

Assessment of whole-body retention to worker after accidental inhalation of ^{99}Mo

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Abstract. In June 2009, an incident occurred at the radiopharmaceutical production plant of the Nuclear Energy Research Institute (IPEN/CNEN-SP), which resulted in internal contamination of one worker with particles containing ^{99}Mo . The measurements were made in the *In Vivo* Monitoring Laboratory (LMIV) of IPEN. The counting system used for measuring high-energy gamma emitters comprises two thallium-activated sodium iodide [NaI(Tl)] detectors. The data used in this assessment include six whole body and five extrathoracic measurements over 21 days. The initial measurements have indicated retention of (136 ± 6) kBq and (25.1 ± 1.6) kBq in whole body and extrathoracic measurements, respectively, after approximately one day from the incident. The effective half-lives obtained were (1.68 ± 0.08) d for whole-body and (1.78 ± 0.02) d for extrathoracic. The estimated effective dose was (0.049 ± 0.002) mSv.

1 Introduction

In June 2009, an incident occurred at the radiopharmaceutical production plant of the Nuclear Energy Research Institute (IPEN/CNEN-SP), which resulted in internal contamination of one worker with particles containing ^{99}Mo .

A special whole body and extrathoracic counting showed that the worker was contaminated with ^{99}Mo . The measurements were made in the *In Vivo* Monitoring Laboratory (LMIV) of IPEN. The counting system used for measuring high-energy gamma emitters comprises two thallium-activated sodium iodide [NaI(Tl)] detectors. The measurements system was calibrated with an anthropomorphic phantom (Alderson Research Labs.) to take account of photon absorption in the tissues.

Furthermore, the follow up time for whole body measurements was sufficient to fitting the data. The data used in this assessment include 6 whole body and 5 extrathoracic measurements over 21 days. No information is available on the physical or chemical form of the inhaled material. Davis et al. [1] presented a guideline for the assessment of intakes by workers following accidental inhalation of radionuclides.

Following Marsh et al. [2], data fits were considered to be adequate if:

- the probability is greater than 5 % that the theoretical chi-squared distribution (χ^2) is less than the calculated chi-squared distribution (χ^2_0), that is $p > 0.05$. In other words the fit is adequate at the 5 % level of significance.
- Data fit displayed graphically looks acceptable.

Additionally, the expected value for the reduced chi-square (χ^2_{red}) is 1 (unity) in the case that the data are described by the model with given statistical uncertainties. If the reduced chi-square is near 1.0 this usually means that it appears to have a good fit to the model [3].

2 Assessment of Case

Whole-body retention was assessed for one worker who accidentally inhaled particles containing ^{99}Mo . The χ^2_0 value is used to determine whether the predictions of the model used to fit the data is consistent with the data.

2.1 Specific Route and Pattern of Intake

The case history indicates that an acute intake by inhalation occurred at a known time, namely 24 June 2009 at 7:30 am. Table 1 shows the measured activities both for whole-body and extrathoracic monitoring.

Table 1. Activity measured in whole-body and extrathoracic monitoring.

Time after intake (d)	Whole-body (kBq)	Extrathoracic (kBq)
1	135.6 ± 6.0	25.1 ± 1.6
2	74.5 ± 3.5	9.4 ± 1.0
3	49.9 ± 2.5	7.0 ± 0.9
6	14.0 ± 1.1	2.3 ± 0.7
8	7.4 ± 1.0	1.4 ± 0.4
9	4.3 ± 0.6	< LLD

2.2 Process Data and Discussion

Measurement uncertainties enabled χ^2_0 value to be calculated. This value was used to determine whether the predictions of the model used to fit the data is consistent with the data. Table 2 gives the χ^2_0 , χ^2_{red} values and p -value. Whole body (WB) and extrathoracic (ET) measurements were assumed to be distributed exponentially and lognormally as specified in ICRP Publication 30 [4] and suggested by Marsh et al. [2], respectively. The fits to the whole body and extrathoracic data using these distributions are shown in Fig. 1.

Table 2. Goodness of fit parameters.

Model	χ^2_0 ^a	χ^2_{red}	p-value (%) ^b
Exponential (WB)	3.45	0.69	63
Exponential (ET)	5.50	1.38	24
Lognormal (WB)	3.16	0.63	67
Lognormal (ET)	3.68	1.84	45

a. The theoretical chi-squared distribution, χ^2 , is equal to the number of degrees of freedom, which for simplicity is assumed to be one less than the number of data points, i.e. $6 - 1 = 5$ and $5 - 1 = 4$.

b. The p-value is the probability that χ^2 is greater than χ^2_0 for 5 and 4 degrees of freedom for whole-body and extrathoracic, respectively.

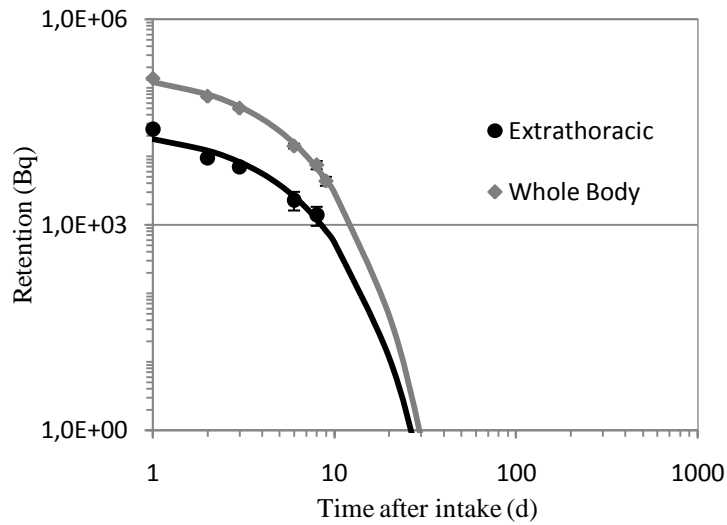


Fig. 1. Fit to whole body and extrathoracic retention assuming an exponential model

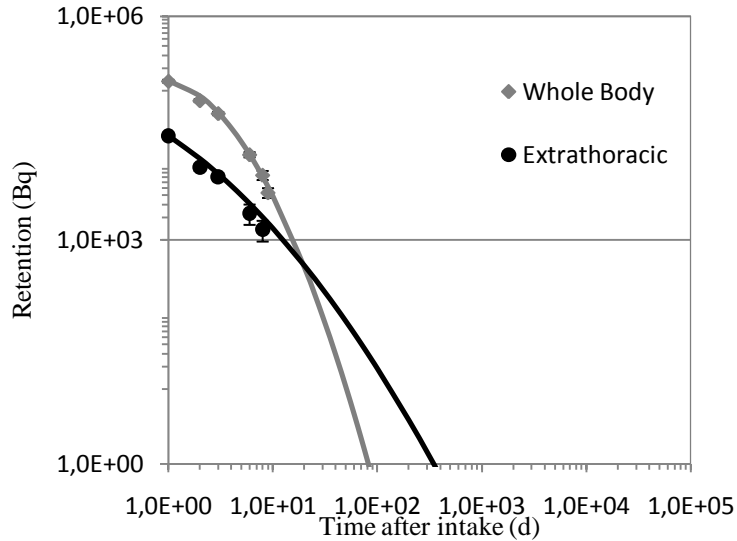


Fig. 2. Fit to whole body and extrathoracic retention assuming a lognormal model.

Fits were visually improved (Fig. 1 and Fig. 2) and the χ^2_0 calculated with the correspondent p-values significantly greater than 5 % (Table 2). The expected values, to a confidence interval of 95% (2σ), for χ^2_0 of 5 degrees of freedom was $1.15 < \chi^2_0 < 11.07$ and of 4 degrees of freedom $0.71 < \chi^2_0 < 9.49$.

The last measurement made 21 days after the incident produced values below the lower limit of detection (<LLD) for whole-body and in extrathoracic measurements the last two were < LLD too. The minimum activity detectable (MDA), calculated with proposed methodology by Lima et al. [5] by system for ^{99}Mo , in 739.5 keV, was 45 Bq.

The calculation of half-lives followed the exponential model. The effective half-lives were obtained from the curves showed in the Figs. 1 and 2 and the values were (1.68 ± 0.08) d and (2.78 ± 0.02) d for whole body and extrathoracic, respectively. The biological half-lives were calculated based on effective half-lives. The values of biological half-lives were (4.3 ± 0.5) d for whole body and (5.17 ± 0.17) d for extrathoracic measurements. The effective and biological half-lives values, for whole-body measurements, are in agreement with those estimated by Dantas et al. [6], for the incorporation of ^{99}Mo by injection. An effective dose of (0.049 ± 0.002) mSv was estimated, for the multiplication of the activity gotten in the first monitoring for the gotten coefficient of dose of 3.6×10^{-10} Sv.Bq⁻¹ for ^{99}Mo [7], and considering that the incorporation occurred via inhalation.

3 Conclusions

Fig. 1 and Fig. 2 compare the fit to the exponential and lognormal models, respectively. Table 2 compares the goodness of fit parameters and the results show that the exponential model has a better fit to this accidental inhalation. The effective

and biological half-lives values, for whole-body measurements are in agreement with literature and half-life value was not found for extrathoracic measurements. Data provided in this article can be useful as a basis for the interpretation of inhalation cases of ^{99}Mo , a situation not widely available in the literature.

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