

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

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Abstract: ^{60}Co is a fission product of ^{235}U and represents a risk of internal exposure of workers in nuclear power plants, especially those involved in the maintenance of potentially contaminated parts and equipment. The control of ^{60}Co intake by inhalation can be performed through *in vivo* monitoring. This work describes the evaluation of a technique through the minimum detectable activity and the corresponding minimum detectable effective doses, based on biokinetic and dosimetric models of ^{60}Co in the human body. The results allow to state that the technique is suitable either for monitoring of occupational exposures or evaluation of accidental intakes.

Keywords: radionuclide, incorporation, ^{60}Co , internal dosimetry, nuclear energy

1. INTRODUCTION

Cobalt-60 is a synthetic radioactive isotope with a half-life of 5.27 years, produced artificially in nuclear reactors. Measurable quantities are also produced as a by-product of typical nuclear power plant operation and may be detected externally when leaks occur.

^{60}Co is the result of multiple stages of neutron activation of iron components of the reactor structure. It decays to the stable isotope nickel-60, emitting β particle. The activated nickel nucleus emits two γ rays with energies of 1.17 and 1.33 MeV [1]. Such emissions represent a risk of occupational internal exposure to workers involved in the handling and maintenance of parts and equipment potentially contaminated in nuclear power units.

Internal monitoring procedures aimed to identify and quantify intakes by inhalation can be performed through *in-vivo* measurement in laboratories so-called whole-body counters. The *In-Vivo* Monitoring Laboratory of IRD is able to perform this type of measurement using a NaI(Tl)8x4 scintillation detector installed in a heavy shielded room [2].

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

2 – MATERIALS AND METHODS

The calibration of the detection system is performed using a LLNL thorax phantom [3] containing a certified ^{60}Co lung phantom. The procedure allows obtaining the 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 lungs of an individual measured *in-vivo*.

2.1 Determination of the calibration factor

The LLNL thorax containing a pair of lung phantoms with a total of 33574 Bq of ^{60}Co was placed on the monitoring chair located inside the shielded room of the IRD whole-body counter and the NaI(Tl)8x4 detector was positioned horizontally at a distance of 2 cm between the surface of the phantom and the front face of the crystal, as shown in Figure 1.

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



Figure 1. Calibration setup for the measurement of ^{60}Co in the lungs using NaI(Tl)8x4

Figure 2 is a γ spectrum of ^{60}Co showing the two characteristic peaks of 1.17 and 1.33 MeV. Three regions-of-interest (ROI) were defined including a range of channels of [347-408] for the first peak, [414-470] for the second and a third region of [347-470], including both peaks. An additional count of an inert phantom was also performed for the calculation of the net count-rate in these regions of interest.

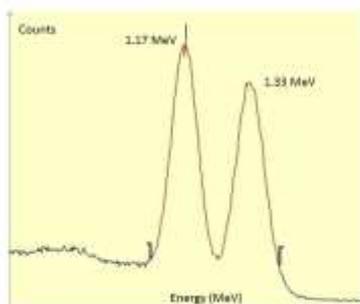


Figure 2. Gama spectrum of ^{60}Co Obtained with a NaI(Tl)8x4 scintillation detector

After the counts have been completed, the calculation of the calibration factors (CF) in each ROI was performed. The CF is expressed as the ratio between the average net count rate of the five counts, in cps, and the activity of the phantom, in Bq, as follows:

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

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

2.2. Evaluation of sensitivity

The evaluation of the sensitivity of the method is based on the calculation of the *minimum detectable activity* and the corresponding *minimum detectable intake* and the *minimum detectable effective dose*, using the biokinetic and dosimetric models of ^{60}Co in human body applied to a realistic internal exposure scenario [4]. The MDA of the method is calculated as follows [5]:

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

Where: N = Total counts of the background in 300 seconds; CF = Calibration Factor (cps/Bq) and T = count time.

The Minimum Detectable Intake (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:

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

Where: MDA = Minimum Detectable Activity (Bq) and $m(t)_{\text{inh}}$ = Retention fraction for inhalation in the thoracic compartment.

The last parameter to be calculated is the Minimum Detectable Effective Dose. It is based on the MDI and the dose coefficients associated, $e(g)$, to the corresponding intake scenario adopted in the simulation. It is calculated as follows:

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

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

The values of “m(t)” and “e(g)”, used for the calculations of the MDI and the MDED are presented in Table 1. In this work it has been used m(t) values corresponding to 1 day after the intake and the dose coefficient, e(g), corresponding to AMAD of inhaled particles of 1 μm and 5 μm . Such values are available in the Publication 78 of the ICRP [4] and can also be generated for specific exposure scenarios and times through the software AIDE [6].

Table 1. Biokinetic and dosimetric parameters of the ^{60}Co model used for the calculation of the Minimum Detectable Intakes and the Minimum Detectable Effective Doses

Intake Scenario	Retention fractions in thoracic compartment m(t) (Bq/Bq)			Total Retention fraction in 1 day m(t) (Bq/Bq)	Dose Coefficient (mSv/Bq)
	Bronchial	Bronchiolar	Alveolar		
1 μm / Tipo S	6.07×10^{-03}	9.33×10^{-03}	1.06×10^{-01}	1.21×10^{-01}	2.88×10^{-05}
5 μm / Tipo S	6.09×10^{-03}	5.34×10^{-03}	5.28×10^{-02}	6.42×10^{-02}	1.66×10^{-05}
1 μm / Tipo M	5.45×10^{-03}	8.36×10^{-03}	9.48×10^{-02}	1.09×10^{-01}	9.61×10^{-06}
5 μm / Tipo M	5.46×10^{-03}	4.78×10^{-03}	4.73×10^{-02}	5.75×10^{-02}	7.13×10^{-06}

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 effective dose below 1 mSv per year for the most likely internal exposure scenario [7].

3 – RESULTS AND DISCUSSION

Table 2 presents the count rates, the calibration factors and the MDA for the three ROI. The ROI #3 was elected for the following calculations since it has shown to be the most sensitive based on its corresponding MDA.

Tabela 2. Results of the calibration of the NaI(Tl)8x4 detector for in vivo measurement of ^{60}Co in the lungs, using three regions of interest

Count	¹ ROI		
	1	2	3
	integral	integral	integral
1	167121	142423	313991
2	167309	143071	314674
3	165739	141771	311731
4	166133	142073	312491
5	166269	142602	313139
Mean	166269	142423	313139
SD	672	498	1169
cps	553.27	474.07	1042.10
Inc cps	2.24	1.66	3.90
CF (cps/Bq)	0.01648	0.01412	0.03104
Inc CF (cps/Bq)	0.00024	0.00021	0.00045
MDA (Bq)	8.1	7.5	5.7

¹Region of interest

Table 3 presents the values of MDI and MDED derived from the MDA, considering four possible intake scenarios via inhalation in which it has been assumed AMAD of 1 μm and 5 μm and solubility classes in lung fluid suggested in ICRP Publication 78 [4] as Type S and Type M.

Tabela 3. Minimum Detectable Intakes and Minimum Detectable Effective Doses assuming four exposure scenarios

Scenario	MDI (Bq)	MDED (μSv)
1 μm / Type S	46.95	1.35
5 μm / Type S	88.74	1.47
1 μm / Type M	52.48	50.4
5 μm / Type M	99.06	70.6

The most critical internal exposure scenario in terms of radiological risk to the workers would be the intake via inhalation of a particle with AMAD of 1 μm and solubility class Type S. In this case a higher fraction of the inhaled particles would be deposited in the thoracic region - bronchial (BB), bronchiolar (bb) and alveolar-interstitial (AI) – which is the most radiosensitive, resulting in a higher health risk.

4 – CONCLUSIONS

Based on the criteria for the evaluation of sensitivity adopted in this work it can be stated that the proposed technique is able to detect an activity of ^{60}Co in the lungs derived from an intake via inhalation that would result in committed effective doses in the order of microsieverts. Such values are far below the Registry Level suggested by the IAEA and established by the National Regulatory Board.

The results obtained in this work allow concluding that the proposed technique is sensitive enough for the control of intakes of ^{60}Co via inhalation. The technique is suitable for routine monitoring programmes of this type of exposure in nuclear power stations either in routine operations or in special tasks like the ones performed during maintenance of the reactor, and it can also be useful for the evaluation of accidental intakes.

5 – ACKNOWLEDGMENT

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