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Original Article

Secondary Standardization of Neutron Fluence Fields at the Argonaut Reactor - IEN: Assessment of Calibration and Irradiation Metrological Capacity for Samples and Instruments

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Abstract: This article evaluates the secondary standardization of neutron fluence fields at the Argonaut Reactor of the Nuclear Engineering Institute (IEN). The study focused on the utilization of the Bonner Sphere Spectrometer (BSS) to determine the neutron spectrum at different positions of the lateral channel (plug 1) of the reactor, essential for characterizing radiation fields in complex environments. Measurements were conducted at varying distances (100 cm to 250 cm). The decrease in counts with increasing diameter indicated a higher presence of neutrons in the absorption energy range (0.1 eV to 2 MeV) for the 2", 3", and 5" spheres, but the 3" sphere exhibited different behavior, suggesting a greater presence of neutrons between 0.1 eV and 700 keV. As the BSS was moved away from the neutron source, the reduction in counts was expected. However, for the 8", 10", and 12" spheres, the analysis revealed a convergence of curves to a union of values between 0.1 eV and 6 MeV. These findings highlight the importance of precise neutron fluence characterization for dosimetric calibration. The data also serve as a basis for validating computational models in neutron metrology, contributing to the enhancement of nuclear research infrastructure. The Precision Long Counter (PLC) will be set up in future studies to complement BSS measurements, further advancing neutron detection capabilities.

Keywords: Neutron Fluence, Bonner Sphere Spectrometer, Secondary Standardization, Dosimetry.

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Padronização Secundária dos Campos de Fluência de Nêutrons do Reator Argonauta - IEN: Avaliação da Capacidade Metrológica de Calibração e Irradiação de Amostras e Instrumentos

Resumo: Este artigo avalia a padronização secundária dos campos de fluência de nêutrons no Reator Argonauta do Instituto de Engenharia Nuclear (IEN). O estudo concentrou-se na utilização do Espectrômetro de Multiesferas de Bonner (BSS) para a determinação do espectro de nêutrons em diferentes posições do canal lateral (plugue 1) do reator, etapa essencial para a caracterização de campos de radiação em ambientes complexos. As medições foram realizadas a distâncias variáveis (de 100 cm a 250 cm). A redução na contagem com o aumento do diâmetro das esferas indicou uma maior presença de nêutrons na faixa de energia de absorção (0,1 eV a 2 MeV) para as esferas de 2", 3" e 5", embora a esfera de 3" tenha apresentado um comportamento distinto, sugerindo maior incidência de nêutrons entre 0,1 eV e 700 keV. A redução nas contagens com o afastamento do BSS da saída do reator era esperada. Entretanto, para as esferas de 8", 10" e 12", a análise revelou uma convergência das curvas para um conjunto de valores compreendidos entre 0,1 eV e 6 MeV. Esses resultados ressaltam a importância da caracterização precisa da fluência de nêutrons para fins de calibração dosimétrica. Os dados obtidos também servem como base para a validação de modelos computacionais em metrologia de nêutrons, contribuindo para o aprimoramento da infraestrutura de pesquisa nuclear. Estudos futuros incluirão a integração do *Precision Long Counter* (PLC) como complemento às medições com o BSS, visando o avanço das capacidades de detecção de nêutrons.

Palavras-chave: Fluência de Nêutrons, Espectrofotômetro de Multiesferas de Bonner, Padronização Secundária, Dosimetria.

1. INTRODUCTION

The characterization and standardization of neutron fluence fields are critical in nuclear metrology, especially when it comes to ensuring the precision and accuracy of measurements in radiation fields. The secondary standardization of neutron fields, particularly in complex environments like research reactors, plays a pivotal role in the calibration of instruments and the irradiation of samples used across various scientific and industrial applications. The Argonaut Reactor at the Nuclear Engineering Institute serves as an ideal facility for such studies due to its unique operational capabilities and controlled experimental conditions [1,2,3].

Neutron fluence, which represents the flow of neutrons through a given area, is a key parameter in nuclear research. Accurate fluence measurements are essential for applications ranging from reactor physics to radiation protection, and they require reliable calibration standards. The Bonner Sphere Spectrometer is widely regarded as a robust tool for neutron spectrum measurements, providing detailed energy distribution data that is crucial for understanding the behavior of neutron fields under various conditions [8,9].

In the context of secondary standardization, the BSS offers a comprehensive approach to analyzing neutron fluence at different reactor positions, particularly in the lateral channel, where neutron flux can vary significantly depending on the configuration and distance from the source. This study aims to build upon previous work in neutron metrology by offering a detailed assessment of neutron fluence fields at the Argonaut Reactor, focusing on how these fields can be standardized for broader applications in nuclear research and industry [5].

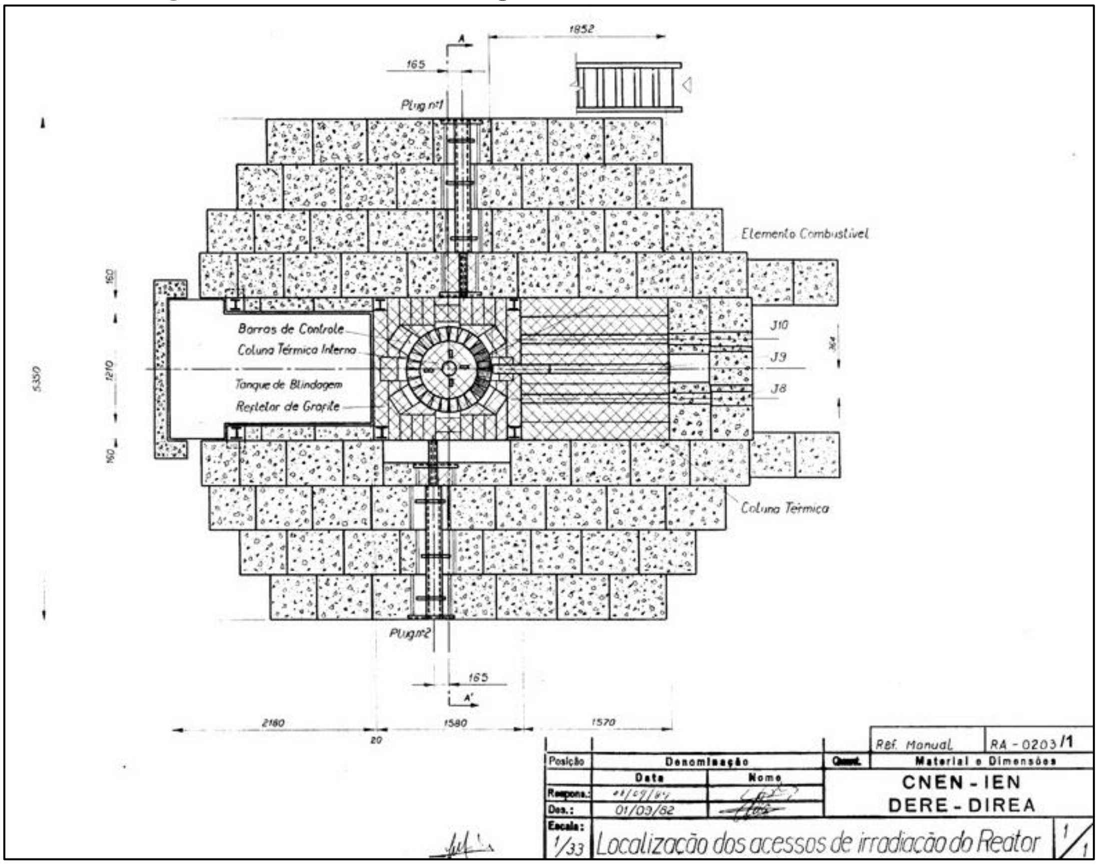
Moreover, the ability to standardize neutron fluence fields has significant implications for the calibration of dosimetric instruments, which are critical for ensuring safety in nuclear facilities. The research conducted here not only contributes to the fundamental understanding of neutron behavior in a low-power research reactor but also enhances the metrological infrastructure needed to support advanced nuclear technologies [7].

2. MATERIALS AND METHODS

The Argonaut Reactor operates at various power levels, with a maximum power of 340 W. For this study, the reactor was operated at approximately 10% of its capacity, or about 34 W.

Experimental measurements were conducted at distances of 100 cm, 125 cm, 150 cm, 175 cm, 200 cm, 225 cm and 250 cm from the lateral channel (plug 1) of the Argonaut Reactor, as show in Figure 1. To measure the neutron spectrum at these positions, the BSS was utilized, employing polyethylene spheres of 2, 3, 5, 8, 10, and 12 inches.

Figure 1: Location of the Argonauta Reactor's irradiation accesses

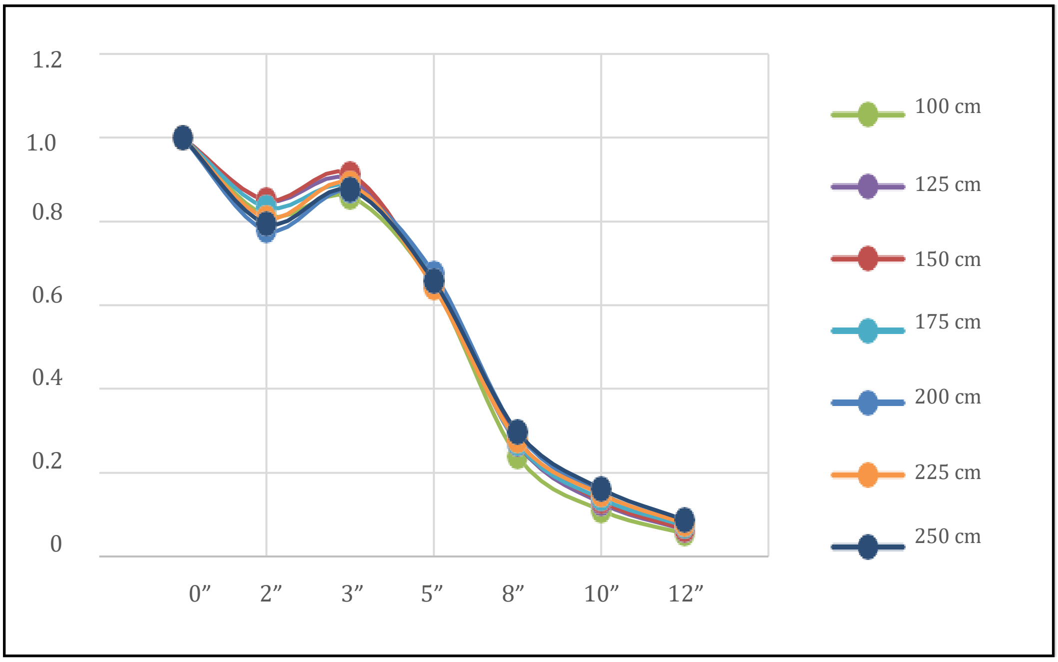


3. RESULTS AND DISCUSSIONS

The results of the experimental measurements revealed several key trends in the behavior of neutron fluence as captured by the BSS across 7 different distances and 7 sphere sizes. As expected, there was a general decrease in recorded counts with increasing sphere diameters, which is consistent with the theory that larger spheres moderate the neutron energy more effectively, reducing the number of high-energy neutrons detected [4].

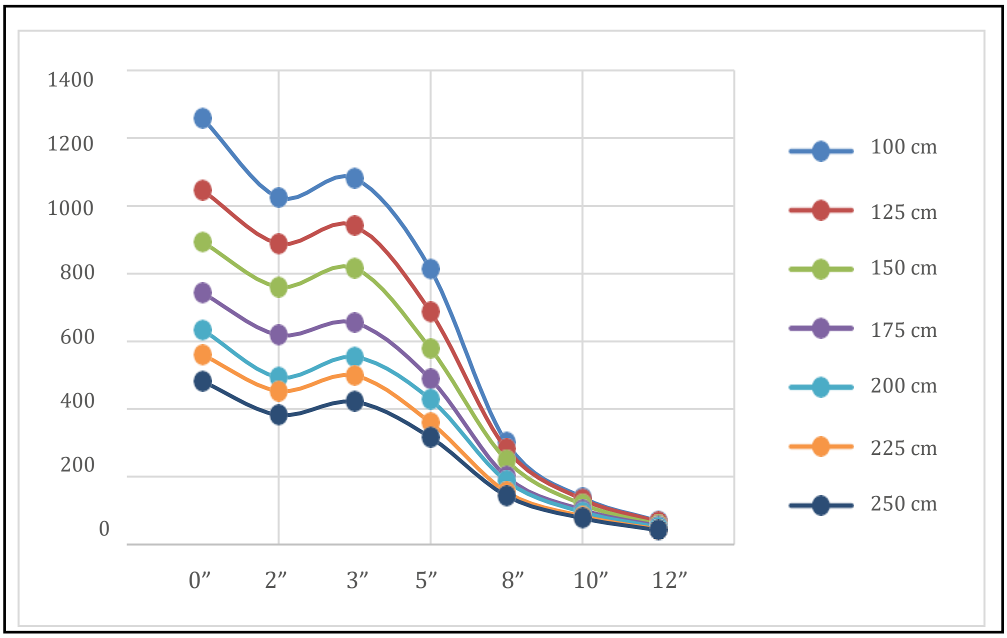
For the 2", 3", and 5" spheres, the results indicated a significant presence of neutrons within the absorption energy range of 0.1 eV to 2 MeV, as shown in Figure 2. Interestingly, the 3" sphere exhibited an anomalous behavior where the expected decrease in neutron counts was not observed. This suggests that the 3" sphere may be more sensitive to neutrons within a narrower energy range, specifically between 0.1 eV and 700 keV, which could indicate a resonance in the moderation process.

Figure 2: Analysis of the normalized counts obtained depending on each of the seven polyethylene sphere in the BSS, starting from the measurement without the sphere up to the 12” sphere



A detailed analysis of the normalized curves for each distance showed that as the BSS moved further from the neutron source, there was a predictable reduction in counts. However, for the 8", 10", and 12" spheres, the neutron energy distribution curves began to converge, particularly in the energy range between 0.1 eV and 6 MeV, as illustrated in Figure 3. This convergence suggests that at higher energy ranges, the influence of distance on neutron fluence becomes less pronounced, likely due to the increased moderation effects of the polyethylene spheres.

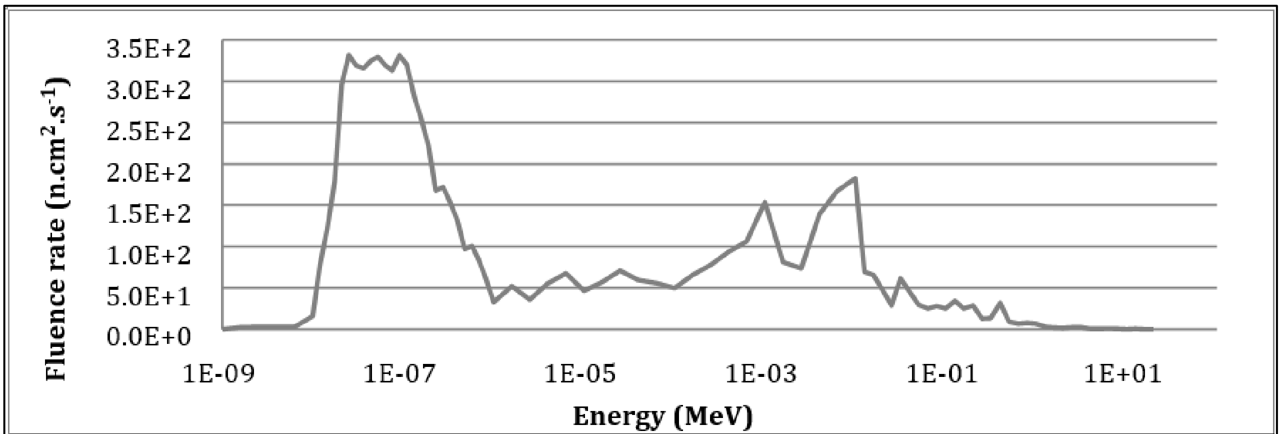
Figure 3: Analysis of BSS measurements of area rate (area/live time) by the seven polyethylene spheres for each of the seven distances



These findings have significant implications for the practical application of neutron fluence measurements in metrological settings. The observed homogenization of neutron distribution at greater distances from the reactor suggests that for certain applications, the positioning of the BSS relative to the neutron source may be less critical than previously assumed. This could simplify the calibration process for dosimetry instruments used in environments with similar neutron energy distributions [6].

The graph in Figure 4 illustrates the relationship between fluence rate and energy for the neutron spectrum obtained from the Argonaut Reactor at IEN. The spectrum demonstrates a typical distribution with a peak corresponding to the thermal neutron region, followed by a gradual decrease in fluence rate as the energy increases towards the fast neutron range. The analysis reveals that the fluence rate diminishes as the neutron energy escalates, which is consistent with the moderation effect of the polyethylene spheres in the BSS. Furthermore, the graph highlights the measured values for average energy, fluence rate, ambient dose equivalent, and personal dose equivalent, which are critical for understanding the neutron field's impact on radiation safety and metrological assessments. The close alignment of the fluence rate with expected theoretical models reinforces the reliability of the experimental setup, providing valuable data for subsequent calibration and standardization procedures. This analysis underscores the importance of accurate neutron spectrum characterization in ensuring the traceability and accuracy of dosimetric measurements in nuclear research environments [5,6,7].

Figure 4: Relationship between fluence rate and energy for the Argonauta Reactor - IEN. In addition, values for average energy, fluence rate, ambient dose equivalent, and personal dose equivalent are also shown.



Average Energy			Fluence Rate			Ambient Eq. Dose Rate			Personal Eq. Dose Rate		
E (MeV)			$\phi(d)$ ($n.cm^{-2}.s^{-1}$)			$H^*(10)$ ($\mu Sv.h^{-1}$)			$H_p(10,0)$ ($\mu Sv.h^{-1}$)		
0.0140	±	0.00	7.66E+03	±	3.8E+02	4.91E+02	±	2.5E+01	5.10E+02	±	2.6E+01

Furthermore, the data obtained from this study are invaluable for validating computational models that simulate neutron behavior in research reactors. By comparing the experimental results with simulations, researchers can refine their models to better predict neutron fluence under varying conditions. This synergy between experimental and computational approaches is crucial for advancing the accuracy and reliability of neutron measurements in nuclear research.

The potential incorporation of the PLC in future experiments will further enhance the detection of high-energy neutrons, complementing the data obtained with the BSS. This combined approach will provide a more comprehensive understanding of neutron sources and processes, ensure the traceability of measurements and contribute to the ongoing development of metrological standards in nuclear science [11].

4. CONCLUSIONS

The experimental study utilizing the Bonner Sphere Spectrometer at the lateral channel (plug 1) of the Argonaut Reactor yielded crucial insights for the secondary standardization of neutron fluence fields. The data analysis revealed distinct behaviors depending on the diameter of the polyethylene spheres and the neutron energy distribution at varying distances.

The results showed a consistent decrease in counts with increasing sphere diameter, except for the 3-inch sphere, which showed higher neutron fluence in a specific absorption energy range. Additionally, the convergence of count curves for the 8", 10", and 12" spheres suggests a more homogeneous neutron distribution at greater distances from the reactor.

In future studies, the integration of a PLC is planned in order to enhance the neutron fluence characterization performed in this work. While the BSS provides detailed spectral information over a wide energy range, the PLC offers a highly stable and well-characterized response to neutron fluence, particularly suitable for standardization measurements. The use of the PLC will allow an independent determination of the neutron fluence rate, serving as a complementary reference to the unfolded BSS spectra. This combined approach will improve traceability, reduce systematic uncertainties, and enhance confidence in the secondary standardization of neutron fields at the Argonaut Reactor.

This characterization enhances calibration and irradiation processes, ensuring better risk management in reactor operations and contributing to the safe advancement of nuclear science and technology.

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CONTRIBUTORSHIP

Conceptualization: FSS, FJOF, WWP.

Investigation: FSS.

Writing – review and editing: FSS, FJOF, WWP.

CONFLICT OF INTEREST

Fellipe Souza is a PhD candidate supported by a scholarship from the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES). Francisco José and Walsan Pereira are public servants at the Brazilian National Nuclear Energy Commission (CNEN). The authors declare that they have no conflicts of interest related to this work.

DATA AVAILABILITY STATEMENT

Interview transcripts and qualitative data are not publicly available due to confidentiality commitments made to research participants. Aggregated data supporting the findings are available from the corresponding author upon reasonable request and subject to participant privacy protections.

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