Radiation Physics and Chemistry 155 (2019) 291–293

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

Influence of the vials radioactive residue in Nuclear Medicine procedure applied to a new "in situ" activimeter calibration methodology

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A B S T R A C T

In this study we present a new "in situ" calibration methodology establishment for activimeters – i.e., this equipment calibration can be made at the hospital and/or the nuclear medicine service (NMS) – and also the importance of considering vials radioactive residue when generating the calibration coefficient in terms of activity (N_A). For the calibration, two methods are presented here: in the first, ^{99m}Tc sample activity (A_C) is measured in the NMS. Then it is sent to the Instruments Calibration Laboratory (LCI/IPEN) where the reference activity (A_R) is obtained under controlled conditions in a reference vial. After geometry and residue corrections, N_A is calculated. In the second method, A_R is obtained at the LCI, then ^{99m}Tc sample is sent to the hospital/NMS, where A_C is measured and N_A calculated. Calibration methodologies were applied to three NMS and to four equipment belonging to the radiopharmaceutical production facility (CR) at the Nuclear and Energy Research Institute (IPEN). Both methodologies were tested with and without residual activity corrections under controlled conditions. Variations of up to 4% were obtained.

1. Introduction

In the last decades, numbers of radiological and nuclear medicine (NM) procedures in the United States have increased massively, from 54 in 1964 to about 500 in 2006 (Mettler et al., 2009). Therefore, radiation dose to population has also increased. In this same year nuclear medicine services (NMS) represented only 5% of total medical procedures, but were responsible for 26% of medical collective dose in the US (Mettler et al., 2009; Fahey et al., 2011).

Both workers and patients security assurance in NMS has been the focus of international organizations (International Atomic Energy Agency, IAEA, 2006; International Atomic Energy Agency, IAEA, 2010). A safe and efficient NMS performance depends, among other factors, on a complete quality assurance program. This includes, mainly, the activimeter quality control, which must meet quality standards provided by international authorities (American Association of Physicists in Medicine, AAPM, 2012; International Atomic Energy Agency, IAEA, 2015). Quality assurance for an activimeter includes tests such as high voltage verification, zero adjust, background radiation, accuracy, repeatability, etc., that must be performed periodically with a specific radioactive source according to international recommendations (National Physical Laboratory, 2006).

Some parameters, such as vials geometry and solution volume, can change the activimeter response, as presented in previous studies (Martins and Potiens, 2012; Zimmerman et al., 2004; Calhoun et al., 1987). Correction factors, F, must be applied and can be determined by means of Eq. (1):

$$F = \frac{A_R}{A} \tag{1}$$

where A_R is the reference activity and A is the indicated activity for a condition to be corrected (vial with different volume, geometry etc.) (National Physical Laboratory, 2006).

Other important procedure that must be performed in order to guarantee workers and patient security in NMS is the activimeter calibration, which establishes a relation between a reference quantity value, provided by measurement standards, and a measurement result from an indicator (International Bureau of Weights and Measures, BIPM, 2008), which is, in this case, the activimeter from an NMS and/or a hospital.

In this study we suggest another influence factor which is normally disregarded, that must be considered in these procedures: remaining residual radioactive solution from a radiopharmaceutical transference from one vial to another that results in an error in the final activity.

Furthermore, we propose a new "in situ" calibration methodology establishment for activimeters, which is performed without the need of

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https://doi.org/10.1016/j.radphyschem.2018.06.021
Received 1 August 2017; Received in revised form 11 June 2018; Accepted 11 June 2018
Available online 15 June 2018
0969-806X/

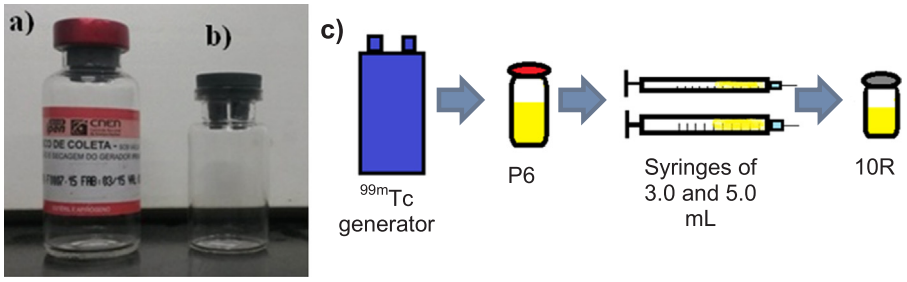

Fig. 1. (a) P6 and (b) 10R vials used in this study. (c) ^{99m}Tc handling scheme.

Table 1
P6 and 10R vials dimensions (Baker, 2005). Numbers in parenthesis are the uncertainties.

	P6 vial	10R vial
Height (mm)	54.00(75)	45.0(5)
Diameter (mm)	21.75(25)	24.0(2)
Wall thickness (mm)	1.2(1)	1.00(4)
Maximum volume (mL)	13.8(1)	13.5(1)

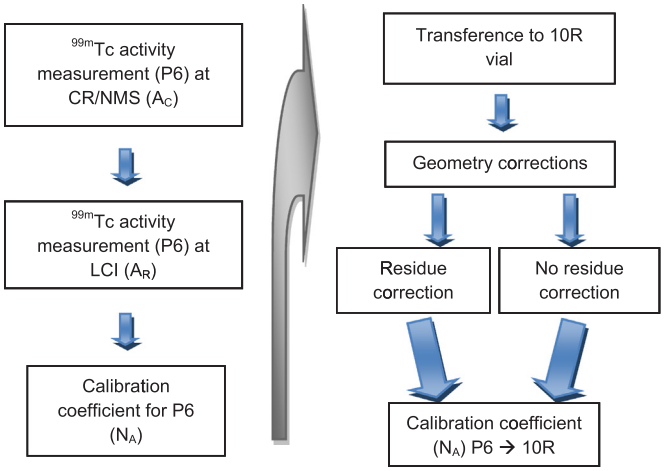

Fig. 2. Methodology 1 flowchart. First measurement is performed at radiopharmaceutical production facility (CR) or Nuclear Medicine Service (NMS), and then P6 vial containing ^{99m}Tc is sent to calibration laboratory (LCI).

Table 2
Methodology 1 applied to radiopharmaceutical center (CR) at IPEN with and without residue corrections. Three central columns present N_A values with respective uncertainties in parenthesis.

Activimeter Model	P6/P6	10 R/P6 w/ corrections	10 R/P6 w/o corrections	Variation (%)
CR-0055	0.999(9)	0.999(9)	0.972(15)	2.7
CR-2096	0.980(9)	0.981(9)	0.945(20)	3.7
CR-1485	0.988(9)	0.988(9)	0.961(13)	2.8
CR-1483	0.988(9)	0.988(9)	0.961(14)	2.8

Table 3
Methodology 1 applied to Nuclear Medicine Service A with and without residue corrections. Three central columns present N_A values with respective uncertainties in parenthesis.

Activimeter Model	P6/P6	10R/P6 w/ corrections	10R/P6 w/o corrections	Variation (%)
NMS-A	0.98(1)	0.98(1)	0.94(2)	4.0

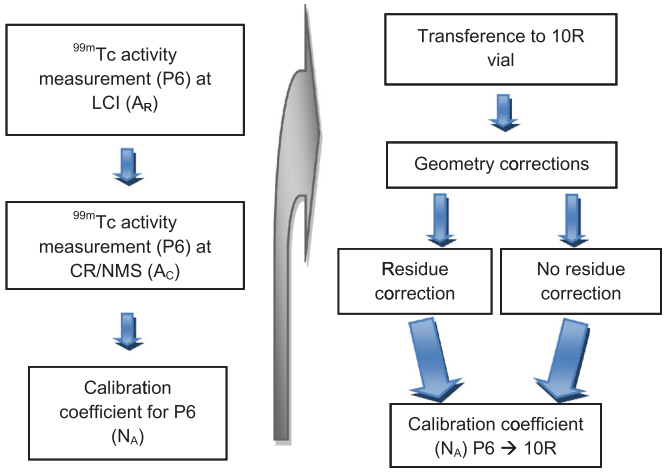

Fig. 3. Methodology 2 flowchart. First measurement is performed at calibration laboratory (LCI), then P6 vial containing ^{99m}Tc is sent to radiopharmaceutical production facility (CR) or Nuclear Medicine Service (NMS).

Table 4
Methodology 2 applied to Nuclear Medicine Service B and C with and without residue corrections. Three central columns present N_A values with respective uncertainties in parenthesis.

Activimeter Model	P6-P6	10R-P6 w/ corrections	10R-P6 w/o corrections	Variation (%)
NMS-B	0.990(9)	0.990(9)	0.964(15)	2.6
NMS-C	1.050(9)	1.051(9)	1.080(13)	2.7

taking the instrument to a calibration laboratory. Finally, a calibration coefficient comparison will be made when the calibration procedure is performed with and without residue corrections.

2. Methodology

2.1. Residual activity determination

For the residual activity determination ^{99m}Tc solution was obtained from a ^{99m}Tc generator (Osso et al., 2002) with a P6 vial (Fig. 1a). This solution was then transferred to the Instruments Calibration Laboratory (LCI/IPEN) reference vial, 10R (Fig. 1b), using 3.0 mL or 5.0 mL syringes. Each container was filled with saline solution to avoid volume errors and the residual activity was measured. A scheme for this procedure is presented in Fig. 1c. Vials dimensions are given in Table 1.

The total activity A_T is given by $A_T = A_F + A_{RC}$, where A_F is the solution in 10R vial and A_{RC} is the sum of the residual activity in the previous containers.

2.2. Calibration methodology establishment

Calibration methodology was established according to National

Physical Laboratory (NPL), United Kingdom (National Physical Laboratory, 2006) recommendation, using P6 and 10R vials. Reference activity was obtained with a Capintec NPL-CRC at LCI.

Activimeters calibration was performed in three NMS and in four different activimeters at IPEN radiopharmaceutical production facility (CR). The main advantage of an "in situ" calibration is the possibility to keep both radiopharmaceutical production and patient care working during the procedure. In both methodologies, a calibration factor in terms of the activity (N_A) was calculated from activities measured at NMS/CR, according to the equation:

$$N_A = \frac{A_R}{A_C} \tag{2}$$

where A_R and A_C are the activities measured with the reference and the NMS/CR equipment, respectively.

Letter *N* is normally used to indicate a calibration factor, and can be applied to different physical quantities, such as air-kerma (N_K), absorbed dose in water ($N_{D,W}$) and activity (N_A) (International Atomic Energy Agency, 2007; International Atomic Energy Agency, 2000)

Having been determined for an activimeter, N_A must be applied for every measurement made in this equipment, along with any necessary correction factor, according to Eq. (3):

$$A_S = A_M N_A \prod_1^n F_n \tag{3}$$

where A_S is the corrected activity, A_M is the measured activity and $\prod_1^n F_n$ is the product of every necessary correction factors (volume, geometry, vial position inside the well-chamber etc.).

3. Results

Results obtained for radioactive residue measurement will be presented with calibration coefficients calculated in each calibration methodology. Two methodologies were performed with and without residue correction and N_A was obtained from both situations. Obviously, in a real calibration situation, this correction must always be made.

First methodology consists of measuring radiopharmaceutical activity at the laboratory where it was produced or in the NMS, using P6 vial. The sample is then sent to LCI for the reference activity measurement using the reference activimeter and subsequently it is transferred to the 10R vial. Geometry correction factor for P6 to 10R must be applied and it had already been determined in previous studies (Martins and Potiens, 2012; Kuahara et al., 2015).

In Fig. 2a procedure overview is presented, and the respective N_A values are presented in Tables 2 and 3.

The second methodology is very similar to the first. However, in this case, LCI receives ^{99m}Tc for the reference activity determination with P6 vial at reference activimeter. The sample is sent to NMS where a measurement and the calibration are made. The transference to 10R vial, geometry corrections and residue measurement are also performed, as previously presented. An overview of this methodology is presented is Fig. 3, and respective results in Table 4.

From Tables 1–3, a variation of up to 4% between procedures performed with and without residue correction can be observed, which is a high percentage considering that the test was made under controlled conditions and less residue was left inside vials. A much higher variation may be expected in NMS measurements. It is important to highlight that these procedures were performed for P6 vial, but can be applied to any other vial used in the NMS.

4. Conclusions

Results show the importance of applying radioactive residue corrections when performing activimeters calibration. Variation of up to 4% in the measurement with and without residue correction was found, even under controlled laboratorial conditions. Greater errors are expected in a NMS. Both calibration procedures applying proper corrections presented high reliability and low uncertainties (lower than 1%).

Acknowledgements

We acknowledge to Brazilian agencies Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES (project 2215/2013), Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq (project 312131/2016-0), Fundação de Amparo à Pesquisa do Estado de São Paulo, FAPESP (project 2015/19584-8) and Instituto Nacional de Ciência e Tecnologia, INCT (project 573659/2008-7).

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