Air Monitoring to Control the Intake of Airborne Radioiodine-131 Contaminants by Nuclear Medicine Workers

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Abstract— **Inhalation of radioiodine–131 is the largest cause of internal dose to nuclear medicine workers. The concentration of radioiodine–131 in air is limited by the Derived Air Concentration (DAC) of 416.67 Bq/m^3. In this study air monitoring shall be performed to measure the radioiodine–131 contaminant in air by sample collection and analysis. Air samples were drawn from areas where there is a potential for I–131 airborne radioactivity e.g. in the hot laboratory, radioiodine treatment rooms, radioactive waste collection areas and waste water treatment plant. A portable battery–operated air sampler, Gilian BDX II with carbon–impregnated cellulose filters was used for air sampling. The flow rate was adjusted to 3 liters per minute and the sampler run for 180 minutes. Iodine–131 radioactivity on filter was measured for 10 minutes by 2 NaI(Tl) gamma counters, Perkin Elmer Wallac Wizard 1480 (3"×3") and Atomlab 950 PC (2"×2") with and objective for inter comparison. Counting efficiency of the counters are 57 and 39 percent respectively. Agreeable results of I–131 radioactivity were obtained from both gamma counters. The mean I–131 concentrations measured by Wallac(Atomlab) were 31.59±16.31 (29.84±14.74) Bq/m^3 in radioiodine fume hood for treatment dose dispensing, 8.98±4.33 (7.58±5.10) Bq/m^3 in fume hood accommodated with a dose calibrator, 7.80±5.39 (7.54±5.04) Bq/m^3 in radioactive waste storage area, 0.03±0.54 (0.03±0.57) Bq/m^3 in patient waiting area, 2.94±3.60 (2.55±2.98) Bq/m^3 in hospital ward waste collection area and 0.03±0.01 (0.03±0.01) Bq/m^3 in the water treatment plant area. Radioiodine concentrations in patient's room increases linearly as the administered dose was increasing. Mean±SD of the measured concentrations were 11.63±9.30 (9.86±8.98) Bq/m^3, 18.57±13.24 (17.35±12.33) Bq/m^3 and 31.90±22.32 (30.90±22.49) Bq/m^3 for the administered doses of 3.7, 5.55 and 7.4 Bq respectively. Radioiodine concentrations in all specified areas were less than the DAC of 416.67 Bq/m^3 assigned for I–131. This demonstrated that the work place condition is satisfactory and the level of protection provided to the worker is sufficient to minimize the internal dose equivalent. The inhalation of radioiodine vapors is the important routes of entry of radioiodine into the human body. The level of airborne I-131 radioactivity should be maintained well below allowable levels to keep the internal dose equivalent contribution to the total effective dose equivalent small.**

Keywords—**airborne radioiodine, concentration, internal dose, inhalation**

I. Introduction

Among the various type of radionuclide therapy with unsealed sources, more than 90% are performed using I-131 [1,2]. Iodine-131 is used extensively in therapeutic procedures in nuclear medicine because of its short half-life and useful beta emission. However, I-131 is highly volatile and is classified as radionuclide in high radiotoxic groups [3]. I-131 can be inhaled as a gas or ingested in food or water. Quantification of airborne I-131 contamination associated with the clinical use of NaI-131 in liquid form has been previously reported in the literature (4,5). The concentration of radioiodine–131 in air is limited by the Derived Air Concentration (DAC) of 416.67 Bq/m^3 [6].

The inhalation of radioactive airborne particles is one of the most important routes of entry of radionuclides into the human body. One of the main requirements for radiation protection in nuclear medicine is workplace monitoring. It is used to determine the potential for exposure of personnel to ionizing radiation. Workplace monitoring is part of the internal dose assessment program to evaluate the radiological conditions in all workplaces designated as controlled and supervised areas in nuclear medicine laboratory.

Air monitoring is performed to identify and monitor airborne radioactive material in order to control the intake of airborne radioactive material by workers. In this study air monitoring shall be performed to measure the I-131 contaminant in air by sample collection and analysis following the method described in the IAEA Safety Standards Series RS-G-1.2 [6] and the ICRP Publication 78 [7]. Air samples are being collected on cellulose filters by personal air sampler (PAS) and analyzed by NaI(Tl) Gamma counters.

II. Materials and Methods

A. Instrumentation and materials

1. Automatic gamma counter: Wallac 1480 Wizard, 3×3" NaI(Tl) crystal, Perkinelmer Life Sciences, Boston, MA, USA.
2. Mobile Thyroid uptake system, Microprocessor-controlled 1024 channel Multi-Channel Analyzer with 2×2" NaI(Tl) detector, flat field collimator IAEA standard and a personal computer interface, and an incorporated well counter 2×2" NaI(Tl) detector. Model Biodex Medical Systems, Atomlab 950 PC.
3. Gilian BDX II Air Sampling Pump powered by rechargeable NiCd battery. Sensidyne Industrial Health & Safety Instrument.
4. Carbon impregnated cellulose filters, dia 2.5 cm, thickness 0.914 mm. Hi Q Environmental Products Company, Inc. San Diego, CA.
5. I-131 standard source obtained from the Office of Atom for peace.

B. Determination of counting efficiency

Counting efficiency of I-131 was determined using a certified source obtained from the Office of Atom for Peace, Ministry of Science and Technology. The counting efficiency of I-131 was 0.57 cps/Bq for Wallac 1480 Wizard automatic gamma well counter and 0.39 cps/Bq for Atomlab 950 single well counter.

C. Calculating minimum detectable activity (MDA)

The smallest amounts of sample activities for the measurements of I-131 by 2 counters were investigated by using the following equation [6]:

$$MDA_{\mu Ci} = \frac{\frac{2.71}{T_s} + 3.27\sqrt{\frac{R_b}{T_b} + \frac{R_b}{T_s}}}{(E)\times\left(2.22\times10^6\ \frac{dpm}{\mu Ci}\right)}$$

T_s = sample counting time
T_b = background counting time
R_b = background counting rate
R_s = sample counting rate
E = counting efficiency

The Minimum Detectable Activity (MDA) was obtained by counting a non-radioactive filter for 4,000 minutes in a window setting for I-131 energy. The calculated MDA for the 2 gamma counters (Wallac/Atomlab) were 0.18 and 0.37 Bq respectively.

D. Monitoring areas

Control and supervised areas in the section of nuclear medicine at Siriraj Hospital were categorized into:

1. Radioiodine fume hood for treatment dose dispensing
2. Fume hood accommodated with a dose calibrator
3. Radioactive waste storage area
4. Hospital ward waste collection area
5. Patient waiting area
6. Water treatment plant areas
7. Radioiodine therapy rooms 1, 2, 3 and
8. Control area

E. Monitoring procedures

As part of a continuous workplace-monitoring program, airborne I-131 concentrations at different workplaces in the section of nuclear medicine and a radionuclide therapy ward in Siriraj Hospital are determined. Air samples were drawn from the ambient room atmosphere from the breathing zones of workers and other nearby zones by personal air samplers (PASs), Gilian BDX II air sampling pump with carbon–impregnated cellulose filters (Figure 1). The flow rate was adjusted to 3 liters per minute and the sampler run for 180 minutes. Triplicate samples were collected from each area. The monitoring position was set at approximately 1.5 m above floor as shown in Figure 2.

Fig. 1. Personal air sampling pump.

Fig. 2. Monitoring position set at 1.5 m above floor.

Iodine–131 radioactivity on the cellulose filter was placed in a counting vial and measured for 10 minutes by 2 NaI(Tl) gamma counters, Perkin Elmer Wallac 1480 Wizard automatic gamma well counters and Atomlab 950 PC, single well counter.

In a radionuclide therapy ward, air samples were also collected during the 3-day isolation of patients who had been administered 3.7 or 5.55 or 7.4 GBq of I-131 to determine the relationship between air concentration of I-131 and activity of the treatment dose.

The measured derived air concentration is given by:

$$DAC(Bq/m^3) = \frac{cps \times e^{\lambda t}}{E \times V}$$

Where:

cps = Net sample counts
E = Counting efficiency
V = Collected air volume (m^3)
$e^{\lambda t}$ = Inverse decay factor
t = time interval between halfway of collecting and halfway of measuring time

The measured airborne activity concentration is expressed as a fraction of the derived air concentration (DAC) limits for I-131.

F. Dose Coefficients and Derived Air Concentration (DAC)

In this study, the DACs limit for I-131 (Type F) are calculated on the basis of an effective dose limit of 20 mSv in a year. For a standard breathing rate of 1.2 m^3/h and the typical particle size distribution inhaled is 5 μm activity median aerodynamic diameters (AMADs). The DAC is obtained by dividing the annual limit on intake (ALI) by the volume of air breathed by an average worker during a working time of 2000 h per year, (50 weeks) assuming a breathing volume of 2400 m^3 [6]. The ALI and the DAC are given by:

$$ALI = \frac{0.02\ Sv}{Dose\ coefficient\ for\ I-131} = \frac{0.02\ Sv}{2\times 10^{-8}\ Sv/Bq} = 10^{6}\ Bq$$

$$DAC = \frac{ALI}{2000\ h\times 1.2\ m^{3}/h} = \frac{10^{6}}{2000\times 1.2} = 416.67\ Bq/m^{3}$$

After a fraction of DAC was determined, an estimate of intake in units of DAC.h can be calculated by multiplying the air concentration (Bq/m^3) by the exposure time in hours. One DAC.h corresponds to 0.025 mSv, 2000 DAC.h corresponds to an ALI or 50 mSv per year [6].

III. Results And Discussion

The mean I-131 air concentrations in 10 areas are given in Table 1. Two gamma counters demonstrated consistent agreeable results and very highly correlated (r = 0.99). This suggests that a mobile thyroid uptake unit incorporated with well counter, 2×2" NaI(Tl) detector is well efficient enough to run this task. The highest concentration up to 32 Bq/m^3 was detected at the fume hood area where the I-131 treatment dose was dispensing. High concentration was also detected in the isolation room where patient was administered 7.4 GBq of I-131 (area 9, Table 1). These values were approximately 13 times below the DAC limits of 416.67 Bq/m^3. A fraction of DAC limit is 0.077 DAC, if the exposure time is 100 hours, 0.77 DAC × 100 hours or 7.7 DAC.h would correspond to 2.5 mSv. Therefore, exposure dose to health personnel or relatives to patients or other related personnel can be reduced only by minimizing time spent in the vicinity of the patient or in the potential risk areas.

Radiation dose from some activities in nuclear medicine laboratory have been published. Jaminez et al. [8] reported higher concentration of I-131, between 0.037 to 0.50 Bq/m^3 while preparing and administering I-131 treatment dose ranges from 0.555 GBq (15 mCi) to 7.4 GBq (200 mCi). Bright et al [9] demonstrated that the amount of I-131, which volatilized daily from the exposed therapy capsules, was only in a small percentage of the capsule activity when compared to the amount of volatile I-131 while dispensing and injecting I-131 solution in to the capsule.

The concentrations at waste collection areas ranged from 2 to 8 Bq/m^3 or approximately 50 to 200 times below the limit. No detectable airborne I-131 concentrations were detected in patient waiting area and wastewater treatment plant area.

The measurements of I-131 activity exhale from thyroid cancer patients undergoing radioiodine therapy in the dose range between 3.7 to 7.4 GBq showed that the I-131 exhale to the isolated rooms environment increases linearly with administered activity (r^2 =0.97). This indicates significant increase in the air concentrations from 11.63 to 31.9 Bq/m^3 with treatment dose range from 3.7 to 7.4 GBq. Distribution of the I-131 concentrations with administered activity range from 3.7 to 7.4 GBq was shown in Figure 1. When compared to the DAC limit of I-131, the measured DAC were ranged from 13 to 40 times below the limit. Experimental study in mice and also in patient by Fisher et al [10] showed that the absolute amount of exhaled radioactivity in Bq rose exponentially in relation to the dose of activity applied. The air concentration of I-131 as high as 80 to 400 Bq/m^3 in isolated room has been reported by Ibis et al [11]. They also demonstrated that I-131 activity in the patients' exhaled breath increased with increasing treatment dose and the room concentration of I-131 dropped 50 to 70 percent between the first and second day of treatment. Gründel et al [12] have estimated dose received by family members by model calculation a possible effective dose to be as high as 765 μSv to a child inhaled volatile I-131 from his mother. Westcott et al [13] reported the use of the robotic floor-washing device to provide effective automated decontamination of the radioiodine ward to reduce the time spent by the physicists in decontaminating the room.

Table 1 Distribution of I-131 concentration in different monitoring areas.

Monitoring areas	I-131 Concentration (Bq/m^3)	
	Gamma 1 (Wallac)	**Gamma 2 (Atomlab)**
1. Radioiodine fume hood for treatment dose dispensing	31.59 ± 16.3	29.84 ±14.74
2. Fume hood accommodated with a dose calibrator	8.98 ± 4.33	7.58 ± 5.10
3. Radioactive waste storage area	7.80 ± 5.39	7.54 ± 5.04
4. Hospital ward waste collection area	2.94 ± 3.60	2.55 ± 2.98
5. Patient waiting area	ND*	ND*
6. Water treatment plant areas	ND*	ND*
7. Radioiodine therapy room 1	11.63 ± 9.30	9.86 ± 8.98
8. Radioiodine therapy room 2	18.57 ± 13.24	17.35 ± 12.33
9. Radioiodine therapy room 3	31.90 ± 22.32	30.90 ± 22.49
10. Control area	ND*	ND*

** ND: Not detectable*

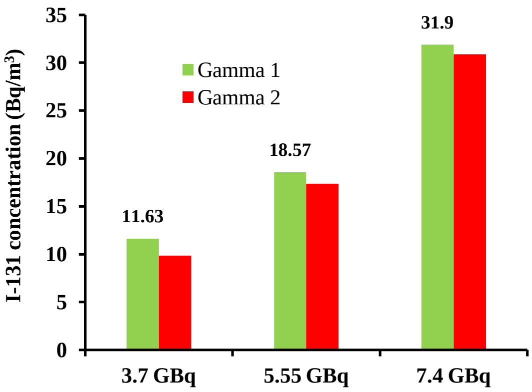

Fig. 2. I-131 concentration in 3 radioiodine treatment rooms when patient was given 3.7 or 5.55 or 7.4 GBq therapeutic dose of radioiodine.

IV. Conclusions

Results for I-131 air concentration analyzed as part of a workplace-monitoring program in controlled and supervised areas in the section of nuclear medicine have been presented. The airborne radioiodine concentrations are observable, but the maximum concentration being 13 times below the DAC limits. These demonstrated that airborne I-131 released into the general environment of nuclear medicine workplaces are well below the allowable limits, and could be concluded that the work place condition is satisfactory. The level of protection provided to the worker is sufficient to minimize the internal dose equivalent in compliance with the international standards.

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