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An estimation of the effective dose for the internal contamination of workers occupationally exposed to open sources of ^{131}i in thyroid treatments

Una estimación de la dosis efectiva para la contaminación interna de trabajadores ocupacionalmente expuesto a abrir fuentes de ^{131}I en tratamientos de tiroide

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Abstract

Handling a variety of unsealed sources in Nuclear Medicine has led to a significant risk of internal exposure for workers. ^{131}I stands out among the radionuclides of frequent use due to its wide application in diagnosis and treatment of thyroid diseases. This study presents the development of in vivo bioassay techniques, in order to quantify the incorporation of ^{131}I used in nuclear medicine. It also presents the results of research related to the internal exposure of a group of workers involved in handling therapeutic doses of ^{131}I. The in vivo detection system was calibrated with a thyroid phantom developed at IRD (Brazil) which is also used at the UTN-IVIC (Venezuela). The workers monitored in this study presented measurable intake. Therefore, it is important to ensure future monitoring of such exposure. It also gives us the possibility of evaluating intake in cases of suspected accidents. The highest estimated effective dose was 1,28x10^{-5} Sv by inhalation and 1,27x10^{-5} Sv by ingestion. The proposed method showed enough sensitivity for its application in the assessment of the effective dose for ^{131}I intake by workers. The minimum detectable effective dose associated with the MDA (244 to 287 Bq) is three orders of magnitude below the recording level of 1 mSv, considering a single intake by inhalation of a Type F compound of ^{131}I in the form of vapor.

Key words: Thyroid, iodine-131, Effective Dose, Internal Contamination.

Resumen

La manipulación de fuentes no selladas en Medicina Nuclear ha dado lugar a un riesgo significativo de exposición interna de los trabajadores. El ^{131}I se destaca entre los radionucleidos de uso frecuente por su amplia aplicación en diagnóstico y tratamiento de enfermedades de tiroides. Este trabajo presenta el desarrollo de técnicas de bioensayos "in vivo", con el fin de cuantificar la incorporación de ^{131}I utilizado en Medicina Nuclear. También se presentan los resultados de la investigación de la exposición interna de trabajadores involucrados en el manejo de dosis terapéuticas de ^{131}I. El sistema de detección "in vivo" fue calibrado con el simulador de tiroides desarrollado en el IRD (Brasil) y con el cual cuenta la UTN-IVIC (Venezuela). Los trabajadores controlados en este estudio tuvieron resultados mensurables en cuanto a la incorporación, por lo cual, es menester establecer su control a futuro y también nos da la posibilidad de evaluar las incorporaciones en casos de sospecha de un accidente. La estimación de la dosis efectiva más alta fue 1,28x10^{-5} Sv por inhalación y 1,27x10^{-5} Sv por ingestión. El método propuesto mostró sensibilidad para su aplicación en la estimación de la dosis efectiva por incorporación de ^{131}I en TOEs sobre la base de AMD calculado (mínimo 244Bq y máximo 287Bq), el cual se encuentra tres órdenes de magnitud por debajo del nivel máximo de 1mSv, considerando el escenario de incorporación único, compuesto en forma de vapor (tipo F) y la inhalación como la principal vía de entrada de ^{131}I en el cuerpo.

Palabras clave: Tiroides, iodo-131, Dosis Efectiva, Contaminación Interna.

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1. Introduction

Iodine-131 (^{131}I) is a radionuclide of high radiotoxicity which is used in nuclear medicine, principally for the diagnosis and treatment of thyroid diseases (differentiated thyroid cancer and hyperthyroidism). ^{131}I is a beta and gamma emitter with a decay half-life of 8.02 days. Activities employed in the practice fall between 3.7 and 111MBq (0.1-3mCi) for the evaluation of thyroid function, between 148 and 925MBq (4-25mCi) for the treatment of hyperthyroidism, and between 1110 and 7400MBq (30-200mCi) for differentiated thyroid cancer (DTC) [1].

It is therefore necessary, in order to have an impact at the national level here in Venezuela, to apply the country's Radiological Protection Program (Programa de Protección Radiológica) for all Iodine-131 treatment. This is done via the direct measurement of the activity incorporated into the thyroid of occupationally exposed workers [OEW], and the radiometric analysis of urine samples collected within 24 hours, in accordance with the recommendations proposed by the International Atomic Energy Agency (IAEA) in Safety Guide No. RS-G-1.2 [2]. The objective is to verify compliance with the primary limits established by Venezuelan legislation regarding occupationally exposed workers, and thus adopt a single procedure for the evaluation of occupational doses within an extensive routine program that monitors radiological exposure in Venezuela.

When estimating internal contamination in nuclear medicine services, an effective alternative for monitoring occupational exposure would be the utilization of thallium-activated sodium iodide crystal (NaI(Tl) 2"x2") detectors which, from previous calibrations, are converted into efficient body activity monitors which can be used to carry out measurements within the departments of nuclear medicine themselves. Hence, the potential unusual event of radionuclide intake (ie: ^{131}I) in occupationally exposed individuals can be detected in advance, allowing for immediate action regarding the individual as well as the revision of procedures adopted for these aims. This allows the verification of compliance with current standards [2] concerning the radiation dose limit of workers and members of the public under normal working conditions.

Likewise, it permits the identification of an atypical contamination situation and the subsequent evaluation of its severity in order to determine appropriate corrective action.

The estimation of the committed effective dose is expressed as $E_{(50)}=\sum w_T H_{T(50)},$ where w_T are the tissue weighting factors and $H_{T(50)}$ is the equivalent dose with an integration time of 50 years [3]. This can be estimated via direct measurements of the whole body, organs, or wounds, or via indirect measurements, analyzing the presence of radionuclides in excreta or in the work environment.

The internal dosimetry evaluates the results of these direct and indirect measurements, taking into account factors such as the physical and chemical characteristics of the radioactive substances, the mode of intake, and the metabolic processes involved. For this, the biokinetic and dosimetric models recommended by international specialists, principally the ICRP [4], are interpreted and applied. Additionally, this aids in the elaboration of applicable monitoring plans at installations, as well as in obtaining specific Annual Limits on Intake (ALI) for a specific workplace.

This study was performed at the Nuclear Medicine Department of La Trinidad Teaching Medical Center (Servicio de Medicina Nuclear del Centro Medico Docente La Trinidad) in Caracas, Venezuela, and the dosimetry was performed on two OEWs without regard for age and gender.

2. Materials and methods

For the in vivo laboratory bioassay, the Venezuelan Institute for Scientific Research (IVIC) acquired, via the Radiological Protection and Dosimetry Institute (IRD) of Rio de Janeiro, a thyroid uptake neck phantom containing a ^{133}Ba source of known activity. The total amount of activity (t = 134471 Bq/g (3,634 µCi/g)) from the ^{133}Ba source was previously calibrated by Radionuclide Metrology services and sent in for preparation of the neck phantom.

The phantom, a thyroid simulator containing a known activity, was developed at IRD's In Vivo Measurement Laboratory [5]. The simulation of the thyroid was achieved by adding 200 mL of standard solution (^{133}Ba) of known activity to filter paper, thus simulating the organ. It was properly sealed, then positioned and placed in the interior of the neck phantom in order to perform the measurements and calibrations.

Figure 1 shows the preparation sequence for the neck phantom, which was constructed by IRD under the project ARCAL LXXVII [6].

The detector consists of an assembly formed by a thallium-activated sodium iodide crystal (NaI(Tl) 2"x2") connected to a photomultiplier, a light guide, a voltage divider, a resistor divider, a dynode, and a preamplifier. The entire assembly is surrounded by 2.0cm-thick shielding. This detector can be used in conjunction with a mobile support model, which allows correct positioning relative to the occupationally exposed worker.

Figure 1. Sequence of preparation for the neck phantom, constructed by the IRD under the ARCAL LXXVII project.

In order to ensure the reliability of the monitoring results, it is important to periodically perform a quality control check, evaluating parameters related to sensitivity, resolution, precision, and linearity, as well as to carry out measurements of the background or natural radiation [7].

Before the calibration of the detector with the neck phantom, the background radiation at the site was measured with a thyroid phantom. This phantom is an optimization of the original prototypes developed during the ARCAL project [6], which involved the calibration of the detectors with a thyroid phantom containing ^{133}Ba (equivalent to ^{131}I).

Additionally, a correction was performed on the effective dose calculations via the software AIDE v6.0. This tool and the routine acquisition of data allow us to attain a better view of the internal contamination that may be occurring within each OEW and thus to bestow adequate and timely attention upon them.

The neck phantom was then used for the calibration of the detector. It simulates the thyroid with an equivalent known activity of ^{131}I (A = 25959 Bq), previously calibrated. The established measurement geometry was 20 cm from the face of the detector to the neck phantom.

A methodology for monitoring internal ^{131}I contamination of OEWs has been established at the Nuclear Medicine Department of the La Trinidad Teaching Medical Center, being the only center in Caracas with the detector available at the time of study. Additionally, the results are presented in order to determine the intake and to estimate the effective dose for two OEWs involved in the handling of therapeutic doses of ^{131}I. The handled activities were found to be in the range of $1{,}11 \times 10^{7}$ Bq and $5{,}55 \times 10^{9}$ Bq. The workers handled ^{131}I activities in both liquid and capsule form.

The OEWs were selected in order to follow the steps of ^{131}I intake and to estimate the committed effective dose via in vivo biassay procedures.

Interpretation of the Bioassay Data: using AIDE Software version 6.0 (Activity and Internal Dose).

The AIDE (Activity and Internal Dose Estimates) software [8] is a program for calculating the activity of the intake of radionuclides. At the same time, it provides an estimation of the effective dose, based on in vivo and in vitro bionalysis data, and is used specifically for OEWs who, in their daily activity, are subject to radionuclide intake, such at Nuclear Medicine departments.

The program allows the selection of biokinetic models associated with radioactive decay data, based on the elements enumerated in the ICRP 78 [9]. For the correct interpretation of the measurement results of the incorporated activity, which were performed through the in vivo and in vitro bioanalysis techniques, it is essential to take into account the volatility of ^{131}I, information about the primary route of intake, the manner of intake, and the form of the compounds. For the specific case in our study, we consider an acute intake of ^{131}I via inhalation, classified as a compound in vapor form.

Besides estimating the intake and the committed effective dose through in vivo and in vitro measurements, the use of AIDE also makes it possible to calculate the derived recording levels (DRL), taking into account the intake (Bq) that corresponds to an effective dose of 1 mSv in different time intervals.

To calculate the minimum detectable intake (I), we considered the relationship between the minimum detectable activity (MDA) of the technique and the function of retention or excretion of the correspondent behavior in which the measurement was carried out (the thyroid) for the pre-defined time interval, whose scenario for the interpretation of the relative data is a single intake. Under these circumstances, the effective dose (E) is calculated via the minimum detectable intake (I) and its dose coefficient ($e_{(g)}$) of the radionuclides of interest (^{131}I). The techniques presented to quantify the activity of incorporated ^{131}I are applicable for routine individual monitoring, since the values found for the MDA of the monthly-measured frequency are below the annual maximum level of 1 mSv.

The detector is located in an area contiguous to the radiation area at the Nuclear Medicine Department at La Trinidad, where measurements for calibration are carried out. The calibration procedure was performed with the methodology employed by the IRD's in vivo Bionalysis Laboratory. It consists of placing the neck phantom on a base 1 meter from the floor, with the collimator flush and perpendicular to it. This separates the NaI (Tl) (2"x2") detector from the phantom at a distance of 20cm. We proceeded to take 5 measurements of the phantom directly and another 5 with the 3cm lead barrier, which is placed between the detector and the phantom to measure the background radiation. All of this is to calculate the decay in the activity of the phantom from manufacturing to the calibration of the detector [10], in accordance with the methodology.

3. Results y discussion

The values of the effective dose $E_{(50)}$ estimated by the measurements made with the detector for the weekly monitoring frequency (9.50 µSv for inhalation and 9.47 µSv for ingestion), based on the MDA value of 244 Bq, determined for 10 minutes of counts, in the geometry of the thyroid, demonstrate the applicability of the technique for the evaluation of ^{131}I intake, since they are below the recording level of 1 mSv.

The obtained $E_{(50)}$ results, based on the MDA for 10 minutes of counts and using the (NaI (Tl) (2x2)) detector, demonstrate the applicability of the system for the evaluation of the intake of ^{131}I by the OEWs, considering intake via inhalation, classified as type F in vapor form.

The different values of MDA were obtained with the portable (NaI (Tl) 2 "x 2") system for the calibration measurements with the phantom containing ^{133}Ba. The lowest value of MDA was obtained when the calibration was performed in a room contiguous to the hot room, where the radiopharmaceuticals that are going to be administered are handled. It is worth mentioning that the lower the MDA, the greater the possibility of detection of incorporated radionuclides. The MDA establishes a detection minimum, from which the obtained measurement results are taken as positive.

With the obtained values in Table 1, the MDA is calculated, which is the minimum activity that was possible to detect in a volunteer that has not worked in areas where radiation is used. The criteria and conditions of measurement are the same as for the exposed workers.

Table 1. Data obtained for an Uncontaminated Person.

DATE	TOTAL (cpm)	BACKGROUND (cpm)	NET (cpm)
16/02/11	421	405	16

Measurements were performed on the OEWs (see Table 2 and Table 3), whose results indicate the presence of small intakes arising from the handling of unsealed source of ^{131}I. This confirms the importance of this routine monitoring – to ensure that workers are carrying out their responsibilities safely and that the staff adopt and comply with radioprotection procedures – and allows the projection of measurements for a year in the future, to see if they surpass the annual limits of 1 mSv of effective dose. Table 2 and Table 3 show that, regardless of the activity handled, an intake exists.

Table 2. Data obtained from Occupationally Exposed Worker # 1

DATE$_1$	**DATE$_2$**	**T (cpm)**	**B (cpm)**	**N (cpm)**	**A_H (kBq)**	**A_T (Bq)**
25/01/11	26/01/11	536	353	183	$6x10^6$	4575
01/02/11	02/02/11	445	368	77	$1x10^4$	1925
08/02/11	09/02/11	518	370	148	$4x10^6$	3700
15/02/11	16/02/11	510	417	93	$4x10^6$	2325
22/02/11	23/02/11	501	462	39	$1x10^4$	975
01/03/11	02/03/11	491	405	86	$1x10^4$	2150

Table 3. Data obtained from Occupationally Exposed Worker # 2

Date$_1$	**Date$_2$**	**T (cpm)**	**B (cpm)**	**N (cpm)**	**A_H (kBq)**	**A_T (Bq)**
25/01/11	26/01/11	419	381	38	$6x10^6$	950
01/02/11	02/02/11	419	386	33	$1x10^4$	825
08/02/11	09/02/11	578	388	190	$6x10^6$	4750
15/02/11	16/02/11	496	312	184	$8x10^6$	4600
22/02/11	23/02/11	489	410	79	$1x10^4$	1975
01/03/11	02/03/11	500	390	110	$1x10^4$	2750

Date$_1$ = Intake date; Date$_2$ = Measurement date; T = Total cpm; B = Background cpm; N = Net cpm; A_H = Activity handled; A_T = Activity detected in thyroid

Taking the highest activity handled, we have a total of $424x10^6$KBq annually and an activity detected in the thyroid of 243KBq and close to 0.8 mSv of annual effective dose. This assumes the administration of ^{131}I once a week in different treatments, the same working conditions, and the same level of caution towards radiological protection.

The calibrations guarantee the reliability of the measurements, since by calculating the decay we know the exact activity in the thyroid phantom we are working with when measuring. Based on these measurements (Table 4) and by calculating the uncertainty, a value of ± 4% was obtained, which is acceptable given the quantity of measurements.

Table 4. Neck Phantom Data

	TOTAL (cpm)	**BACKGROUND (cpm)**	**NET (cpm)**
	10707	568	10139
	11472	594	10878
	11787	575	11212
	11072	567	10505
	11548	555	10993
AVERAGE ($\dot{X}$)	**11317.2**	**571.8**	**10745.4**
$X(\sigma_{n-1})$	**427.3**	**14.3**	**424.9**

Source: ^{133}Ba; Time: 10 minutes; Distance: 20cm from the detector to the neck; Date: 16/02/11.

Table 5 and 6 display the in vivo measured values of the thyroid for the workers. The proposed scenario for the evaluation of the $E_{(50)}$, based on the MDA technique, is as follows: single intake, via inhalation and ingestion, Type F ^{131}I compound in vapor form.

Table 5. Data from the In Vivo Measurement of Thyroid Performed on TOE #1

$Date_E$	A_T (Bq)	MDA (Bq)	I_{inh} (Bq)	$E(50)_{Inh}$ (Sv)	I_{ing} (Bq)	$E(50)_{Ing}$ (Sv)
25/01/2011	4575	277	799	1,58E-05	726	1,58E-05
01/02/2011	1925	253	336	6,66E-06	306	6,63E-06
08/02/2011	3700	272	646	1,28E-05	587	1,27E-05
15/02/2011	2325	270	406	8,04E-06	369	8,00E-06
22/02/2011	975	268	170	3,37E-06	155	3,36E-06
01/03/2011	2150	265	376	7,44E-06	341	7,41E-06

For a better appreciation, the intake and effective dose $E_{(50)}$ by inhalation and ingestion for each OEW are represented graphically (Figures 2 and 3). This demonstrates the sensitivity of the proposed system, allowing us to guarantee the methodology of our study so that routine monitoring of the OEWs generates figures which aligned with the reality of the occurring internal contamination.

Table 6. Data from the In Vivo Measurement of Thyroid Performed on TOE #2

$Date_E$	A_T (Bq)	MDA (Bq)	I_{inh} (Bq)	$E(50)_{Inh}$ (Sv)	I_{ing} (Bq)	$E(50)_{Ing}$ (Sv)
25/01/2011	950	244	166	3,29E-06	150,79	3,27E-06
01/02/2011	825	244	144	2,97E-06	130,95	2,84E-06
08/02/2011	4750	287	830	1,64E-05	753,97	1,64E-05
15/02/2011	4600	266	803	1,59E-05	730,16	1,58E-05
22/02/2011	1975	264	345	6,83E-06	313,49	6,80E-06
01/03/2011	2750	267	480	9,50E-06	436,51	9,47E-06

Time interval: 24 hours; m(t) inhalation: $2{,}29\times10^{-1}$Bq; e(g) inhalation: $1{,}98\times10^{-8}$Sv/Bq; m(t) ingestion: $2{,}25\times10^{-1}$Bq; and e(g) ingestion: $2{,}17\times10^{-8}$Sv/Bq. $Date_E$ = Date de exposure; A_T = Activity detected in the thyroid; MDA = Minimum Detectable Activity; I_{inh} = Intake by inhalation; I_{ing} = Intake by ingestion

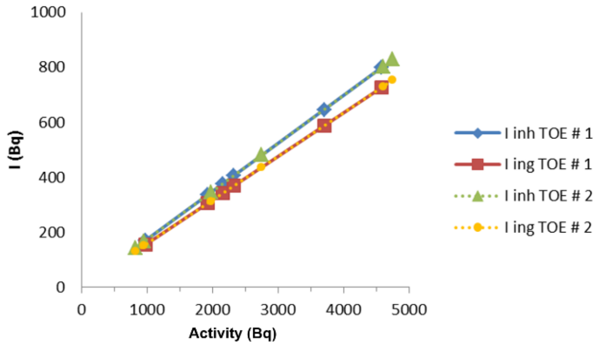

Figure 2. Comparison of intake by inhalation and ingestion of detected activity in the thyroid of OEWs 1 and 2.

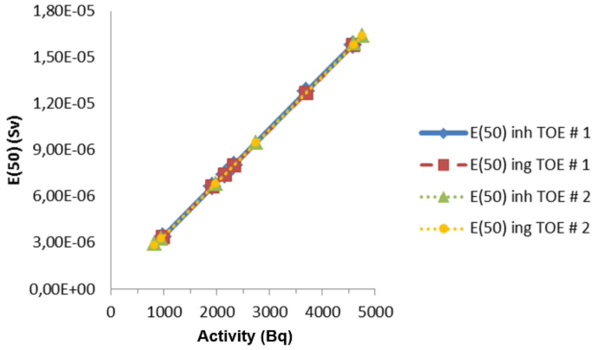

Figure 3. Comparison of the effective dose $E_{(50)}$ by inhalation and ingestion of detected activity in the thyroid of OEWs 1 and 2.

The low observed doses in this small group, with the measureable existence of intake, indicate the importance of continued monitoring of intake and give the possibility of evaluating the intakes in cases of suspected accidents. As seen in Figures 2 and 3, there is no significant difference in the dose estimation when comparing the two routes of intake (inhalation or ingestion). Additionally, a calculation of tendencies was performed to determine how close the data are among themselves and the $R^2=1$ in the four effective dose estimations for both inhalation and ingestion in the two OEWs. It indicates that the correspondence between the effective dose $E_{(50)}$ and the activity measured in the thyroid is linear – at greater activities there is a greater effective dose $E_{(50)}$, providing the principles of radiological protection are not followed.

4. Conclusions

The Secondary Laboratory of Dosimetric Calibration at the IVIC can perform a trial to carry out the calibrations of the in vivo systems via its neck phantom and instruct nuclear medicine services staff to perform the conversion of ^{133}Ba to ^{131}I. The proposed method showed sensitivity for its application in our monitoring as values estimated over a base of calculated MDA (244Bq minimum and 287Bq maximum). It is three orders of magnitude below the maximum level of 1 mSv, considering a scenario of a single intake, a compound in vapor form (Type F), and inhalation as the principal route of entry of the ^{131}I into the body.

The sensitivity of the detector permitted the detection of small quantities (144.10 Bq) of intake in the two OEWs, whose routine procedures included the use of open sources of ^{131}I with therapeutic purposes. The range of handled activity falls between 11 MBq and 7500 MBq (0.3 mCi and 203 mCi), while the findings of incorporated activity fall between 825 Bq and 4750 Bq.

Based on the minimum and maximum values of the activity measured through in vivo bioanalysis, estimations of the effective dose were approximately $3x10^{-6}$Sv – $20x10^{-6}$Sv for inhalation and $3x10^{-6}$Sv – $20x10^{-6}$Sv for ingestion, which indicates a measurable figure that is below the effective dose threshold of 1 mSv.

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