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ON LINE SYSTEM FOR POWER MONITORING OF THE IPR-R1 TRIGA REACTOR BY THERMAL METHODS

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ABSTRACT

The IPR-R1 Research Reactor is a TRIGA Mark I type reactor. The IPR-R1 is a pool reactor, and the fuel elements at the core are cooled by water natural convection. The heat removal capacity of this process is great enough for safety reasons at the current maximum 250 kW power levels of the reactor. However, a heat removal system is provided for removing heat from the reactor pool water. Power monitoring of nuclear reactors is always done by means of neutronics instruments. In the IPR-R1 the power is measured by four nuclear channels. This work presents the results and methodology for monitoring the power of this reactor by thermal processes. Three improved methods for thermal measuring channels are described using the fuel element temperature and the steady-state energy balance of the primary and secondary cooling loops.

1. INTRODUCTION

The IPR –R1 reactor fuel is an alloy of zirconium hydride and uranium enriched at 20% in ^{235}U. Figure 1 shows two photographs of the reactor pool and the core. The reactor core has 58 aluminum-clad fuel elements and 5 stainless steel-clad fuel elements located in five rings around the central thimble. One of these steel-clad fuel elements is instrumented with three thermocouples along its centerline. This instrumented fuel element was put in the reactor core in order to evaluate the thermal hydraulic performance of the IPR-R1 reactor [1].

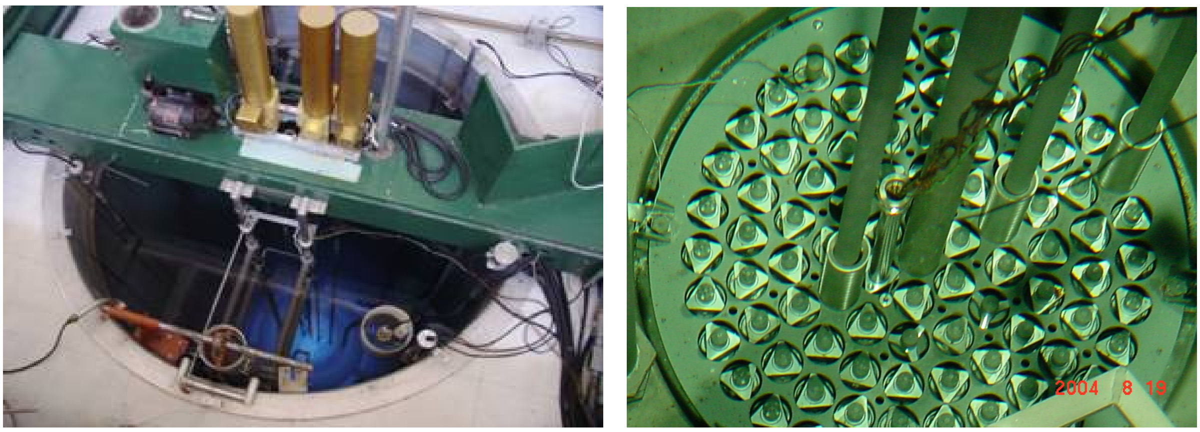

Figure 1. The IPR-R1 TRIGA Research Nuclear Reactor.

Fuel temperatures were measured in various locations throughout the core with the use of the instrumented fuel element at different power levels. Three new processes for reactor power measurement by thermal ways were developed as a result of the experiments. These process make it possible on-line or off-line evaluation of the reactor power and the analysis of its behavior.

2. POWER MEASURING CHANNELS USING NEUTRONIC METHODS

Power monitoring of nuclear reactors is always done by means of nuclear detectors, which are calibrated by thermal methods. In the IPR-R1 Reactor four neutron-sensitive chambers are mounted around the reactor core for flux measurement. The departure channel consists of a fission counter with a pulse amplifier that a logarithmic count rate circuit. The logarithmic channel consists of a compensated ion chamber, the signal is an input to a logarithmic amplifier, which gives a logarithmic power indication from less then 0.1 W to full power. The linear channel consists of a compensated ion chamber, the signal is an input to a sensitive amplifier and recorder with a range switch, which gives accurate power information from source level to full power on a linear recorder. The percent channel consists of an uncompensated ion chamber, the signal is an input to a power level monitor circuit and meter, which is calibrated in percentage of full power. Finally, the ionization chamber neutron detector measures the flux of neutrons thermalized in the vicinity of the detector. This signal is not always proportional to the integral neutron flux in the core and consequently to the core power. Besides the response of a single nuclear detector is sensitive to the changes in the core configuration, particularly to the control rod position. This is important in the TRIGA reactor, which do not have distributed absorbers for reactivity control and criticality maintenance is doing by insertion of control rods [2].

3. POWER MEASURING CHANNEL USING THERMAL PROCESS

3.1. Power Measuring Channel by Thermal Balance

The reactor core is cooled by natural convection flow of demineralized light water in the reactor pool. Heat is removed from the reactor pool and released into the atmosphere by primary cooling loop, secondary cooling loop and a cooling tower (Fig. 2). Pool temperature depends on reactor power, as well as external temperature, because the latter affects heat dissipation in the cooling tower. The total dissipated power is determined by making the thermal balance of the inlet and outlet cooling water that flows through in the primary and secondary loops and the calculation of the heat losses. These losses represent a very small fraction of the total power (about 1.5% of total) [3].

The inlet and outlet temperatures are measured by four platinum resistance thermometers (PT-100) positioned at the inlet and at the outlet pipes of the primary and secondary cooling loops. The flow-rate in the primary loop is measured by on an orifice plate and a differential pressure transmitter, in the secondary loop the flow is measured by a flowmeter. The pressure transmitter and the temperature measuring lines were calibrated and an adjusted equation was added to the data acquisition system [4].

The steady state is reached after some hours of reactor operation, then the power dissipated in the cooling system added with the losses is equal to the core power. The uncertainty in the power measurement considered all the uncertainty propagation from primary parameters, according to the methodology described by Coleman and Steele [5].

The thermal power dissipated in the primary and secondary loops were given by:

$$q_{cool} = \dot{m} \,.\, c_p \,.\, \Delta T \quad . \qquad (1)$$

Where q_{cool} is the thermal power dissipated in each loop [kW], $\dot{m}$ is the flow rate of the coolant water in the loop [kg/s], c_p is the specific heat of the coolant [kJ/kg^{o}C], and ΔT is the difference between the temperatures at the inlet and the outlet of the loop [^{o}C]. The data acquisition computer program calculates the power dissipated in the cooling loop with the collected data being used in Equation 1, and with the $\dot{m}$ and c_p values corrected as function of coolant temperature [6].

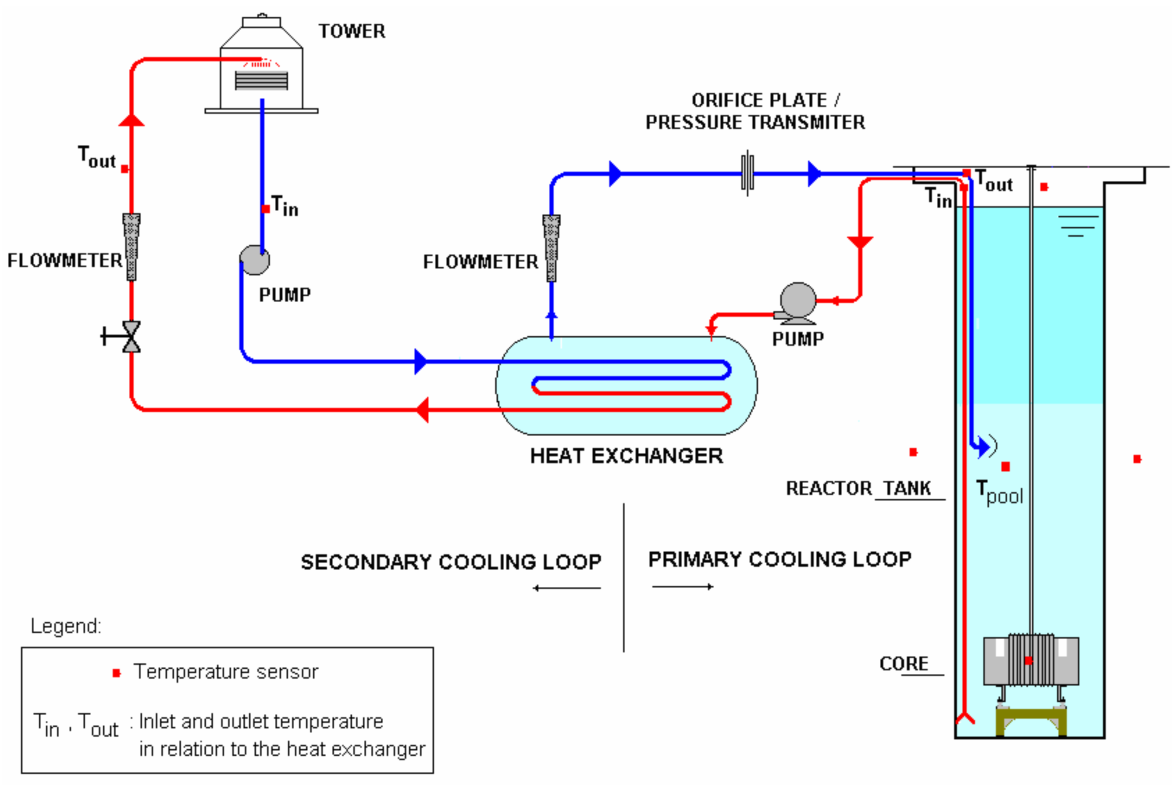

Figure 2. The reactor cooling system.

To calculated the heat losses, one resistance thermometer (PT-100) was positioned inside the pool to measure the water pool temperature. A type K thermocouple was placed just above the pool surface to measure the air temperature at the reactor room. Two type K thermocouples were distributed around the pool, in holes in the reactor room floor, to measure the soil temperature. The core of the TRIGA Mark I IPR-R1 Nuclear Reactor is placed below the room floor, in the bottom of a cylindrical pool, 6.625 m deep and 1.92 m in diameter, whose upper surface is 25 cm below the level of the floor. The reactor pool transfers heat to the environment by conduction to the soil, through the lateral walls and through the bottom of the pool, and by convection and evaporation to the air at the reactor room, through the upper surface. All this losses is calculated by the data acquisition system as described by Mesquita *et al*. [3]. Figure 3 shows the power evolution in the primary and secondary loops during one reactor operation.

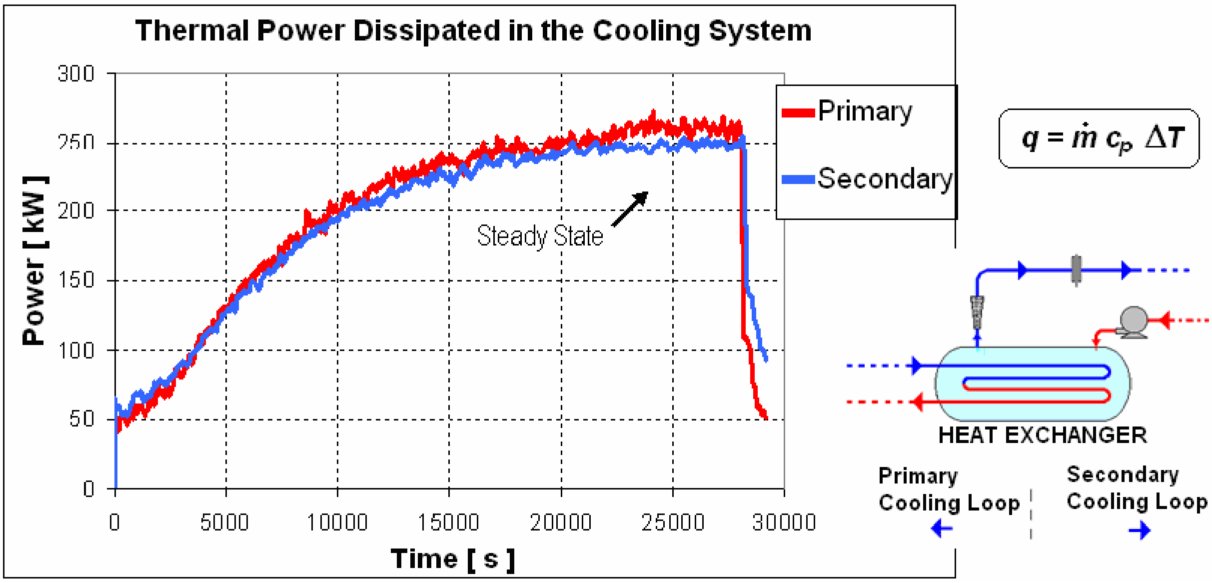

Figure 3. Thermal power evolution in the cooling system.

3.2. Power Measuring Channel by Fuel and Pool Temperature

One instrumented fuel element was put in the core for the experiments to evaluate the thermal hydraulic performance of the IPR-R1 Reactor [1]. The instrumented fuel is identical to standard fuel elements but it is equipped with three chromel-alumel thermocouples, embedded in the zirconium centerline pin. The sensitive tips of the thermocouples are located one at the center of the fuel section and the other two 25.4 mm above, and 25.4 mm below the center. Figure 4 shows the diagram and design of the instrumented fuel element [7], The core upper view shown on the right in the Figure 1 we can see the instrumented fuel element in ring B of the core.

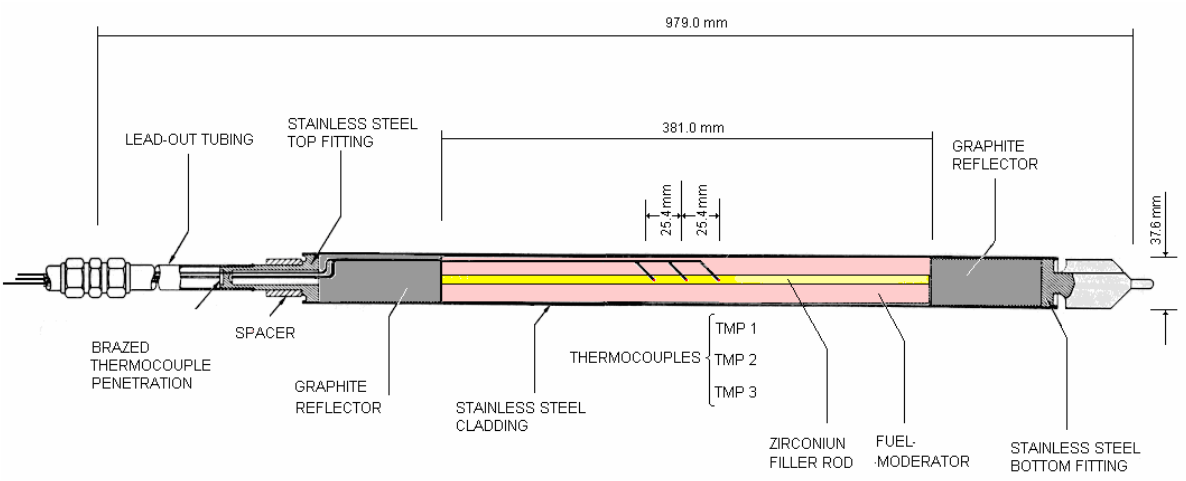

Figure 4. Diagram of the instrumented fuel element.

During the experiments it was observed that the temperature difference between fuel element and the pool water bellow the reactor core (primary loop inlet temperature) do not change for the same power value as can been seen on Fig. 5. With the instrumented fuel element in the hottest fuel element of the core (position B1), the power measured in linear channel (with the values corrected by the calibration results) was plotted as a function of the temperature difference between the fuel and the primary loop inlet temperature. The following polynomial expression was obtained that relates the two values:

$$q = 2 \,.\, 10^{-5}\,(\Delta T)^3 - 0.0045(\Delta T)^2 + 0.7666\,\Delta T - 2.4475 \quad . \qquad (2)$$

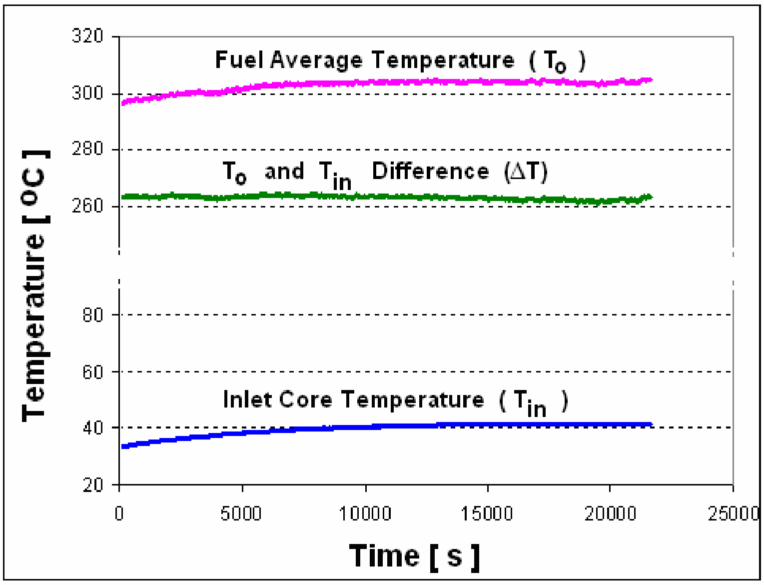

Figure 5. Fuel and inlet core water temperatures evolution.

Where q is the calibrated reactor thermal power, in [kW] and ΔT is the difference between the average fuel temperature and the primary loop inlet temperature, in [^oC]. The determination coefficient obtained was one ($R^2 = 1$). Equation 2 was included in the data acquisition system and this new power measurement channel is available for the IPR-R1 TRIGA Reactor. After the experiments the instrumented fuel element was maintained in position B1 of the core to monitor the reactor power and core temperature in all reactor operation. Figure 6 shows reactor power measuring results using the linear neutron channel and the temperature difference channel method.

The fuel temperature limit defined in the IPR-R1 TRIGA Reactor Accidents Report [8] during steady state operation is 550 ^oC. A power operation limit over 1 MW was found based in this temperature and using Equation 2.

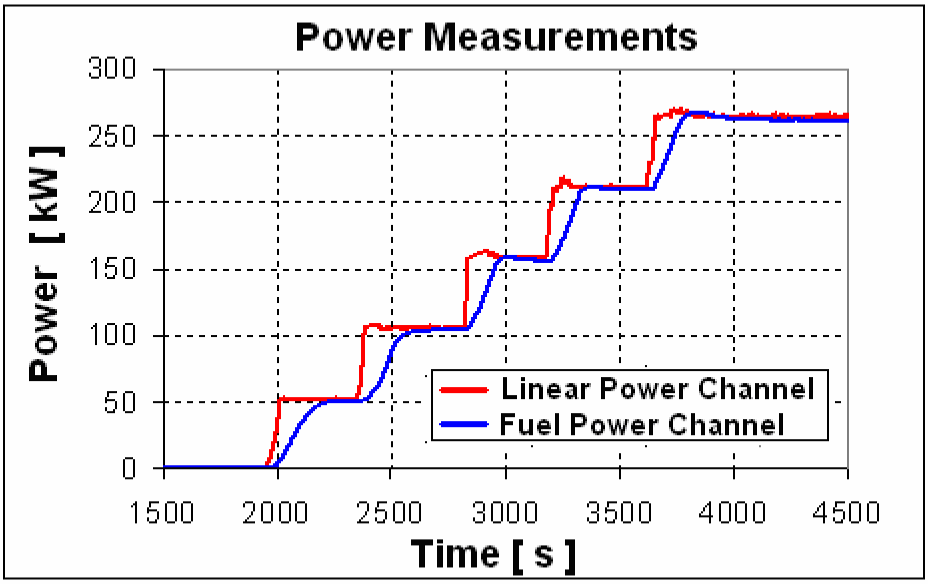

Figure 6. Reactor power measured by neutron channel and by fuel element temperature.

Figure 7 shows one of the video-screens displays of the digital monitoring system computer that consolidates information, in real time, of the reactor power status. This screen monitors the power measured by the neutronics channels and by the three new thermal channels [4].

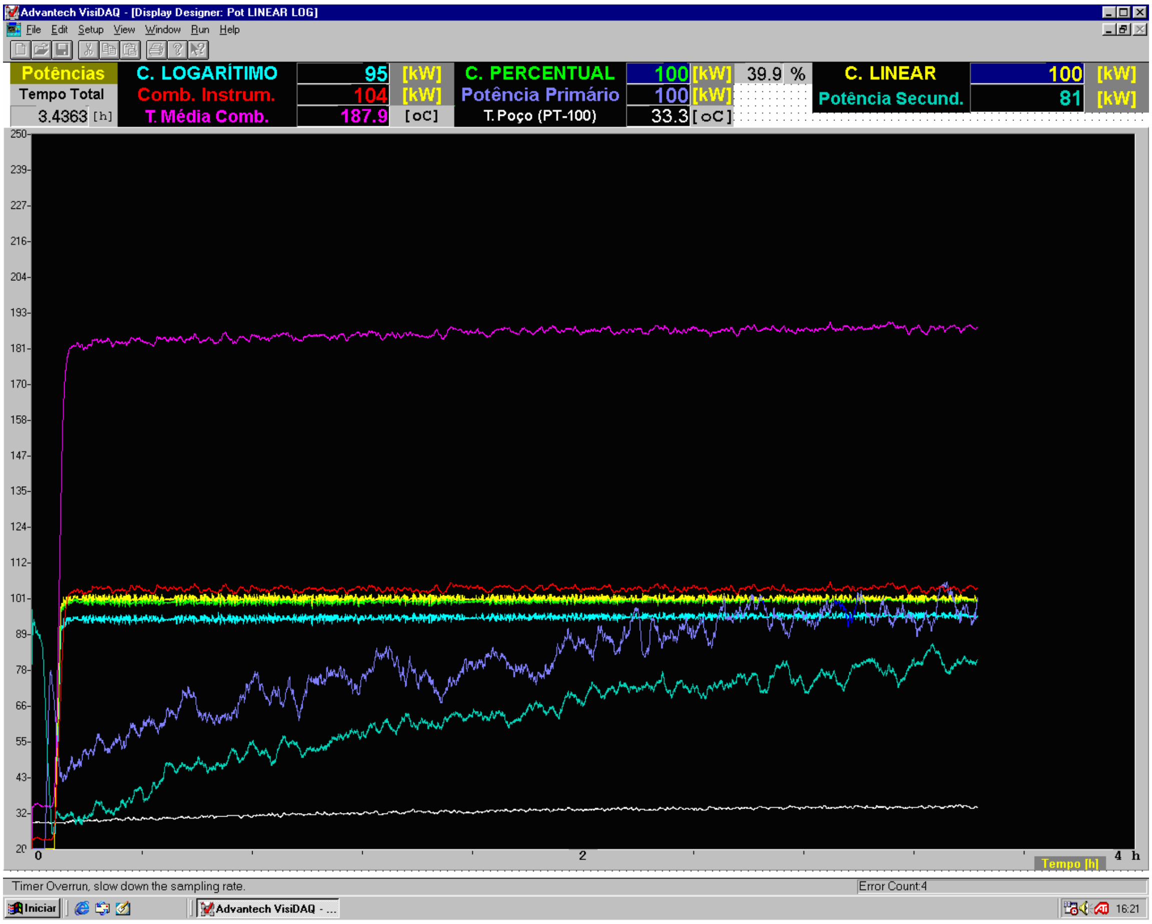

Figure 7. Power monitoring on the screen of the data acquisition system.

3. CONCLUSIONS

The knowledge of the reactor thermal power is very important for precise neutron flux and fuel element burnup calculations. The burnup is linearly dependent on the reactor thermal power and its accuracy is important to the determination of the mass of burned ^{235}U, fission products, fuel element activity, decay heat power generation and radiotoxicity. The thermal balance method presented in this report is now the standard methodology used for the IPR-R1 TRIGA Reactor power calibration [8]. The uncertainty value obtained does not differ significantly from another thermal calibration processes described in technical literature [2]. The heat balance and fuel temperature methods are accurate, but impractical methods for monitoring the instantaneous reactor power level, particularly during transients. For transients the power is monitored by the nuclear detectors, which are calibrated by the thermal balance method. On the other hand, the response of one nuclear detector is sensitive to the changes in the core configuration, mainly to the control rod position. This is important in research reactors, which do not have distributed absorbers for reactivity control and the normal mode of maintaining criticality is by insertion of control rods. The heating of the thermocouple due the gamma ray is negligible because the small mass and good thermal radiation equilibrium with the surrounding fuel.

ACKNOWLEDGMENTS

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