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Implementation of internal monitoring programs for workers occupationally exposed by ^{131}I in nuclear medicine services in Brazil

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ABSTRACT

In nuclear medicine services (NMS), workers routinely handle radionuclides for diagnostic and therapy. This practice represents a risk of incorporation by these radionuclides. The International Atomic Energy Agency (IAEA) recommends the implementation of an internal monitoring program on workers potentially exposed to annual effective doses higher than 1 mSv, as for example, those who handle ^{131}I for therapy. Currently, in Brazil, there are not enough available laboratories qualified to provide internal monitoring services to attend all possible demand of internal monitoring if such regulation were applied by the Brazilian Nuclear Regulatory Board (CNEN). Therefore, the objective of this work is to provide simple and inexpensive methods for *in vivo* routine thyroid monitoring of ^{131}I using equipment available in the clinics itself. Thus, diagnostic devices available in four public hospitals located in the city of Rio de Janeiro were calibrated for use in occupational internal monitoring. The devices evaluated in this work to measure ^{131}I in workers´ thyroid presented enough sensitivity to estimate intakes that would deliver committed effective doses below 1 mSv per year.

Keywords: **internal dosimetry, radiation protection, iodine-131, nuclear medicine.**

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1. INTRODUCTION

In Nuclear Medicine Services (NMS), a wide variety of radionuclides in the form of unsealed sources are handled routinely for diagnostic and therapeutic purposes. Such professional activity represents a significant risk of external exposure of occupationally exposed workers, as well as the possibility of intakes via inhalation and ingestion and the subsequent internal exposure.

In spite of a consensus that external exposure is predominant, significant intakes may occur simultaneously in nuclear medicine practice. However, depending on the exposures scenario, and based on international criteria of evaluation, the permanent risk of intakes of radionuclides requires the implementation of a routine monitoring plan, aiming to control and limit internal doses [1].

According to national and international regulations, the Radiation Safety Officer (RSO) of the facility is responsible for managing the Radiation Protection Programme (RPP) and, based on monitoring results, to implement the necessary measures to keep exposure levels as low as possible [2]. The RPP may include an evaluation of internal occupational exposures to be carried out through specific methodologies which allow identification and quantification of intakes as well as the estimation of the committed effective doses of the workers [3]. In Brazil, there are approximately 90 nuclear medicine clinics authorized to handle ^{131}I for therapy purposes [4], resulting in a significant number of workers routinely exposed to a risk of intake. It should also be pointed out that ^{131}I presents the higher risk of internal exposure among the radionuclides used in nuclear medicine. Although the national regulations require the implementation of internal monitoring programs of this group of workers, in Brazil there are not enough qualified laboratories available to offer internal dosimetry services and attend the possible demand of internal monitoring. Consequently, it would represent an impeditive high cost to the medical institutions if the Brazilian Nuclear Regulatory Board would apply the requirements of internal monitoring [5].

The objective of this work is to develop feasible methodologies for *in vivo* thyroid monitoring aiming to implement low-cost internal monitoring Programs applied to nuclear medicine workers who handle unsealed sources of ^{131}I, mainly for therapy, where high activities are routinely handled representing a significant risk of intakes and consequently internal doses.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Detectors

Table 1 presents the detectors which are intended to be applied in internal routine monitoring in professionals who handle ^{131}I in the form of unsealed sources in nuclear medicine clinic.

Table 1: Detectors available evaluated in four Nuclear Medicine Clinics.

Detector	Trade Mark	Model	Type	Facility
Surface Contamination Monitor	Ludlum	C14	Geiger-Muller	A B
Gamma Camera	Phillips	Bright View XCT	Scintillator	A
	GE	Millenium MG		B
	GE	Discovery MN/CT 670		C
	Siemens	E.cam 180		D
Thyroid Uptake probe	IEN - CNEN	13004	Scintillator	B

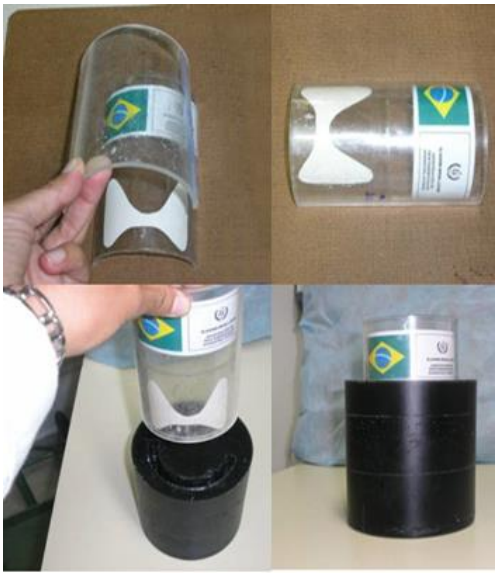
2.1.2 Neck-thyroid Phantom

The neck-thyroid phantom (Figure 1) used for the calibration of the detectors for the measurement of ^{131}I in thyroid was developed at the *In Vivo* Monitoring Laboratory of the IRD. The neck phantom is made of polyurethane-base tissue equivalent material. A filter paper simulating a human thyroid is spiked with a known amount of a ^{133}Ba liquid standard source.

It is conventional practice to use sources of ^{133}Ba as a surrogate for measuring ^{131}I since the energy and yield of photons emitted by ^{133}Ba are very similar to the photon emissions from ^{131}I. Furthermore, the half-life of ^{133}Ba is long (10.5 years) compared with ^{131}I (8 days), so that a certified calibration standard containing ^{133}Ba can be used for many years.

After being sealed with a plastic film, the filter paper is fixed in the proper position with an acrylic part and inserted in the neck phantom. The phantom used in this work contained originally 29771 Bq of ^{133}Ba in 28/04/2004.

Figure 1: *Neck-thyroid phantom produced in the In Vivo Monitoring Laboratory of IRD [6].*



2.2 Methods

The methodology consisted basically in determining the calibration factors for the measurement of ^{131}I in the thyroid, calculation of the minimum detectable activities and the corresponding minimum detectable effective doses.

2.2.1 Calibration of the Detection System

Step 1 – Calculation of ^{131}I Equivalent Activity: The ^{133}Ba activity on phantom was corrected between fabrication and calibration dates. The equivalent ^{131}I activity content of the phantom is calculated by multiplying the activity of ^{133}Ba added to the phantom by the ratio between the sum of ^{133}Ba and ^{131}I photon yields in the region of interest for the measurement, using the information of Table 2, as shown in the following equation:

$$^{131}\text{I Eq Ac}_{Bq} = \text{A } (^{133}\text{Ba}) \text{ x } \frac{\Sigma\,(\gamma\,^{133}\text{Ba})}{\Sigma\,(\gamma\,^{131}\text{I})} \quad (1)$$

where **^{131}I Eq Ac** is the equivalent activity of ^{131}I, in Bq; **A (^{133}Ba)** is the activity of ^{133}Ba present in the phantom, in Bq; **Σ (γ^{133}Ba)** is the sum of emission intensities γ of ^{133}Ba and **Σ (γ^{131}I)** is the sum of emission intensities γ of ^{131}I.

Table 2: Energy photons and emission intensity for ^{133}Ba e ^{131}I.

Energies γ ^{133}Ba (keV)	**Emission Intensity γ**
276.39	0.071
302.85	0.183
356.01	0.620
383.85	0.089
Energies γ ^{131}I (keV)	**Emission Intensity γ**
284.30	0.061
364.48	0.817

Step 2 – Determination of Measurement Setup (Figure 2): The standard geometry consisted in positioning the phantom at 12 cm distance to the front of the Gamma-Camera (GC), 0 cm distance to Portable Surface Contamination Monitor (PSCM) probe and 0 cm distance to Thyroid Uptake probe (TUP). The count time (except for the PSCM) was determined according to detectors sensitivity for a monitoring interval of 1 and 7 days after intake, considering a weekly generic monitoring frequency, resulting in 48 monitoring periods per year.

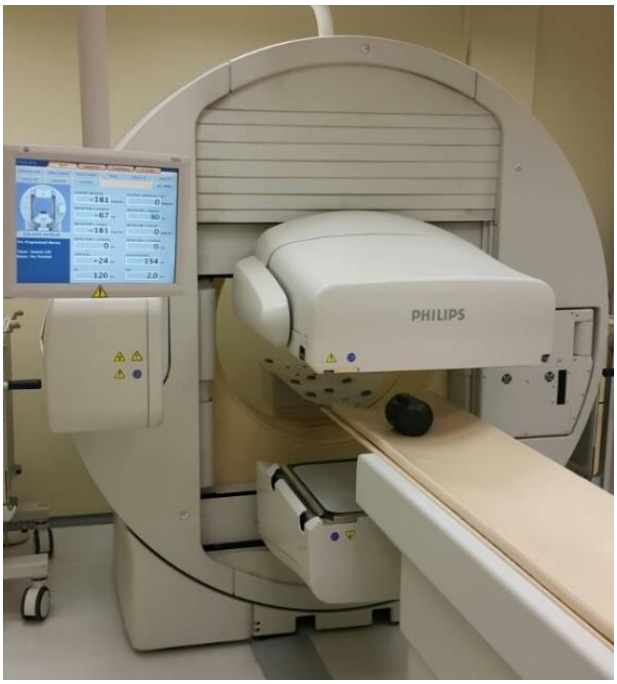
Step 3 – Calculation of Calibration Factor (CF):

The calibration factor is given by:

$$CF_{ctg/Bq} = (phanton\ conts - background\ counts)\ /\ ^{131}\text{I Eq Ac} \quad (2)$$

The ^{131}I equivalent activity of the phantom used in this work is in the order of 14000 Bq, depending on the date of its use for the calibration of the equipment.

Figure 2: *Measurement geometry for gamma-camera.*



2.2.2 Evaluation of Sensitivity

The evaluation of the sensitivity of the method for its application in routine internal monitoring is based on the calculation of the Minimum Detectable Activity (MDA), Minimum Detectable Intake (MDI) and Minimum Detectable Effective Dose (MDED).

The MDA of the method is given by equation 3 or equation 4 [7]:

$$\mathrm{MDA}_{Bq} = (4{,}65 \,.\, \sqrt{\mathrm{N}}) \,/\, \mathrm{CF} \tag{3}$$

$$\mathrm{MDA}_{Bq} = (4{,}65 \,.\, \sigma) \,/\, \mathrm{CF} \tag{4}$$

where **N** is the total counts of the background of a non-exposed subject, when the calibration is made with only one measurement; **σ** is the standard deviation of the background, when the calibration is made in a series of background measurements; and **CF** is the calibration factor.

The Minimum Detectable Intake (MDI), a function of the MDA and the exposure scenario, is given by:

$$\mathrm{MDI}_{Bq} = \mathrm{MDA} / \mathrm{m(t)}_{inh\ or\ ing} \tag{5}$$

where **MDA** is the minimum detectable activity and **m(t)** is the retention fraction in the compartment of interest for inhalation or ingestion.

The last parameter to be calculated is the Minimum Detectable Effective Dose, which is based on the MDI, and is given by:

$$\mathrm{MDED}_{Bq} = \mathrm{MDI}_{ina/ing} \times \mathrm{e(g)}_{ina/ing} \tag{6}$$

where **MDI** is the minimum detectable intake and $\mathbf{e(g)_{ina/\ ing}}$ is the dose coefficient (mSv/Bq).

In order to be considered useful for internal dosimetry purposes, the technique should, at least, be able to detect an activity that would result in an annual effective dose below 1 mSv for the most likely internal exposure scenario [8]. The values of "m(t)" and "e(g)" are available in the publication 78 of the ICRP [9] and can also be generated for specific exposure scenarios and times through the software AIDE [10].

The monitoring period is determinant to evaluate the sensitivity of the proposed method to be applied on a routine internal monitoring in a specific clinic. This evaluation can be made by the following equation:

$$\text{Annual Sensitivity}_{mSv} = \mathrm{MDED}_{mSv} \times n \tag{7}$$

where **MDED** is the minimum detectable effective dose and **n** is the number of annual monitoring periods, e.g., 48 when workers are monitored once a week.

3. RESULTS AND DISCUSSION

Table 3 shows the total counts and background counts results, count times, calibration dates and its respective ^{131}I equivalent activities present in the neck-thyroid phantom for each detector evaluated in this study.

Table 3: Calibration parameters and counts results of the detectors analyzed.

Detector	Facility	Count Time (min)	Counts	BG Counts	Calibration Date	^{131}I Eq Ac (Bq)
PSCM	A	Instant count rate	398	70	04/17/17	13874
GC	A	3	106838	26248	04/17/17	13874
PSCM	B	Instant count rate	408	68	06/21/17	13712
GC	B	7	255825	103282	06/21/17	13712
TUP	B	4	4875	755	07/04/17	13679
GC	C	3	31408	4050	10/03/17	13456
GC	D	3	69133	15188	03/23/18	13047

Table 4 shows the results for CF and MDA of the detectors evaluated at the different facilities using the neck-thyroid phantom. The GCs were calibrated in a single measurement of the neck-thyroid and the background, using equation 3 to calculate the MDA, while the PSCMs and TUPs were calibrated through a series of counts of the neck-thyroid phantom and the background, using equation 4 to calculate the MDA.

Table 4: CF and MDA of the detectors analyzed.

Detector	Facility	CF (Bq/cpm)	MDA (Bq)
PSCM	A	0.023	1994
GC	A	1.936	130
PSCM	B	0.024	1837
GC	B	1.589	134
TUP	B	0.075	227
GC	C	0.677	146
GC	D	1.378	139

The parameter MDI depends on the exposure scenario and the time elapsed between intake and *in vivo* measurement. In this work it was used the retention fraction values for 1 and 7 days between ^{131}I intake by inhalation and *in vivo* measurement (Table 5). Such values were obtained through the software AIDE [10]. The MDED was calculated based on the MDI, considering the dose coefficient for inhalation associated to the corresponding intake scenario adopted in this study, as shown in Table 5.

Table 5: Retention fractions and dose coefficient for inhalation obtained with the software AIDE.

m(t) (Bq/Bq)		**e(g) (mSv/Bq)**
1 day	**7 days**	1.98×10^{-5}
0.229	0.139	

Table 6 shows the results for MDI and MDED of the detectors evaluated, considering 1 and 7 days after intake by inhalation.

Table 6: MDI and MDED of the detectors evaluated for 1 and 7 days after intake by inhalation.

Detector	**Facility**	**MDI (Bq)**		**MDED (mSv)**	
		1 day	**7 days**	**1 day**	**7 days**
PSCM	A	8706	14343	0.172	0.284
GC	A	566	933	0.011	0.018
PSCM	B	8023	13219	0.159	0.262
GC	B	587	966	0.012	0.019
TUP	B	991	1633	0.020	0.032
GC	C	636	1047	0.013	0.021
GC	D	605	997	0.012	0.020

In order to evaluate the sensitivity of the detectors, it was simulated a weekly generic monitoring period, totalizing 48 annual monitoring periods. Table 7 shows the annual sensitivities obtained for a weekly monitoring period.

Table 7: Annual sensitivities (mSv) for 48 monitoring periods per year.

Detector	Facility	Sensibility (mSv)	
		1 day	7 days
PSCM	A	8.16	13.44
GC	A	0.53	0.88
PSCM	B	7.62	12.56
GC	B	0.55	0.92
TUP	B	0.94	1.55
GC	C	0.60	0.99
GC	D	0.57	0.95

The gamma-cameras available in facilities “A”, “C” and “D” are newer and more sensitive than the model in operation in facility “B”, which is approximately 20 years old. Even though, it presented enough sensitivity for occupational monitoring in a reasonable short count time.

The gamma-cameras and the thyroid uptake probe are made up of NaI scintillation detectors, which provide a high intrinsic efficiency for the detection of gamma photons emitted by ^{131}I. However, the size of the NaI crystal used in the uptake probes area smaller in comparison with the ones used in gamma-cameras, resulting in much less sensitivity.

The surface contamination monitors evaluated in this study are *Geiger-Muller* detectors. Such detectors are much less sensitive than scintillator detectors. Therefore, none of then showed sufficient sensitivity for routine occupational monitoring.

The sensitive values obtained with NaI-based equipment (gamma-cameras and thyroid uptake probes), as shown in Table 4, may be increased by optimizing two basic measurement parameters; (*i*) reducing distance between detector and subject and (*ii*) increasing measurement count time.

In order to avoid disturbing the routine of the clinic, it is proposed to use the minimum count time, but keeping the necessary sensitivity of the method for its application in occupational

monitoring. The counting distance was optimized to provide a reasonable comfort to the subject. Furthermore the monitoring plan should be more effective if the measurements are schedule according to the radionuclide handling of the facility, when it is more likely to detect significant intakes by the workers.

4. CONCLUSION

Considering a generic weekly monitoring frequency, the gamma-cameras of the four facilities evaluated in this study presented enough sensitivity for use as a monitoring device up to 7 days after intake. The thyroid uptake probe showed sensitivity only for measurements performed 1 day after intake. The portable surface contamination monitors are not suitable for routine occupational monitoring. Alternatively, this device can be useful for the investigation of possible accidents involving intakes of significant amounts of ^{131}I. It should also be highlighted that the proposed methodology is easy, simple and inexpensive, since the measurements are performed by the staff of the clinic and there is no need to purchase new equipment for the implementation of the monitoring plan.

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