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THERMAL BEHAVIOUR OF THE IPR-R1 TRIGA NUCLEAR REACTOR

Amir Z. Mesquita, Hugo C. Rezende, Fausto Maretti Jr., Paulo F. Oliveira e Luiz O. I. S. Câmara

Centro de Desenvolvimento da Tecnologia Nuclear (CDTN / CNEN – MG)
Campus da UFMG - Pampulha
30.123-970 - Belo Horizonte, MG
amir@cdtn.br, hcr@cdtn.br, fmj@cdtn.br, pfo@cdtn.br e lois@cdtn.br

ABSTRACT

This work presents the experiments analysis to determine the temperature distribution in the -IPR-R1 TRIGA Research Nuclear Reactor of the CDTN, Belo Horizonte, Minas Gerais. A methodology for the calibration and monitoring the reactor thermal power was also developed. This methodology allowed adding others power measuring channels to the reactor by using thermal processes. A data acquisition and processing system and a software were developed to help the investigation.

1. INTRODUCTION

The IPR-R1 Research Nuclear Reactor of the Nuclear Technology Development Center – CDT*N*, in Belo Horizonte, Minas Gerais, is a TRIGA Mark I type reactor. This reactor is a pool type reactor with a natural circulation core cooling system. The first scope for this work was the development of a methodology for the reactor power calibration. Another important result of this investigation was the addition of three more channels for reactor power measuring i.e.: the power removed through the primary cooling loop; the power removed from the secondary cooling loop and the power obtained by measuring the temperature at the centre of the instrumented fuel element (Fig. 1) which was included in the reactor core as a result of this project. This last measuring channel can also be used as a safety device to scram automatically the reactor if the fuel temperature rises over a safety limit.

Figure 1. Instrumented fuel-moderator element

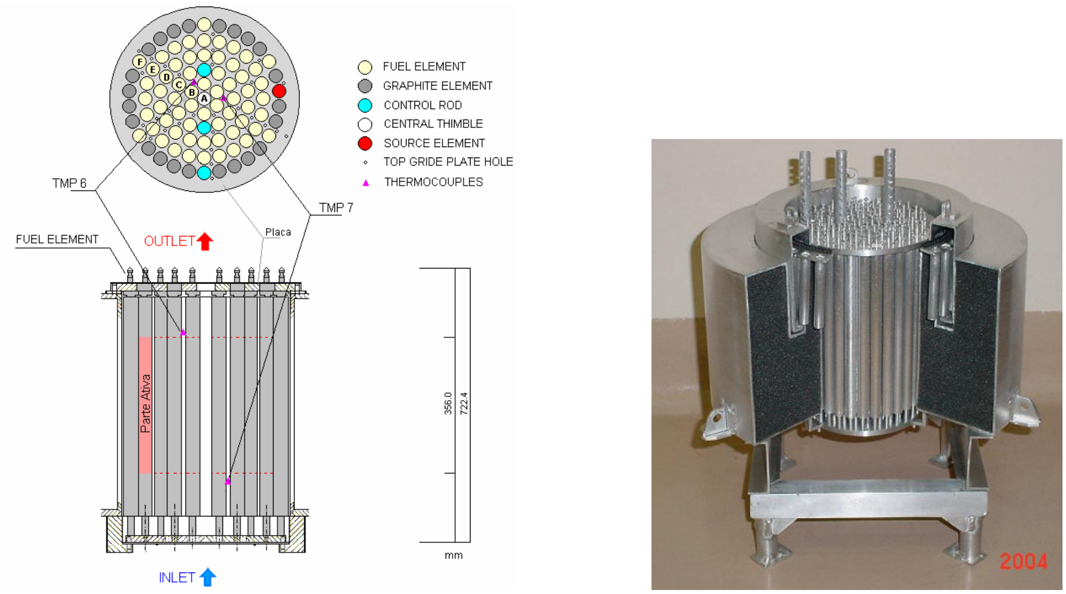

Figure 2. Thermocouple positions in the reactor and core model

2. METODOLOGY

The original fuel element at the position B1 (Fig. 2) was removed from the reactor core and replaced by an instrumented fuel element with three type k thermocouples positioned in the fuel center line. The position B1 has the greater power of the core, according to the neutron calculations (Dalle, 2003). Two additional type k thermocouples were placed in the reactor core in two channels close to the position B1. Nine thermocouples and one platinum resistance thermometer have been used to monitor the reactor pool temperature. The thermocouples were positioned in a vertical aluminum probe and the first thermocouple was placed 143 mm above the core top grid plate. The reactor power was increased from 50 kW to 250 kW (measured by the neutron linear channel) in 50 kW steps. The reactor thermal power calibration as described in the next section was carried out at 250 kW. After finding the power reference value, the instrumented fuel element was replaced to other positions in each fuel ring from B to F. At the some way, the two flow channel thermocouples probes were replaced to channels close to the instrumented fuel element. After these experiments, the temperature measuring probes were taken out from the reactor and the instrumented fuel element was placed at position B1. The original fuel element that was at this position was positioned in the fuel-element storage rack at the reactor pool.

3. THERMAL POWER CALIBRATION

The thermal power calibration of the reactor was based in the energy balance of the reactor forced primary cooling system. This is doing by measuring the values of the inlet and outlet temperatures of the water and its flow rate. At the steady state the energy produced in the reactor core must be equal the heat transferred through the cooling loop with the addition of the thermal looses from the pool to the environment. The power dissipated in the secondary loop was also measured with a thermal balance.

4. CORE THERMAL CALIBRATION

The reactor stayed critical for around eight hours with the neutron linear channel measuring 250 kW. The power transferred through the primary cooling loop was monitored during the full test and the steady state occurs in the last one hour. Figure 3 shows the power evolution in the primary and secondary loops during the test. Table 1 presents the results and some calibration data. The uncertainty of the power measurement considered all the uncertainty propagation of primary parameter, according to the methodology described by Mesquita (2005).

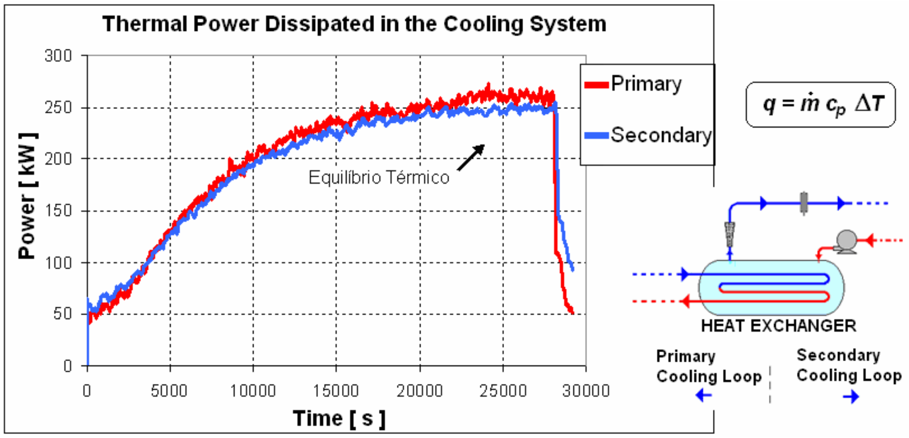

Figure 3. Thermal power evolution in the cooling system

Table 1. TRIGA IPR-R1 Reactor thermal power

Calibration date	August 19, 2004
Average inlet pressure	32.7 ± 0.4 m^3/h
Average inlet primary temperature	41.7 ± 0.3 °C
Average outlet primary temperature	34.8 ± 0.3 °C
Heat power transferred to the primary loop	261 kW
Thermal losses from the reactor pool	3.8 kW
Reactor thermal power	**265 kW**
Standard deviation of the measuring	3.7 kW
Average power uncertainty	±19 kW (±7.2%)
Heat power transferred to the secondary loop	248 kW

5. TEMPERATURE DISTRIBUTION IN THE REACTOR POOL

The reactor was operated during a period of about eight hours at a thermal power of 250 kW indicated at the linear channel, and then the steady state was obtained. Figure 4 shows the water temperatures evolution at the reactor pool and the inlet and outlet flow channel temperature, before the steady state has been obtained. The flowing channel used was the one close to the fuel element position B1 (channel 1). Figure 4 also shows that the thermocouple positioned 143 mm over the top grid plate (Inf 7) measures a temperature level higher than other thermocouples positioned over the reactor core. It means that the chimney effect is not much high, less than 400 mm above the reactor core, in agreement with the experiments of Rao et al. (1988). Finally, the primary loop suction point at the pool bottom has the lowest temperature of the reactor pool.

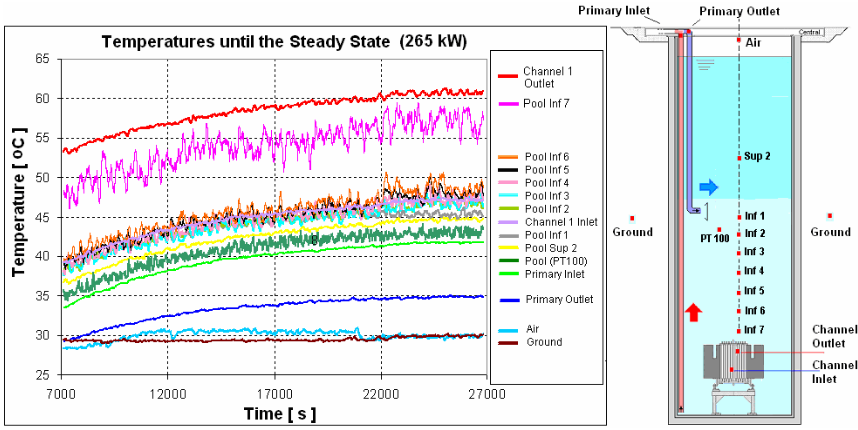

Figure 4. The temperatures evolution until the stead state at power of 265 kW

6. TEMPERATURE DISTRIBUTION IN THE CORE RINGS

The instrumented fuel element position was changed during the experiments in such way that it was placed in all fuel rings at the reactor core. The first position was the most central at ring B, the second at ring C finishing at ring F. The experiments were carried out with the power changing from 50 kW to 250 kW in steps of 50 kW for each position of the instrumented fuel element. These power were measured in the neutron linear channel what means that, by the calibration, 250 kW represents 265 kW of thermal power. Figure 5 gives the following values for each core ring: average fuel temperature, inlet and outlet temperatures at the flow channel close to the instrumented fuel, and the experimental results of Özkul and Durmayaz (2000) obtained with the I.T.U. TRIGA Mark II Reactor at the Istambul University. The radial power profile found with theoretical neutron calculations (Dalle, 2003) were plotted on the same graphic.

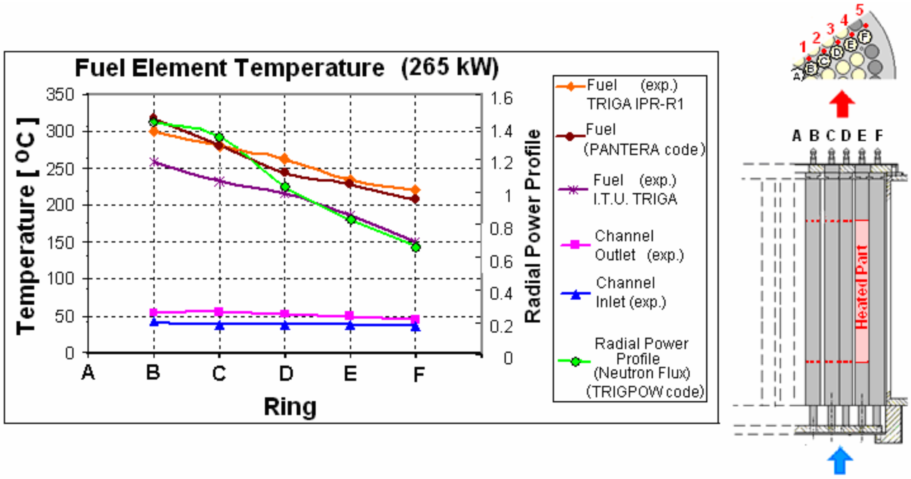

Figure 5. Fuel temperature radial power profile at 265 kW

Figure 6 shows the radial temperature profiles measured at inlet and outlet core and compare it with theoretical calculations made with PANTERA code. Figure 7 shows the measured temperatures of the instrumented fuel element as a function of the reactor thermal power at each core ring. Figure 8 shows the measured temperatures at the core flow channels outlet as a function of the reactor power in each core ring.

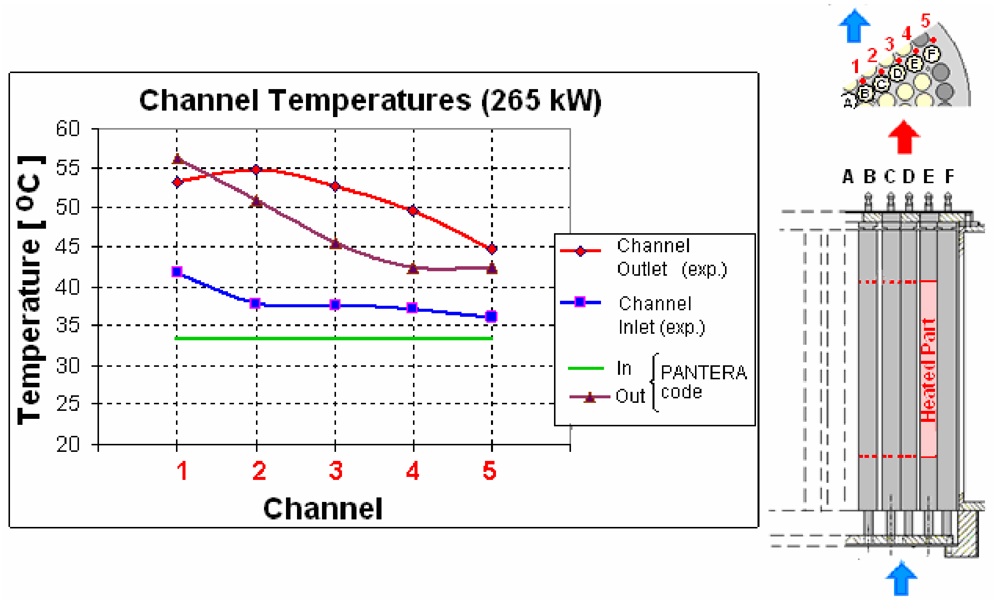

Figure 6. Temperature radial profile of the core channels at the power of 265 kW

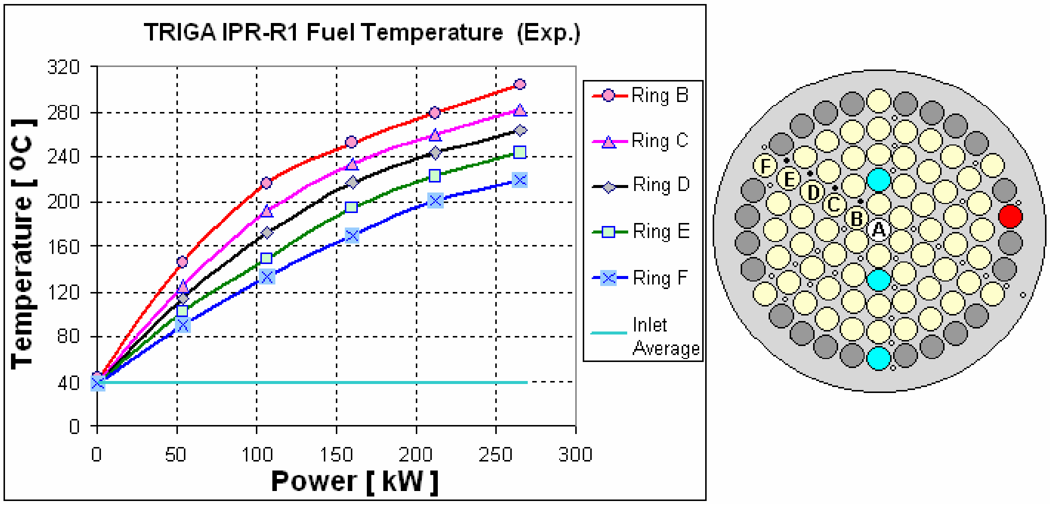

Figure 7. Instrumented fuel element temperature in all core rings

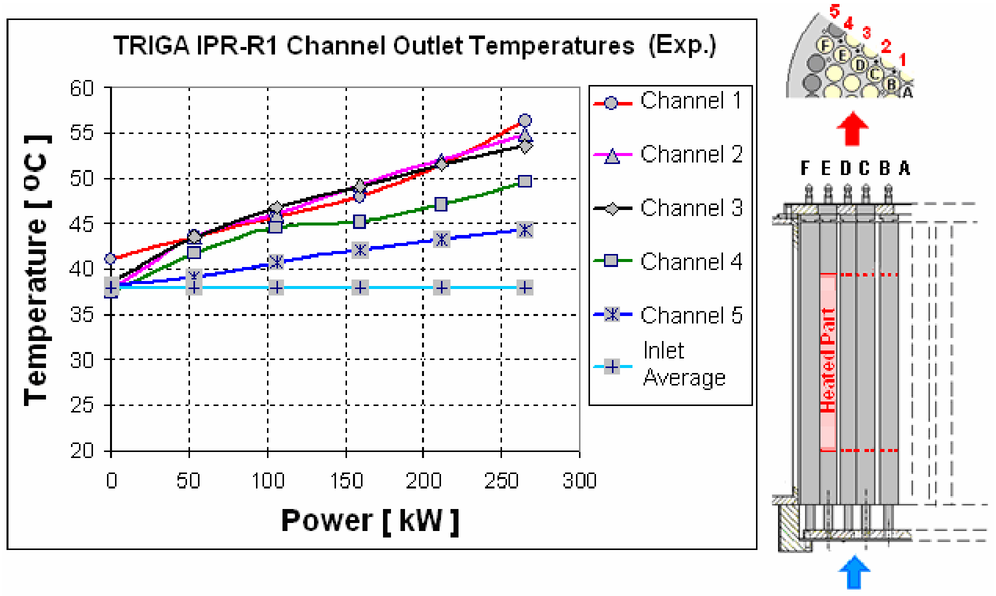

Figure 8. Outlet channels temperature as function of the power

7. CONCLUSION

The experiments had shown the core heat is cooled efficiently by natural circulation. At the power of 265 kW, with the forced refrigeration turn off, the instrumented fuel temperature maintained the temperature around 300° C.

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