Monitoring Radioactive Xenon Gas in Room Air Using Activated Charcoal

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A method for monitoring room air for radioactive xenon gas is described. It uses activated charcoal vials, a vacuum source and a well-type scintillation counter. The method may be adapted for detection and identification of any radioactive gas excluding those with ultra-short half-lives. Sampling room air during xenon-133 (^{133}Xe) ventilation lung studies was performed using this technique. The results show that low concentrations of ^{133}Xe in room air can be reliably detected and that staff exposure to ^{133}Xe at this institution was within ICRP recommendations.

The purpose of this paper was to investigate the feasibility of monitoring radioactive xenon gas by adsorption onto activated charcoal for the following reasons:

1. To assess radiation exposure to staff performing xenon-133 (^{133}Xe) nuclear medicine studies.
2. To develop a flexible alternative to the purchase of a commercial monitor for the measurement of radioactive gaseous contamination.

Xenon-133 is widely used for pulmonary ventilation and for brain or muscle blood flow measurements. It is exhaled from the lungs of patients following administration by either inhalation or by intravenous injection of ^{133}Xe in saline.

The expired ^{133}Xe is a source of radiation exposure for nuclear medicine staff unless it is sucessfully contained or vented to the atmosphere. Containment is usually effected by an activated charcoal trap; however, if these traps saturate they will permit ^{133}Xe to escape. The efficiency of exhaust fans and vents in clearing ^{133}Xe from the room will vary with the size and shape of the room and the exhaust flow rate. Some leakage of ^{133}Xe gas into the ambient air may occur.

The most likely source of leakage comes from poorly fitting face masks or early termination of the study due to patient breathing difficulties. Room air should, therefore, be routinely monitored to assess radiation exposure to staff. Commercial monitors are available for ^{133}Xe measurement, but they are relatively expensive and inflexible for use with other radioactive gases.

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MATERIALS AND METHODS

Adsorption of ^{133}Xe by activated charcoal is mainly due to van der Waal's forces in a process analogous to chromatography, with charcoal as the suspension media and air as the solvent. The theoretical adsorption capacity for ^{133}Xe by activated charcoal is in the region of 10^{10} GBq/kg (10^8 Ci/kg) at standard temperature and pressure (*1,2*), but as charcoal will become saturated by other gases in the air, especially nitrogen, adsorption discontinues long before this figure is approached. Changes of xenon adsorption with temperature can be neglected as the hospital environment is temperature controlled.

Preparation of Sampling Apparatus

Sample tubes were prepared by placing 1.00 g of activated charcoal and a few self-indicating silica gel beads into lengths of laboratory glass tubing. Glass wool was used to plug each end. The tubes were heated in a hot-air oven set at 200°C for three hours to dispel any moisture, which would ruin the adsorption potential of activated charcoal. Both ends of the sample tubes were promptly heat-sealed for storage by melting the ends in a bunsen burner.

Just prior to sampling, one of these tubes was opened by filing and snapping both ends and a moisture trap, which was constructed by filling a 10-ml plastic syringe with dried calcium chloride, was connected upstream of the sample tube by nylon tubing. A portable vacuum pump was connected to the other end to draw air through the apparatus (Fig. 1). The vacuum pump was adjusted to give a reading of 6, which corresponded to a value of 1.94 l/min (determined by downward displacement of water). This flow rate was chosen arbitrarily as a convenient value on the adjustable flow meter of the vacuum pump, allowing a reproducible flow rate to be applied to all samples.

Preparation of Reference Standards

A ^{133}Xe standard was prepared by passing 111 MBq (3 mCi) through a sample tube and heat-sealing the ends immediately. The exact amount of radioactivity was measured in a dose calibrator and periodic measurements over 31 days gave good correlation ($r = -0.99$) with the theoretical decay

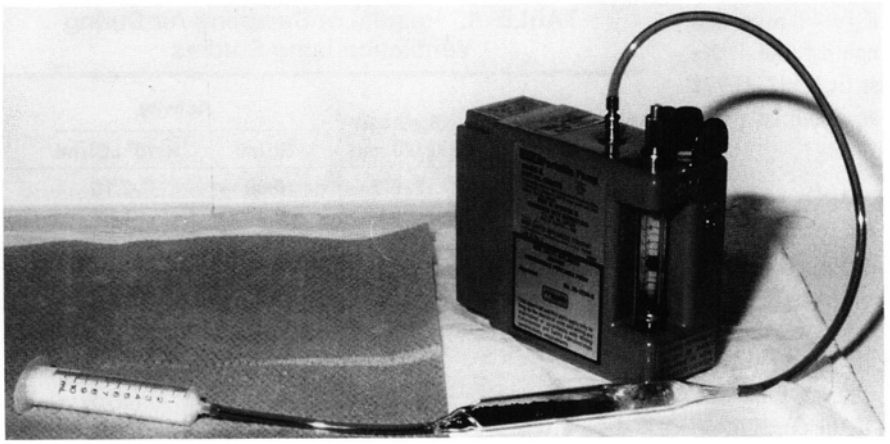

FIG. 1. Assembled sampling apparatus.

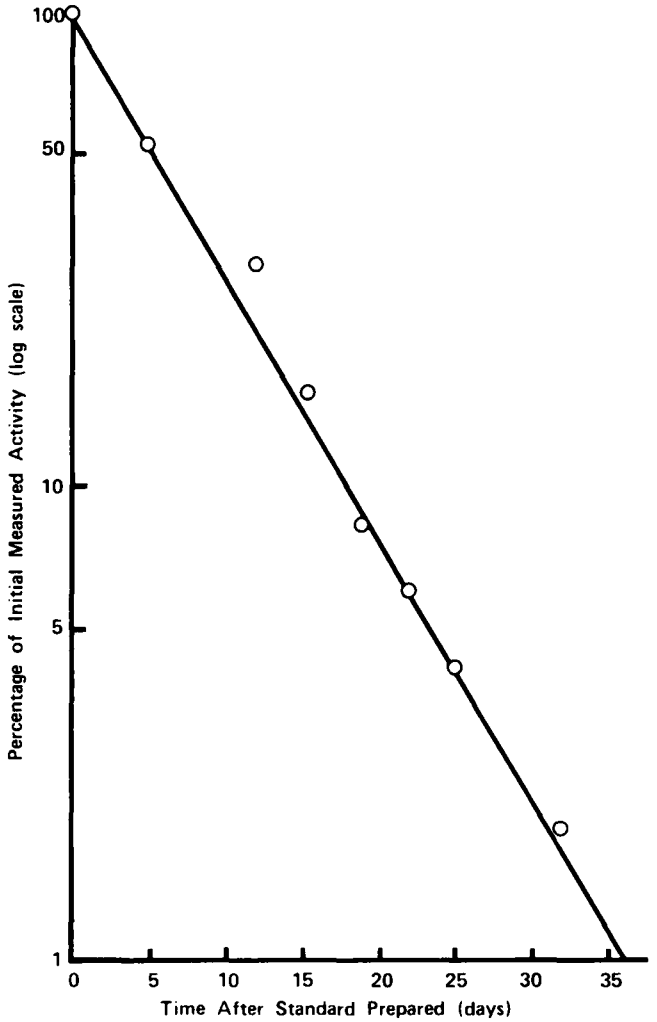

FIG. 2. Xenon-133 standard decay in dose calibrator.

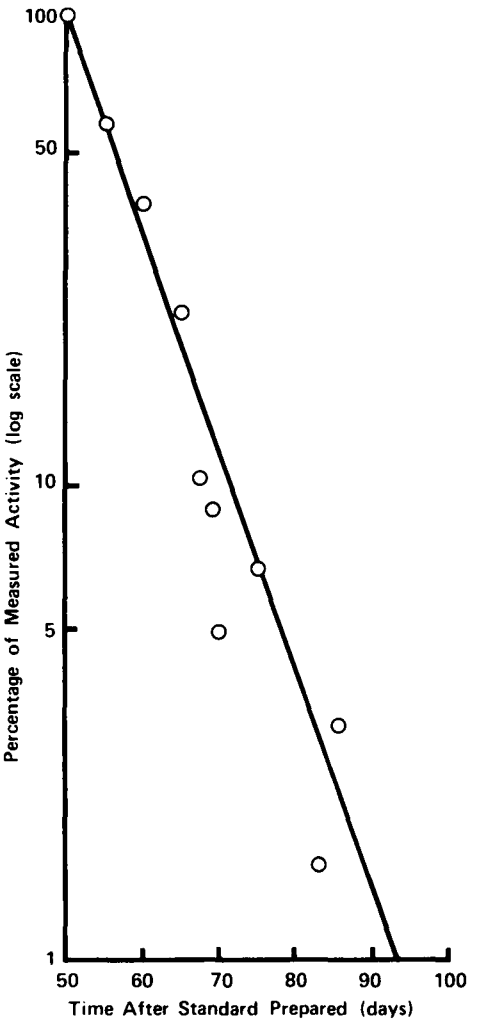

FIG. 3. Xenon-133 standard decay in gamma spectrometer.

curve calculated from the 5.27-day half-life of ^{133}Xe (Fig. 2). When sufficient decay had occurred, counting of the standard was commenced in a well-type gamma spectrometer, with a window centered on the 81 keV of ^{133}Xe. After correction for dead-time (calculated at 2×10^{-6} sec), good correlation ($r = -0.98$) with the theoretical decay curve was obtained (Fig. 3).

Determination of the Efficiency of Sample Tubes

Using a gas-tight cabinet, an atmosphere of known concentration was created following background sample measurements. A measured activity of ^{133}Xe gas was admitted and mixed with the air using an internal fan. Sampling was

performed at various times at a flow rate of 1.94 l/min, and the tubes promptly sealed and counted against the ^{133}Xe standard. From the exponential line of best fit ($r = -0.97$), the value of 1.86% sampling efficiency was obtained when pumping for 6 min at 1.94 l/min (Fig. 4).

Room Air Sampling

Background samples were taken for six minutes prior to the ventilation studies with the sample tube positioned ~50 cm from the patient's mask. New sample tubes were then placed in the same position and sampling undertaken for 6 min during ventilation lung studies at Sir Charles Gairdner Hospital, Nuclear Medicine Department. The distance of 50 cm from the patients mask was chosen to relate to the closest position a staff member would be standing to the patient during the study. The tubes were heat-sealed immediately following exposure in a bunsen flame and counted in the well-type gamma spectrometer against the reference standard. Samples also were taken at varying times following completion of the last ^{133}Xe study. These approximated background after 1 hr.

A ventilation machine was used for all lung studies with a patient dose of ~370 MBq (10 mCi) ^{133}Xe. The exhaust line was connected to an external flue. A ceiling exhaust fan operated during the ventilation studies.

RESULTS

Results obtained during 20 ventilation lung studies are presented in Table 1. Column 2 shows observed counts per 10 min, corrected for background. Column 3 lists activity in milliliters of sampled room air.

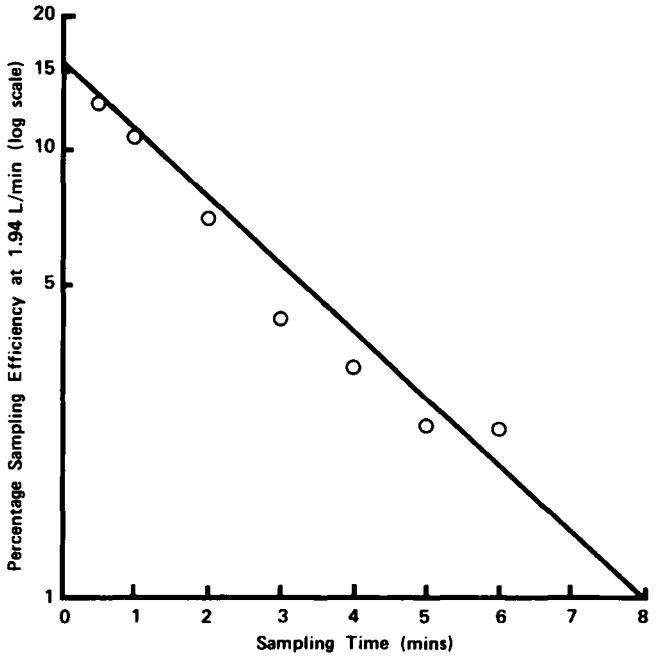

FIG. 4. Sampling efficiency of charcoal vials at 1.94 l/min.

TABLE 1. Results of Sampling Air During Ventilation Lung Studies

Sample number	Observed cts/10 min	Activity	
		Bq/ml	× 10^5 μCi/ml
1	22925	0.80	2.16
2	12814	0.45	1.22
3	9528	0.33	0.89
4	16650	0.58	1.57
5	14977	0.52	1.41
6	185480	6.50	17.57
7	61400	2.15	5.81
8	58615	2.05	5.34
9	155161	5.44	14.70
10	125196	4.39	11.87
11	39193	1.37	3.70
12	29229	1.02	2.76
13	77152	2.70	7.30
14	12003	0.42	1.14
15	10156	0.36	0.97
16	37291	1.31	3.54
17	42331	1.48	4.00
18	54271	1.90	5.14
19	62231	2.18	5.89
20	45172	1.58	4.27

Calculation of the Safety Factor

The derived air concentration (DAC) of ^{133}Xe gas for occupationally exposed workers in Australia is 4×10^6 Bq/m^3 (100 μCi/ml). The DAC is obtained by dividing the annual limit of intake (ALI) by the volume of air inhaled by "Reference Man" in a working year of 40 hr/wk for 50 wk at a breathing rate of 1.2 m^3/hr (*3*).

The highest sample recorded was 6.5 Bq/ml (17.6×10^5 μCi/ml). At that time, each technologist at this institution performed an average of six ventilation studies per week each lasting ~10 min, i.e., 1 hr/wk. The annual safety factor thus becomes:

$$(4 \times 40 \times 50)/(6.5 \times 1 \times 50) = 24.6,$$

suggesting that staff exposure to ^{133}Xe at this hospital is within ICRP recommendations.

DISCUSSION

The results indicate that this method is accurate and reasonably simple to perform. It allows sampling of air anywhere in the room where ^{133}Xe is administered to patients. Some potential sources of error are inherent in the technique, but may easily be avoided, such as:

1. Loss of ^{133}Xe with heat-sealing sample tubes which was prevented by drawing the ends of the tubes very fine prior to sealing. "Before and after" measurements detected no loss of ^{133}Xe during heat sealing.
2. Leakage of ^{133}Xe from poorly sealed sample tubes which was tested by serial counting and comparison to theoretical decay.
3. Contamination of the standard with gaseous contami-

nants from the manufacturing process such as ^{131m}Xi, ^{133m}Xe, ^{85}Kr, and ^{131}I, or leakage of gas from the standard would be apparent by deviation from the theoretical decay curve.

4. Dose calibrator errors for low-activity ^{133}Xe can be high due to the attenuation of the low-energy photons (31–35 keV). For this reason, a relatively high activity of 111 MBq (3 mCi) was used to make the standard, which had identical geometry to the sample tubes. The dose calibrator* used was found to be the most accurate of 11 dose calibrators tested for ^{133}Xe accuracy by Ponto and Loken (*4*).
5. Ten-minute counts of exposed sample tubes gave more than 10,000 counts in all, but in one case, a standard deviation of <1% was noted.
6. Flow rate variation of the vacuum pump was tested by repetitive downward displacement of water and found to be within 6%.

CONCLUSION

This method offers a cheap and sufficiently accurate alternative to the purchase of a commercial monitor for keeping track of low-activity radioactive gases in ambient air. Institutions performing fewer ^{133}Xe studies due to the advent of alternative radiopharmaceuticals for ventilation lung scanning, e.g., ^{99m}Tc aerosols and ^{81m}Kr gas, may find the cost of a commercial monitor specifically for radioxenon hard to justify. Other advantages of this technique compared to a commercial xenon monitor are:

1. Portable, self-powered, safe-sterilizable equipment suitable for use in theatre during ^{133}Xe blood flow measurements.
2. It is unaffected by high transient background radiation, for example, a radioactive patient walking close to the monitor.
3. Gamma spectroscopy of the sample is possible, allowing the presence of a mixture of radioactive gases such as ^{127}Xe and ^{133}Xe to be detected.
4. Any radioactive noble gas, apart from those with ultrashort half-lives, could be monitored by this technique.

Other alternatives to this technique have been suggested, such as monitoring ^{133}Xe by using its solubility in water (*5*), and sampling small volumes of air (*6,7*). Advantages of this technique compared to small-volume sampling are that a greater volume of air is sampled (11.64 liters, giving a better survey, improved counting statistics, and allowing lower concentrations of radioactive gases to be quantified. Also, sampling is performed for the duration of the nuclear medicine study with less chance of missing a significant leak. Lastly, a rubber-free apparatus is used. Radioxenon adheres to the rubber septa of vials, which can cause variations in counting geometry.

NOTE

*Mark V, RADX, Houston, TX

ACKNOWLEDGMENT

Practical work was performed at the Nuclear Medicine Department, Sir Charles Gairdner Hospital, Nedlands, Western Australia.

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