Radiation Physics and Chemistry 167 (2020) 108219

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Contribution of the scattered radiation on the neutron beam fluence at the calibration laboratory of IPEN

Tallyson S. Alvarenga[a,*], Ivon O. Polo[a], Walsan W. Pereira[b], Felipe S. Silva[b], Evaldo S. Fonseca[b], Linda V.E. Caldas[a]

[a] *Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear (IPEN/CNEN), Av. Prof. Lineu Prestes, 2242, 05508-000 São Paulo, SP, Brazil*
[b] *Instituto de Radioproteção e Dosimetria, Comissão Nacional de Energia Nuclear (IRD/CNEN), Av. Salvador Allende, 9, 22780-160 Rio de Janeiro, RJ, Brazil*

ARTICLE INFO

Keywords:
Monte Carlo code
Scattered radiation
Neutron fluence

ABSTRACT

In recent years, an upsurge in demand for neutron calibrations has been experienced in Brazil and several other countries in Latin America, mainly due to the increase in oil prospection and extraction procedures. The only laboratory for calibration of neutron detectors in Brazil is located at the Institute for Radioprotection and Dosimetry (IRD/CNEN), Rio de Janeiro. This laboratory is the national standard dosimetry laboratory in Brazil. With the increase in the demand for the calibration of neutron detectors, the need for more calibration services became evident. In this context, the Calibration Laboratory of IPEN/CNEN, São Paulo, which already offers calibration services of radiation detectors with standard X, gamma, beta and alpha beams, recently projected a new calibration laboratory for neutron detectors. One of the main problems in this kind of calibration laboratory is related to the knowledge of scattered radiation. In order to evaluate it, simulations were performed without the presence of the structural elements and with the complete room. Thirteen measurement points were evaluated at various distances. As part of the characterization process of the radiation fields of the new Neutron Calibration Laboratory, this work presents results on the influence of the radiation scattered by the structural components of the room: walls, doors, ceiling and floor, in different calibration positions, on the detector response. Therefore, the neutron radiation attenuation and the scattering parameters were determined at different source-detector distances, through computational simulation, using the MCNP5 Monte Carlo code.

1. Introduction

Currently, there is an increase on the activity of the oil sector, medical applications and scientific research employing neutron sources, leading to an increased demand for radiological monitoring services. Thus, it is necessary to develop tools and methods to ensure the reliability of radiation measurements (INMETRO, 2012). In this sense, the first step is to ensure the precision and accuracy of the instruments (Schuhmacher, 2004) by means of a proper calibration process. In Brazil, according to the CNEN NE 3:02 standard, the calibration is compulsory, and must be carried out by authorized institutions (CNEN, 2011).

In Brazil, there is only one calibration laboratory for neutron detectors, located at the National Laboratory for Metrology of Ionizing Radiation (LNMRI-IRD/CNEN, Rio de Janeiro). This laboratory is also the only Secondary Standard Dosimetry Laboratory (SSDL/IAEA network) in Latin America, which offers this kind of service, thus with a high demand of services per year. In practical situations involving the calibration of neutron radiation detectors, one of the main problems is related to scattered radiation, which may vary depending on the size of the laboratory used in the calibration procedures (McCall et al., 1999; Khabaz, 2015). Because of scattered neutrons, their spectrum, measured at a certain point in the calibration laboratory, is not the same spectrum as that emitted by the neutron source, thus influencing the reading of the instrument being calibrated. This fact may cause a systematic error in the calibration of the neutron measuring devices (Guzman et al., 2015; Vega-Carrillo et al., 2007a; Vanhavere et al., 2001).

As part of the characterization process of the radiation field of the new Neutron Calibration Laboratory of IPEN (LCN), the objective of this work was to evaluate the influence of the radiation scattered by the structural components of the room: walls, doors, ceiling and floor, in

* Corresponding author.
E-mail addresses: tallysonalvarenga@gmail.com (T.S. Alvarenga), ivonoramas67@gmail.com (I.O. Polo), walsanwagner@gmail.com (W.W. Pereira), fellipesouza@gmail.com (F.S. Silva), evaldo@ird.gov.br (E.S. Fonseca), lcaldas@ipen.br (L.V.E. Caldas).

https://doi.org/10.1016/j.radphyschem.2019.03.023
Received 13 November 2018; Received in revised form 15 March 2019; Accepted 18 March 2019
Available online 18 March 2019
0969-806X/

different calibration positions, on the response of the detectors, by means of simulation using the Monte Carlo Method. MCNP5 calculations present the advantage to be a low cost technique that allows the detailed study of the laboratory under evaluation including geometrical set-ups and material selections (Vega-Carrillo et al., 2007b; Campo et al., 2018).

2. Materials and methods

To perform the simulation of the LCN/IPEN, the Monte Carlo code MCNP5 was utilized. This code was developed and is maintained by the Los Alamos National Laboratory (USA); it is a statistical method in which a sequence of random numbers is used for the purpose of solving mathematical and physical problems, which are very difficult to obtain directly; it can be used to calculate the radiation transport of neutrons, photons and electrons (Pelowitz, 2008).

A total of 2×10^9 histories were simulated, with the F4 tally, aiming to obtain results with smaller uncertainties. The geometry used was based on the low floor of the laboratory, available at IPEN, to ensure that all dimensions used in the simulation are in agreement with those of the laboratory. The LCN is an installation that integrates the Calibration Laboratory of Instruments, of the Radiation Metrology Center. The LCN has dimensions of 6.88 m × 5.46 m and walls of concrete with thickness of 15 cm and covered by drywall. The laboratory is 2.8 m high, the concrete ceiling is 15 cm thick, and the granite floor is 5 cm thick. For a more realistic simulation, the surrounding areas, which are composed by different materials, have also been incorporated into the geometric arrangement for the MC simulations.

The composition of the LCN materials in the MCNP5 code was taken based on the PNNL-15870 report (McConn et al., 2011), where concrete has a density of 2.35 g/cm^3, granite of 2.69 g/cm^3, wooden doors of 0.42 g/cm^3 and an iron gate of 7.874 g/cm^3. In order to evaluate the scattered radiation, which occurs due to the interaction of the neutrons with air and the structural components of the laboratory such as: floor, ceiling, walls and doors, and to determine the main scattering structure of the LCN, simulations using the MCNP5 code were performed. The spectrum used in this simulation was obtained by means of ISO 8529-1 (ISO, 2001) from a ^{241}AmBe source (37 GBq), positioned at a height of 140 cm from the floor.

3. Results

Thirteen positions of special interest were evaluated at distances varying from 30 cm to 258 cm. In these positions were localized (virtually) air spheres with 1.0 cm radius, filled with atmospheric air; the neutron fluence values and the energy spectra were obtained directly from the MCNP5 code. Fig. 1 shows the positions of interest and the room geometry, used with the MCNP5 code.

In each of the thirteen positions of interest, the neutron fluence was determined in the laboratory without and with the structural components. In order to avoid the uncertainties arising from changes in geometry in the Monte Carlo code, all surfaces and cells were maintained, but the density of the materials was set to zero, so that the volumes were of vacuum, avoiding the occurrence of radiation scattering. The neutron fluence values were obtained directly from the MCNP5 code (Pelowitz, 2008).

The scattering was determined by means of the ratio between the obtained values of the room neutron fluence without the structural components and the values of the room neutron fluence with the structural components, where the scattering caused by the ceiling and the floor was to be evaluated in detail. Table 3.1 presents the results of the neutron scattered radiation fluence obtained at the thirteen measurement positions, from 30 cm to 258 cm.

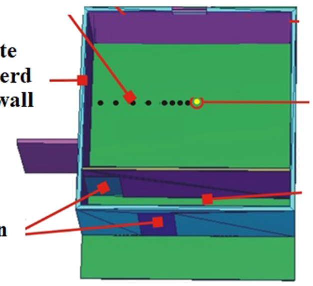

Fig. 3.1. The LCN installation geometry, used in Monte Carlo simulations with the MCNP5 code.

The percentual scattered neutron fluence was obtained by the difference between the fluence with and without components, divided by the total fluence, multiplied by 100 and by the air-attenuation factor and the anisotropy correction factor (ISO, 2000).

It can be verified that at the source-detector distances of 30 cm occurs the lowest influence of the scattered radiation on the neutron fluence: 13% with the complete room, 6% without the floor and 5% without the ceiling; this is probably due to the proximity of the source. For the largest source-detector distances, the influence of the scattering radiation on the neutron fluence becomes much larger at the distance of 258 cm, reaching 84% with the complete room, 49% without the floor and 20% without the ceiling; this influence occurs due to the interaction of neutrons with the structural components of the laboratory. The results obtained show significant changes in the fluence values at the distances of 240 cm and 258 cm for both cases without the floor and without the ceiling, due to the proximity of the wall (30 cm), resulting in a large radiation scattering on the wall.

Figs. 3.2, 3.3 and 3.4 show the simulated spectra obtained at the

Table 3.1
Influence of the scattered radiation on the neutron fluence, at the source-detector distances of 30–258 cm.

Source-detector Distance (cm)	Neutron scattered radiation (%)		
	Complete laboratory	Laboratory without floor	Laboratory without ceiling
30	13	6	5
50	31	20	7
70	44	28	10
90	56	37	13
100	60	38	14
110	61	40	15
130	67	43	18
150	73	47	20
170	75	49	23
190	79	52	25
220	81	53	26
240	82	50	22
258	84	49	20

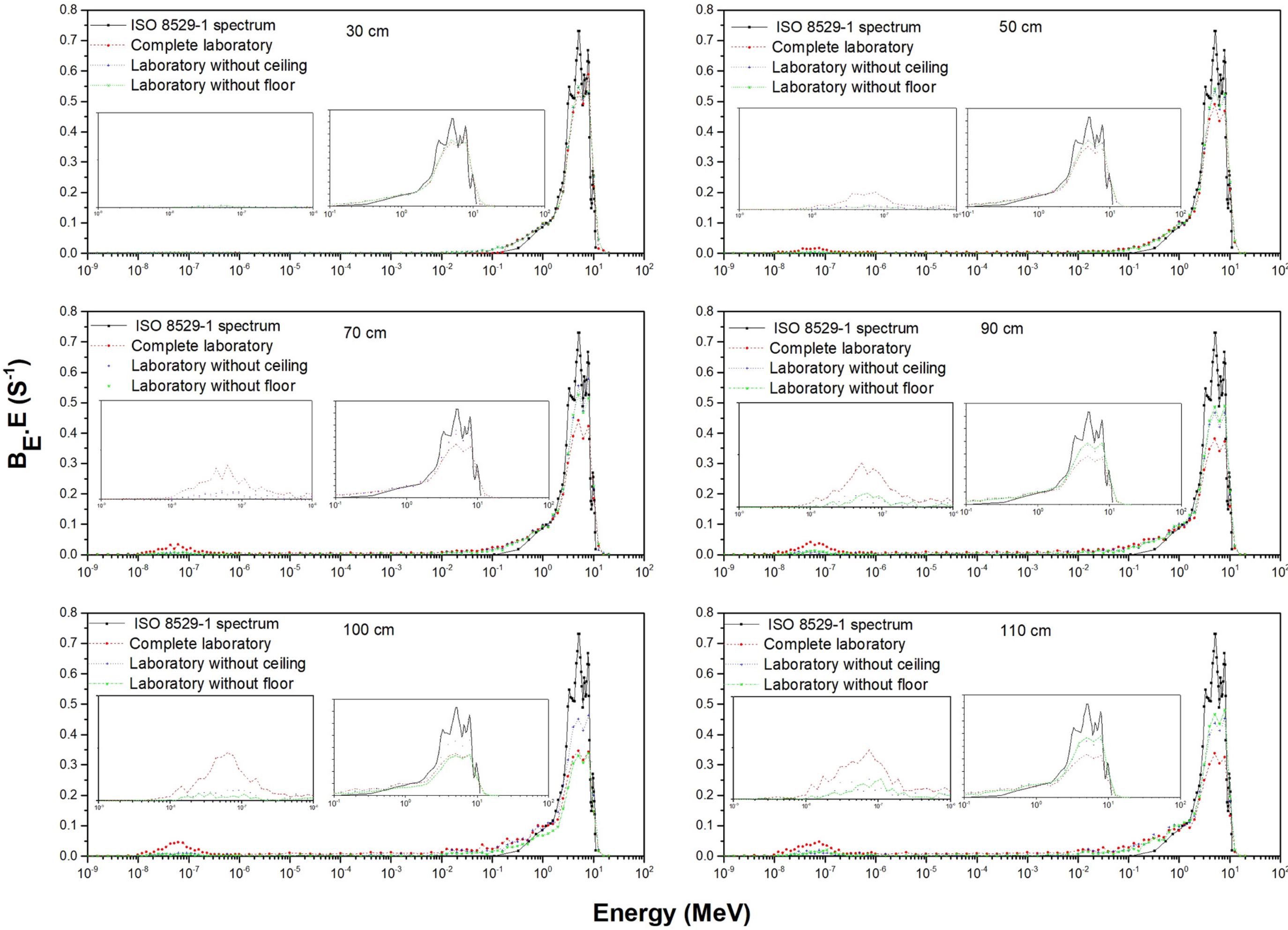

Fig. 3.2. Simulated spectra obtained at the measurement points at the distances of 30–110 cm without the presence of the structural elements (floor and ceiling) of the laboratory, compared to the reference spectrum of ISO8529-1 (ISO, 2001). The maximum uncertainty obtained in the energy bins is lower than 3%.

thirteen measuring points without the presence of the structural elements of the laboratory. The simulated spectra obtained with the complete laboratory, without floor and without ceiling were compared with the reference spectrum ISO8529-1 (ISO, 2001), that is, without scattering radiation.

From the spectra obtained by means of the simulation, when compared to the reference spectrum, at the source-detector distances of 30–258 cm, it can be observed that for the shortest distance (30 cm), the spectrum does not show significant peaks in the range of thermal energies. This fact is due to the proximity of the source. For the largest distances ranging from 70 cm to 258 cm, it was observed that as the source-detector distance increases, the simulated spectra present low similarity when compared to the reference ones. It is possible to observe that the spectra become considerably degraded and thermalized, where it is possible to observe peaks in the thermal energy range between energies of 10^{-8} MeV and 10^{-4} MeV; they probably occur as a consequence of the large scattering caused by the proximity of these measuring points of the wall (30 cm).

From the results presented in Table 3.1, it is possible to see that the floor is the main structural component of the laboratory, which contributes to the increase of the scattering radiation; it presents a value of 57% for the distance of 258 cm. This problem is very significant and recurrent in this type of laboratory; ISO 8529-2 (ISO, 2000) recommends that the maximum calibration distance shall be fixed so that the increase of the reading due to scattering radiation in the room is less than 40%.

4. Conclusions

Due to the behavior of scattered radiation in the simulations, the maximum calibration distance should be 50 cm, thus meeting the limitations imposed by ISO 8629-2 (ISO, 2000) in the simulated laboratory configuration. Thus, to allow the laboratory to carry out its activities, it is necessary to evaluate the options for reducing the radiation scattering of the site or limiting the distances to be used in order to meet the standard recommendations.

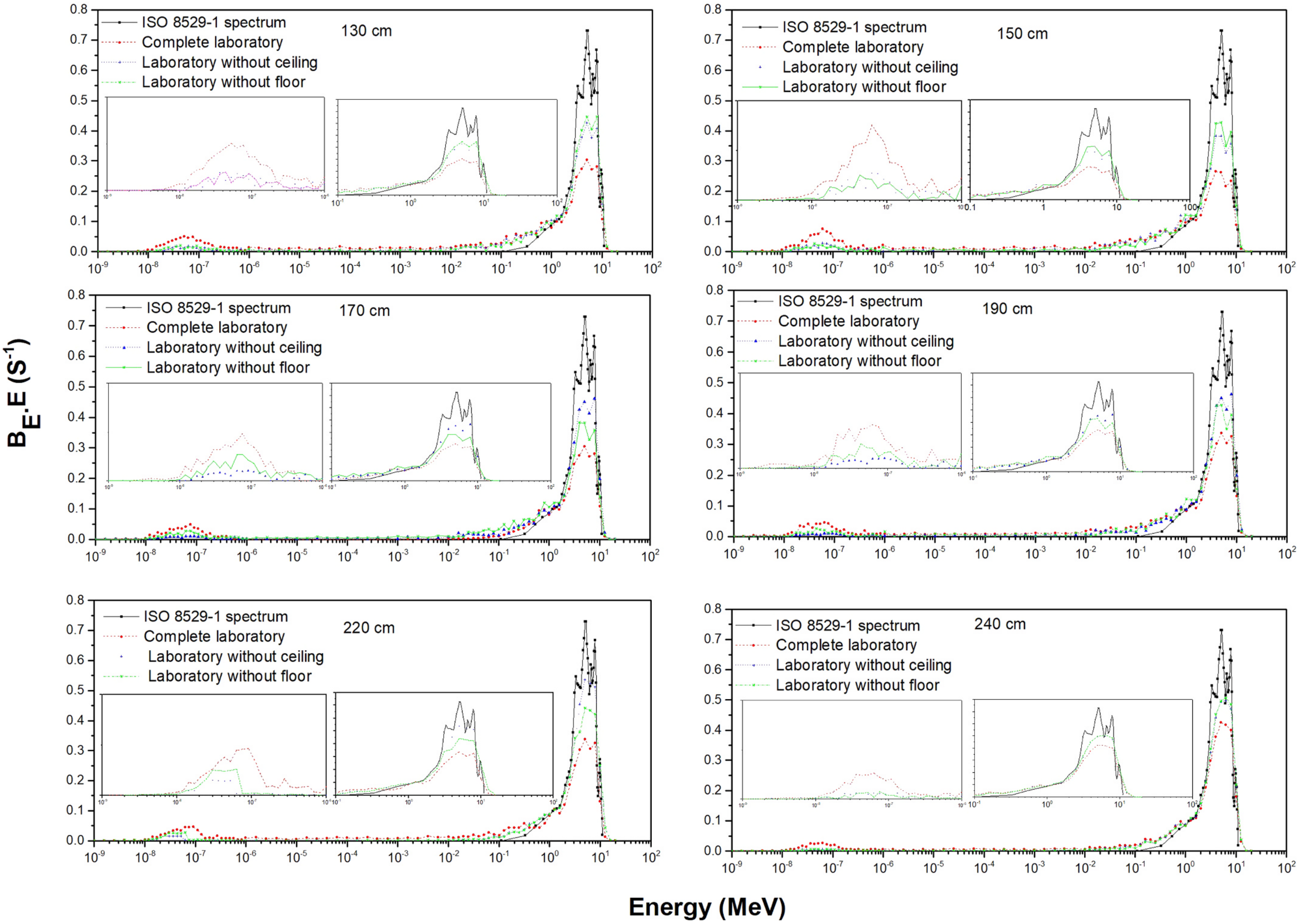

Fig. 3.3. Simulated spectra obtained at the measurement points at the distances of 130–240 cm without the presence of the structural elements (floor and ceiling) of the laboratory, compared to the reference spectrum of ISO8529-1 (ISO, 2001). The maximum uncertainty obtained in the energy bins is lower than 3%.

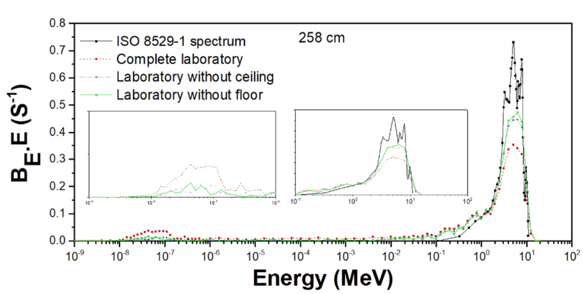

Fig. 3.4. Simulated spectra obtained at the measurement points at the distance of 258 cm without the presence of the structural elements (floor and ceiling) of the laboratory, compared to the reference spectrum of ISO8529-1 (ISO, 2001). The maximum uncertainty obtained in the energy bins is lower than 3%.

Acknowledgments

The authors acknowledge the Brazilian agencies FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo; CNPq: Conselho Nacional de Desenvolvimento Científico e Tecnológico) (Grant No. 2008/57863-2), CNPq (Grants No. 301335/2016-8 and 573659-2008/7), CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) (Grant No. 47659/2014) and MCTI (Instituto Nacional de Ciência e Tecnologia): Project INCT for Radiation Metrology in Medicine, for the partial financial support.

References

Campo, X., Méndez, R., Lacerda, M.A.S., Garrido, D., Embid, M., Sanz, J., 2018. Experimental evaluation of neutron shielding materials. Radiat. Prot. Dosim. 180 (1–4), 382–385.

CNEN, 2011. Comissão Nacional de Energia Nuclear, Basic Guidelines of Radioprotection, NN-3.01/004, Rio de Janeiro, (In Portuguese).

Guzman, G.K.A., Mendez, V.R., Vega-Carrillo, H.R., 2015. Neutron field characteristics of Ciemat's Neutron Standards Laboratory. Appl. Radiat. Isot. 100, 84–90.

INMETRO, 2012. Instituto Nacional de Metrologia, Qualidade e Tecnologia. International Vocabulary of Metrology. Basic and General Concepts and Associated Terms - JCGM 200:2012. 1st Portuguese –Brazilian Edition (In Portuguese).

ISO, 2000. International Standard. Reference neutron radiations – Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field. Report 8529-2, First Edition. Geneva.

ISO, 2001. International Standard. Reference Neutron Radiations – Part 1: Characteristics and Methods of Production. Report 8529-1, First Edition. Geneva.

Khabaz, R., 2015. Analysis of neutron scattering components inside a room with concrete walls. Appl. Radiat. Isot. 95, 1–7.

McCall, R.C., McGinley, P.H., Huffman, K.E., 1999. Room scattered neutrons. Med. Phys.

26, 206–207.
McConn, J.R., R.J., Gesh, C.J., Pagh, R.T., Rucker, R.A., Williams III, R.G., 2011. Radiation portal monitor project. Compendium of material composition data for radiation transport modeling. PNNL-15870, Rev. 1 Pacific Northwest National Laboratory.
Pelowitz, D.B., 2008. MCNP — A general Monte Carlo N-particle Transport Code, Version 5. Los Alamos National Laboratory, Novo México.
Schuhmacher, H., 2004. Neutron calibration facility. Radiat. Prot. Dosim. 110 (1–4), 33–42.
Vanhavere, F., Vermeersch, F., Cuynen, P., 2001. Procedures for neutron-scattering corrections in a calibration facility with a non-symmetric set-up. Radiat. Prot. Dosim. 93 (1), 5–10.
Vega-Carrillo, R.H., Manzanares-Acuña, E., Iñiguez, P.M., Gallego, E., Lorente, A., 2007a. Study of room-return neutrons. Radiat. Meas. 42, 413–419.
Vega-Carrillo, R.H., Manzanares-Acuña, E., Iñiguez, P.M., Gallego, E., Lorente, A., 2007b. Spectrum of isotopic neutron sources inside concrete wall spherical cavities. Radiat. Meas. 42 (8), 1373–1379.