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

EVALUATION OF POWER BEHAVIOR DURING STARTUP AND SHUTDOWN PROCEDURES OF THE IPR-R1 TRIGA REACTOR

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ABSTRACT

The IPR-R1 nuclear reactor of *Centro de Desenvolvimento da Tecnologia Nuclear* - CDTN/CNEN is a TRIGA Mark I pool type reactor cooled by natural circulation of light water. In the IPR-R1, the power is measured by four nuclear channels, neutron-sensitive chambers, which are mounted around the reactor core: the Startup Channel for power indication during reactor startup; the Logarithmic Wide Range Power Monitoring Channel; the Linear Multi-Range Power Monitoring Channel and the Percent Power Safety Channel. A data acquisition system automatically does the monitoring and storage of all the reactor operational parameters including the reactor power. The startup procedure is manual and the time to reach the desired reactor power level is different on each irradiation which may introduces differences in induced activity of samples irradiated in different irradiations. In this work, the power evolution during startup and shutdown periods of IPR-R1 operation was evaluated and the mean values of reactor energy production in these operational phases were obtained. The analyses were performed on basis of the Linear Multi-Range Channel data. The results show that the sum of startup and shutdown periods corresponds to 1% of released energy for irradiations during 1h at 100kW. This value may be useful to correct experimental data in neutron activation experiments.

1. INTRODUCTION

The IPR-R1 TRIGA Mark 1 nuclear reactor of CDTN/CNEN operates since 1960. It is a pool type reactor cooled by natural circulation. The fuel is an alloy of zirconium hydride and uranium enriched at 20% in ^{235}U. One of its main applications is the neutron activation analysis (NAA). The reactor power level is controlled by three control rods containing boron carbide. The reactor has three irradiation facilities: a rotary specimen rack (RSR) outside the reactor core with 40 irradiation channels for large scale isotope irradiation; the central tube (CT) placed at the center of reactor core, which permits sample irradiation with maximum neutron flux, besides neutron beam extraction; a pneumatic transfer tube (PTT) which makes possible the analysis of short half life radioisotopes. The IPR-R1 was originally designed to operate at continuous power up to 30kW and today can operates at continuous power up to 100kW. After the final licensing, the IPR-R1 is going to operate at a continuous thermal power level of 250 kW steady-state [1].

The principal instrumentation for the operation of the IPR-R1 TRIGA Mark 1 consists of four neutronic channels for power measuring and channels for monitoring temperature, water conductivity, radiation level, etc. The neutronic channels are: the Startup Channel, the Logarithmic Wide Range Power Monitoring Channel, the Linear Multi-Range Power Monitoring Channel and the Percent Power Safety Channel. The Startup Channel, which consists of a fission chamber detector, circuits and associated meters, monitors the neutron flux in the range of the reactor startup. The Logarithmic Channel, which consists of a compensated ionization chamber detector, circuits and associated meters, monitors the neutron flux ranging from the Startup Channel scale ending to levels slightly higher than the maximum power. The Linear Channel, which consists of an analog meter and strip chart recorder, indicates the power from the source level until the maximum power level. The Percent Power Channel consists of a percentage meter that indicates power in percentage (0 to 120%), relative to the maximum power level. It is composed of an uncompensated ionization chamber and associated meters [1, 2]. Figure 1 shows the core of the IPR-R1 where is possible to see its power monitoring channels.

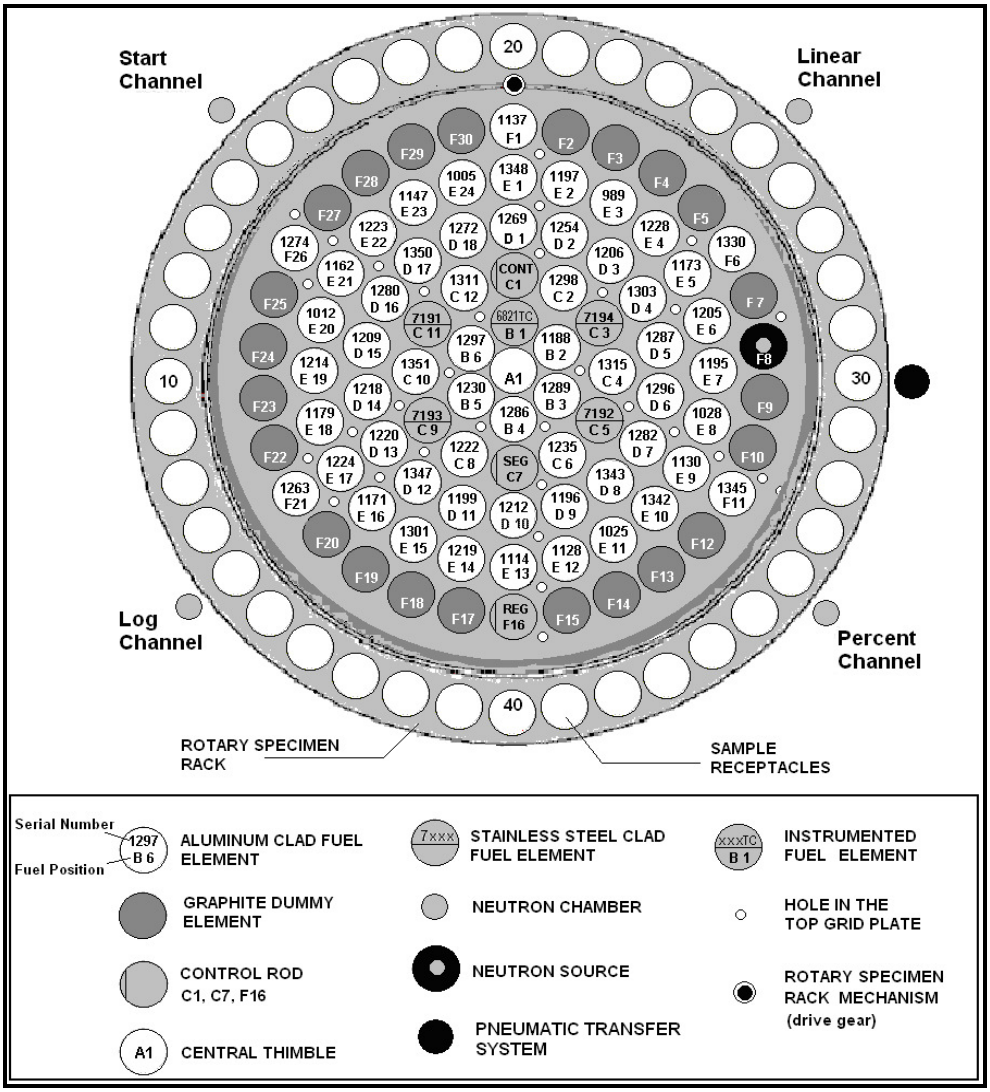

Figure 1. IPR-R1 TRIGA reactor core [3].

A data acquisition system developed for the IPR-R1 [4] collects all operation data and the vast majority of the reactor operational parameters can be monitored by scans from 1.0 ms (sampling frequency equal to 1 kHz). All data are stored for posterior treatment and analysis. Figure 2 shows the reactor control console and the graphical interface of the data acquisition system.

Figure 2. IPR-R1 TRIGA console and the data acquisition system [4].

The IPR-R1 startup procedure is manual. The reactor operators adjust the control rods vertical position until the reactor reaches the desired power level. The standard shutdown procedure is to pull the emergency button, which causes the simultaneous fall of the three control rods by gravity. This operational philosophy was defined about 50 years ago, when automation was not usual. Today, with the modern technology and computers, it is possible to automate all nuclear plant operations [5]. Instrumentation and control systems for all new TRIGA reactors have now evolved into compact, microprocessor-driven systems. Nowadays TRIGA reactors consoles are designed to provide safe and reliable operation in different modes: manual, automatic, square wave, pulse [6].

At present, in the CDTN research program there is a project supported by the *Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG)* that intends to do a modernization of the IPR-R1 TRIGA reactor instrumentation and also to provide a more refined control of its operational variables. One of the project goals is the implementation of the IPR-R1 reactor automatic control [7].

Once the TRIGA IPR-R1 startup and shutdown procedures are manuals, the energy releasing during these periods may vary significantly between different reactor operations. The aim of this work is to evaluate the dissipated energy during startup and shutdown periods of reactor operation at 100kW and to compare this energy with the dissipated energy during the period of stable power for different times of operation. The results may be useful to neutron activation analysis, which requires an accurate knowledge of the sample irradiation time.

2. MATERIALS AND METHODS

In this work, it was used data obtained from the IPR-R1 data acquisition system. A set of 10 irradiations performed between March/2008 and October/2008 was analyzed [8]. All irradiation took 1 hour and the reactor operates at the 100kW nominal power. The used data consists of Linear Channel power measurements. The temporal evolution of the reactor power was evaluated and the dissipate energy in each irradiation was obtained (area under the "Power x Time" curve). The dissipated energy was analyzed for three different periods:

- from the reactor startup until the steady-state power of 100kW;
- during the period of 100kW steady-state power;
- during the reactor shutdown (power reduction from 100 to 0kW).

The obtained "Power x Time" curves were fitted and a mathematical expression was found to describe the power evolution during the startup procedure.

3. RESULTS AND DISCUSSIONS

The IPR-R1 power evolution obtained through the neutronic Linear Channel is shown in Figure 3. The result belongs to the first irradiation occurred on March/2008.

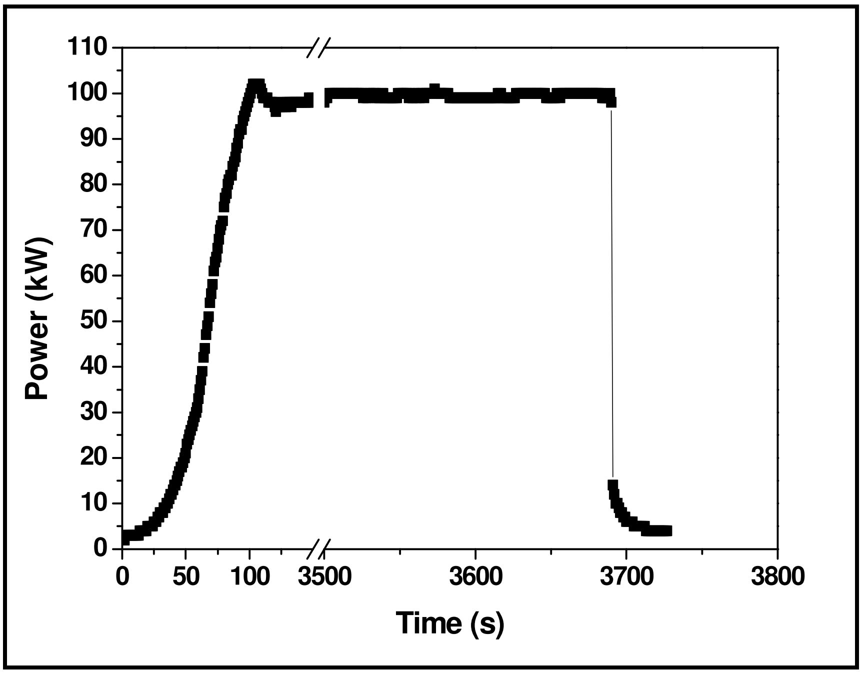

Figure 3. Linear Channel power evolution during the first irradiation.

From the Figure 3, the area under the "Power x Time" curve (dissipated energy) was calculated for three periods of interest in this work:

- from the reactor startup until the steady-state power of 100kW: **3,384kJ**;
- the period of steady-state power of 100kW: **360,093kJ**;
- the reactor shutdown: **164kJ**.

Similar results were obtained for the other irradiations. The energy values found for all the irradiations are shown in Figure 4.

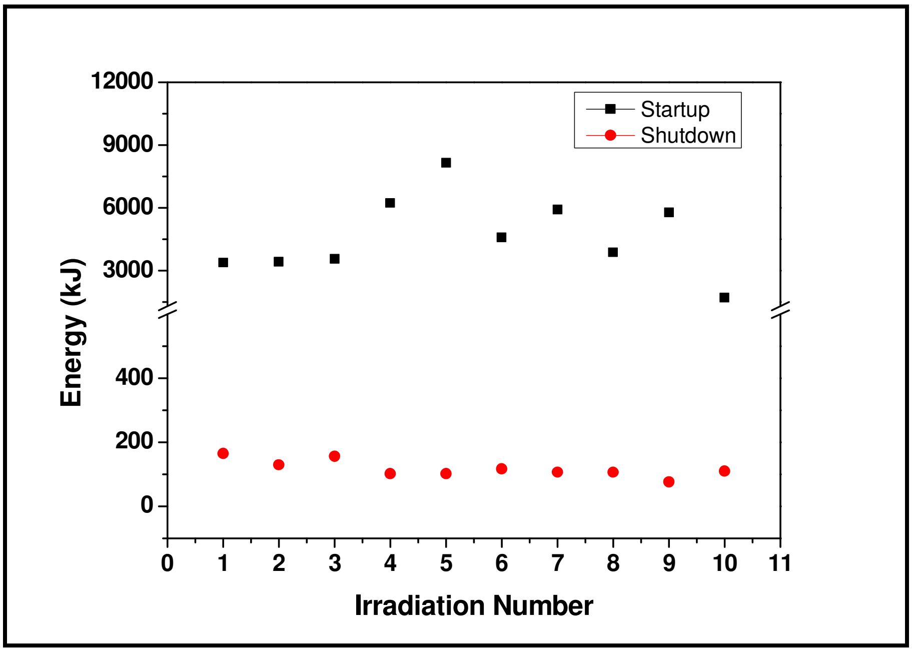

Figure 4. Released energy at Startup and Shutdown periods of IPR-R1.

The mean areas (energy) obtained and the standard deviation (SD) from the results shown in Figure 4 are:

- from the reactor startup until the steady-state power of 100kW: (**3,284 ± 1,861**)kJ (40% SD);
- the period of steady-state power of 100kW: (**360,191 ± 5,156**)kJ (1.4% SD);
- the reactor shutdown: (**164 ± 27**)kJ (23% SD).

Figure 4 shows a large dispersion of the values obtained for the IPR-R1 startup procedure (40% SD). This large dispersion is due to the fact that the startup procedure is done manually and by different operators. From the data analysis, it is possible to note that the ratio between the area of the variable power period (startup + shutdown) and the area of the steady-state power period is approximately 1% for 1 hour irradiation time.

In the case of sample irradiations, the induced activity is proportional to the area under the "Power x Time" curve [9]. Therefore, the induced activity during the variable power periods represents about 1% of the induced activity at the ending of an hour of 100kW steady-state power period. At Neutron Activation Analysis Laboratory of CDTN/CNEN, routinely it is used 4 and 8 hours of irradiation time, at 100kW reactor power. For these times, the estimated induced activity during the variable power periods represents about 0.25% and 0.125% of that of the steady-state power period.

Figure 5 presents the first irradiation power evolution during IPR-R1 startup. The data presented in Figure 1 were fitted with a sigmoid function to describe the power behavior. The sigmoid fitted function is done by:

$$P(t) = 100 - \frac{100}{1 + e^{\frac{t-68}{11}}} \tag{1}$$

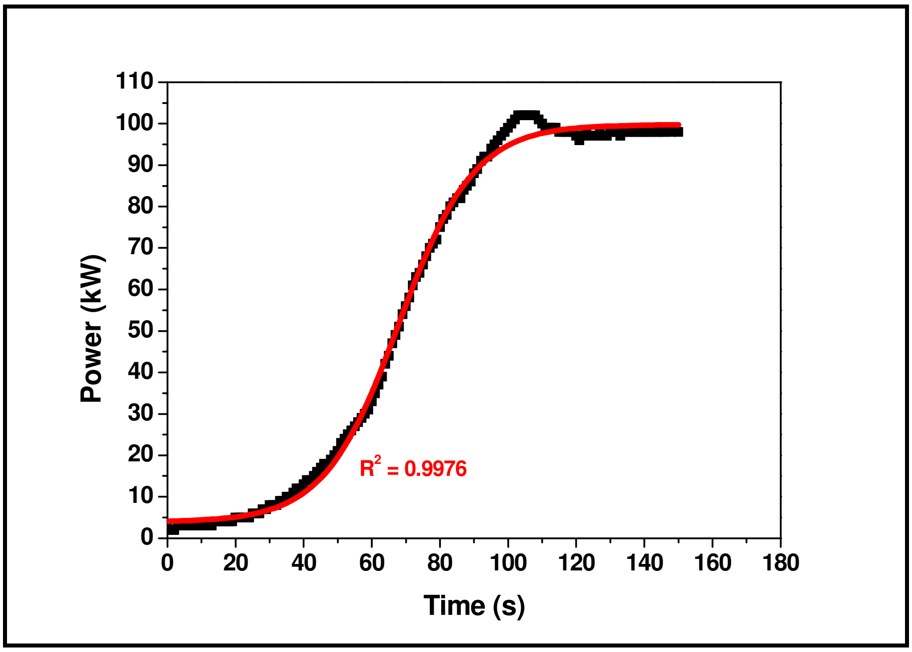

Figure 5. Power evolution during IPR-R1 startup.
The red line indicates the sigmoid fitted curve.

4. CONCLUSIONS

The data reveal that IPR-R1 power evolution during the startup procedure follows a sigmoid function. However, the IPR-R1 startup procedure presents 40% standard deviation on its released energy. This large value is due to the manual procedure depending on the reactor operators. The sum of startup and shutdown periods corresponds approximately to 1% of the released energy for irradiations during 1h at 100kW. For 4 and 8 hours irradiation times, these values are respectively 0.250% and 0.125% at the same thermal power. These results may be useful to correct neutron activation data providing a more accurate analysis.

ACKNOWLEDGMENTS

The authors express their thanks to the IPR-R1 operational staff: M.Sc Fausto Maretti Júnior, supervisor of the IPR-R1 TRIGA and the reactor operators Paulo Fernando Oliveira and Luiz Otávio Ivanenko Sette Câmara. Work supported by the *Minas Gerais* State *FAPEMIG* (*Fundação de Amparo a Pesquisa do Estado de Minas Gerais*).

REFERENCES

1. CDTN/CNEN - Centro de Desenvolvimento da Tecnologia Nuclear **-,** *XXII Curso de Treinamento de Operadores em Reatores de Pesquisa (CTORP)*, Vol. I and II, Belo Horizonte, Brazil, (2001).

2. CDTN/CNEN - Centro de Desenvolvimento da Tecnologia Nuclear –, *Manual de Operação do Reator TRIGA IPR-R1*, Belo Horizonte, Brazil, (2007).

3. Mesquita, A.Z., "Experimental Investigation on Temperatures Distribuitions in a Research Nuclear Reactor TRIGA IPR-R1", Ph.D thesis, 169p, Universidade Estadual de Campinas, São Paulo, Brazil (in Portuguese), (2005).

4. Mesquita, A. Z. ; Souza, R. M. G., "On-Line Monitoring of the Reactivity and Control Rods Worth at the IPR-R1 TRIGA Reactor", *Proceeding of INTERNATIONAL NUCLEAR ATLANTIC CONFERENCE*, Santos, Brazil, (2007).

5. Safety Systems of Nuclear Power Plants". Regulatory Guide 1.152, Revision 2, Office of NRC – US Nuclear Regulatory Commission, "Criteria for Use of Digital Computers in Nuclear Regulatory Research, January (2006).

6. General Atomics Electronic Systems Inc., "Reactor Instrumentation & Control System Console for CDTN IPR-R1 TRIGA® Reactor Facility at Brazil", GA-ESI, USA (2008).

7. Mesquita, A.Z. Costa, A.C.L. Souza, R.M.G.P., "Upgranding of the IPR-R1 TRIGA Nuclear Research Reactor Instrumentation and Control", Proceedings of 20th INTERNATIONAL CONGRESS OF MECHANICAL ENGINEERING COBEM (2009).

8. Zangirolami, D. M., *Fluxo neutrônico a 100kW, nos terminais de irradiação do reator TRIGA IPR-R1*. Dissertation, 103p, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, (2009).

9. De Corte, F. "*The* k_0 *- standardization method; A move to the optimization of neutron activation analysis"*. Ph.D thesis, 464p, Ghent University, Ghent (Belgium), (1986).