2017 International Nuclear Atlantic Conference - INAC 2017
Belo Horizonte, MG, Brazil, October 22-27, 2017
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

Agência Brasileira do ISBN
ISBN 978-85-99141-07-6

DEVELOPMENT OF A RESEARCH REACTOR POWER MEASUREMENT SYSTEM USING CHERENKOV RADIATION

Brício M. Salles and Amir Z. Mesquita

Centro de Desenvolvimento da Tecnologia Nuclear - CDTN
Avenida Presidente Antônio Carlos, 6.627 – Campus UFMG
31270-901 Belo Horizonte, MG
briciomares@hotmail.com
amir@cdtn.br

ABSTRACT

Nuclear research reactors are usually located in open pools, to allow visibility to the core and bluish luminosity of Cherenkov radiation. Usually the thermal power released in these reactors is monitored by chambers that measure the neutron flux, as it is proportional to the power. There are other methods used for power measurement, such as monitoring the core temperature and the energy balance in the heat exchanger. The brightness of Cherenkov's radiation is caused by the emission of visible electromagnetic radiation (in the blue band) by charged particles that pass through an insulating medium (water in nuclear research reactors) at a speed higher than that of light in this medium. This effect was characterized by Pavel Cherenkov, which earned him the Nobel Prize for Physics in 1958. The project's objective is to develop an innovative and alternative method for monitoring the power of nuclear research reactors. It will be performed by analyzing and monitoring the intensity of luminosity generated by Cherenkov radiation in the reactor core. This method will be valid for powers up to 250 kW, since above that value the luminosity saturates, as determined by previous studies. The reactor that will be used to test the method is the TRIGA, located at Nuclear Technology Development Center (CDTN), which currently has a maximum operating power of 250 kW. This project complies with International Atomic Energy Agency (IAEA) recommendations on reactor safety. It will give more redundancy and diversification in this measure and will not interfere with its operation.

1. INTRODUCTION

In any nuclear facility, the main concern is safety. The IAEA states that the fundamental safety objective is to protect people and the environment from harmful effects from ionizing radiation and suggests ten other safety principles to be followed. The IAEA recommendations are focused on the concepts of redundancy, diversity and independence, in other words, there must be more than one device, with different operating principles and completely independent to perform the same function [1].

Safety begins at the controls of parameters and variables in a nuclear reactor, and the main one is the power, which allows the determination of other relevant factors. In power measurements, redundancy and diversity are fundamental and accuracy and reliability are very important. For this reason, nuclear reactors use various devices to measure core power [2].

In the IPR-R1 TRIGA research reactor (Fig. 1) (to be used for the tests proposed by this paper) four devices are used to determine the power of the core, all of which are neutron sensitive chambers: a fission chamber, two chambers of compensated ionization and a non-compensated ionization chamber [3]. This research reactor is located at the Nuclear Technology Development Center (CDTN), it is an open-pool type reactor and the fuel is cooled by natural convection. The system was upgraded in the 70’s to reach up to 100 kW. Later it was again upgraded to its current system, allowing to reach up to 250 kW at steady state.

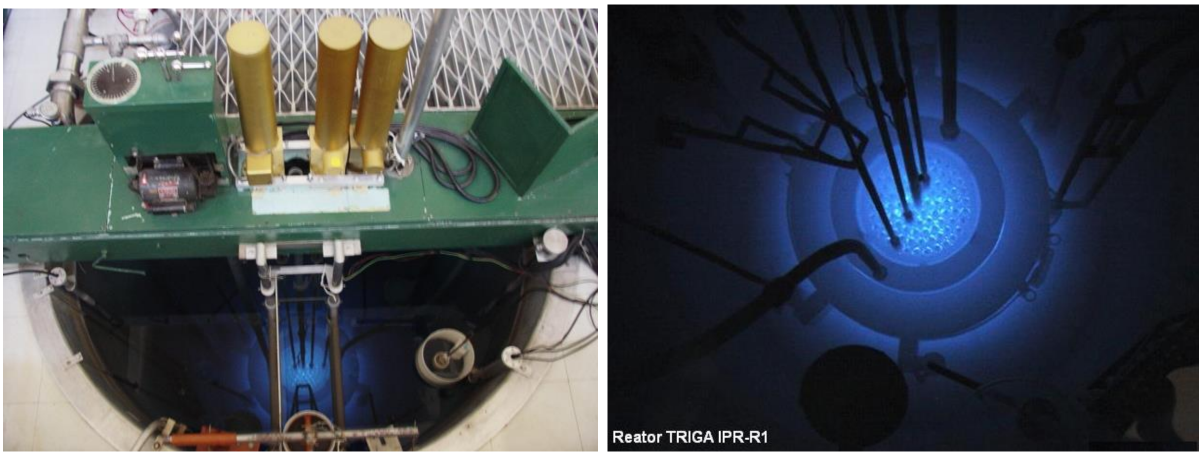

Figure 1: Cherenkov Radiation in the IPR-R1 Research Reactor Pool [3].

TRIGA reactors are the most popular research reactors around the world. There are over sixty facilities running in several countries [4]. Its popularity is due to being the only research reactor that can provide true inherent safety, aside from the usual engineered safety. It is possible due to the fuel’s properties, the uranium-zirconium hydride provides unrivaled safety characteristics, which also permit flexibility in sitting, with minimal environmental effects [5].

The project’s objective is to develop an innovative and alternative method for monitoring the power of nuclear research reactors. It will be performed by analyzing and monitoring the intensity of luminosity generated by Cherenkov radiation in the reactor core. This method will be valid for powers up to 250 kW, since above that value the luminosity saturates, as determined by previous studies.

2. CHERENKOV RADIATION

When a fast charged particle passes through a transparent medium, a blue light is produced. It is a characteristic radiation known as Cherenkov radiation. In nuclear reactor cores, the bluish color is mainly due to beta and gamma particles from fission products or from the fission process [6].

2.1. Cherenkov Radiation in Nuclear Research Reactors

Most of the research reactors are designed with open pools, therefore, the Cherenkov effect is easily observed. In that case, the Cherenkov radiation is produced by charged particles (mainly electrons) passing through water faster than the phase velocity of light in that medium, which is 220000 km/s. For an electron to reach that speed, the threshold energy must be at least 260 keV [6]. It is the principal basis of Cherenkov light production in pool type research reactors in which the light is readily visible.

One can observe that the intensity of Cherenkov radiation in the reactor core grows as the power rises, beginning when the Cherenkov emissions from the fissions are dominant above the emissions from the fission products and up to a certain level, where the luminosity saturates [3].

2.2. Power Measurement by Cherenkov Radiation

The power produced in fissions is linear related to the neutron intensity, the fission rate and power density, which brings up the direct proportionality between Cherenkov intensity and the total power [7].

If a device measures the light intensity in the core, it is possible to determine the instantaneous power using simple math and then acquire the total power, when proper calibrated.

3. EXPERIMENTAL SETUP

For the purpose of measuring the reactor's power, there are two outstanding proposals using photo diodes (as similarly done by Tehran researchers), and using microcontrollers (such as Arduino) with compatible luminosity sensors.

3.1. Photo Diode Proposal

In this setup, photo diodes (Fig. 2) will be arranged in a two dimensional polar array, to amplify the light absorption range. When the Cherenkov radiation reaches the diode, it creates a free electron and a positive "hole" in the depletion region. Moving the holes toward the anode, and the electrons toward the cathode, producing a photocurrent [3]. This "sensor" is connected to a signal conditioner and amplifier, which will carry the output signal to a data acquisition system, to calculate the core power through the luminosity reads and show it on a display. A block diagram for this proposal is presented is Fig. 3.

Figure 2: Photo diode [8].

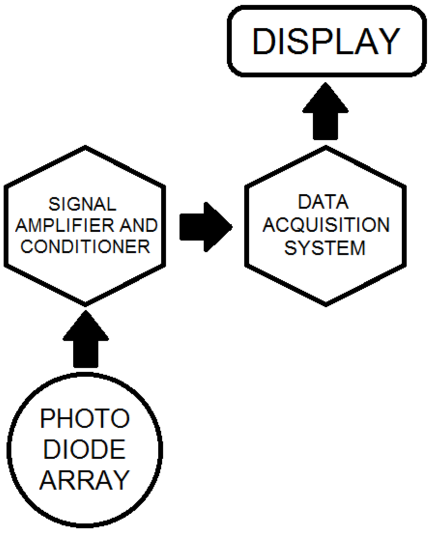

Figure 3: Block diagram for the photo diode proposal.

3.2. Microcontroller Proposal

For this setup, will be used an Arduino board (Fig. 4), with an attached luminosity or color sensor, to be chosen by testing the market available models, and the core power will be calculated by an algorithm and presented in a display unit, which can be a computer screen, a smartphone or a dedicated screen for the device. The first prototypes will be built with the TSL2561 Digital Luminosity Sensor (Fig. 5) and the TCS3200 Color Sensor (Fig. 6), because they are most popular sensors to acquire data from light. A block diagram for this proposal is presented is Fig. 7.

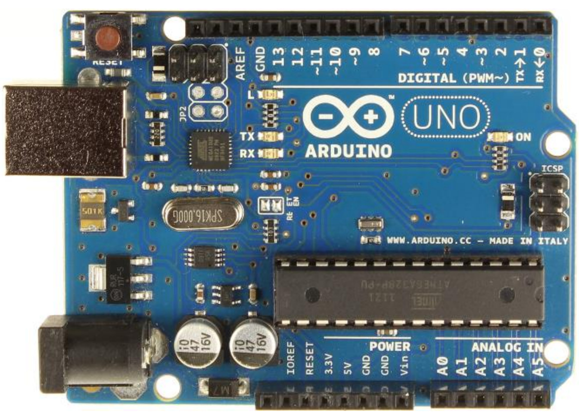

Figure 4: Arduino UNO board [9].

Figure 5: TSL2561 Digital Luminosity Sensor [10].

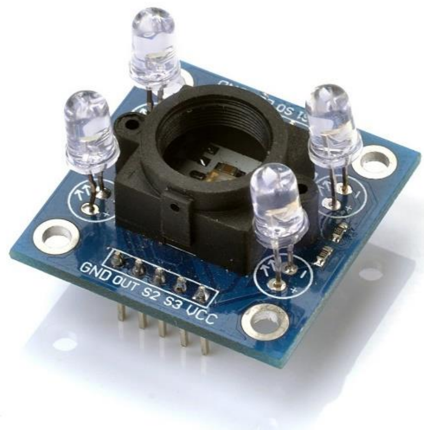

Figure 6: TCS3200 Color Sensor [11].

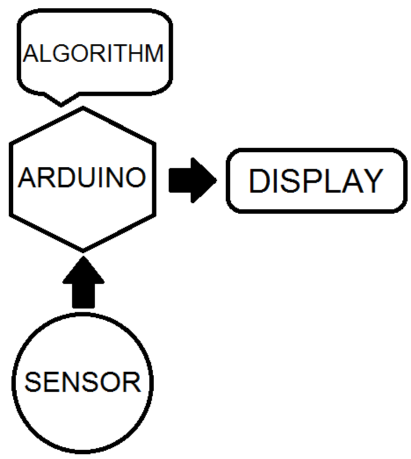

Figure 7: Block diagram for the microcontroller proposal.

The Cherenkov radiation will produce an analog output by reaching the sensor, and the algorithm will make the proper calculations to translate it into core power and send the information to the display unit in a friendly disposal.

4. CONCLUSIONS

The core power is fundamental for accurate knowledge of the neutron flow, necessary for irradiation experiments and fuel burnup estimate. The precise burnup estimative is important for the determination of fission products, fuel element activity, decay heat power generation and radiotoxicity. As noted by the IAEA, a higher number of channels for power measurement results in a more reliable and safe is the reactor operation [12]. For research reactors, the proposed device can be considered an auxiliary measurement tool, increasing redundancy and diversity and providing stable and reliable reads for the core power of medium-range reactors, and can improve the reactor operation, by adding safety interlocks.

The advantages of the proposed device is that it will be installed far from the core, which makes the maintenance and tuning easier than the conventional power measurement methods. Also, it is a low cost device, with no consumable materials and easy allows modifications for improving the accuracy and trustworthiness.

ACKNOWLEDGMENTS

The following institutions supported this work: Nuclear Technology Development Center (CDTN), Brazilian Nuclear Energy Commission (CNEN), Research Support Foundation of the State of Minas Gerais (Fapemig), and Brazilian Council for Scientific and Technological Development (CNPq).

REFERENCES

1. IAEA - International Atomic Energy Agency, “Safety of Research Reactors”, *Safety Standards Series No. SSR-3*, Vienna (2016).
2. IAEA - International Atomic Energy Agency, “Safety of Nuclear Power Plants: Design”, *Safety Standards Series No. SSR-2/1*, Vienna (2016).
3. Z. Mesquita, H.C. Rezende, A. A. C. Santos, V. V. A. Silva, “Development of Methods for Monitoring and Controlling Power in Nuclear Reactors”, *Engenharia Térmica*, **v. 13**, pp.24-27 (2014).
4. IAEA - International Atomic Energy Agency, “Reactor Search”. Available at: https://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx. Accessed in May (2017).
5. General Atomics, “Triga Advantages”. Available at: http://www.ga.com/triga-advantages. Accessed in June (2017).
6. M. Arkani, M. Gharib, “Reactor Core Power Measurement using Cherenkov Radiation and its Application in Tehran Research Reactor”, *Annals of Nuclear Energy 36*, pp.896–p900 (2009).
7. W. M. Stacey, *Nuclear Reactor Physics*, WILEY-VCH, Whenheim & Germany (2007).
8. “Photo Diode”. Available at:

https://www.hamamatsu.com/blobs/1328779697620?blobheadername1=content-disposition&blobheadervalue1=inline%3Bfilename%3D1328482676720.jpg&ssbinary=true . Accessed in July (2017).

9. "Arduino Uno". Available at: http://www.meccanismocomplesso.org/wp-content/uploads/2014/06/ArduinoUno_R3_Front.jpg. Accessed in February (2017).
10. "TSL2561 Digital Luminosity Sensor ".Available at: http://s3.amazonaws.com/img.iluria.com/product/152BD1/3174AD/450xN.jpg. Accessed in July (2017).
11. "TCS3200 Color Sensor". Available at: http://mekhos.com.br/mekhos/wp-content/uploads/2017/04/GY-31-Color-Sensor-using-TCS3200.jpg. Accessed in July (2017).
12. IAEA - International Atomic Energy Agency, "Operational Limits and Conditions and Operating Procedures for Research Reactors", *DS261 Draft Safety Guide*, Vienna. (2006).