Determination of scattering factors associated to the *in vivo* monitoring of ^{131}I in the thyroid

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Abstract: The internal dose due to incorporation of radionuclides can be estimated direct measurements in the human body. This technique consists on the determination of radionuclides in the total body and in organs. This study aims to evaluate the sources of uncertainty associated with the *in vivo* monitoring of ^{131}I in the thyroid. The benchmarks are based on the criteria suggested by the European IDEAS Project. Measurements were performed with a NaI(Tl)3x3 detector and a IRD-neck-thyroid phantom. Scattering factors were calculated for different counting parameters. The technique presents reproducibility equivalent to international quality standards for this type of *in vivo* monitoring.

Keywords: measurement uncertainty, *in vivo* monitoring, iodine-131, thyroid

1. INTRODUCTION

The internal dose from the incorporation of radionuclides can´t be measured directly. It must be assessed from monitoring, either *in vivo* monitoring or through the analysis of biological indicators (*in vitro* monitoring). The use of *in vivo* methods for internal dosimetry consists in the qualitative and quantitative determination of radionuclides present in the human body and in specific organs or tissues (IAEA, 1999).

When reporting the result of the measuring of a physical quantity, it is required to report any quantitative indication of the quality of the result, so that those who use it can evaluate their reliability. Without this indication, measurement results can´t be compared, either among themselves or with reference values provided in a specification or a norm. Therefore it is necessary to have a procedure readily implemented, easily understood and generally accepted to characterize the quality of a result of a measurement, that is, to evaluate and express their uncertainty (ABNT, 2008).

According to the European IDEAS Project (Doerfel et al, 2006), the main sources of uncertainty associated to the *in vivo* monitoring process are: (1) Counting statistics; (2) Variation of detector positioning; (3) Variation of background signal; (4) Variation of overlaying structures; (5) Variation of activity distribution and (6) Calibration.

The aim of this study is to assess the sources of uncertainty associated with *in vivo* monitoring of ^{131}I in the thyroid carried out at the IRD Whole Body Counter.

2. MATERIALS AND METHODS

The standard procedure for *in vivo* measurement of ^{131}I in the thyroid consists in positioning a NaI(Tl)3”x3” detector 15 cm distant to the neck of the subject to be monitored.

The uncertainty associated to IDEAS parameters were evaluated using a thyroid phantom containing a standard source of ^{133}Ba, a simulator for ^{131}I, frequently used for this application because of its longer half-life compared to ^{131}I and the equivalence of their photon emissions.

The thyroid phantom is made of a filter paper with the shape of the organ, spiked with 0.17509 g of a standard solution of ^{133}Ba with specific activity of 155659.0 Bq/g, and sealed with adhesive plastic film (Dantas et al, 2011).

2.1. Counting statistics

A series of ten 15-minutes counts were carried out in thyroid geometry in order to quantify the effect of counting statistics on the measurement uncertainty.

2.2. Detector positioning

This experiment aims to simulate the movement of the subject during the measurement; therefore, a series of fifteen 5-minutes counts were performed varying *x*, *y*, *z* coordinates in relation to the standard geometry (15 cm distance between the thyroid phantom and the detector front face), as shown in figure 1.

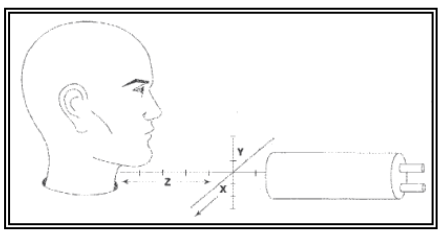

Figure 1: Schematic representation of the displacement axis of the phantom in relation to the detector.

2.3. Background signal

This experiment was performed in the standard thyroid geometry. The procedure comprised three series of five 15-minutes counts each; (i) inert thyroid phantom and thorax; (ii) inert thyroid phantom only; (iii) empty room.

2.4. Overlaying structures

Acrylic plates of different thicknesses were used to simulate soft tissue over the thyroid gland. Besides the low cost, acrylic resin was chosen due to its ideal mechanical characteristics, availability in the market in different thicknesses, as well as its photons attenuation and scattering properties that are similar to human tissue (ICRU, 1989). Five neck-shaped plates were produced with thicknesses ranging from 5 to 25 mm. Such values were based on the premise that a normal adult has a minimum of about 6.3 mm of soft tissue over the thyroid region (Kramer and Meyerhof, 1994).

A series of five 5-minutes counts were performed with each thickness and the background count was measured with the inert phantom without any plate.

2.5. Activity distribution

The thyroid phantom was sectioned into four quadrants (I, II, III and IV) as seen in figure 2. Such quadrants were combined with non-spiked pieces into nine different configurations as described in table 1. Upon completion of the marking and cutting, the paper pieces were weighed and the thyroid phantom was assembled and positioned to be counted with the NaI(Tl)3”x3” detection system, in the standard thyroid geometry.

Figure 2: Thyroid phantom marks representing the division into quadrants.

Table 1. Combinations of quadrants to simulate different activity distributions of activity in the thyroid

Configuration	Spiked pieces
A	(I+II+III+IV)
B	(III+IV)
C	(I+II)
D	(I+III)
E	(II+IV)
F	(I)
G	(II)
H	(III)
I	(IV)

Each combination was measured five times for 15-minutes, comprising forty-five measurements for the nine combinations.

2.6. Calibration

This procedure was performed in order to verify the reproducibility of standard counting geometry. In this experiment, a series of five 15-minutes counts were performed with the chest and thyroid phantoms spiked with the standard ^{133}Ba source homogeneously distributed over the filter paper. At the end of each count the phantom was disassembled and replaced on the same geometry.

2.7. Calculations of Total Scattering Factor

The uncertainties evaluated in this work are given in terms of dispersion factors. It is assumed that the distribution of the counts can be described by a log-normal function. Thus, the dispersion factor is the geometric standard deviation of the distribution, as suggested in the IDEAS Guide. The calculation of the total scattering factor follows the equation below.

$$SF = \exp\left[\sqrt{\sum_i \ln^2(SFi)}\right] \quad (1)$$

Where SF is the total scattering factor and SFi is the scattering factor due to component i.

3. RESULTS AND DISCUSSIONS

Table 2 presents the results of the uncertainty evaluation as a comparison to the values provided in the IDEAS Guide.

Table 2. Comparison between experimental values of the scattering factors obtained in this study and the reference values provided in the IDEAS Guide.

Source of uncertainty	**SFi exp**	**SFi IDEAS**
Counting statistics	1.01	1.07
Detector positioning	1.08	1.05
Background signal	1.06	1.05
Overlaying structures	1.12	1.12
Activity distribution	1.03	1.05
Calibration	1.08	1.05
SF Total	**1.19**	**1.18**

The scattering factors presented in the IDEAS Guide should be used for comparison purposes only. They should not be considered as reference values applicable to all detection systems and all geometries. It is then important to point out that scattering factors are clearly system-dependent.

The statistical fluctuation of standard source and background count rates remarks the importance of preventive maintenance and routine quality control of the detection systems in

order to guarantee the stability of the electronics and the reliability of the monitoring process itself.

The sources of uncertainty associated to systematic errors on *in vivo* monitoring can be minimized by performing a series of measurements to obtain the calibration factor and its associated SFs. This also applies to the study of uncertainties associated with detector positioning and repositioning.

Towards higher standardization of the positioning of the detectors and elimination of systematic errors, it is recommended to adopt a mechanic coordinates system in the detector supports. This would provide a significant improvement in quality and reliability in the measurement results.

Regarding the study aimed to evaluate the effect of non-homogeneity of activity distribution in the organ it was found that this parameter poses an important hole in the calibration factor depending on the configuration adopted. Therefore, it is very important to include the evaluation of this parameter in the calculation of the total SF of the technique.

The results obtained in this study show the importance of determining scattering factors associated to other *in vivo* monitoring techniques, since it was clearly observed the influence of systematic and non-systematic errors in overall measurement uncertainty.

The comparison of experimental and reference SF values allows to conclude that the parameters associated to the *in vivo* measurement of ^{131}I in thyroid performed in the IRD Whole Body Counter presented reproducibility and uncertainties compatible with international standards for this type of *in vivo* monitoring technique.

4. REFERENCES

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