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Air contamination measurements for the evaluation of internal dose to workers in nuclear medicine departments

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ABSTRACT

Radionuclides handled in nuclear medicine departments are often characterized by high volatility and short half-life. It is generally difficult to monitor directly the intake of these short-lived radionuclides in hospital staff: this makes measuring air contamination of utmost interest. The aim of the present work is to provide a method for the evaluation of internal doses to workers in nuclear medicine, by means of an air activity sampling detector, to ensure that the limits prescribed by the relevant legislation are respected. A continuous air sampling system measures isotope concentration with a NaI(TI) detector. Energy efficiency of the system was assessed with GEANT4 and with known activities of ^{18}F. Air is sampled in a number of areas of the nuclear medicine department of the IRST-IRCCS hospital (Meldola- Italy). To evaluate committed doses to hospital staff involved (doctors, technicians, nurses) different exposure situations (rooms, times, radionuclides etc) were considered. After estimating the intake, the committed effective dose has been evaluated, for the different radionuclides, using the dose coefficients mandated by the Italian legislation. Error propagation for the estimated intake and personal dose has been evaluated, starting from measurement statistics.

1. Introduction

The use of unsealed radiation sources exposes personnel of nuclear medicine facilities to a potential risk of external and internal exposure (Valentin, 2007). Currently the most widely used radiopharmaceutical in nuclear medicine imaging is ^{18}F -FDG. The ^{18}F isotope is a pure β^+ emitter with a half life of 110 min, and it is produced, commercialized and utilized in radiopharmacy in liquid form. The volatility of the FDG and the radiological impact of contaminated air has been investigated thoroughly, see e.g. (Calandrino et al., 2009, 2007).

Contamination by airborne agents needs to be evaluated reliably, or the absence thereof established clearly, in view of obeying the limits on effective dose to exposed personnel (EURATOM 1996).

Evaluation of intake activities to be used with biokinetic models (Valentin, 2007) can be conducted with direct and indirect methods (Kocher, 2000). Direct whole body measurements can determine the occupational radionuclide intake to hospital staff (Terranova et al., 2011). Indirect measurements, on the other hand, derive intake activities from measurement of the activity present in biological samples (e.g. excreta) and physical samples (e.g. air filters). In the ICRP 103 recommendations (Valentin, 2007) the DAC (Derived Air Concentration) is defined as the activity concentration in air that given the breathing rate and yearly exposure time of a worker would result in a dose at the Annual Limit of Intake, and used as the operative quantity to estimate the internal dose due to inhalation. Measurements connected with the utilization of the DAC can be made with PAS (Personal Air Sampler) that are individual filter based air sampler worn by the exposed workers. As a general remark, PAS sampling technique is limited by the fact that the airflow through the device will not be representative of the breathing rate of a human, and the air sampled is not the same air that the worker will breathe, so 'hot particles' in the air may cause a substantial difference in dosimetry if care is not taken. But coming specifically to the present case, the short half-life of ^{18}F, like that of many other isotopes used in nuclear medicine, and a weak correlation with biological sampling measures (Britcher and Strong, 1994), are strongly limiting factors for the evaluation of intake radioactivity through this method, rendering the PAS essentially useless for the purpose, hence the need to evaluate the concentration of airborne activity from instant environmental radioactivity concentration: measuring air contamination becomes the most practicable possibility to evaluate inhalation-related doses to personnel. The present work presents a method for the evaluation of internal doses to personnel

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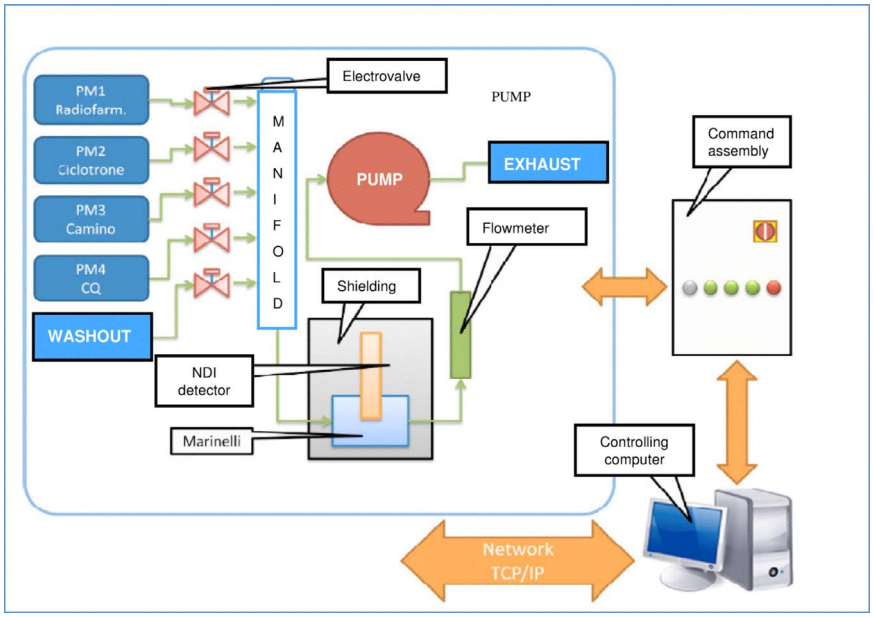

Fig. 1. Functional scheme of the air sampling system.

Table 1
Washout, drain and acquisition times.

Area	*Washout [s]*	Drain [s]	Acquisition [s]
Hot lab	30	10	600
Hall	30	15	600
Hot waiting room	30	25	600
^{18}F cell	30	10	600
Radiopharmacy	30	60	600

Table 2
Ventilation rates (ICRP 66).

Activity	Ventilation rates [m^3 h^{-1}]
Sleep	0.45
Rest, Sitting	0.54
Light exercise	1.5
Heavy exercise	3.0

in the nuclear medicine department of the IRST-IRCCS Hospital (Meldola – Italy) based on a continuous air sampling system and on individual workload evaluation.

The method is of more general applicability, however, to demonstrate it, in what follows its specific application to ^{18}F will be presented.

Table 3
Mean concentration 1-OCT to 31-DEC, 2015 [Bq/m3].

Area	Hot waiting room (C3)	Hot cell ^{18}F (D4/1)	Hall (B2)	Hot Lab. (A1)	Radiopharmacy (G7)
Mean concentration	137	132	141	129	194

2. Materials and methods

2.1. Radioactivity measurements

A continuous air sampling system (MecMurphil® MP-AIR) with a flow of 10 m^3/h was used, equipped with a series of valves operated automatically through a dedicated computer; the system is connected, through these valves and an appropriate system of air ducts, to a number of locations of interest. Through the valve system, the computer selects which locations to sample: in fact, all locations are sampled in sequence, and the process is repeated continuously, 24 h/d. Fig. 1 presents a scheme outlining the operation of the device.

The air sampled is run through a 0.00312 m^3 Marinelli beaker positioned on a 2"×2" NaI(TI) detector (DI-65/50 by Gamma Technical Corporation, 50 diameter by 50 mm length), and the assembly is contained in a low background shielding (lead, 5 cm around, 6 cm top and bottom, all with 3 mm copper coating); concentration of isotopes in the air flushed is assessed measuring the gamma rays from annihilation of the β+ positrons emitted in the decay.

Energy efficiency of the detector is assessed filling the Marinelli beaker with water containing known concentrations of ^{18}F: some adjustment is needed to account for the fact that the measurements of interest are conducted on air, whereas calibration uses water. For instance, the positrons emitted in the decay of ^{18}F have a range in air such that annihilation with air electrons is rare, and the positrons emitted in the volume of the beaker have a large probability of reaching the beaker walls and annihilate there (Sarnelli et al., 2015). Hence, in most cases the gamma ray pairs produced in the annihilation will be generated within the walls of the Marinelli beaker. On the contrary, when the beaker is filled with ^{18}F loaded water, annihilations happen essentially at the point of emission, giving rise to a uniform volume source of gamma rays. As a result, when the filling is ^{18}F in air (as is the case in actual measurements), gamma emission takes place farther, on average, from the detector. On the other hand self absorption in air is practically negligible, but this is not so in water. To correct for these opposing measurement phenomena, a calibration factor was calculated using GEANT-4 (Sarnelli et al., 2015).

As mentioned above, radionuclide concentration is determined flushing the possibly contaminated air through the Marinelli beaker and counting it with the NaI detector. For the measurement to be representative the air flushed through the counting system needs to have the same radionuclide concentration as that in the room sampled. Deposition in the piping