

# 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 Departure 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 do 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. In this work, we have evaluated the power evolution during startup of IPR-R1 and obtained the mean value of reactor energy production in this phase of operation. The analysis was made on basis of the Linear Multi-range Channel data. As a complement, the same analysis has been made to reactor shutdown period (scram).

## 1. INTRODUCTION

The IPR-R1 TRIGA Mark 1 nuclear reactor of CDTN/CNEN operates since 1960. It is a pool type reactor which is cooled by natural circulation. The fuel is an alloy of zirconium hydride and uranium enriched at 20% in  $^{235}\text{U}$ . 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 which provides large scale isotope irradiation; the central tube (CT) placed at the center of reactor core which permits sample irradiation with maximum neutronic flux, besides neutron beam extraction; a pneumatic transfer tube which makes possible the analysis of short half life radioisotopes. The IPR-R1 was originally designed to operate at continuous powers up to 30kW and today can operates at continuous powers up to 100kW. After the final licensing, the IPR-R1 is going to operates 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 of temperature, water conductivity, radiation level, etc. The neutronic channels are: the Departure Channel, the Logarithmic Channel, the Linear Channel and the Percent Power Channel. The Departure Channel consists of a fission chamber detector, circuits and associated meters, which monitor

the neutron flux in the range of the reactor's startup. The Logarithmic Channel consists of a compensated ionization chamber detector, circuits and associated meters, which monitor the neutron flux ranging from the ending of the Departure Channel scale to levels slightly higher than the maximum power. The Linear Channel consists of an analog meter and strip chart recorder which 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.

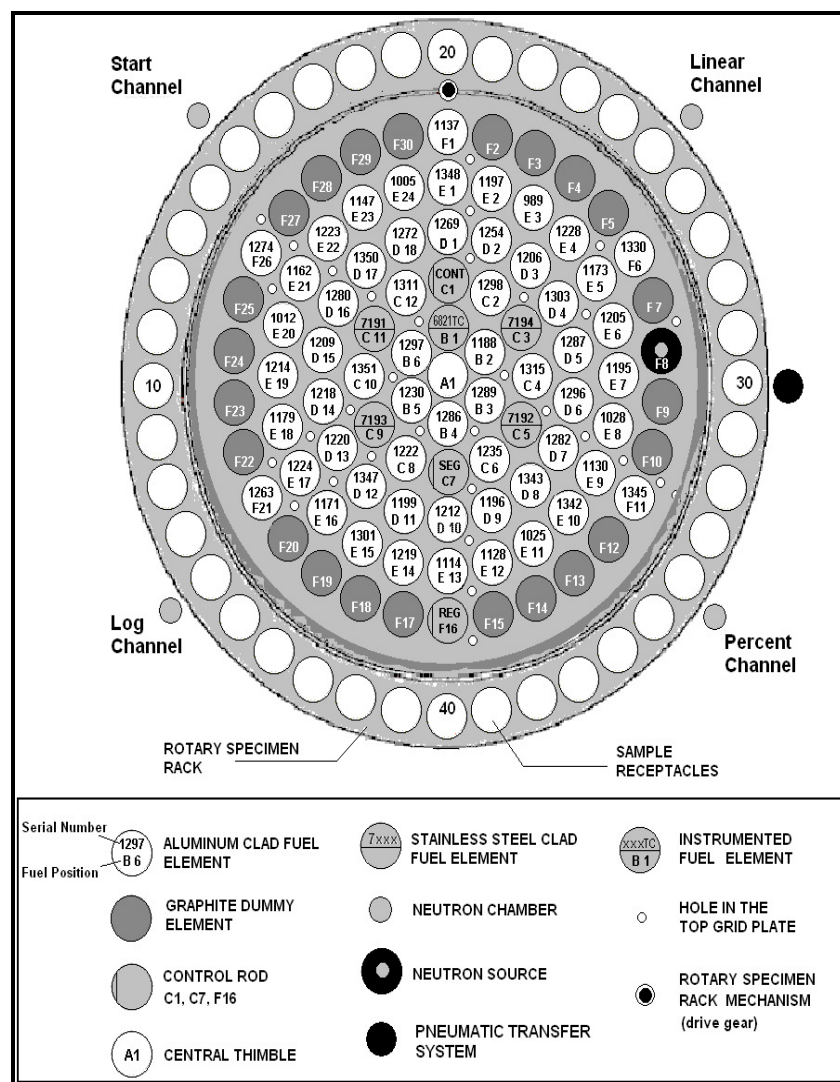


Figure 1. IPR-R1 TRIGA reactor core [3].

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 controls 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.

The aim of this work is to evaluate the dissipated energy during startup and shutdown periods of reactor operation at 100kW, and compare this energy with the dissipated energy during the period of stable power for different times of operation.

## **2. MATERIALS AND METHODS**

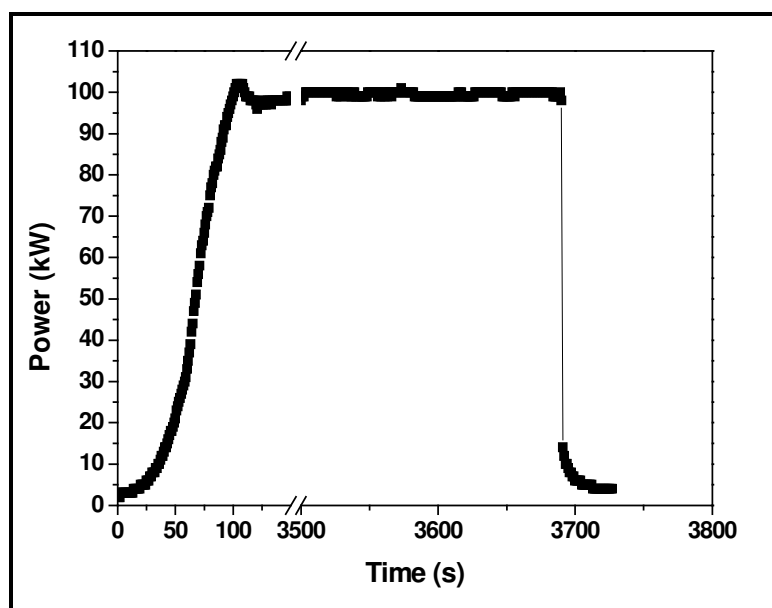
In this work, it was used data obtained from the IPR-R1 data acquisition system. A set of 10 irradiations performed between March/2008 and October/2008 was analyzed [5]. All irradiation took 1hour and the reactor operates at the 100kW nominal power. The used data consists of Linear Channel power measurements. The temporal evolution of the reactor power was evaluated and the dissipate energy in each irradiation was obtained (area under the “Power as a function of 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;
- from the reactor shutdown (power reduction from 100 to 0kW).

The obtained “Power versus Time” curves were fitted and a mathematical expression was found to describes 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. These results were from the first irradiation occurred on March/2008.

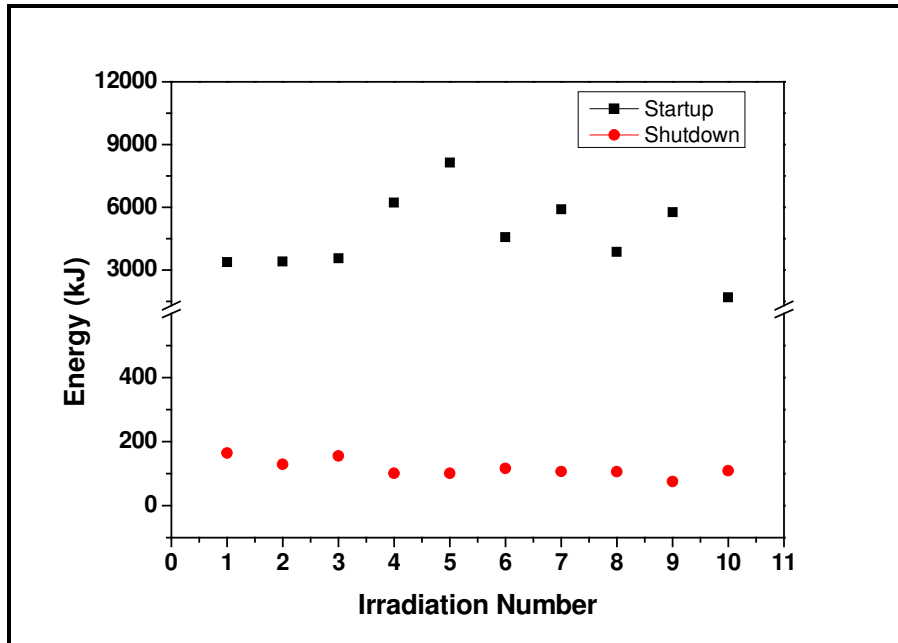


**Figure 3. Linear Channel power evolution during the first irradiation.**

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

- 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:

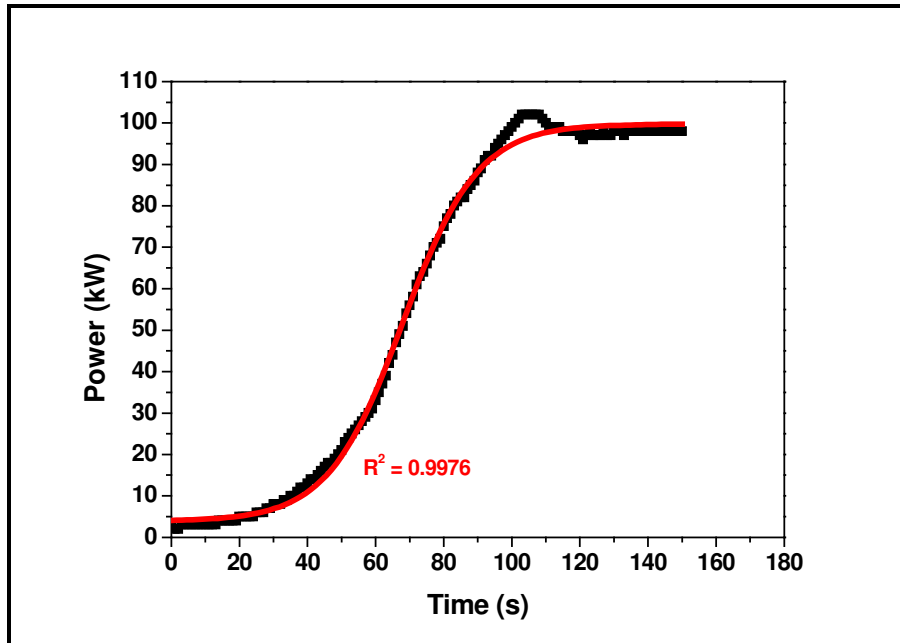
- the reactor startup until the steady-state power of 100kW: **(3,284 ± 1,861)kJ** (40% SD);
- the period of steady-state power of 100kW: **(360,191 ± 5,156)kJ** (1.4% SD);
- the reactor shutdown: **(164 ± 27)kJ** (23% SD).

Figure 4 shows a large dispersion of the values obtained in 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 1hour irradiation time.

In the case of sample irradiations, the induced activity is proportional to the area under the “Power x Time” curve [6]. 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:

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



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

#### 4. CONCLUSIONS

The data reveal that the IPR-R1 startup procedure presents 40% standard deviation on its released energy. This large value is due to the manual procedure which depends on the reactor operators. The sum of startup and shutdown periods corresponds to 1% released energy for irradiations during 1h at 100kW. For 4 and 8 hours irradiation times, these values are respectively 0.250% and 0.125%. The IPR-R1 power evolution during the startup procedure follows a sigmoid function.

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