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DESIGN OF A VISUAL SYSTEM TO MONITORING THERMAL POWER AND ENHANCEMENT OF PHYSICAL SECURITY AT THE IPR-R1 TRIGA RESEARCH REACTOR

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ABSTRACT

The IPR-R1 Research Nuclear Reactor at the Nuclear Technology Development Centre – CDTN, in Belo Horizonte (Brazil), 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 purpose of this paper is to present a proposal of implementation of a visual monitoring system in the IPR-R1 TRIGA research nuclear reactor installations, with the objective to enhance its physical security, and a power measuring system based on measurement of Cherenkov radiation produced within and around the core.

1. Introduction

The IPR-R1 TRIGA Mark-I research reactor at the Nuclear Technology Development Center (CDTN) reached its first criticality on November 11th, 1960 with a maximum thermal power of 30 kW. The IPR-R1 TRIGA is an open-pool type reactor and the fuel refrigeration is done by natural circulation. The actual forced cooling system for pool water was built in the 70th and the power was upgraded to 100 kW. Recently the power was upgraded again to 250 kW at steady state.

The IPR-R1 was designed for research, training and radioisotope production. The reactor regime of operation is about 4 hours per week. Like other TRIGA reactor the IPR-R 1 could also be used in many diverse applications, including production of radioisotopes for medicine and industry, nondestructive testing, basic research on the properties of matter, education, neutron radiography, reactor physics including burnup measurements and calculations, treatment of tumors by boron neutron capture therapy (BNCT), prompt gamma neutron activation analysis (PGNAA), solid state physics, semiconductor doping, environmental studies and researches of advanced materials.

It was performed calculations for IPR-R1 reactor using the codes: Monte Carlo (MCNP), ORIGEN 2.1 and MONTEBURNS [1]. The results showed 4% of average burnup of ^{235}U in 45 years of operation. This represents a reduction of 96 grams of ^{235}U in mass in relation to the initial value of 2.3 kg. This burning is much less than the maximum recommended by the fuel manufacturer that is 20% [2]. Therefore, if the IPR-R1 expands its research activities with daily operations, it is estimated that their life would be about 25 years more.

TRIGA reactors are the most widely used research reactor in the world. There is an installed base of over sixty-five facilities in twenty-four countries on five continents. General Atomics (GA), the supplier of TRIGA research reactors, continues to design and install TRIGA reactors around the world, and has built TRIGA reactors in a variety of configurations and capabilities, with steady state thermal power levels ranging from 100 kW to 16 MW. The TRIGA reactor is the only nuclear reactor in this category that offers true "inherent safety", rather than relying on "engineered safety". It is possible due to the unique properties of GA's uranium-zirconium hydride fuel, which provides unrivaled safety characteristics, which also permit flexibility in sitting, with minimal environmental effects [3].

2. Power Measure by Cherenkov Radiation

Two important criteria for power measurement in nuclear reactors are redundancy and diversity. Other criteria such as accuracy, reliability and speed in response are also of major concern. 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 type of chamber used and its position with respect to the core determine the range of neutron flux measured, as described below:

- The departure channel consists of a fission counter with a pulse amplifier that feeds a logarithmic count rate circuit and gives useful power indication from the neutron source level to a few watts.
- The logarithmic channel consists of a compensated ion chamber feeding a logarithmic (log n) amplifier and recorder and a period amplifier, which gives a logarithmic power indication on a recorder from less than 0.1 W to full power.
- The linear channel consists of a compensated ion chamber feeding 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 feeding a power level monitor circuit and meter, which is calibrated in percentage of full power.

The nuclear instrumentation is used to detect neutrons when sub-critical multiplication occurs during the reactor starp-up, and after achieving the criticality the variation of neutron flux, to obtain the automatic control of reactivity for maintaining a stable power level.

Unfortunately, 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 maintaining criticality is by insertion of control rods [4].

In order to improve the power measuring system, two more channels have also been considered for implementation in recent years by thermal processes [5]. One of these channels is based on the fuel element and the water pool temperatures. The other channel is based in the steady-state energy balance of the primary cooling loop of the reactor. For this balance, the inlet and outlet temperatures and the water flow of the cooling loops are measured. The heat balance and fuel temperature methods are accurate and reliable, but impractical methods for monitoring the instantaneous reactor power level, particularly during transients. One other channel, at the center of our attention in this paper, is based on measurement of Cherenkov radiation produced within and around the core. This channel will be a fast response to power change like the system that was developed in Tehran Research Reactor [6].

Cherenkov radiation is a process that could be used as an extra channel for power measurement to enhance redundancy and diversity of a reactor. This is especially easy to establish in a pool type research reactor. A simple photo diode array can be used to measure and display power in parallel with the existing conventional detectors. Experimental measurements on this channel showed that a good linearity exists above 100 kW range [6].

Light produced by charged particles when they pass through an optically transparent medium at speeds greater than the speed of light in that medium. In research nuclear reactor the electrons from the core travel through shielding water, they do so at a speed greater than that of light through water and they displace some electrons from the atoms in their path. This causes emission of electromagnetic radiation that appears as a weak bluish-white glow, as shown in Figure 1. Cherenkov radiation is used to detect high-energy charged particles. In pool-type nuclear reactors, the intensity of Cherenkov radiation is related to the frequency of the fission events that produce high-energy electrons, and hence is a measure of the intensity of the reaction. Cherenkov radiation is also used to characterize the remaining radioactivity of spent fuel rods.

The operation principle of a photodiode is a PN junction or PIN structure. When a photon of sufficient energy strikes the diode, it excites an electron, thereby creating a mobile electron and a positively charged electron hole. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.

The Figure 2 shows the circuit for signal conditioning and amplification.Hundreds or thousands (up to 2048) photodiodes of typical sensitive area 0.025 x 1 mm each arranged as a one-dimensional array, which can be used as a Cherenkov radiation sensor. One advantage of photodiode arrays (PDAs) is that they allow for high speed parallel read out since the driving electronics may not be built in like a traditional CMOS or CCD sensor.

The general block diagram of the system suggested is shown in Figure 3. The entire system consists mainly of three units: the Cherenkov detection unit, a display unit, and a data acquisition system. Cherenkov light emanating from core can be collected by a collimator right above the core and reflected by a mirror onto a sensitive part of the photo diode.

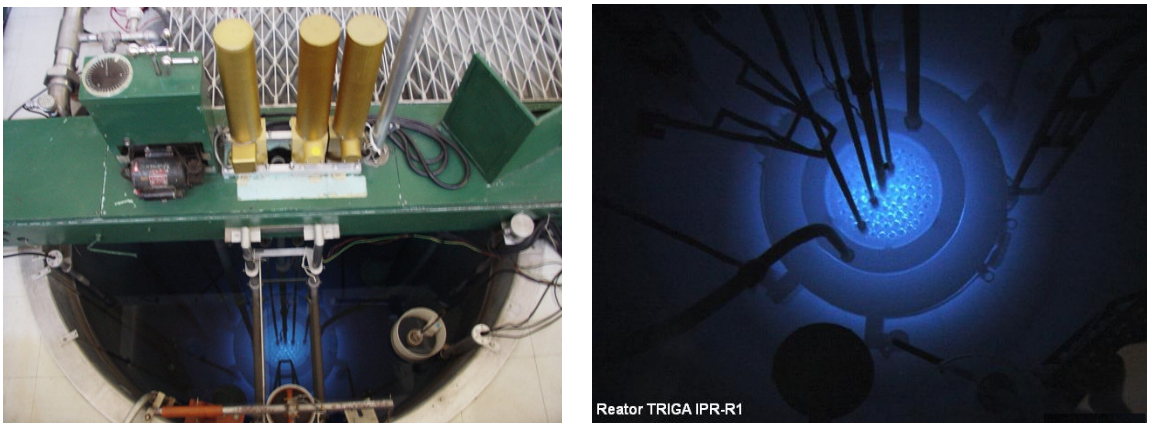

Fig. 1. Cherenkov Radiation in the IPR-R1 Research Reactor Pool

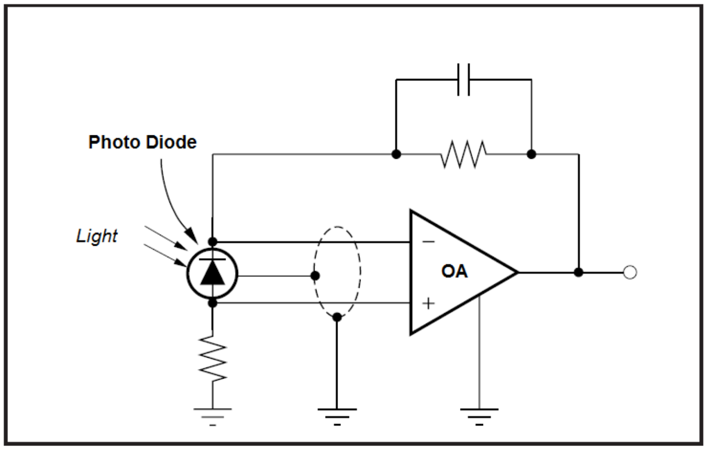

Fig. 2. High-Sensitivity Photodiode Amplifier

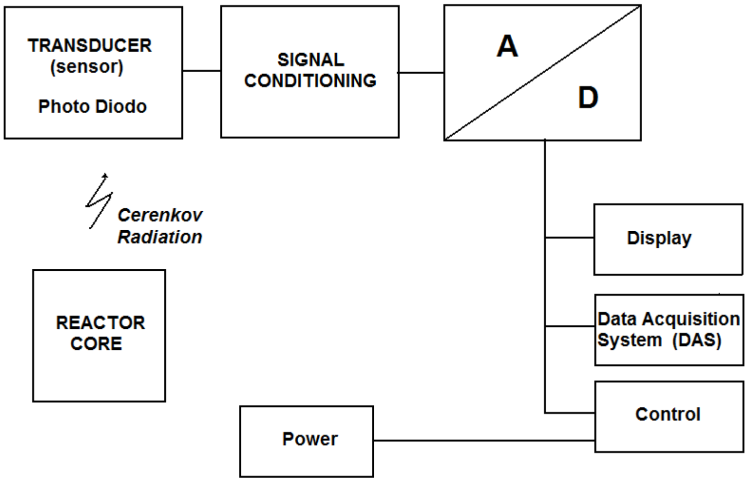

Fig. 3. Simplified Functional Block Diagram of the Measurement System Proposed

3. Physical Security

This article also presents an implementation proposal of a physical security system in the IPR-R1 TRIGA research nuclear reactor installations, with the objective to enhance of physical security of the reactor, according with International Atomic Energy Agency recommendation [7]. The physical security proposal covered aspects such as the installation of physical barriers, armoured doors, electronic access controls, alarms, intercommunications and, mainly, cameras and LCD video monitors, as the system describe in [8].

The visual monitoring system can improve the safety of the reactor area providing an effective safety measure. The entrances to the reactor will be monitored from different points, as well the reactor control room, the reactor hall, the reactor pool and the reactor staff office, via closed circuit television (CCTV) systems. It intends to use, in the system, video capture cards and TV capture card modules to allow to send a video or TV signal to the computer and by fast Ethernet network. The signal can then be recorded to the computer’s hard disk with TV or video capture software. They plug directly into expansion slots and provide analog/digital video signal conversion from cameras, for use in surveillance systems or security applications.

4. Conclusion

The reactor thermal power is very important for precise neutron flux knowledge for many irradiation experiments 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. So the greater the number of channels for measuring power, greater reliability and safety in reactor operation. At least for the case of research reactors, one can simply increase redundancy and diversity of medium-range reactors by employing the Cherenkov detector as an auxiliary tool for monitoring purposes. It is seen that such a system can provide a stable and reliable tool for the major part of power range, and it can assist in the reactor operation with additional safety interlocks to issue appropriate signals. The advantage of the present detector system over conventional ones is that it is far from the radiation source and thus easily accessible for maintenance and fine tuning. It contains no consumable materials to degrade in long term, and it is relatively inexpensive and simple [6].

Physical protection, also called physical security, consists of a variety of measures for the protection of nuclear material and facilities. Nowadays it is becoming increasingly important investment in safety [9]. This article proposes the installation of on physical security system, with facilities for viewing and recording in video of the dependencies of IPR-R1 reactor. The IPR-R1 instrumentation upgrade contemplates the International Atomic Energy Agency (IAEA) recommendations, for safe research reactors operation [10].

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