

Development and evaluation of a technique for *in vivo* monitoring of ^{60}Co in human liver

BM Dantas, ALA Dantas, GH Gomes, MC Silva and JQ Mello

¹Instituto de Radioproteção e Dosimetria- CNEN

E-mail: bmdantas@ird.gov.br

Abstract: ^{60}Co is an artificial radioactive metal produced by activation of iron with neutrons. It decays by beta particles and gamma radiation and represents a risk of internal exposure of workers involved in the maintenance of nuclear power reactors. Intakes can be quantified through *in vivo* monitoring. This work describes the development of a technique for the quantification of ^{60}Co in human liver. The sensitivity of the method is evaluated based on the minimum detectable effective doses. The results allow to state that the technique is suitable either for monitoring of occupational exposures or evaluation of accidental intakes.

Keywords: Cobalt 60, internal dosimetry, *in vivo* measurement, nuclear energy

1. INTRODUCTION

^{60}Co is a synthetic radioactive isotope with a half-life of 5.27 years produced in nuclear reactors. It decays to the stable isotope ^{60}Ni , emitting β particle. The activated nickel nucleus emits two γ rays with energies of 1.17 and 1.33 MeV [1]. ^{60}Co is a result of multiple stages of neutron activation of iron components of the reactor structure, posing a risk of occupational internal exposure to workers involved in the handling and maintenance of parts and equipment potentially contaminated in nuclear power units. Measurable quantities are also produced as a by-product of typical nuclear power plant operation and may be detected externally when leaks occur.

Internal monitoring procedures aimed to identify and quantify intakes by inhalation and ingestion may be accomplished through *in vivo* measurements.

The IRD whole-body counter has been recently calibrated to perform lung monitoring

using a NaI(Tl)8x4 scintillation detector [2] installed in a shielded room designed originally for low activity measurement [3].

This work describes the standardization and evaluation of the sensitivity of a technique for *in vivo* measurement of ^{60}Co in human liver.

2 – MATERIALS AND METHODS

The calibration of the detection system is performed using a LLNL thorax phantom [4] containing a certified ^{60}Co liver phantom supplied by the University of Cincinnati. The procedure allows obtaining a calibration factor which correlates the net count rate in specific regions of interest (ROI) and the activity present in the phantom. This parameter is necessary to calculate the activity content in the liver of an individual potentially exposed and measured *in vivo* using the whole body counter detection system.

2.1 Determination of the calibration factor

The LLNL thorax containing a liver phantom (Figure 1) with a activity of (34501 +/-

345) Bq of ^{60}Co was placed on the monitoring chair located inside the shielded room of the IRD whole-body counter and the Pb-collimated NaI(Tl)3x3 detector was positioned at a distance of 2 cm between the surface of the phantom and the front face of the crystal.

A series of five counts of 300 seconds were performed at the standard geometry and the spectra saved for subsequent calculations.



Figure 1. The LLNL thorax containing a liver phantom

Figure 2 presents a γ -spectrum of ^{60}Co showing the two characteristic peaks of 1173 and 1332 keV. Three regions-of-interest (ROI) were defined including a range of energy from [1086-1264] for the first peak, [1264-1438] for the second and a third region of [1086-1438].

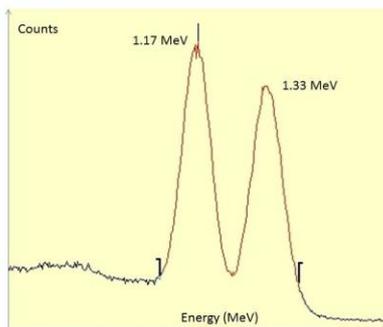


Figure 2. Gama spectrum of ^{60}Co obtained with a NaI(Tl)3x3 scintillation detector

After the counts have been completed, the calculation of the calibration factors (CF) in each ROI was performed. The CF expresses the ratio between the average net count rate of

the five counts, in cps, and the activity of the phantom, in Bq, as follows:

$$CF_{cps/Bq} = \text{cps}/A \quad (1)$$

Where: cps is the net count rate (averaged cps of the phantom and A (Bq) = ^{60}Co activity content of the liver phantom.

2.2. Evaluation of sensitivity

In order to be considered useful for internal dosimetry purposes, any technique should, at least, be able to detect an activity that would result in a committed effective dose below 1 mSv, taking into consideration the most likely internal exposure scenario [5]. Thus, the evaluation of the sensitivity of the method was based on the calculation of the MDA (minimum detectable activity) and the corresponding MDI (minimum detectable intake) and the MDED (minimum detectable effective dose)

Such calculations were based on the biokinetic and dosimetric models of ^{60}Co in human body applied to a realistic internal exposure scenario. According to the model ICRP 78 [6], ^{60}Co is distributed throughout the whole body and a significant fraction is retained in the liver.

The MDA of the method is calculated as follows [7]:

$$MDA = \frac{4.65\sqrt{N}}{CF \times T} + \frac{3}{CF \times T} \quad (2)$$

Where: N = Total counts of the background in the ROI; CF = Calibration Factor (cps/Bq) and T = count time.

The MDI is a function of the MDA and depends on the exposure scenario and time elapsed between intake and the *in vivo* measurement. It is calculated as follows:

$$MDI = MDA / m(t)_{inh} \quad (3)$$

Where: MDA = Minimum Detectable Activity (Bq) and $m(t)$ = Retention fraction in the compartment of interest, in Bq/Bq.

The last parameter to be calculated is the MDED, which is a function of the MDI and the dose coefficient, $e(g)$, associated to the intake scenario adopted in the simulation. It is calculated as follows:

$$MDED_{Bq} = MDI_{inh} \times e(g)_{inh} \quad (4)$$

Where: MDI = Minimum Detectable Intake (Bq) and $e(g)_{inh}$ = Dose coefficients (mSv/Bq).

The values of “m(t)”, in Bq/Bq, were generated for a period of 1 to 14 days after a single intake of ^{60}Co via ingestion using the software AIDE [7]. The dose coefficient, $e(g)$, in mSv/Bq, correspond to the committed effective dose resulting from an intake of 1 Bq.

3 – RESULTS AND DISCUSSION

Table 1 presents the calibration parameters (Regions of Interest, Calibration Factors and respective MDAs).

Table 1. Results of the calibration of the NaI(Tl)3x3 detector for *in vivo* measurement of ^{60}Co in the liver, comparing three regions of interest

	Region of Interest		
	1	2	3
ROI (Channels)	347-418	418-488	347-488
ROI (keV)	1086 - 1264	1264 - 1438	1086 - 1438
CF (Cps/Bq)	0.00142	0.00131	0.00291
MDA (Bq)	114	126	79

ROI #3 was elected since it has shown to be the most sensitive based on its corresponding MDA. Therefore, the following calculation where all based on this ROI. The next step was to calculate the MDI and the MDED in the period of 1 to 14 days after the intake,

Table 2 presents the values of MDI and MDED derived from the selected MDA, considering a scenario of a single intake of ^{60}Co via ingestion.

Table 2. Minimum Detectable Intakes and Minimum Detectable Effective Doses assuming a scenario of a single intake of ^{60}Co by ingestion. (Dose coefficient = 3.41×10^{-6} mSv/Bq)

T (d)	m(t) (Bq/Bq)	IMD (Bq)	DEMD (mSv)
1	3.21E-03	2.48E+04	0.084
2	4.20E-03	1.89E+04	0.065
3	4.23E-03	1.88E+04	0.064
4	4.04E-03	1.97E+04	0.067
5	3.81E-03	2.09E+04	0.071
6	3.60E-03	2.21E+04	0.075
7	3.41E-03	2.33E+04	0.079
8	3.23E-03	2.46E+04	0.084
9	3.08E-03	2.58E+04	0.088
10	2.94E-03	2.70E+04	0.092
11	2.81E-03	2.83E+04	0.096
12	2.70E-03	2.94E+04	0.100
13	2.59E-03	3.07E+04	0.105
14	2.50E-03	3.18E+04	0.108

4 – CONCLUSIONS

Based on the sensitivity of the method, expressed by the MDED, it is concluded that the technique is able to detect activity levels of ^{60}Co in the liver derived from intakes via ingestion that would result in committed effective doses in the order of microsieverts.

One should note that up to 14 days after the intake, the MDED is still about 10 times below 1 mSv, the suggested Registry Level for occupational exposure, according to the IAEA [5]

The results obtained in this work allow concluding that the proposed technique is sensitive enough for the control of intakes of ^{60}Co via ingestion. The technique is suitable for a routine monitoring program aimed to control this type of exposure in nuclear power stations. The methodology is valid either in routine operations or in special tasks like the

ones performed during maintenance of the reactor. It can also be useful for the evaluation of accidental intakes.

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5 – ACKNOWLEDGMENT

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