USE OF ACTIVATED CHARCOAL FOR THE COLLECTION AND CONTAINMENT OF ^{133}Xe EXHALED DURING PULMONARY STUDIES

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The radioactive gas most widely used for pulmonary studies is ^{133}Xe (*1*). Unless properly contained or vented, expired ^{133}Xe will be a source of radiation exposure for medical and paramedical personnel working in the area of its use. Since ^{133}Xe is soluble in fatty tissue (*2*) and consequently accumulates with repeated exposures it can be an internal as well as an external source of radiation exposure.

In a previously reported method for collecting ^{133}Xe (*3*), liquid nitrogen is used to solidify xenon on a suitable adsorbent screen. This method requires the availability of liquid nitrogen and an apparatus capable of withstanding moderate pressures.

The purpose of this paper is to present a simple method for the collection and containment of ^{133}Xe which takes advantage of the high adsorbability of activated charcoal for xenon. A trap containing activated charcoal as the adsorbent has been studied for use in directly collecting ^{133}Xe from the exhaled breath of patients. Efficiency of xenon collection and containment were studied as a function of temperature.

MATERIALS AND METHODS

Basic apparatus. The basic trap unit consists of a cylindrical glass vessel containing 100 gm of loosely packed activated carbon granules* with a glass tube running axially the length of the vessel and excluding the charcoal (Fig. 1). The central tube is connected to the inlet at the top of the vessel; the outlet is at the was then imaged with a Pho/Gamma III scintillation is conducted to the bottom of the vessel and passes up through the carbon to the outlet. Stopcocks are attached at the inlet and outlet. A moisture pretrap consisting of a glass cylinder filled with $CaSo_4$ (drierite) is connected integrally to the inlet to avoid moisture condensation on the charcoal.

Vacuum pumping was used to draw gases through the trap system at a rate of approximately 6 liters/min which simulates the respiratory minute volume of normal humans. Tygon plastic tubing was used to conduct gases to the trap and pump. Rubber tubing and fittings should be avoided because of the high affinity of xenon for rubber (*4*). Cooling was achieved by suspending the carbon trap in a polystyrene bucket filled with a coolant. The coolants used were ordinary ice and water and dry ice with methanol. Figure 2 shows the trap with coolant bucket ready for use.

Efficiency determinations. To determine the trapping efficiency for ^{133}Xe from air with a flow rate

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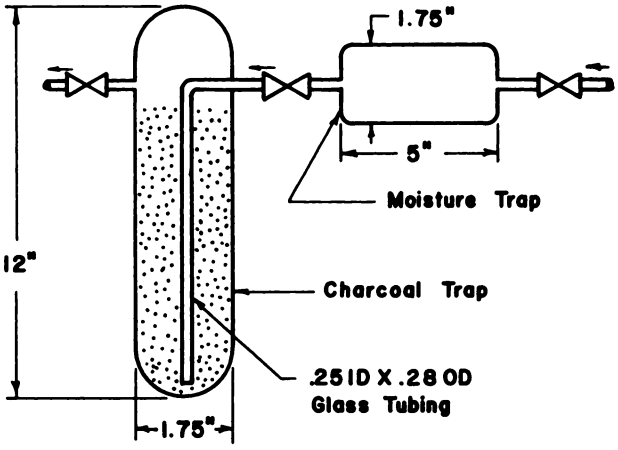

FIG. 1. Schematic of activated carbon trap with moisture pretrap.

* H-M-1 grade 6 GC 10/20 mesh, provided by courtesy of The Union Carbide Co.

FIG. 2. First trap with moisture pretrap arranged for cooling.

of 6 liters/min, a second identical carbon trap was constructed. The two traps were then assumed to have the same xenon trapping efficiency at the same temperature.

Efficiency measurements were performed by drawing a ^{133}Xe-air mixture through the two identical traps in series for a suitable length of time and then separately counting the activity in each trap under identical conditions. The ^{133}Xe-air mixture was produced by having a 3-in.-diam glass bulb whose exit was connected to the moisture trap of the first carbon trap by tygon tubing. Saline containing dissolved ^{133}Xe was then injected with a syringe into the glass bulb through the entry opening while air was being drawn through the bulb and traps. Air flow was maintained for 5 min after injection. Well within this time interval a maximum counting rate is achieved in the first trap as monitored by a scintillation detector. After passing the ^{133}Xe-air mixture through the two-trap system, stopcocks isolating each trap were closed and each trap removed from the system. Each trap was then imaged with a Pho/Gamma III scintillation camera to obtain integral counting rates as well as scintiphotographs showing the spatial distribution of the activity within each trap. The traps were placed at the center of the crystal field with the axis parallel to the face of the camera at a distance of 15 cm from the front of the collimator.

The efficiencies of the traps (assumed to be equal) were then calculated with the equation $E = 1 - C_2/C_1$, where E is the fraction of ^{133}Xe removed from the air passed through the traps, C_1 the observed net counting rate in the first trap, and C_2 the observed net counting rate in the second trap.

Retention and redistribution of ^{133}Xe within the trap. Retention of ^{133}Xe within the trap was studied with a NaI(Tl) scintillation detector used in conjunction with a count-rate meter and strip-chart recorder. The detector was collimated to view the first trap only. Air was pulled through the trap for periods of up to 2 hr after injection of ^{133}Xe-laden saline into the mixing bulb and counting rates recorded by the strip-chart recorder. Times at which the activity in the trap was reduced by 10 and 50% of the maximum were determined from the chart recordings for the various conditions of cooling.

Redistribution of ^{133}Xe within the trap was studied by comparing scintiphotographs of the sealed-off trap taken after the initial 5-min collection period, under the various cooling conditions, and again 24 hr after the trap was removed from the coolant. In addition, the 24-hr redistributed trap was counted before and after a 5-min ventilation at the normal flow rate. The percentage of redistributed activity removed in 5 min was determined for each condition of collection.

RESULTS

Table 1 contains a summary of efficiencies and retention data for various conditions of trapping. Average efficiencies are given for 4, 6, and 2 determinations, respectively, with the trap at room temperature, cooled with ice and water and cooled with dry ice and methanol. In all cases, the efficiency exceeded 99%. Ventilation times for 10 and 50% removal were determined once for each trapping temperature. Retention is seen to increase at decreased coolant temperatures.

The percentage decrease in activity due to 5-min ventilation after 24-hr room temperature redistribu-

TABLE 1. ^{133}Xe COLLECTION EFFICIENCIES AND RETENTION IN ACTIVATED CARBON

Collection condition	Efficiency (%)	Ventilation times (min)*		Percent removed for 5-min ventilation† (24-hr redist.)
		10%	50%	
Room temp.	99.5 ± 00.2 n = 4	13.0	17.0	0.59
Ice and water	99.9 ± 00.07 n = 6	31.5	41.0	0.56
Dry ice and methanol	99.3, Δ = 00.4 n = 2	63.0	90.0	0.57

* Time after initial 5-min collection at which 10 or 50% of trapped activity is removed with the same flow rate (6 liters/min).

† Percent of trapped activity removed during a 5-min flow at 6 liters/min after trap was allowed to stand at room temperature for 24 hr.

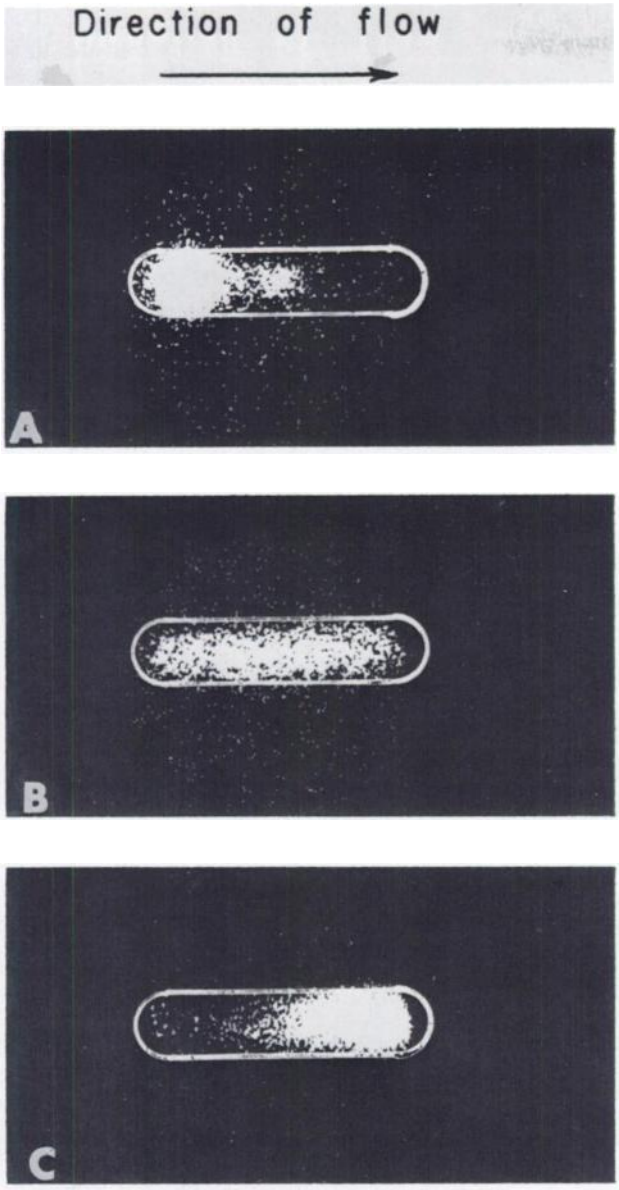

FIG. 3. Scintiphotographs showing distribution of ^{133}Xe within same charcoal trap (A) after 5-min collection with ice and water, (B) after 24 hr at room temperature, and (C) after subsequent 5-min pull-off. Direction of flow was from left to right.

tion was also measured once for each trapping coolant condition. After redistribution has occurred, retention is markedly reduced and is seen to be essentially independent of the initial temperature condition of trapping; approximately 57% is removed during 5 min of flow at 6 liters/min.

Figure 3 shows scintigraphs of a trap at various times subsequent to the injection of xenon-laden saline into the experimental bulb. The upper scintiphotograph shows the distribution of xenon after a 5-min collection with the trap in ice and water; the activity is seen to be concentrated toward the inlet end of the charcoal. The middle scintiphotograph was taken after the trap was allowed to remain at room temperature for 24 hr; uniform redistribution is clearly evidenced. The lower scintiphotograph was taken subsequent to a 5-min ventilation at room temperature from the 24-hr redistributed trap represented in the middle scintiphotograph. One sees the results of migration of the xenon toward the exit side of the charcoal where xenon is leaving the trap.

DISCUSSION AND CONCLUSIONS

Adsorption of xenon to activated charcoal is due mainly to Van der Waal's forces. Individual bound states of xenon and carbon will have finite lifetimes so that one would expect redistribution toward equilibrium as seen experimentally in the redistribution experiment. With continued bulk flow through the trap, xenon will migrate in the direction of the bulk gas flow. This is clearly evident in Fig. 3. The effect of the activated carbon is to selectively slow down the net flow rate of the xenon. The important parameters, then, for effective collection at any given temperature are the velocity of the bulk gas and the path length through the charcoal (for a given quality of activated charcoal). One would expect that there is a relationship between the migration velocity of the xenon and the velocity of the bulk gas, and the temperature of the gas and charcoal. These phenomena account for the nonpermanent trapping as the xenon passes through the charcoal and for the fact that the xenon will eventually come off the charcoal if gas continues to flow through the trap.

Figure 4 shows a pilot setup for use of the trap system in a clinical perfusion study. A suitable (nonrubber) pulmonary mouthpiece is used and gases are conducted through a large-diameter tube to a pulmonary bag (upper right-hand corner in Fig. 2) and then to the trap system. The mouthpiece contains two one-way check valves to direct flow in such a way that the exhaled breath exits to the trap tube only while the inhaled air enters from the room only. The pulmonary bag serves as a damping volume to accommodate the nonuniform flow of exhaled air. Nasal occlusion is necessary and may be achieved as indicated in Fig. 4 or by the cooperation of the patient in exhaling through the mouth only. The double-trap system has been used in a number of perfusion studies with humans so that efficiencies could be determined and compared with the experimental results. The system was similarly used in a number of pulmonary experiments with dogs using a full face mask. In all cases the computed efficiencies were comparable to those obtained experimentally. Indeed, in some patient applications the efficiencies were somewhat better than those obtained experimentally, most likely because collection

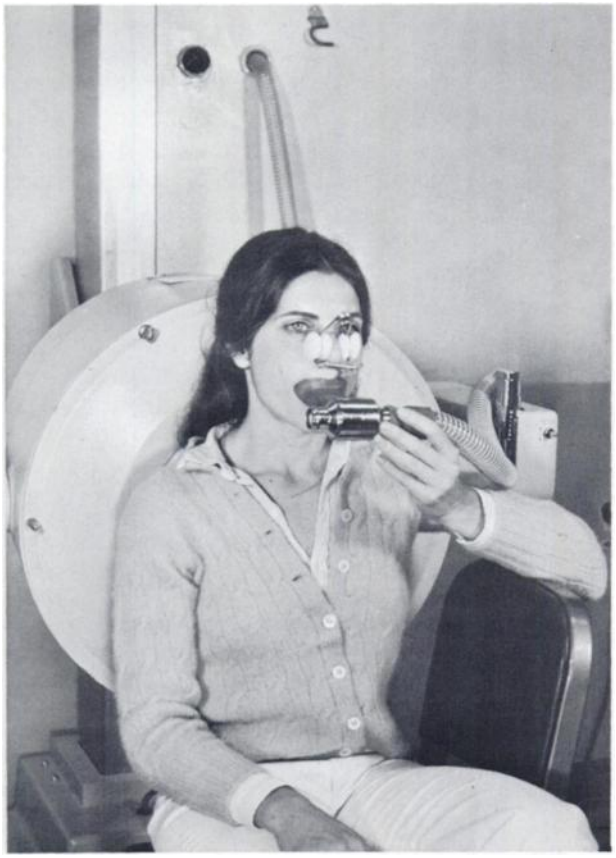

FIG. 4. Breathing apparatus arrangement for patient use of carbon trap system. Breathing bag, traps, and pump are located behind wall through which hose is led.

times for patients were generally shorter than those in the experimental situation.

The results clearly indicate the feasibility of using activated charcoal as a means of controlling the escape of radioactive xenon used in clinical pulmonary studies. Since the trap works quite well at room temperature, a collection system may not require the complexity associated with a cooling requirement. The charcoal trap can be used in essentially two ways: for total trapping and containment, or as a delay line in conjunction with a venting system.

In the first case, individual nonradioactive traps would be used for each study with flow times limited to the order of 4 or 5 min for the trap configuration used in these studies. Flow times could be extended with longer traps and/or lower bulk flow velocities related to the total mass of activated charcoal. Traps should not be reused until they have been cleared of radioactive xenon either by storage and natural decay or ventilation in a suitable facility. This follows since any xenon initially in the trap will migrate out with the bulk gas flow. In addition, as seen, xenon initially trapped and nonuniformly distributed will with time distribute throughout the trap so that in the first instance of flow the distal gas will begin to come off immediately.

In the second instance long traps will effectively delay the time over which xenon is released to a vent system. The longer the trap, the longer the delay time. Although in a perfusion study nearly all of the injected xenon is removed in the exhaled breath within about 2 min, significantly long holdup times can be achieved with large traps. It is important to use a moisture pretrap since the exhaled breath is essentially 100% water-saturated. If this is not done, the charcoal can become moisture laden, thus decreasing the adsorbability of the carbon for xenon.

An additional interesting feature of using activated charcoal to trap xenon from the exhaled breath is that it is quite possible to recover the xenon subsequently. Xenon can easily be removed from the activated carbon by heating. In a simple experiment, a xenon-laden trap was connected to a volumetric flask with all valves closed. The flask was evacuated, sealed off, and subsequently cooled with liquid nitrogen. The trap was heated by placing it in boiling water, and while the flask was in liquid nitrogen, the valve between the two components was opened. The valve was then closed after about 5 min and the trap counted. It was found that approximately 80% of the xenon contained in the trap was transferred to the flask. This clearly indicates the feasibility of using or recirculating exhaled ^{133}Xe.

SUMMARY

From the results of this limited study of xenon trapping with activated charcoal it seems clear that a relatively simple means of trapping, containing, and recovering exhaled radioactive xenon effluence during pulmonary studies can be effected.

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