two parts: the front panel and the block diagram. The front panels and their respective block diagrams are programmed according to the design until achieving the desired simulator [6].

3. Results and discussion

3.1 Context diagram

The context diagram (CD) shown in *Figure 3* represents the most general form of the system to be simulated. This diagram is the most basic design format. The CD is divided into several other diagrams, including the data flow diagram (DFD). These diagrams have more detail than does the CD [7].
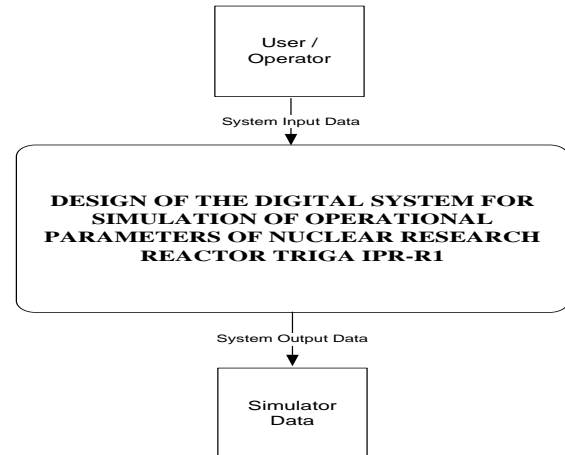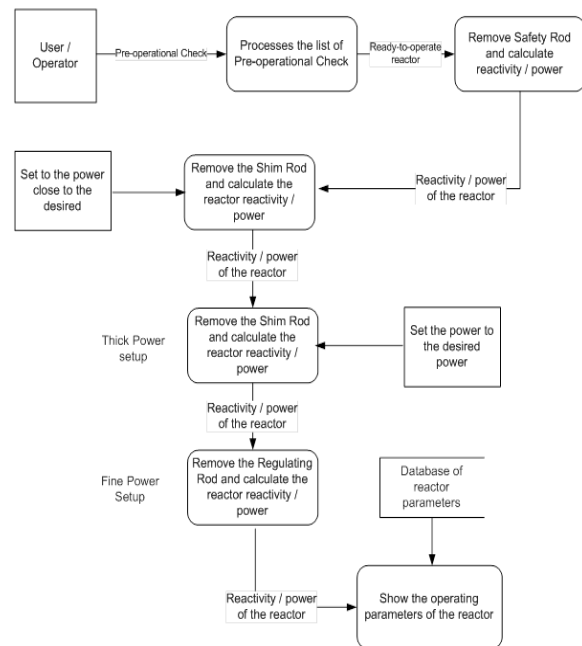

Figure 3 Context diagram of the IPR-R1 Triga reactor simulator

3.2 First-level data flow diagram

From the context diagram, the previous chart to DFD is expanded and detailed, and its various levels will be discretized and detailed for the system to be implemented. *Figure 4* shows the first level of detail.


**Figure 4** First-level data flow diagram

3.3Second-level data flow diagrams

Each of the first-level DFD processes can be expanded and detailed in several levels such that the programmer can implement the simulator tool closer to the real reactor's operation. *Figure 5* presents in more detail two modules of the DFD-1: the processes of the pre-operational check and the operation of the safety rod.
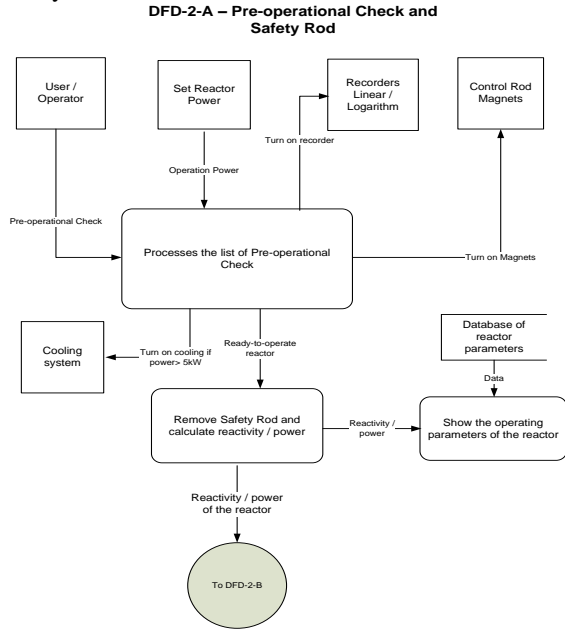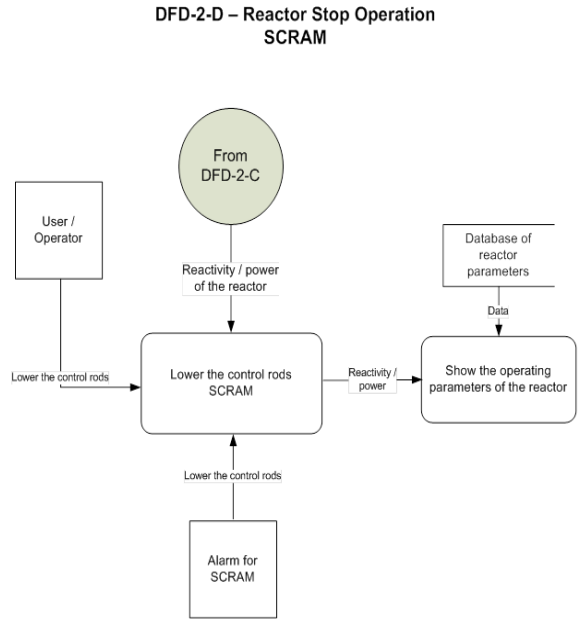

Figure 5 Data-flow diagram of pre-operational check and safety rod operation

Figure 6 shows a more detailed description of the shim rod operation that roughly adjusts the desired power.
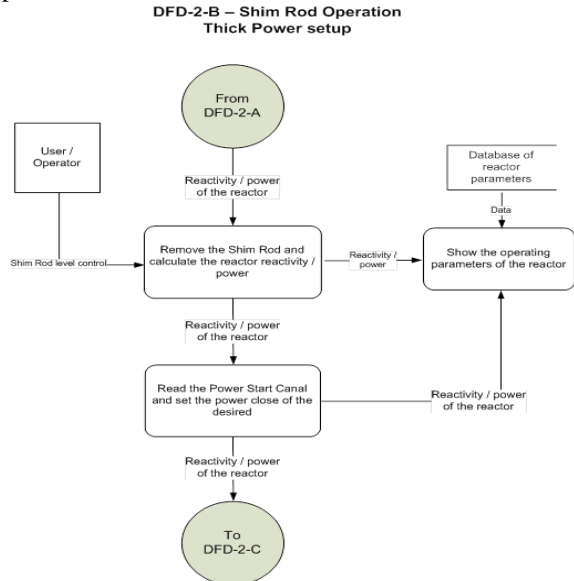


Figure 6 Shim rod operation data flow diagram

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The reactor shutdown process is described in *Figure 7*, either by intervention of the operator or by the action of an alarm that causes the shutdown of the reactor due to safety concerns.

**Figure 7** Data flow diagram of reactor shutdown operation

3.4Virtual instruments of the simulator

For the initial results of the simulator design, there is the initial implementation of the simulator that will be programmed in LabVIEW® using the modern technique of virtual instruments. The central operating panel is shown in *Figure 8* and *Figure 9* details part of the block diagram operating the central panel.
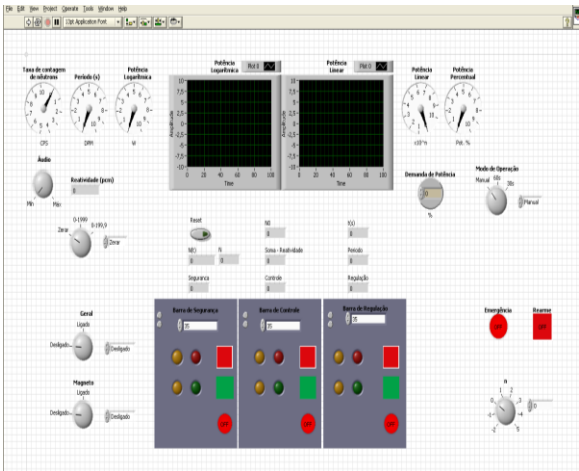
**Figure 8** Front panel of the reactor control console

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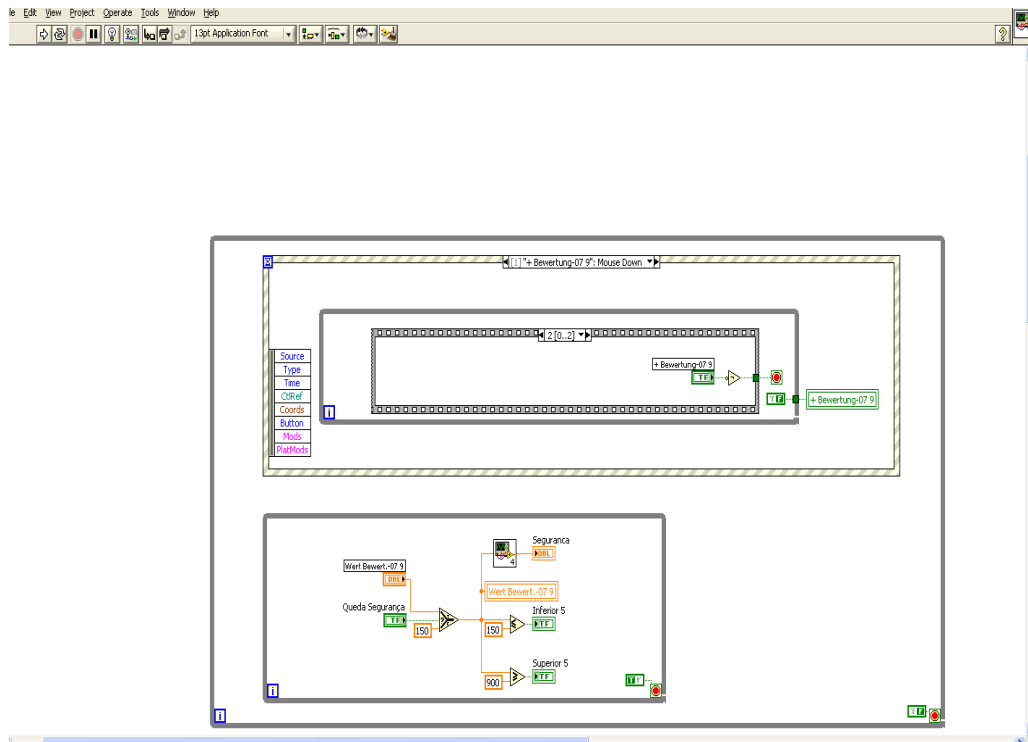
**Figure 9** Block Diagram of the central panel of the control console of the reactor

Figure 10 shows the block diagram implemented in LabVIEW® software, representing the logic of the "Inhour" equation. The graph of the implementation is shown on the front panel *(Figure 11)*, where there are: the configuration values of the equation and the "Inhour" graph that shows the reactivity of the control bars versus the reactor period.
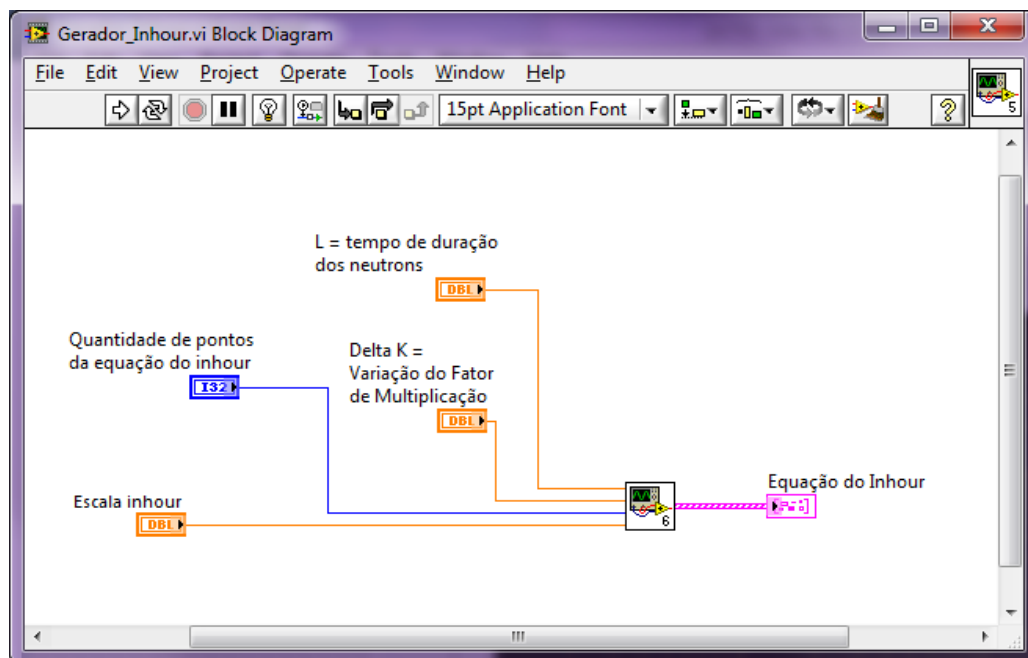
Figure 10 Block Diagram of the logic of the "Inhour" equation

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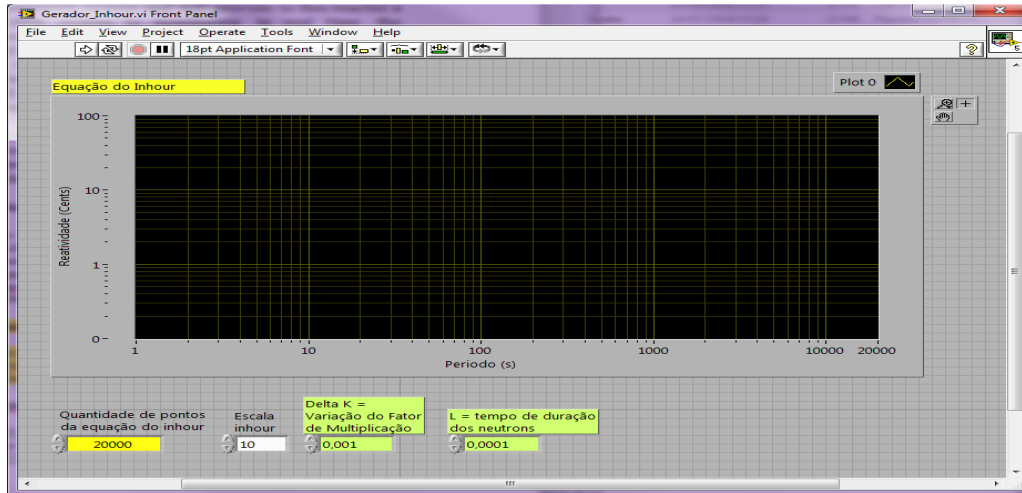
Figure 11 Front panel showing the graph of the "Inhour" equation

4.Conclusion and future work

To date, the simulator input and output lists have been carried out and the operational procedures of the IPR-R1 Triga reactor have been studied, as well as other simulators of nuclear reactors; as previously seen, the simulator project was initiated. The presented diagrams underwent new expansions refining the functional processes.

The system described here, simulating the behaviour of the operational variables of the IPR-R1 Triga reactor, was developed using LabVIEW® software using the modern concept of virtual instruments that are visualized on a video monitor [8]. The system will contribute to safety, quality and reliability in the operation of nuclear reactors. This system, with minor modifications, can be transformed into a supervisory system that will provide this reactor with a modern system to monitor, in real time, the operational variables. Operational data will be stored and made available to staff and potential surveys may be conducted on site.

Currently, the simulator project is not yet finished. The drawing of console and all its components have been completed: the central panel that is used to operate the reactor, the left panel that shows the indications and controls of temperatures and the right panel that visualizes and treats the alarms and the radiations. It is in the midst of simulator programming, lacking only program testing and validation of the logics of the alarms and visualization of the power in logarithmic, linear and percentage form [9].

The use of virtual instruments with visual interfaces in video monitors will allow the use of this reactor in the training of personnel and training in nuclear technology [10].

This developing system complies with updated recommendations of the International Atomic Energy Agency IAEA regarding nuclear reactor control rooms [11−13].

Acknowledgment

Conflicts of interest
The authors have no conflicts of interest to declare.

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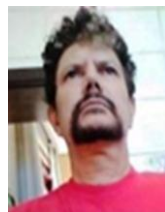
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