

air, such methods are not generally reliable. Therefore, the measurements must be made in specially equipped laboratories by experienced technicians along the lines now to be described. This requires that the samples of expired air be sent to the laboratories in suitable flasks. The half-life of the radon is sufficient to permit its shipment by air to any point in the United States for measurement with no delay in handling. The activity decreases 18 per cent per 24-hour day, and even two days after sampling a significant fraction of the original activity remains. Measurement in a central laboratory has the additional advantage that all observations are more likely to be directly comparable than those made locally or in several laboratories under slightly different conditions. However, radon standards, in the form of dilute solutions containing known amounts of radium, are available from the National Bureau of Standards so there is no real excuse for marked variations in measurements made at several laboratories. An apparatus of comparable sensitivity and reliability is used.

Laboratory measurements of samples of air containing radon are based on a comparison between the radon in the sample and a standard quantity of radon of similar magnitude. The standard quantity of radon is obtained from a standard solution of radium carefully prepared for this purpose. From the known rate of accumulation of radon in such a solution, various quantities of radon can be obtained up to the equilibrium amount, by allowing the radon to accumulate over various periods of time. The growth of radon is given by the relation $R = E(1 - e^{-0.18t})$, where R is the amount of radon at any time t , measured in days since its removal from the radium source; e is the base of natural logarithms, and E is the equilibrium amount, equal in curies to the number of grams of radium in the standard solution. About 30 days are required to reach practically the equilibrium amount since after this time $e^{-0.18t}$ is for practical purposes equal to zero. One half the equilibrium amount is obtained in 3.83 days so that various fractions of this amount may readily be obtained down to those so small that the accumulation time is difficult to measure accurately.

The comparisons may be made by several methods, but in each the ionization produced in an ionization chamber, by the alpha particles, is the effect customarily used. The number of alpha particles produced per hour, or other convenient unit of time, is proportional to the quantity of radon in the chamber. This number may be determined by direct counting of the current pulses in the ion chamber produced by the alpha particles, or by measuring with a sensitive electrometer the current produced by the alpha particles traversing the gas in the chamber at any time, which is indirectly a method of determining the number of alpha particles emitted per unit of time.

In addition to being dependent on the properties of the equipment used, the accuracy of all such measurements is dependent on statistical laws governing the evaluation of random events, since alpha particles are emitted by any radioactive source at a purely random rate. When this rate is low, as for the smaller quantities of radon, these fluctuations become obvious. This means that a suffi-

cient number of particles must contribute to the measurement to reduce the standard deviation to the required percentage of the total number observed. Since in this case the standard deviation is equal to $\pm\sqrt{N}$, where N is the total number of particles recorded, an observation including 100 particles has a standard deviation, on a statistical basis alone, of ± 10 or $\pm 10\%$. To achieve a statistical accuracy of $\pm 1\%$ it is necessary to record 10,000 particles. Whether this condition is properly fulfilled is most conveniently determined in a method in which the alpha particles are counted directly. The counting method offers other advantages that make it more convenient to use. If, to secure the desired statistical accuracy, the time of observation must be extended over a significant fraction of the half-life of radon, correction must be made for the decay of the radon in the

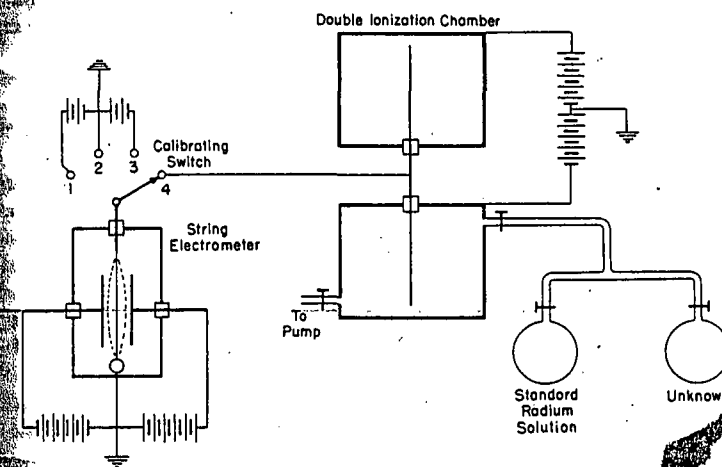


Figure 4. Schematic diagram of the essential elements of equipment for measuring samples of radon by the use of a string electrometer to measure the ionization current produced by the alpha rays from radon in an ionization chamber.

chamber. Furthermore, because some of the immediate decay products of radon emit alpha particles and contribute to the measurements, observations can be begun only after these have come into transient equilibrium with the radon after its introduction into the ion chamber. This period is of the order of three hours.

A schematic diagram showing the method^{15,16} of using an electrometer for comparing radon samples is shown in Figure 4. A double ionization chamber, with the collecting voltages of the two chambers opposed, is used, as shown, to equalize the effects of external sources of radiation. The radon is introduced

¹⁵ W. D. Urry and C. S. Piggot, *Am. J. Sci.*, **239**, 633 (1941).

¹⁶ R. D. Evans, *Rev. Sci. Instr.*, **6**, 99 (1935).