Assessment of Radiation Exposure of Nuclear Medicine Staff using Personal TLD Dosimeters and Charcoal Detectors

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Abstract

Although the main concern regarding exposure to ionizing radiation for nuclear medicine workers is external radiation, inhalation of radionuclides can significantly contribute to the imparted doses. We propose a new approach to assess exposure to inhalation of ^{131}I based on passive monitoring using activated charcoal detectors. We compared the inhalation doses to the staff of a nuclear medicine department, based on the measurements derived from charcoal detectors placed at various locations, and the external doses monitored using personal TLD dosimeters.

1. Introduction

Nuclear medicine staff is potentially exposed to a wide range of radionuclides, as ^{99m}Tc, ^{67}Ga and ^{131}I. Usually, their dosimetric follow-up is based only on external gamma radiation using thermoluminescence detectors. Nevertheless, doses due to inhalation of airborne nuclides can be non negligible.

Several authors have assessed, for instance, the intake of ^{131}I by members of the staff using in vivo measurements with NaI detectors placed close to the neck (Hirota et al. 2004, Valentine 2004), reporting doses to the thyroid which vary from 50 to 200 mSv/yr. We propose, instead, to implement an area surveillance program using activated charcoal vials, which are subsequently measured in a low-level liquid scintillation spectrometer. Because of the high efficiency of the measuring technique, the charcoal detectors can be directly exposed, without need for using pumps to force air circulation through them. This provides an inexpensive and convenient method to estimate radionuclide concentrations in air, and in turns, the corresponding doses. Although a limitation of diffusive sampling is that only gases and vapours are retained, the aerosol radioiodine fraction is about a few hundred times lower than the gas fraction in hospital environments, and therefore it can be neglected in dose calculations (Mietelski et al. 2005)

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In this work, we assess the doses due to external gamma radiation and inhalation of ^{131}I to the staff of the Nuclear Medicine (NM) Department from the Salamanca University Hospital during the year 2004. The most commonly used isotopes in this hospital are ^{99m}Tc, ^{67}Ga and ^{131}I. The use of the latter isotope per year is in the order of 500 GBq, including diagnosis and cancer and hyperthyroidism treatment. The results for external doses were obtained from personal LiF TLD dosimeters and the inhalation doses by means of charcoal detectors placed in several locations along the department.

2. Experimental

2.1. Method description

Properties of activated charcoal for retention of radioiodine have been extensively used to measure or to reduce its concentration in a given environment by forcing air circulation through cartridges or traps. But they can also be applied to passive sampling. The processes of diffusion and permeation on which passive samplers rely, can both be described in derivations of Fick's first law. The resulting expressions relate the mass uptake by the sampler to the concentration gradient, the time of exposure, and the sampler area exposed to the iodine's atmosphere.

To sample ^{131}I, we used commercial charcoal vials (Picorad) in order to attain a better reproducibility compared to home-made charcoal detectors. In addition, they are provided with a diffusion barrier which minimizes the effects of humidity. Although Picorad vials are intended to measure indoor radon, we show that they can also be used to determine ^{131}I concentrations.

Along the year 2004, we performed several measuring campaigns, placing the vials in several locations of the Nuclear Medicine Department, including the bedrooms and bathrooms where the patients remain after the ^{131}I administration. The vials were opened and exposed for a period of three days. After this time, they were sealed and sent to the laboratory for analysis. Once in the laboratory, 10 ml of the mineral-oil based scintillation cocktail Instafluor were pipetted into the vial. Iodine was allowed to desorb from the cocktail for 8 h in the dark. Every vial was then counted for 250 min in an ultra low-level background QUANTULUS 1220 (Wallac).

2.2.- Calibration

In order to calibrate our system, we have used a small cylindrical chamber made of stainless steel where charcoal canisters were placed and then exposed for 72 h to different concentrations of ^{131}I in air.

The mean concentration of ^{131}I in air in the chamber, C_a (Bq m^{-3}), can be related to the net count rate in the interest region of the spectra, N (s^{-1}), by the following equation:

$$C_a = f \frac{N}{T} \cdot \frac{1}{k_c} \cdot \frac{1}{k_w}$$

where T is the exposure time of the vial, k_c the correction for decay during the counting time, k_w the correction factor for decay during the waiting time between sample collection and the start of the measurement, and f is a calibration factor. It can be in turns calculated as $f = f_a \cdot f_{LSC}$, f_{LSC} being the counting efficiency of the detector for ^{131}I, and f_a the retention efficiency, i.e., the adsorption in the charcoal canister per unit air ^{131}I concentration.

The detection efficiency (f_{LSC}) was determined as the relationship between the count rate in the spectrum and the ^{131}I activity in the vial. Several PicoRad vials were spiked with different concentrations of the radionuclide. Then, 10 ml of Instafluor Scintillation cocktail were added to each vial and they were immediately closed.

The retention efficiency (f_a) depends on environmental factors, as temperature and relative humidity. The calibration was performed at 20ºC and 30% relative humidity, which are the conditions found nearly stable along the year at the NM Department.

To inject ^{131}I iodine into the chamber a two steps procedure was undertaken. First, molecular iodine was generated from a certified $Na^{131}I$ source. Second, a known quantity of sublimated iodine was produced. The desired iodine amount was generated by oxidation using $KMnO_4$ at acid media HCl 1M and then extracted using diethylether, 1-octanol 5:1 V/V mixture. Solvents and iodine were separated by distillation techniques and only iodine was allowed to get into the chamber.

To calculate the concentration of ^{131}I in the chamber during the exposure period, one has to take into account that given the chamber volume, adsorption in the charcoal detector will reduce the concentration in air (C_a) during the experiment.

For tube type samplers in a steady-state situation, the uptake in the detector, ΔQ_d (Bq) depends on the ambient concentration of the substance C_a (Bq/cm^3) and the exposure time Δt (s):

$$\Delta Q_d = \frac{DA}{L} C_0 \Delta t \,, \qquad (1)$$

D being the diffusion coefficient of the pollutant in air, A the cross section of the tube, and L its length.

On the other hand, the iodine adsorbed in the detector: $Q_d(t)=kmC_a(t)$, where k is the absorption coefficient of charcoal and m its mass.

To take into account the reduction in the concentration in air (C_a) due to adsorption in the charcoal:

$$\frac{dQ_a(t)}{dt} = \frac{D.A}{L}\left[C_a(t) - C_d(t)\right], \qquad (2)$$

where $C_d(t)=Q(t)/V$, V being the chamber volume.

Assuming the calibration chamber has no leakage, the concentration of iodine in the chamber (C_a) will decrease due to radioactive decay and to adsorption in the charcoal detector:

$$\frac{dC_a(t)}{dt} = -\lambda C_a(t) - \frac{1}{V} dQ_a(t), \qquad (3)$$

λ being the decay constant for ^{131}I.

Considering that $Q_a(t)+Q_d(t)=Q_0e^{-\lambda t}$ (Q_0 being the ^{131}I concentration initially inserted in the chamber) and substituting equation (2) into (3) using boundary conditions $C_a(0)=C_0$ and $C(\infty)=0$ we obtain:

$$C_a(t) = C_0\left(\frac{km}{V+km}e^{-at} + \frac{V}{V+km}e^{-\lambda t}\right), \qquad (4)$$

where $a = \left(\frac{DA}{L}\right)\left(\frac{V+km}{Vkm}\right)$.

The average radon concentration in the chamber during the exposure time (T) can be calculated as:

$$\overline{C}_a = \frac{\int_0^T C_a(t)dt}{T}$$

3. Results

3.1. Estimation of ^{131}I air concentrations

We have collected 78 samples along the years 2004 and 2005. Vials were exposed between 72 and 96 h. The sampling took place during the isolation periods of patients, who had been administered 15, 100, 150 or 200 mCi of ^{131}I, and also in empty patient rooms. The exposures in the dose preparation and administration room always started immediately after these activities were performed.

The vials exposed simultaneously in several points of the patient's room showed no significant difference, indicating a good mixing of ^{131}I in air within the room (Jimenez et al.2004). Average measured concentrations are shown in Table 1.

Table 1. Mean values of observed ^{131}I concentration in air referred to 72 h.

C_a (Bq/m^3)	Administrated dose (mCi)
0.0079	0
0.037	15
0.14	100
0.50	200

^{131}I concentrations were also measured in the rooms where radiopharmaceutics are prepared and administrated too. Values varying between 0.5 Bq/m^3 and 1Bq/m^3 have been found (after 72 h), with a mean value of 0.53Bq/m^3 and a standard deviation of 0.2Bq/m^3.

3.2 Estimation of doses

Exposure to iodine gases occurs in different chemical forms, such as elemental iodine, inorganic and organic iodine compounds. Because ^{131}I is released from the body as organic iodine, in the rooms where patients are confined and in nearby locations, we consider the dose coefficient factor for methyl iodide (1,5 x 10^{-8} Sv/Bq) given in ICRP 71, while for rooms where radiopharmaceutics are prepared and administered, we take the ICRP coefficient for elemental and inorganic forms of iodine (2,0 x 10^{-8} Sv/Bq). For nursing staff, we considered conservative estimates for the permanency factors: 1 h per week in the patient's rooms, and 3 h per week in the rooms where ^{131}I is directly handled. To the rest of their working time, we assigned the ^{131}I concentrations in air measured in background locations (corridors, offices…). For doctors, we assumed 1,5 h per week in the administration room and 1h per week in patient's confinement rooms. The default breathing rate is 1,2 m^3/h.

Considering the above dose parameters and the mean results for the determinations of ^{131}I, the dose estimation of the exposure to this radionuclide for the ward staff are summarized in Table 2. Most of the patients are administrated a dose of 100mCi, so we assumed a mean activity in the patient's room of 0.14Bq/m^3.

Table 2. Dose estimation by exposition to ^{131}I for nurses and doctors

Location	Nurses (mSv/yr)	Doctors (mSv/yr)
Patient's room	0.001	0.001
Administration room	0.014	0.007
Total	0.015	0.008

Regarding external doses, which were monitored by personal TLD dosimeters, the personal dose equivalent, Hp(10), for nurses (7 persons) is on average 3.8±2.9 mSv/yr and for doctors (6 persons) 0.8±0.4 mSv/yr.

4. Conclusions

The estimated dose due to inhalation of ^{131}I is much lower than external doses monitored with TLD dosimeters. The highest doses by inhalation are received in the preparation and administration room. It is necessary to determine the contribution of the other radionuclides in the air in order to estimate the total inhalation dose to the staff.

5. References

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