BJRS

BRAZILIAN JOURNAL
OF
RADIATION SCIENCES
05-03(2017)01-09

SBPR
Sociedade Brasileira de Proteção Radiológica

Calibration of the LDI/CDTN Whole Body Counter using three physical phantoms

F.G. Paiva[a]; B.M. Mendes[b]; T.A. da Silva[b]; M.A.S. Lacerda[b]; J.R. Pinto[b];
S. Prates[b]; N.N.A. Filho[b]; A.L.A. Dantas[c]; B.M. Dantas[c] ; T.C.F. Fonseca[b]

[a] *Dep. de Engenharia Nuclear – DEN / Universidade Federal de Minas Gerais - UFMG*
Campus da UFMG - Belo Horizonte - MG, Brazil
[b] *Centro de Desenvolvimento da Tecnologia Nuclear CDTN/CNEN, Belo Horizonte/MG, Brazil*
[c] *Instituto de Radioproteção e Dosimetria - IRD/CNEN, Rio de Janeiro - RJ, Brazil*
fgpaiva92@gmail.com

ABSTRACT

The Laboratory of Internal Dosimetry of the Center for Development of Nuclear Technology (LDI/CDTN) is responsible for routine monitoring of internal contamination of the Individuals Occupationally Exposed (IOEs) at the Unit for Research and Production of Radiopharmaceuticals (UPPR/CDTN), the Research Reactor TRIGA-IPR-R1/CDTN and other workplaces of the institute where there is a risk of accidental intakes. Additionally, LDI supports the Institute of Radiation Protection and Dosimetry (IRD/CNEN) to attend radiological emergencies. The determination of photon emitting radionuclides in the human body requires the use of calibration techniques in different counting geometries for converting the count rates into activity in organs and tissues. This paper presents and discusses the calibration of the LDI/CDTN Whole Body Counter (WBC) using a standard BOMAB phantom (Bottle Mannequin Absorber) compared to a home-made phantom produced with Polyethylene Terephthalate bottles (PET). Initially, the BOMAB was filled with a cocktail containing ^{60}Co, ^{137}Cs and ^{133}Ba. The phantom was counted at the LDI whole body counter and an Efficiency x Energy curve was obtained. Subsequently the PET-BOMAB was filled with the same standard source and a second curve was determined. The efficiency values in each region of interest as well as the shape of both curves were found to be equivalent. The results validate the use of the PET-BOMAB for the calibration of whole body geometry applied to the measurement of high energy photon emitting radionuclides in the energy region evaluated in this work.

Keywords: **Internal Dosimetry, Whole Body Counter, BOMAB, Radioprotection.**

1. INTRODUCTION

The identification and quantification of photon-emitting radionuclides in the human body can be performed by means of *in vivo* measurement techniques. According to the International Atomic Energy Agency, "*For worker who usually or occasionally works in a controlled area and may receive a significant dose from occupational exposure, individual monitoring should be undertaken where appropriate, adequate and feasible*". Furthermore, individual monitoring is mandatory where effective doses are higher than 1 mSv [1].

Whole Body Counter systems (WBC) generally employ NaI(Tl) scintillators and/or HPGe semiconductor detectors used in an appropriate counting geometry. Usually, a bed or chair geometry is adopted and the subject is accommodated in a flat or sitting position under the detector. When the detector is placed to cover specific organ or region of the body it should be pointed where the highest counting efficiency is expected, for example, the torso or pelvis of the monitored worker [2].

In general terms, the subject is counted for a certain period of time, and the spectrum analysis allows the identification and quantification of the radionuclides in the body. A variety of setups may be applied in order to obtain a better counting efficiency of the whole system [3,4]. The accuracy of the measurement relies on the quality of the calibration in regard to the distribution of the radionuclide in the whole body or in various organs and tissues compared to the individual biotype. Calibrations usually refer to a standard human being or groups of individuals or populations, established by the International Commission on Radiological Protection [5]. The reference physical phantom should simulate human tissues in terms of shape, volume, density, and attenuation coefficient [6,7].

This paper presents and discusses the calibration of the WBC system installed at the Laboratory of Internal Dosimetry of the Center for Development of Nuclear Technology (LDI/CDTN) using a BOMAB phantom in comparison of a low cost physical phantom produced with Polyethylene Terephthalate bottles (PET).

2. MATERIALS AND METHODS

The WBC system of the LDI/CDTN is composed of a bed-type shadow shield and a NaI(Tl) 8"x4" (20.32 x 10.16 cm) crystal in a 1.5 mm thick aluminum housing, positioned at a fixed height of 53.2 cm above the bed.

The BOMAB phantom PM-95 HMLTD-90-1 (Canus Plastics INC) was loaned to the LDI/CDTN by the Institute of Radiation Protection and Dosimetry (IRD/CNEN) in the frame of the IAEA TC-Project BRA 9055 which involves a network of Internal Dosimetry Laboratories in Brazil. This phantom is composed by a set of different bottle sizes that closely approximate the ICRP reference values [8,9].

During the period in which the BOMAB was used for the calibration of the WBC, leakage points had to be fixed delaying the completion of the measurements. Thus, a PET-BOMAB has been developed as a low cost alternative phantom to overcome the difficulties and problems related to the original BOMAB. Furthermore, the PET-BOMAB may be assembled in different configurations by varying the number of bottles used in order to obtain a new phantom size with different height and weight. Therefore, it may be used to obtain efficiencies curves for different individual sizes.

Two versions of the physical PET-BOMAB phantom were built. The PET-BOMAB #1 was designed in an attempt to approach the geometry of the original BOMAB phantom. It is comprised of 33 PET bottles of different volumes and simulates a human individual with 181.5 cm height and about 62 kg. The PET-BOMAB #2 was assembled with 28 PET bottles, 5 bottles of 2 L less than version #1. These bottles were taken off from the trunk, pelvis and thigh, reducing the total weight in 10 kg and keeping the same height. The two new geometries allow investigating differences in the efficiency curves and studying the variation on weight and shape of the phantoms. Table 1 shows the volumes and heights of each section of the BOMAB and both versions of the PET-BOMABs.

Table 1: Comparison of section dimensions of the three physical whole body phantoms.

Section	BOMAB		PET-BOMAB #1		PET-BOMAB #2	
	Volume (L)	Height (cm)	Volume (L)	Height (cm)	Volume (L)	Height (cm)
Head	5.4	21.5	3.5	24.5	3.5	24.5
Neck	1.8	10.4	1.0	7.0	1.0	7.0
Trunk	21.8	28.0	16.0	40.0	12.0	40.0
2 Arms	6.2	72.0	7.0	64.0	7.0	64.0
Pelvis	20.7	22.0	12.5	35.0	10.5	35.0
2 Thighs	8.7	43.5	12.0	37.0	8.0	37.0
2 Legs	6.3	44.0	6.0	38.0	6.0	38.0
Total	70.9	169.5	58	181.5	48	181.5

The commercial BOMAB was used initially in this study to determine the horizontal position of the detector in relation to the phantom which results in the highest counting efficiency. In this experiment, the phantom was filled with a potassium chloride solution (KCl) and placed on the bed of thet WBC system. Eight measurements at different positions along the horizontal axis were performed and the highest detector efficiency was obtained when the detector is positioned at a specific coordinate located over the torso of the phantom [10].

Afterwards, the BOMAB phantom was filled with a solution containing 60 L of deionized water, 500 mL of hydrochloric acid and a standard radioactive cocktail containing ^{60}Co, ^{137}Cs and ^{133}Ba. Such solution was used to obtain a counting efficiency (CE) curve over the energy range between 356 and 1332 keV. A region of interest (ROI) for each photopeak energy was defined and the respective counting areas and associated uncertainty were calculated. The PET-BOMABs #1 and #2 were filled up with the radioactive cocktail, measurements were performed and counting efficiency (CE) curves were obtained and compared. Figure 1 shows the detection system with the BOMAB positioned for the calibration and the PET-BOMAB #1.

Figure 1: *LDI/CDTN WBC system: (left) the bed, the BOMAB and detector; (right) PET-BOMAB 1*

The LDI/CDTN instrumentation is controlled with Genie2000 Basic Spectroscopy Software [11], a comprehensive environment for data acquisition and management. The counting efficiencies were calculated after spectrum acquisition at each setup using different phantoms. Calculations are based on equation 1, as follows:

$$\varepsilon = \frac{N}{t.A.\gamma} \tag{1}$$

where: “N” is the area under the photopeak energy of interest (excluding the Background contribution); “t” is the counting time of the measurement (s); “A” is the activity of each radionuclide corrected for decay (Bq) and “γ” (yield) is the probability of gamma emission of the photon of interest.

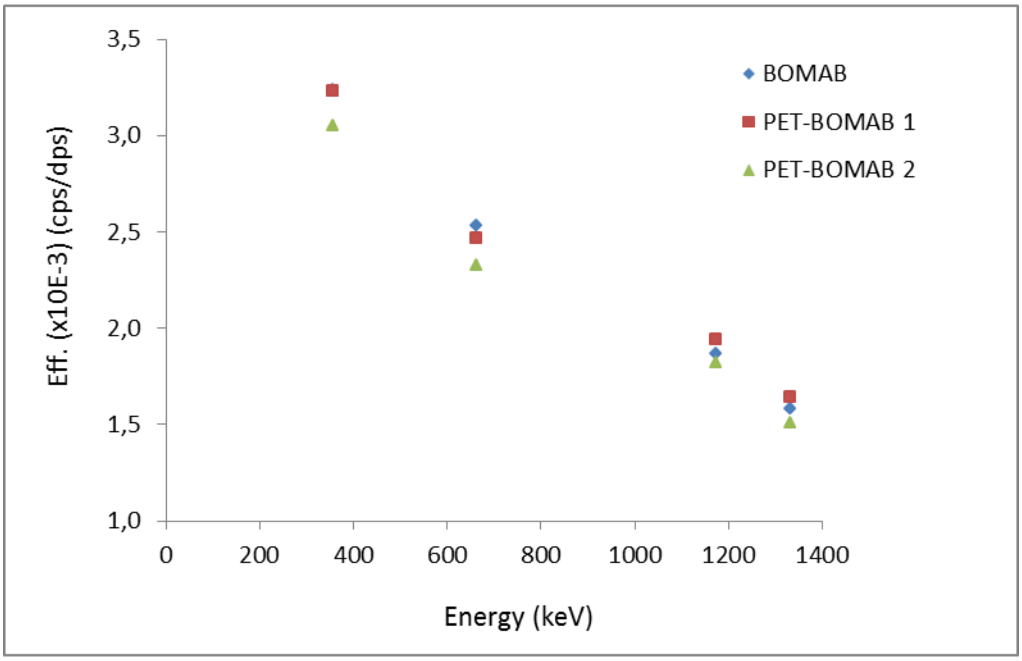
3. RESULTS AND DISCUSSION

Table 2 shows the counting efficiency values for each gamma-ray energy for the BOMAB, PET-BOMAB #1 and PET-BOMAB #2. Figure 2 shows the efficiency curve as a function of energy range of interest.

Table 2: Comparison of Counting Efficiency for BOMAB, PET-BOMAB 1 and PET-BOMAB 2

Peak	**Radionuclide**	**Energy (keV)**	**ε ($x10^{-3}$) (cps/dps)**		
			BOMAB	**PET-BOMAB 1**	**PET-BOMAB 2**
1	^{133}Ba	356.0	3.24 ± 0.04	3.23 ± 0.04	3.05 ± 0.04
2	^{137}Cs	661.6	2.53 ± 0.07	2.47 ± 0.07	2.33 ± 0.07
3	^{60}Co	1173.2	1.87 ± 0.02	1.94 ± 0.02	1.82 ± 0.01
4		1332.5	1.58 ± 0.02	1.64 ± 0.02	1.51 ± 0.01

Figure 2: *Comparison of the Efficiency curves in function of energy for BOMAB, PET-BOMAB 1 and PET-BOMAB 2.*



The slight differences observed in counting efficiencies when comparing the BOMAB with the two versions of the PET-BOMAB are probably related to the size and weight of the phantoms which affect the irradiation geometry. It is also important to notice that the material used to construct the PET-BOMAB, as well as the bottle thickness, are different from the original BOMAB, thereby modifying the attenuation of the photons.

Efficiency values obtained with the PET-BOMAB #1 and #2 presented significant differences due to the fact that the thoracic region of the PET-BOMAB #2 is thinner and consequently its surface is more distant from the detector, resulting in a lower counting efficiency.

It should be highlighted that whole body counting calibration is strongly dependent on geometry, i.e., counting efficiencies vary according to size, weight, tissue thickness and overall dimensions of the individual to be monitored [3,4]. The calibration performed with the PET-BOMAB #1 resulted in an efficiency curve equivalent to the original BOMAB. Therefore it can be used for calibration at the geometry adopted in the LDI/CDTN whole body counter.

4. CONCLUSION

The PET-BOMAB phantom described in this work has the advantage of being produced with readily-available, inexpensive and rough materials. Furthermore, the use of PET bottles allows assembling a phantom with different configurations just by varying the number and shape of the bottles.

The efficiency x Energy curves obtained with the original BOMAB and the PET-BOMAB #1 were found to be equivalent for the geometry adopted at the LDI/CDTN whole body counter.

Efficiency values obtained with the PET-BOMAB #1 and PET-BOMAB #2 presented significant differences, with average value about 6.8 %.

The results validate the use of the PET-BOMAB for the calibration of whole body geometry applied to the measurement of high energy radionuclides in the energy region evaluated in this work.

5. ACKNOWLEDGMENT

The following Brazilian institutions supported this research project: Nuclear Technology Development Center (CDTN), Brazilian Nuclear Energy Commission (CNEN), Research Support Foundation of the State of Minas Gerais (FAPEMIG), Brazilian Council for Scientific and Technological Development (CNPq), Coordination for Capacitation of High Level Personnel (CAPES). This project is part of the Brazilian Institute of Science and Technology (INCT) for Radiation Metrology in Medicine. M.A.S. Lacerda is grateful for financial support provided by CNPq (MCTI/CNPq/Universal Proc.449199/2014-2) and FAPEMIG (PPM-00208-15).

REFERENCES

[1] IAEA, International Atomic Energy Agency, 2014. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. Part 3 No. GSR., Vienna.

[2] IAEA, International Atomic Energy Agency, 1996. Direct Methods for Measuring Radionuclides in the Human Body, Safety Series No. 114, IAEA, Vienna.

[3] FONSECA, T. C. F.; BOGAERTS, R.; HUNT, J.; VANHAVERE, F. A. Methodology to develop computational phantoms with adjustable posture for WBC calibration. **Phys. Med. Biol.** v. 59(22), p. 6811-6825, 2014.

[4] FONSECA, T. C. F. *et al*. MaMP and FeMP: computational mesh phantoms applied for studying the variation of WBC efficiency using a NaI(Tl) detector. **Journal of Radiological Protection**, v. 34, n. 3, p. 529, 2014.

[5] ICRP, International Commission on Radiological Protection, 1991. ICRP Publication 60: 1990 Recommendations of the International Commission on Radiological Protection (No.60). Elsevier Health Sciences.

[6] ANSI, American National Standards Institute, 1999. Specifications for the Bottle Manikin Absorption Phantom, ANSI N13.35, NewYork.

[7] ICRU, International Commission on Radiation Units and Measurements, 1992. ICRU Report 48: Phantoms and Computational Models in Therapy, Diagnosis and Protection. Library of Congress, USA.

[8] DANTAS, B. M. *et al*. Accreditation and training on internal dosimetry in a laboratory network in Brazil: an increasing demand. **Radiation Protection Dosimetry.** Rio de Janeiro, v. 144, n. 1-4, p. 124-129, 2011.

[9] Canus plastics manual - http://canusplastics.com/wp-content/uploads/2012/02/Phantoms.pdf, (accessed July, 2017)

[10] PAIVA, F.G. *et al*. Improvement of the WBC calibration of the Internal Dosimetry Laboratory of the CDTN/CNEN using the physical phantom BOMAB and MCNPX code. **Applied Radiation and Isotopes**, 2015.

[11] CANBERRA. Genie2000 Gamma Acquisition & Analysis, Version 3.1. Canberra Industries Inc., 2006.