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A study of a H2O-moderated 241AmBe source for neutron metrology

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Abstract: The update to ISO 8529-1 (2021) reduces the variety of neutron fields from sources. For neutron metrology, it is crucial to have a standard radiation field with known fluence and energy well-defined. This study focuses on analyzing new energy ranges and characterizing moderated neutron fields, emphasizing the importance of low-energy neutrons and their impact on dose assessment. Experiments and simulations were conducted with the moderation of the 241AmBe source in light water, enabling the characterization of a new moderated spectrum and the presentation of reference values for physical and radioprotection quantities. This expands the energy options for irradiation and instrument calibration.

Keywords: Neutron Metrology, 241AmBe moderated, Bonner Spheres Spectrometry, Monte Carlo Simulation.

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Um estudo de uma fonte de 241AmBe moderada por H_2O para metrologia de nêutrons

Resumo: A atualização da ISO 8529-1 (2021) reduz a variedade de campos de nêutrons provenientes de fontes. Para a metrologia de nêutrons, é crucial dispor de um campo de radiação padrão com fluência e energia bem definidas. Este estudo concentra-se na análise de novas faixas de energia e na caracterização de campos de nêutrons moderados, sublinhando a importância dos nêutrons de baixa energia e seu impacto na avaliação de doses. Foram realizadas experimentações e simulações com a moderação da fonte de 241AmBe em água leve, permitindo a caracterização de um novo espectro moderado e a apresentação de valores de referência para grandezas físicas e de radioproteção. Isso amplia as opções de energia para irradiações e calibrações de instrumentos.

Palavras-chave: Metrologia de Nêutrons, 241AmBe Moderado, Espectrometria com Esferas de Bonner, Simulação de Monte Carlo.

1. INTRODUCTION

In occupational environments, neutron fields span a wide energy spectrum. Accurate spectrometric assessments are essential to cover this broad range, particularly in sectors such as calibration and irradiation [1]. The ISO 8529 series, divided into three sections, establishes standards for neutron radiation related to the production, standardization, and calibration of neutron fields. Recent revisions to this standard have reduced the availability of neutron fields for practical use, prompting increased interest in investigating the spectra of neutron sources across different energy levels [2]. This study will specifically focus on the 241AmBe reference source.

The accuracy of personal neutron monitoring is highly dependent on the neutron spectrum, underscoring the importance of characterizing neutron fields in the nuclear sector. The Bonner Sphere Spectrometer (BSS) stands out for its well-established and precise isotropic response for neutron radiation, capturing fluence uniformly from all directions, which enhances its accuracy and comprehensive energy characterization capabilities [3]. Spectral data obtained from Bonner sphere measurements are adjusted to reference values using a response matrix and then subjected to an unfolding process employing neural network techniques [4].

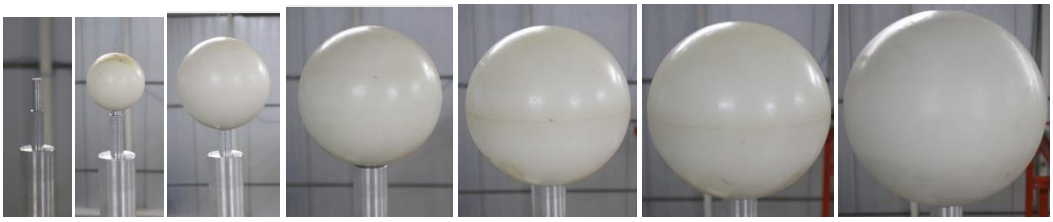
The objective is to derive additional metrics such as mean energy, fluence rate, and both personal and ambient dose equivalents. The NeuraLN software, which was specifically developed for this purpose, leverages the Monte Carlo method - MCNPX for implementation [5]. MCNPX's computational frameworks are utilized for modeling both physical and mathematical constructs within nuclear metrology. It executes analyses based on statistical sampling techniques, extensively utilizing sequences of random or pseudo-random numbers, thus, it's well-suited for intricate computational tasks [6].

The MCNPX approach was also used to simulate the particles from their origins in the source to their terminations including interactions such as absorption in the spheres of different diameters containing distilled water used in this study for the moderation of the neutron source [6,7].

2. MATERIALS AND METHODS

A Bonner Sphere Spectrometer equipped with a 6LiI thermal neutron detector was used. The detector was placed along the central axis of various polyethylene spheres with different diameters: 5.08 cm (2''), 7.62 cm (3''), 12.70 cm (5''), 20.32 cm (8''), 25.40 cm (10''), and 30.48 cm (12''), as shown in Figure 1. To moderate the neutrons, two aluminum spheres with radii of 16 cm and 20 cm filled with light water were used, as illustrated in Figure 2.

Figure 1: Bonner Sphere Spectrometer system setup



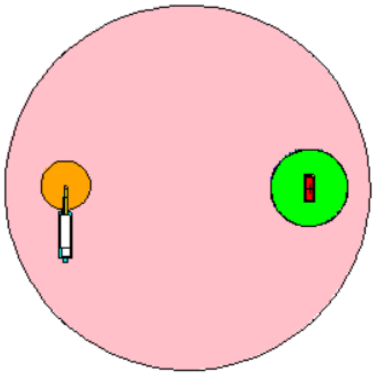
Source: Author's image

Figure 2: Aluminum spheres filled with light water, with radii of 16 cm and 20 cm

Source: Author's image

Simulations were performed using the radiation transport code MCNPX (version 2.7), replicating the same geometry and setup. The system was modeled to include all the materials used (source, detector, Bonner Sphere Spectrometer, and moderating spheres). The simulations followed the same distance parameters (100 cm from the source) as those used in the laboratory measurements, as shown in Figure 3. A total of 21 measurements were conducted: 7 without moderation, 7 with a moderating sphere of 16 cm radius, and 7 with a moderating sphere of 20 cm radius.

Figure 3: Simulation with the BSS detector setup positioned 100 cm from the 20 cm moderating sphere.



Source: Author's image

3. RESULTS AND DISCUSSIONS

The moderation phenomenon can be tracked through fluence measurements, which result from the interaction between lower-energy neutrons released from the source and their capture by hydrogen atoms in the water within the aluminum moderation spheres. This interaction reduces the number of neutrons reaching the target (detector), resulting in a decrease in fast neutrons and a shift towards the epithermal neutron spectrum. The spectra result for both the moderated and unmoderated conditions in the Figures 4 and 5 show the spectra obtained, the graphics are overlapping to enhance visualization and comparison of the spectra.

Figure 4: Experimental spectrum for 241AmBe source free and with moderating spheres

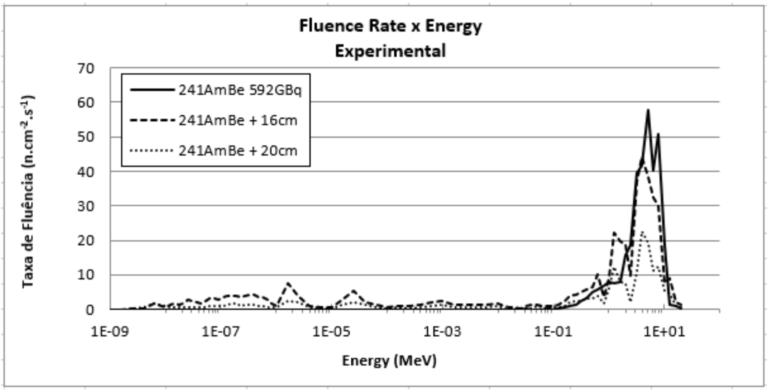


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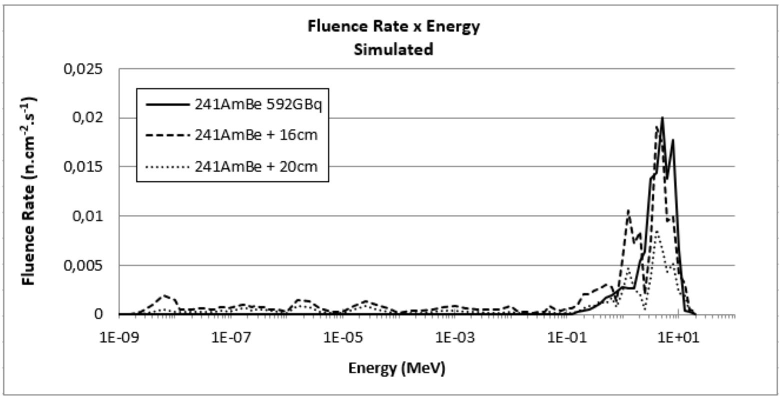
Figure 5: Simulated spectrum for 241AmBe source free and with moderating spheres



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Using the data from NeuraLN for the conversion of neutron fluence made possible the calculation of the ambient dose equivalent H*(10) and the individual dose equivalent Hp (10) values, as shown in the Table I. the values vary for the same source depending on the type of moderation used, resulting in lower doses.

Table 1: References for physical and radioprotection quantities determined

^{241}AmBe Sphere	Average Energy E (MeV)		Fluence Rate φ˙(d) (n.cm^{-2}.s^{-1})		Conversion Coefficient Fluence-to-H*(10) *H*(10) (pSv/n)		Conversion Coefficient Fluence-to-H_p(10,0) *Hp*(10,0) (pSv/n)	
	Simulation	Experimental	Simulation	Experimental	Simulation	Experimental	Simulation	Experimental
0 cm	4,23 ± 0,21	4,23 ± 0,21	0,1164 ± 0,0058	335 ± 17	403 ± 20	413 ± 21	425 ± 21	439 ± 22
16 cm	2,67 ± 0,13	2,65 ± 0,13	0,0538 ± 0,0027	149 ± 7	304 ± 15	423 ± 21	317 ± 16	446 ± 22
20 cm	2,83 ± 0,14	2,73 ± 0,14	0,0353 ± 0,0018	97 ± 5	302 ± 15	424 ± 21	316 ± 16	448 ± 22

4. CONCLUSIONS

The reduction in spectra outlined in ISO 8529-1 (2021) leads to a decrease in the variety of neutron fields from radionuclide sources. Since a neutron metrology requires a standard radiation field—a neutron source with a known fluence and a well-defined energy spectrum. It is crucial to consider the broad energy range of neutrons and the interest in studying moderated neutron source spectra. With the rising prevalence of low-energy neutrons, investigating both unmoderated and water-moderated neutron sources have become important, highlighting the significant impact of energy on dose assessment. This need has driven the development of reference neutron fields that replicate the spectral characteristics of sources like 241AmBe through moderation techniques. This research outlines the detailed methodology for creating such fields, which serve as benchmarks for defining operational parameters for neutrons with variable fluences and energys due to source moderation. This effort enhances metrological capabilities for calibrating instruments across different energy spectra.

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