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# Power Monitoring in Nuclear Reactors

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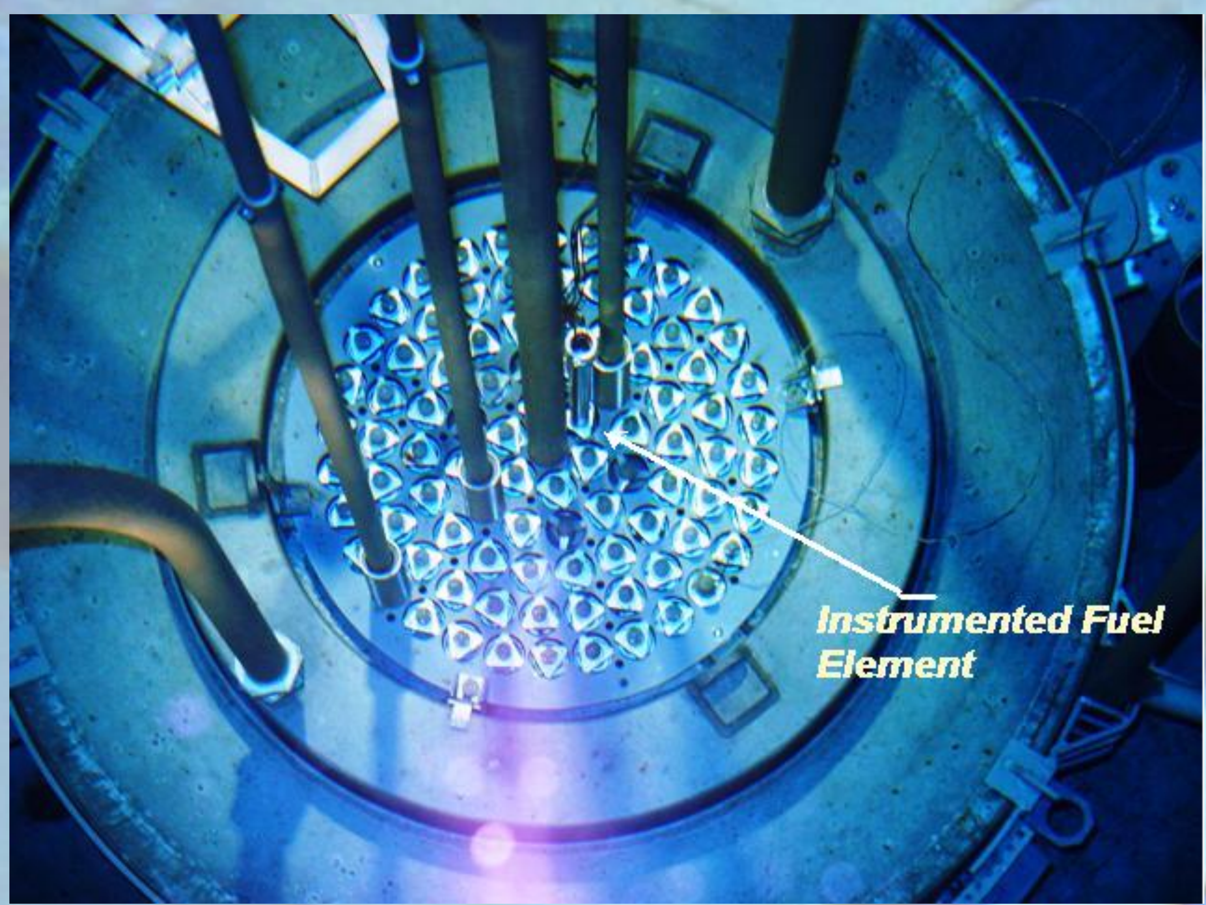
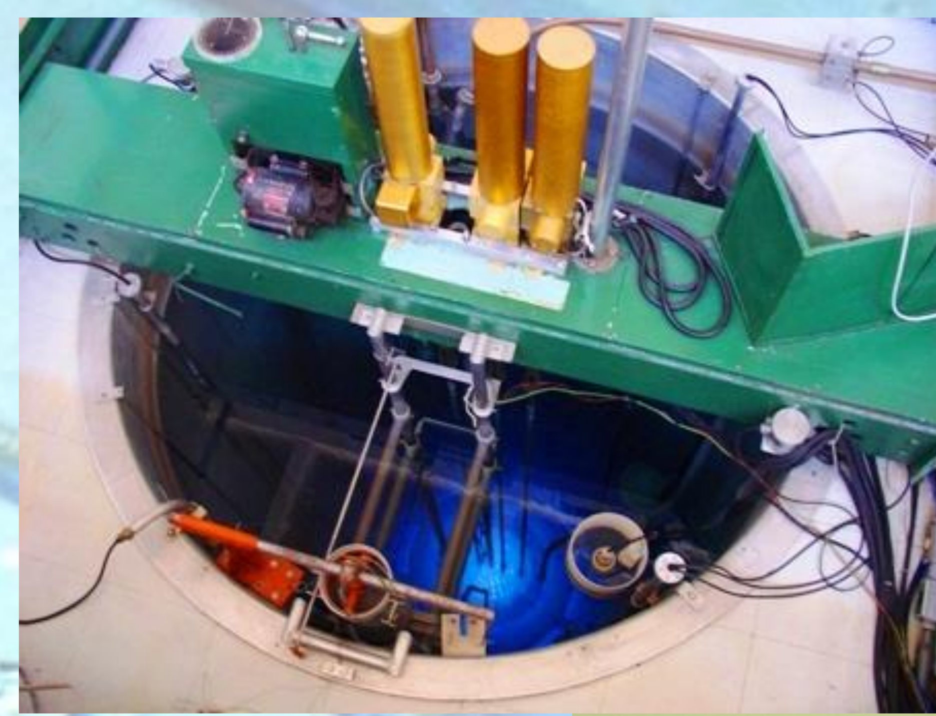
## ABSTRACT

Power monitoring of nuclear reactors is done by means of neutronic instruments, but its calibration is always done by thermal procedures. The reactor thermal power calibration is very important for precise neutron flux, fuel element burn up calculations, and mainly to electrical power. The burn up is linearly dependent on the reactor thermal power and its accuracy is important to the determination of the mass of burned U-235, fission products, fuel element activity, decay heat power generation and radiooxicity. Different methods for monitoring and controlling power in nuclear reactors are used.

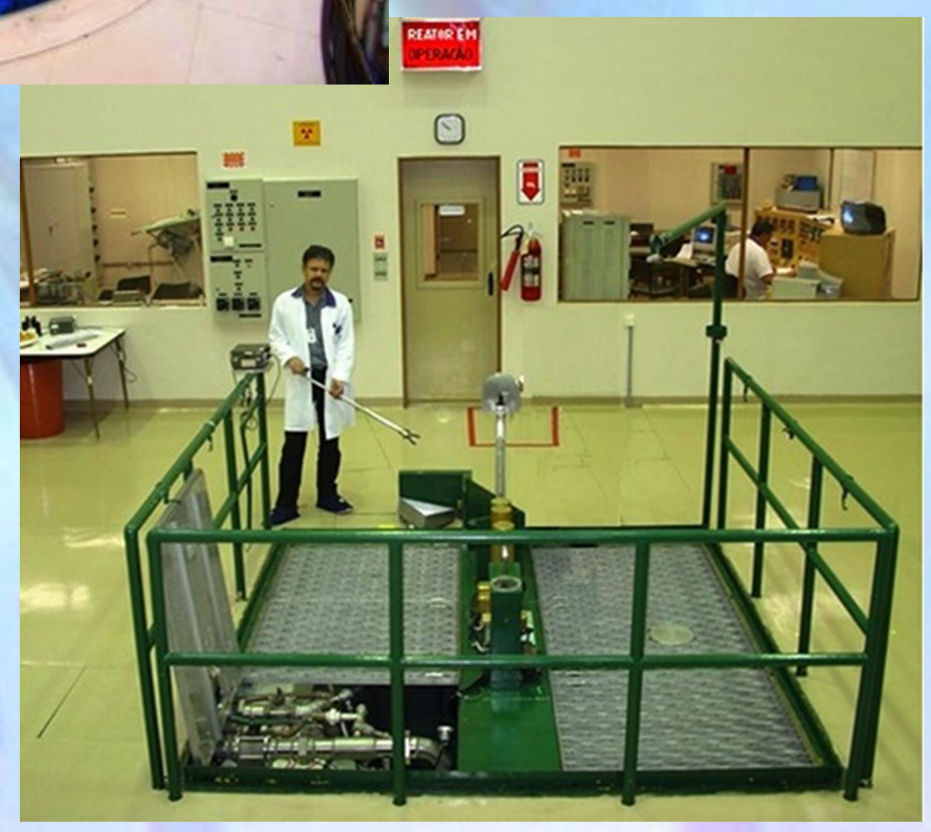



*IPR-R1 TRIGA core top view with the instrumented fuel element*

The purpose of this paper is to analyze and present the monitoring processes of thermal power supplied by nuclear reactors and new methods under implementation. Optimization on power monitoring channel will result in a better reactor control and increase the safety parameters of reactor during operation. At first, some primary concepts like neutron flux and reactor power are introduced. Then, some new researches about improvements on power-monitoring channels, which are instrument channels important to reactor safety and control, are reviewed. Furthermore, some new research trends and developed design in relation with power monitoring channel are discussed. Power monitoring channels are employed widely in fuel management techniques, optimization of fuel arrangement and reduction in consumption and depletion of fuel in reactor core. Power reactors are equipped with neutron flux detectors, as well as a number of other sensors (e.g. thermocouples, pressure and flow sensors, ex-vessel accelerometers). The main purpose of in-core flux detectors is to measure the neutron flux distribution and reactor power..



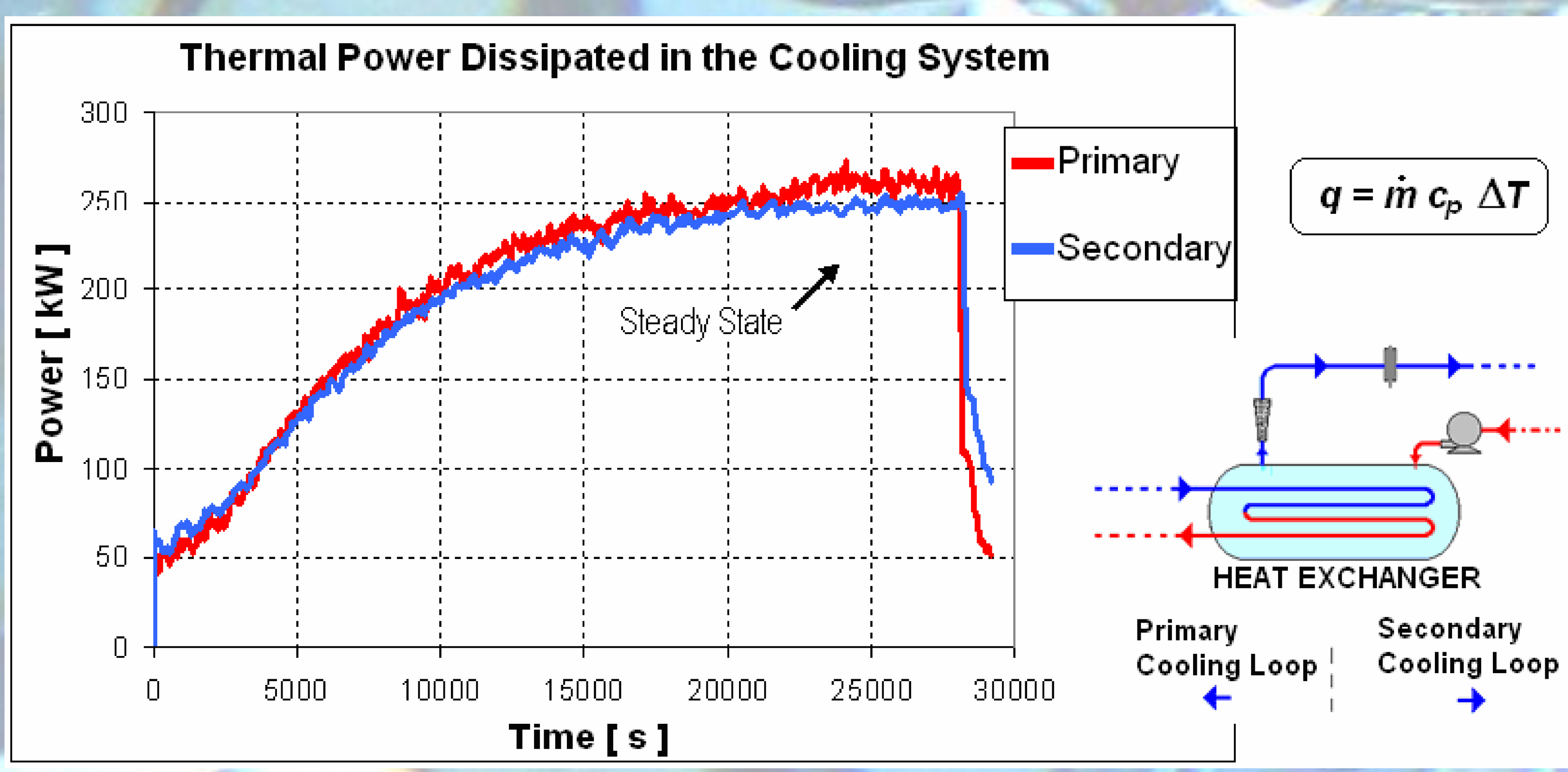
*The IPR-R1 TRIGA Reactor*



## Introduction

Rising concerns about global warming and energy security have spurred a revival of interest in nuclear energy, giving birth to a "nuclear power renaissance" in countries the world over. As humankind seeks abundant and environmentally responsible energy in the coming decades, the renaissance of nuclear power will undoubtedly become reality as it is a proven technology and has the potential to generate virtually limitless energy with no greenhouse gas emissions during operations. In addition, basic research and nuclear technology applications in chemistry, physics, biology, agriculture, health and engineering have been showing their importance in the innovation of nuclear technology applications with sustainability.

Nuclear reactor instrumentation is designed so as to emphasize the reliability, redundancy and diversity of control systems. Other criteria such as accuracy, and speed in response are also of major concern. Power monitoring in nuclear reactors is of crucial importance with respect to safety and efficient operation. Since the first criticality of a nuclear reactor carried out by Fermi and collaborators on December 2, 1942 at the Chicago University, there has been concern about safely monitoring the parameters involved in the chain reaction. Power monitoring of nuclear reactors is always done by means of neutronic instruments, i.e. by the measurement of neutron flux. The greater the number of channels for measuring power, the greater is the reliability and safety of reactor operations




### Power measuring channel using thermal balance

The reactor core is cooled by natural convection of demineralized light water in the reactor pool. Heat is removed from the reactor pool and released into the atmosphere through the primary cooling loop, the secondary cooling loop and one external cooling tower. Pool temperature depends on reactor power, as well as external temperature, because the latter affects heat dissipation in the cooling tower. The total power is determined by the thermal balance of cooling water flowing through the primary and secondary loops added to the calculated heat losses. These losses represent a very small fraction of the total power (about 1.5% of total).

The inlet and outlet temperatures are measured by four platinum resistance thermometers (PT-100) positioned at the inlet and outlet pipes of the primary and secondary cooling loops. The flow-rate in the primary loop is measured by an orifice plate and a differential pressure transmitter. The flow in the secondary loop 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. The steady state is reached after some hours of reactor operation, so that the power dissipated in the cooling system added to the losses should be equal to the core power. The thermal power dissipated in the primary and secondary loops are given by:

$$q_{cool} = . c_p . \Delta T \ .$$

## CONCLUSION

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 in the determination of the mass of burned $^{235}U$, fission products, fuel element activity, decay heat power generation and radiotoxicity. Power monitoring channels are employed widely in fuel management techniques, optimization of fuel arrangement and reduction in consumption and depletion of fuel in reactor core

The methodologies and graphical interfaces implemented in this project provide greater reliability and transparency in its operations. Besides allowing visualization in real-time, transmission through the internet or in the networks, the data is stored and can be made available to the authorities and to the public. Developments and innovations used for research reactors can be later applied to larger power reactors. Their relatively low cost allows research reactors to provide an excellent testing ground for the reactors of tomorrow.

Both the method using thermal balance and that which employs the increase in fuel temperature are efficient and precise for obtaining the thermal power. The uncertainty values obtained do not differ from those obtained from conventional nuclear measure channels using neutron flux.

The system described here for monitoring nuclear reactor power by thermal process has been developed and experimentally validated in the IPR-R1 TRIGA research reactor. This work contributes to the safe and reliable operation of nuclear reactors and diversification of the methods used to monitoring the energy released by nuclear fission.

### Power measuring channels by neutronic methods

Power monitoring of nuclear reactors is always done by means of nuclear detectors, which are calibrated by thermal methods. The IPR-R1 TRIGA research reactor was originally equipped with four neutron-sensitive chambers mounted around the reactor core for flux measurement (nuclear channels). The departure channel consists of a fission counter with a pulse amplifier that a logarithmic count rate circuit.

### Power measuring channel using fuel and pool temperature

To evaluate the thermal hydraulic performance of the IPR-R1 TRIGA nuclear reactor, one instrumented fuel element was placed in the core for the experiments. The instrumented fuel is identical to standard fuel elements, but it is equipped with three chromel-alumel thermocouples, embedded in the zirconium pin centerline. One of the sensitive tips of the thermocouples is located at the center of the fuel section, while the other two are placed 25.4 mm above, and 25.4 mm below the center [4].

During the experiments it was observed that the temperature difference between the fuel element and the pool water below the reactor core (primary loop inlet temperature) did not change for the same power value. With the instrumented fuel element in the hottest fuel element position of the core, the power measured in the 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 relating the two values was obtained [5]:

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

### Data Acquisition System

An operational computer program and a data acquisition and signal processing system were developed as part of this research project to allow on line monitoring of the operational parameters. The system registers the variables once a second in a historical database [5].

Figure 3 shows one of the video-screen displays of the digital monitoring system computer that consolidates information for the reactor power status in real time. This screen monitors the power measured by the neutronic channels and by the new thermal channels