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ABSTRACT

An apparatus for the physical separation and purification of CO_2 from human breath is described. These CO_2 samples have been measured in a series of ionization chambers varying from 100 to 1500 cc. The optimum sample size was found to be 1000 cc for these unshielded atmospheric-pressure ionization chambers. With such equipment it is possible to carry out experiments in humans with as little as one microcurie of carbon-14.

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INTRODUCTION

Since the use of carbon-14 as a tracer element in humans has become accepted and important,[1-4] more adequate methods for low-level radioactive measurements have been developed.[5-8] This has been necessary because in experiments in man high dilution of injected activity is common and radioactive doses are limited by health hazards. In this paper, equipment is described for the separation by a physical method of carbon dioxide from the expired breath of patients given C^{14}-labeled compounds and for the radioassay of this CO_2 by a series of large-size ionization chambers. This method depends on the analysis of large samples, which permits in spite of low specific activity C^{14}, reliable assay of radioactive samples.

A normal human breathes some 5 to 7 liters of air per minute, which contains some 100 to 200 cc of carbon dioxide at NTP. Almost all of this carbon dioxide comes from his body metabolism (if he is in a well ventilated room). It is a slow process to absorb in alkali the carbon dioxide from this air, precipitate the CO_2 as barium carbonate, and finally convert it into pure CO_2 to be introduced into large-size ionization chambers (500 cc and larger). Furthermore, such a procedure usually introduces a large radioactive contamination, largely due to radon, which is in equilibrium with the trace amounts of radium that are present as contaminants even in carefully purified barium or calcium compounds.

EXPERIMENTAL

Equipment has been devised for the direct separation of the CO_2 from the air by physical means on a vacuum line; it is shown in Fig. 1. In this apparatus a two-way valve system admits fresh air to the patient's face mask or BMR mouthpiece and passes this air out through a large stopcock, (10-mm bore), through a short ice-water-cooled condenser, and into the large balloon.*

*Weather Bureau observation balloon, about two feet in diameter when filled loosely.

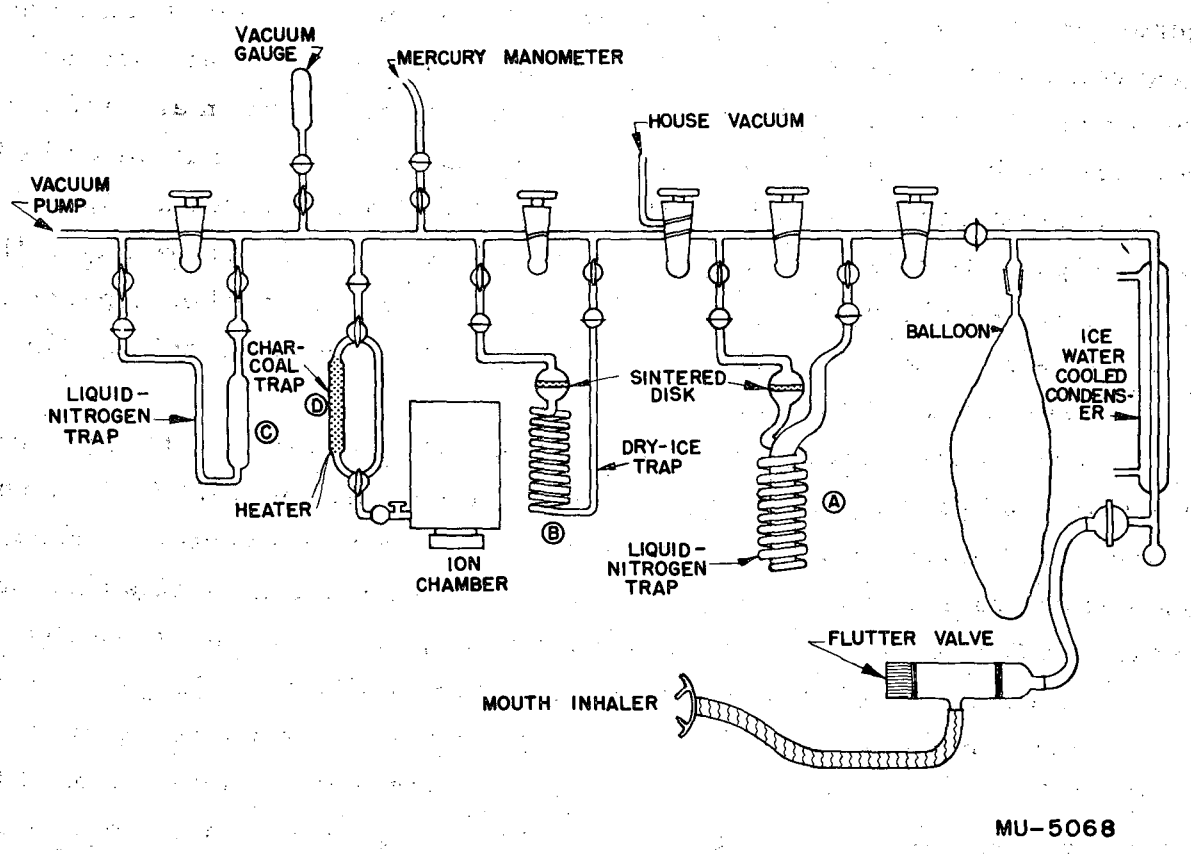

Fig. 1. Vacuum system for direct separation of CO_2 from exhaled air.

Air is withdrawn from this system through trap A, which is cooled in liquid air or nitrogen and exhausted to a house vacuum.

The construction of this trap is rather important, as it must be able to condense all the CO_2 from air which should conveniently flow through at about 5 liters/min. The quantitative condensation of the CO_2 is accomplished by means of the spiral trap coupled with a sintered-glass disk filter. Much of the condensible material in the air is cooled to a solid-particle state suspended in the air. At high gas-flow rates these are normally blown through a trap, but the addition of the sintered disk filters out these particles, and an excellent recovery of the CO_2 is achieved.[9] This step separates nitrogen and oxygen from CO_2, water, and other gases condensible in a liquid-nitrogen-cooled trap.

After a desired amount of air has been processed, trap A is evacuated; the contents are allowed to warm and pass through trap B, which is cooled in an isopropyl alcohol–dry ice mixture and removes water. The CO_2 finally condense in trap C, which is cooled with liquid nitrogen. (Trap B is constructed similarly to trap A, but may be made of smaller-size glass tubing.)

The CO_2 is then allowed to volatilize into the closed-off evacuated system, and in so doing passes through a 1 x 10-cm section of activated charcoal, D,* until the ionization chamber is filled to a pressure of 76 cm Hg. The adsorption of CO_2 on this charcoal trap is not large and its important function is to remove radon, a short-half-life alpha-radioactive element.

Radon has melting and boiling points very close to the sublimation point of CO_2 and is not removed by any of the previous steps. The amount of radon in the air varies a great deal and depends on the nature of the surroundings. Thus, concrete buildings in the West have been noted for large radon concentrations due to the uranium content of many of the western sands. Unless the radon is carefully removed from the CO_2 in the experiments described in this paper, no correction for α emission can be made and the sensitivity of the method is greatly decreased.

Most of the radon in the carbon dioxide, however, may be easily adsorbed on clean degassed charcoal at room temperatures. Furthermore, it is not necessary to use new charcoal for each sample, since radon may be desorbed by heating the charcoal to 200° C in an evacuated system (10 microns pressure). This heating is easily accomplished by wrapping the charcoal section with a

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*The activated charcoal was taken from a gas mask chemical cartridge, Cat. No. DR-44135, Mine Safety Appliances Co., Pittsburgh, Pa.

nichrome wire in asbestos, which can be electrically heated.

The ionization-chamber measurements discussed in this paper were made with a vibrating-reed electrometer* and continuous recorder,** using the rate-of-drift method.[10] An automatic grounding mechanism returns the center electrode to ground potential whenever it reaches the limit of the chart scale, so that continuous traces for several hours at a time can be made and analyzed. In the analysis the drift with and without α's is measured for 10-minute intervals for at least 2 hours. By this method any instrument variations such as insulator hysteresis currents can be detected. Only after constant drift rates are reached are the data used.

A series of chambers were constructed, from 450 to 1500 cc in volume, and compared with a 100-cc chamber in common usage.[5,7] The sizes and characteristics of the chambers are listed in Table I and the general design shown in Fig. 2. The collecting-electrode insulators were purchased from the Applied Physics Corporation*** and were equipped with a sapphire insulator.

DISCUSSION

The background current of an ionization chamber is due to insulator drift current plus ionization current derived from cosmic rays, radiation emitted from chamber walls, and activity in the chamber gas. When an ionization-chamber current is analyzed with a sensitive electrometer and continuous recorder, the α-contribution derived from the chamber walls and gas may be subtracted if such events are not numerous. The effects of other radiations can not be so easily eliminated.

The efficiency of the production of ion pairs in an ionization chamber at constant pressure for soft β-radioactivity increases with size of the chamber, rapidly if the dimensions of the chamber are small compared to the range of the particle, and less rapidly when the beta range is small compared to chamber size.

As the size of the ionization chamber is increased, therefore, the sensitivity of the radioactive assay is increased owing to the following factors:

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* Vibrating reed electrometer, Applied Physics Corp., Pasadena, Calif.

** Brown potentiometer recorder, 0-25 mv, Minneapolis-Honeywell Regulator Co., Philadelphia, Pa.

*** Applied Physics Corp., Pasadena, Calif.

Table I*

Chamber Size vs. Collection Voltage and Sensitivity

Chamber Size Diam. (in.)	Length (in.)	Vol. (cc)	Beginning of plateau voltage** (v)	Voltage used	Sensitivity dis/min/mg $BaCO_3$	Equiv. value in of background in dis/min/mg $BaCO_3$	Bg. in mv/min drift rate
0.70	2.75	100	22	90	0.01	0.07	0.50
3.25	3.0***	450	135	270	0.004	0.04	1.80
3.25	3.50	500	135	270	0.004	0.05	2.20
4.75	3.50	1000	30	60	0.001	0.04	4.10
3.75	5.50	1000	30	60	0.001	0.04	4.20
5.25	4.25	1500	30	60	0.002	0.04	6.40
42.5	6.50	1500	90	180	0.002	0.04	6.30

* All values are with α-background subtracted.

** The distances between the end of the probe and the top of the chamber were not kept constant.

*** Made with a rounded top of 1-5/8" radius.

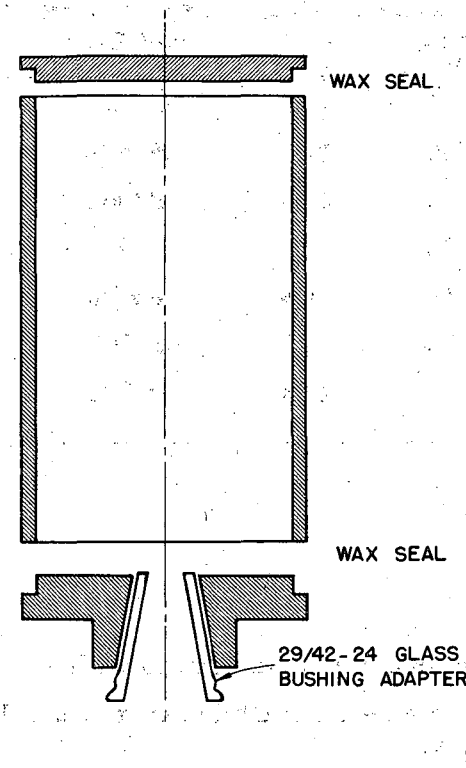

Fig. 2. Cylindrical ionization chamber with a 29/42 - 24 short glass bushing adapter.

(a) increased precision of measurements of electrical potentials for higher drift rates, achieved mostly through reduction in importance of short-term instrument variation, such as tube noise and insulator hysteresis; (b) more efficient absorption of β-particles in the gas, and therefore more ion-pair production per β-particle; (c) relative decrease in background from chamber-wall material as compared to activity from the sample. Increasing the size of the sample does not influence the ratio of sample activity to cosmic-ray background.

For a given set of physical conditions there must be, therefore, a certain size of ionization chamber beyond which further volume increase gives only slight advantages. The major source of error at low drift rates in ionization chambers is instrument variation, probably mostly due to insulator hysteresis. This effect may be largely due to deformation of the insulator by pressure changes.[11] When this variation in drift rate, ± 0.05 mv/min, becomes equal to the precision of the electrical instruments, which is about ± 1%; further size increase gives no improved sensitivity. The limiting sensitivity for this work occurs at about 4 mv/min which is the drift rate for the 1000-cc chamber.

In carbon dioxide at one atmosphere pressure the maximum range of the C^{14} β-particle is 15.5 cm and the average range is 5 cm. (E_{max} = 0.154 Mev, or 27.9 mg/cm^2, E_{av} = 0.050 Mev. Density of CO_2 is about 1.8 mg/cm^2 at 25°C.) The dimensions of the 1000-cc ionization chamber are of the same order of magnitude as the average range of the C^{14} β-particle, in agreement with the data in Table I. The sensitivity of this size chamber (about 0.001 dis/min/mg $BaCO_3$) makes it quite possible to carry out extensive experiments in humans with as little as one microcurie of C^{14}.

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