2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
Associação Brasileira de Energia Nuclear - ABEN
ISBN: 978-85-99141-03-8

SUPERVISORY SYSTEM TO MONITOR THE NEUTRON FLUX OF THE IPR-R1 TRIGA RESEARCH REACTOR AT CDTN

Antonio Juscelino Pinto[1], Amir Zacarias Mesquita[2], Clédola Cássia Oliveira de Tello[3]

Centro de Desenvolvimento da Tecnologia Nuclear - CDTN/CNEN
Caixa Postal 941 Cidade Universitária
30 123 970. Belo Horizonte, MG
[1]ajp@cdtn.br ;
[2]amir@cdtn.br ;
[3]tellocc@cdtn.br

ABSTRACT

The IPR-R1 TRIGA Mark I nuclear research reactor at the Nuclear Technology Development Center - CDTN (Belo Horizonte) is a pool type reactor. It was designed for research, training and radioisotope production. The International Atomic Energy Agency- IAEA – recommends the use of friendly interfaces for monitoring and controlling the operational parameters of nuclear reactors. This paper reports the activities for implementing a supervisory system, using LabVIEW® software, with the purpose to provide the IPR-R1 TRIGA research reactor with a modern, safe and reliable system to monitor the time evolution of the power of its core. The use of the LabVIEW® will introduce modern techniques, based on electronic processor and visual interface in video monitor, substituting the mechanical strip chart recorders (ink-pen drive and paper) that monitor the current neutrons flux, which is proportional to the thermal power supplied by reactor core. The main objective of the system will be to follow the evolution of the neutronic flux originated in the Linear and Logarithmic channels. A great advantage of the supervisory software nowadays, in relation to computer programs currently used in the facility, is the existence of new resources such as the data transmission and graphical interfaces by net, grid lines display in the graphs, and resources for real time reactor core video recordings. The considered system could also in the future be optimized, not only for data acquisition, but also for the total control of IPR-R1 TRIGA reactor.

1. INTRODUCTION

The IPR-R1 TRIGA Mark I nuclear research reactor at the Nuclear Technology Development Center - CDTN (Belo Horizonte) is a pool type reactor. It was acquired from General Atomics by Minas Gerais State Government in 1960, through the U.S. government program "Atoms for Peace". It was installed in the earlier Radioactive Research Institute (IPR), current CDTN of the Brazilian Nuclear Energy Commission (CNEN). The IPR-R1 was the second nuclear reactor installed in the country and, until now, only two of these research reactors exist in Brazil. Despite its age its fuel is low "burned" (about 4% on average) and can still operate for several years in: technological research, radioisotope production, training in reactor operation and education exclusive of this type of installation. Figure 1 shows aspects of the IPR-R1 TRIGA pool and core, where it can be seen the Cerenkov radiation when the reactor is critical.

TRIGA reactors (Training, Research, Isotopes, General Atomics) are characterized by their safety, and therefore they are typically installed in universities, hospitals, industries and research centers in many countries and used, mainly for training. The IPR-R1 TRIGA is a reactor that works with demineralised water and its fuel is a metallic alloy of uranium with zirconium hydride moderator (ZrH-U), containing from 8% to 8.5% by weight of uranium enriched to 20% in ^{235}U. The IPR-R1 reactor core has a cylindrical reticulated form, where are currently installed 63 fuel elements, moderator, being 59 aluminum-clad original elements, and 4 stainless steel-clad fuel elements inserted recently.

Figure 1. The IPR-R1 TRIGA reactor: view of the pool and the core.

Initially the maximum power of the IPR-R1 reactor was 30 kW thermal. Then, fuel elements were added to the core increasing its power to 100 kW, which is the current maximum licensed power. In 2004 changes were made in the core and new fuel elements were added allowing its power to reach 250 kW.

This paper reports the activities for implementing a supervisory system, using LabVIEW® software, with the purpose to provide to the IPR-R1 TRIGA research reactor with a modern, safe and reliable system to monitor the time evolution of the power of its core.

2. OBJECTIVES AND JUSTIFICATION

2.1 - Objectives

The aim of this work is to develop a supervisory system to monitor the IPR-R1 TRIGA temporal evolution of the power (neutron flux), using modern techniques which use visual interface and electronic processor in the video monitor, substituting the mechanical strip chart recorders (ink-pen drive and paper). This will facilitate and improve the classes done to the operators of nuclear reactors.

The use of the supervisory system and associated instrumentation will allow an accurate measurement of process variables as well as the visualization of neutron flux parameters trend graphs originated in the Linear Channel and in the Logarithmic Channel, which is proportional to the thermal power supplied by the reactor core. The use of this type of supervisory system also allows a continuous improvement in the process variable monitoring only with the development of new software screens, without new equipment acquisition.

2.2 - Justification

The IAEA recommends the use of friendly interfaces for monitoring and controlling the operational parameters of nuclear reactors. The IAEA first publication about research reactor safety dates from 1960, the same year of the first criticality of the IPR-R1 TRIGA. This edition recommended for monitoring and recording the values of safety operating parameters. Since the first publication several revisions occurred, adapting it to engineering development. In the 1971 review [1] the concept of automatic control was presented, especially for the shutdown: "a human reaction is much slower than the instruments and the human attention can not be constantly focused on all security parameters”.

In accord of Safety Guide Ns-G1-3 [2] it is recommended automatic operation, since in this case it will be independent of the operator. In addition it is also recommended the use of visual interfaces that allow easy visualization and quick perception of the process status. With respect to the control rooms in this document it is introduced the concept of man-machine interface: "The monitoring and control of systems important to safety involve a combination of automatic measurement and control functions, and monitoring and control by human operators”.

The installation of LCD video monitors for monitoring the operating parameters is important in the normal reactor operation and in the training courses for the reactor operators. As it is emphasized in the IAEA [3], the instrumentation and control systems of a nuclear reactor are the "eyes and ears" of the operator, so as easier is the visualization, safer the operation becomes.

It will be developed a variable database of the installation and a suitable instrumentation will be added, and that will allow a safer operation of the reactor. The project intends to monitor and treat the different variables of the IPR-R1 reactor operation, mainly the power measurement, which will be monitored according to the behaviour of the linear and the logarithmic channels.

With the current control console it is difficult for the operator to keep all the indicators in his field of vision, what can be solved by using video monitors. Additionally this improves the usability and the reliability of the operator actions, reducing the possibility of human errors. The instrumentation and control upgrade of the IPR-R1 TRIGA reactor operating variables, as described in this document, will achieve the goals of CDTN to meet the requirements of ISO 17025 [4] in the laboratories, demonstrating reliability in the results, and the recommendations of IAEA for the safe operation of research reactors [5].

3. IPR-R1 TRIGA REACTOR ACTIVITIES

The main activities carried out by the CDTN using the IPR-R1 TRIGA reactor, are: training, analysis by neutron activation, production of radioisotopes and research.

3.1. Training

CDTN staff gives regularly training courses for research reactors operators – CTORP – [6] as part of mandatory training for operators of Brazilian nuclear power plants. In addition the reactor facilities are regularly visited by teachers and students from sciences courses.

With the construction of new power plants in the next years it is expected an increase in the training courses. The IPR-R1 TRIGA reactor also plays an important role for CDTN Post-graduation Course, not only in the applications of neutron activation, but also in the neutron physics experiments and other areas.

3.2. Neutron Activation

The technique of neutron activation is used in several fields of the research allowing precise analysis of 70% of chemical elements. In CDTN it is used in the environmental, industrial, biomedical, food and geology areas. The samples are irradiated with neutrons in IPR-R1 available devices, and the spectrometric analysis of the gamma radiation emitted by the activated samples, which is unique for each element, allows determining the components of these samples and their concentrations [7].

3.3. Production of Radioisotopes

The radioisotopes are produced in the IPR-R1 reactor by irradiation with neutrons of stable elements. The radioisotopes produced are applied mostly in environmental and industrial studies. They are mainly used as tracers, for example, in studies of hydrological cycles and other processes where it is not possible to deal directly with the studied environment. Due to the fact of emitting radiation, the radioactive elements incorporated into the system can be detected by the instruments and their behaviour tracked, to study the whole process or phenomenon [7]. The tracers are radioisotopes of short half-life (some hours or days), so that after some time there is no more significant radiation in the system.

3.4. Research

Although it is not currently a priority area for the IPR-R1 TRIGA reactor use, some research has been conducted in the neutron physics and thermal-hydraulics. Examples are the neutron experiments carried out by Souza et al [8], the study of theoretical reactor physics implemented by Dalle [9], research on thermo-hydraulic experiments performed by Mesquita [10] and theoretical thermo-hydraulic made by Fortini [11] and Veloso [12].

4. IPR-R1 TRIGA INSTRUMENTATION CHARACTERISTICS

The IPR-R1 reactor first criticality was in 1960 and at that time it was used electron tubes (vacuum tubes) in the reactor control panel, and the record of the power (neutron flux) was performed using mechanical strip chart recorders (ink-pen drive and paper). In 1995 the control system was changed. Although video monitors and computers were already available to process control and, especially, for the operational data acquisition, it was adopted in the IPR-R1 control console an analogical system constituted by electromagnetic relays. Two graphical mechanical registers were included in this control console to record the neutron flux, and the operation registration was done by manual data logging.

The TRIGA reactors are characterized by their inherent safety due to the large prompt negative temperature coefficient, which leads to the safety against reactivity accident. This means that the reactor power increase leads to the consequent temperature increase of the moderator-fuel mixture, causing the appearance of a negative reactivity, and than the rate of the power increase diminishes and this tends to stabilize it. Another safety characteristic of TRIGA reactors is the passive system of heat removal in the core during operation. The IPR-R1 is a nuclear research reactor of pool type, cooled by natural circulation. The accumulated heat can be removed by the forced circulation cooling. The circuit of forced cooling was designed mainly to reduce the levels of radiation in the reactor room during operations with power higher than 50 kW. Figure 2 shows the longitudinal section of the pool with the accessories.

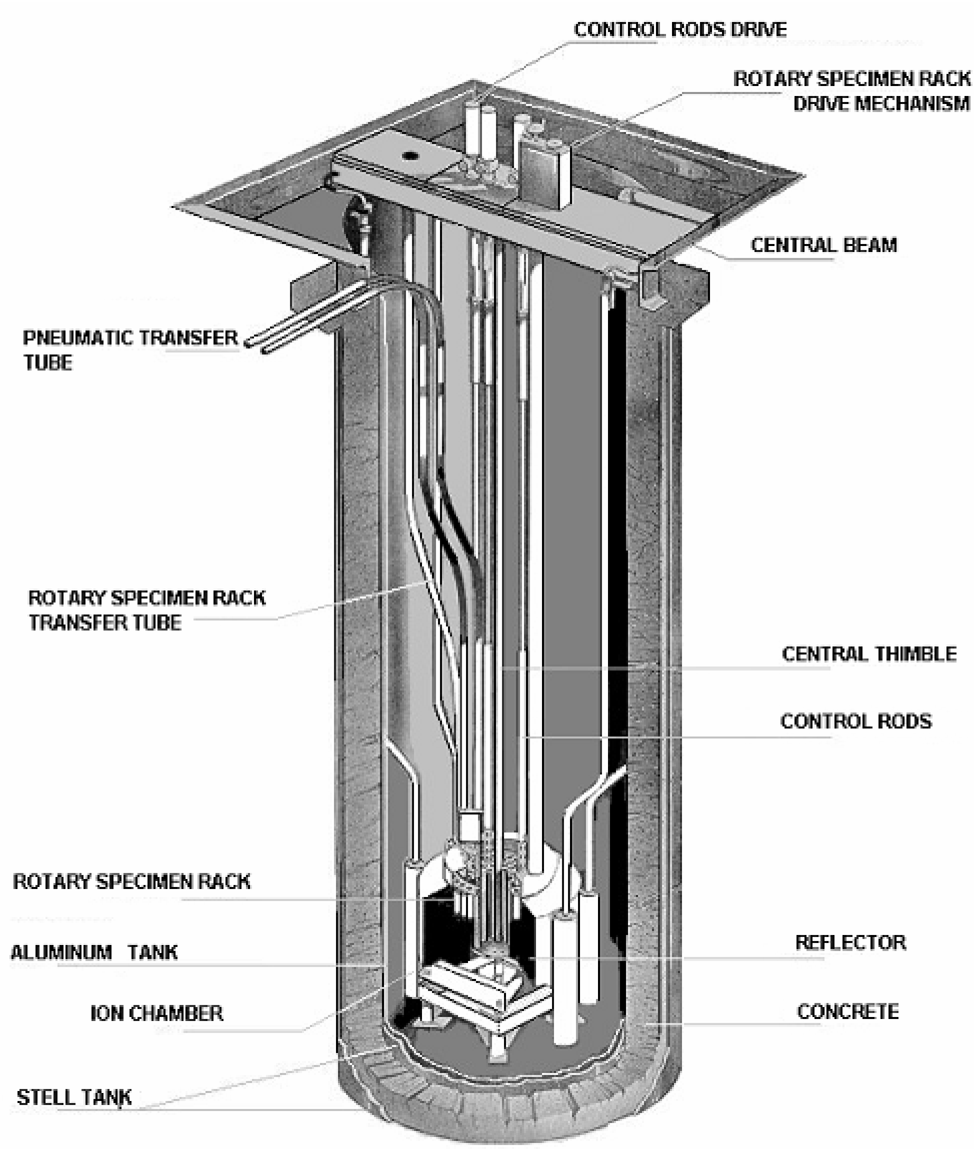

Figure 2. Longitudinal section of the IPR-R1 TRIGA.

5. METHODOLOGY

The man-machine interface is being developed using the software LabVIEW® (Laboratory Virtual Instrument Engineering Workbench) version 8.6 provided by National Instruments, and also a module of data acquisition board NI USB-6210 from National Instruments [13], [14].

The LabVIEW® software offers direct control of the hardware on the data acquisition board. It is programmed with a set of graphical icons which are connected with "wires". The combination of a DAQ board and LabVIEW® software makes a Virtual Instrument (VI). A “VI” can perform like an instrument and is programmable by the software with the advantage of logging data flexibility that is being measured. The LabVIEW® is programmed with a set of icons which represents controls and functions, available in the software menu, and it is called visual programming. The user interface consists of two parts: a front panel and a block diagram. This is similar to an instrument where a front panel is used for input and output controls, and to display the data whereas the circuit resides on the circuit board. Similarly, it can bring buttons, indicators, and graphing and display functions on the front panel. The VI also calculates mean and standard deviation of the data and plots them. Alarms have been set up so that if the signal falls below or above a certain set value the alarm goes ON. The LabVIEW® can be used to perform system simulations, since it contains filters, digital signal processing, and statistical functions.

A data acquisition system was designed, specified and assembled for this project [15]. It is composed by a power supply, one analogical/digital converter (model ADAM 4018) [16] and an interface that changes (ADAM 4520) the RS-485 standard to the RS-232 [17]. Nowadays the neutron parameters are being studied in order to define which ones will be monitored and stored in the supervisory system.

The analogical variables that will be monitored are collected in various points of the facility by sensors. The measurements are sent directly to the instrumentation or to a rack in which they are collected. These signals, the majority from thermocouples, thermal resistance, and signals of instruments, ranging from 0 (zero) to 10 (ten) volts, are sent to the analogical/digital converter to correct the communication protocol (RS-485 to RS-232) and then they are sent to the software.

In software engineering development some important resources will be developed for the facility, such as screens, alarms, reports and data storage. A great advantage of this supervisory software, in comparison to the computer programs currently used in the facility, is the existence of new resources such as the data and graphical interfaces, their transmission by net, the existence of grid lines in the graphs, resources to film the reactor core in real time and the data treatment using the developed program.

The LabVIEW® can work with the modern operational systems such as Windows XP® and Vista®, in contrast with the current system that works only in Windows 98® environment. The considered system could also in the future be optimized, not only for data acquisition, but also for the total control of IPR-R1 TRIGA reactor

6. RESULTS

The main indications of the control console could be monitored by this data acquisition system, including the three control rod positions. These signs come from the rack of the instruments and from the reactor control console. At the moment the reactor neutron flux is been simulated by the own LabVIEW® program on the Microsoft Windows XP platform. The program generates an exponential signal, similar to the reactor neutron flux. Some screens and resources are already developed using this tool. Figures 3 and 4 show some of them.

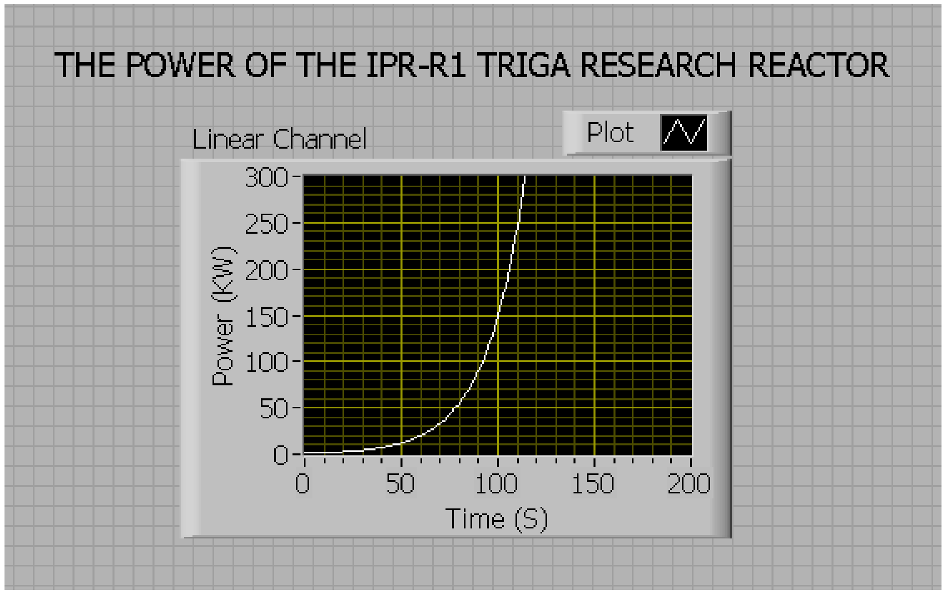

Figure 3. Time behavior of the linear channel.

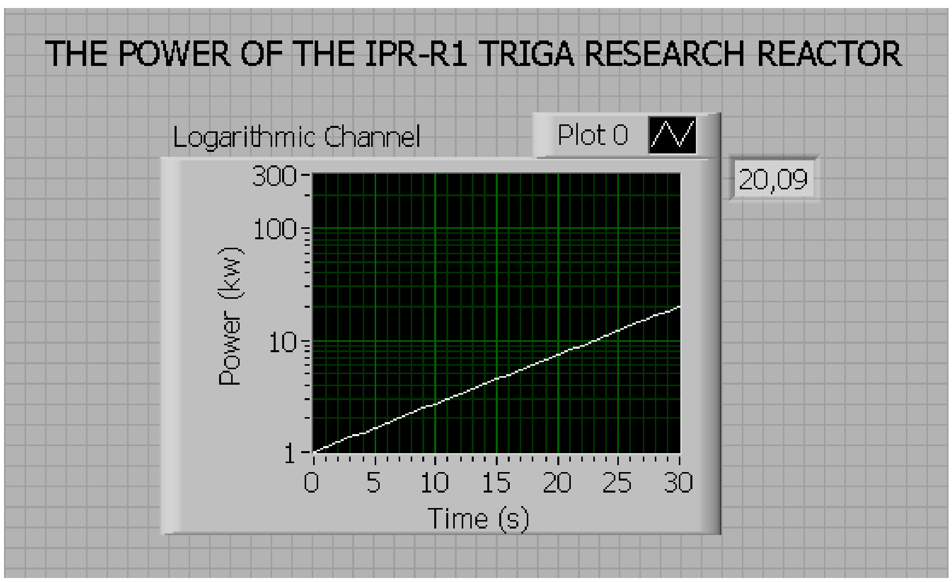

Figure 4. Time behavior of the logarithmic channel.

7. CONCLUSION

This work aims to improve the IPR-R1 TRIGA reactor processes taking into account the new concepts and systems which are based on the use of microprocessors and video monitors, similar to modern reactor control rooms (Figure 5). In addition, this development follows the IAEA recommendation [18] to use digital equipment to increase the reliability, the flexibility as well as the use of man-machine interface which is similar to the control systems used in the industry [18].

Figure 5. Control console of a typical nuclear power plant.

ACKNOWLEDGEMENTS

The authors express their thanks to CDTN and to the *Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG)* for the partial financial support.

REFERENCES

1. IAEA. International Atomic Energy Agency. *Safe Operation of Critical Assemblies and Research Reactors.* IAEA ,Vienna (1971).
2. IAEA. International Atomic Energy Agency, *Safety Standards Series, Instrumentation and Control Systems Important to Safety in Nuclear Power Plants*, IAEA, Vienna (2002).
3. IAEA. International Atomic Energy Agency, *Modern Instrumentation and Control for Nuclear Power Plants: A Guidebook*, IAEA, Vienna (1999).
4. ABNT - Associação Brasileira de Normas Técnicas, *NBR ISO/ IEC 17025:* Requisitos Gerais para Competência de Laboratórios de Ensaio e Calibração. Rio de Janeiro (2005).
5. A.Z Mesquita, et al. *Melhoria e Atualização da Instrumentação, do Controle e dos Procedimentos Operacionais no Reator TRIGA IPR-R1*. Nota Interna CDTN/CNEN, TR3-01/08, Belo Horizonte (2008).
6. CDTN/CNEN. *Curso de Treinamento de Operadores em Reatores de Pesquisa* – CTORP. CDTN/CNEN. Belo Horizonte (1997).
7. CDTN/CNEN. http://www.cdtn.br/pesquisa/tec_nuclear.asp#2. (2008).

8. R.M.G.P. Souza; M.F.R. Resende; A.Z. Mesquita, *Procedimentos dos Testes Finais Para o Aumento de Potência do Reator* TRIGA IPR-R1. Nota Técnica CDTN/CNEN, NI-IT4-03/02 (2002).
9. H.M. Dalle, *Simulação do Reator TRIGA- IPR – R1 Utilizando Métodos de Transporte por Monte Carlo*. Tese de Doutorado, Universidade Estadual de Campinas, São Paulo (2005).
10. A.Z. Mesquita, *Experimental Investigation on Temperatures Distribuitions in a Research Nuclear Reactor IPR-R1 TRIGA*, Ph.D thesis, Universidade Estadual de Campinas, São Paulo, Brazil (in Portuguese), (2005).
11. M.A. Fortini, *Análise Teórico-Experimental da Termofluidinâmica de Reatores de Pesquisa Refrigerados a Água em Regime de Convecção Natural*. Tese de Doutorado, Universidade Estadual de Campinas, São Paulo (2004).
12. M.A. Veloso, *Análise Termohidráulica do Reator TRIGA IPR-R1 em 250 kW*. Nota Técnica EC3-05/05, CDTN/CNEN (2005).
13. ISO - International Organization for Standardization: Human-Centred Design Processes for Interactive Systems ISO 13407. Geneva (1999).
14. National Instruments Co, Measurement and Automation - Graphical Programming for Instrumentation. Austin, USA (2007).
15. A.J. Pinto, *Implantação de Sistema Supervisório na Planta de Betuminização*. Belo Horizonte; CDTN (NI – CT3 – 02/01) (2001).
16. Advantech, ADAM – 4018/4510S Converter Analogic Digital Thermocouple ADAM – 4018/4510S; Users Manual 4 ed. Taiwan, 1v (1998).
17. Advantech, ADAM, – 4520/4510S RS – 422/485 *Repeater*, ADAM – 4520/4522 RS – 232 to RS422/485 Converter; Users Manual 4 ed. Taiwan, 1v. (1998).
18. IAEA - International Atomic Energy Agency, Specifications of Requirements for Upgrades Using Digital Instrumentation and Control Systems, IAEA, Vienna (1999).