Measurement of Ventilation Rates with Radioactive Tracers

MARTHA GERRARD

THE need for adequate ventilation of buildings is well understood by both builders and laymen, and ventilation requirements are taken into consideration in designing heating systems. For more than a century, non-radioactive tracers—e.g., carbon dioxide exhaled by the occupants of a room, water vapor, tertiary butyl hypochlorite, hydrogen, and helium—have been used for measuring ventilation rates. These tracer methods, reviewed by Collins and Smith[1] in 1955, do have several disadvantages. In addition to the need for sampling and analysis at a later time, which are disadvantages of all the chemical tracers, specific problems are offered by some of them: hydrogen may create an explosion hazard, water vapor is sorbed by walls and furnishings, and butyl hypochlorite does not give consistent results. These disadvantages can be avoided by using radioactive inert gases (the so-called "noble" gases) as tracers.[2] In the minute amounts used, these materials are safe. There is no need for sampling, since the tracer can be measured *in situ* by determining the amount of radiation present. The data are thus obtained immediately, and experimental conditions can be changed at once so that several parameters can be evaluated in a short time. Results may be recorded continuously, and both accuracy and sensitivity of the radiotracer method are high.

Radioactive tracers are radioactive elements (often used in the form of compounds) that gradually lose their activity, or "decay," according to a definite pattern. The energy of the radiation emitted in this decay process and the time required for the decay to be essentially complete vary with the isotope. The decay rate is measured by the half-life: that is, the amount of time required for half of any given amount of radioactivity to decay.

METHOD

The radioisotope-tracer method for determining the ventilation rate of an enclosed space consists, basically, in introducing a radioactive substance into the space, mixing the tracer homogeneously with the air in the space, and determining the decrease in tracer concentration with time. Of course, if the half-life of the radioisotope is short compared with the time interval over which measurements are made, corrections for decay must be made.

The ventilation rate, R, is less calculated from the data obtained in the test, using the relation

$$R = \frac{1}{t - t_0} \ln \frac{C_0}{C_t}$$

where C_t is the tracer concentration determined by the instruments at time t, a finite time after the tracer has been mixed with the air, and C_0 is the concentration immediately after mixing: i.e., at time t_0. This relation is derived from

$$C_t = -\frac{V_0}{Q}\frac{dC_t}{dt} = {}^{Q(t - t_0)/V_0} = C_0 e^{R(t - t_0)}$$

where Q is the volume of air introduced per unit time and V_0 the total volume of the enclosed space, so that $R = Q\ V_0$.

SAFETY IN USE OF RADIOACTIVE TRACERS

For ventilation studies, the tracer used should be in gaseous form, and this gas must not only be safe for a human being to handle but must also be harmless to any living thing that might accidentally come in contact with it. On the other hand, its half-life must be long enough for measurements to be made before the substance has decayed significantly, and the energy of its radiation must be intense enough for minute amounts to be detected by available instrumentation. These criteria are filled best by the gas krypton-85. On the safety side, it is both chemically and biologically inert. If a person should accidentally inhale it, it would not be retained by the body but would be rapidly expelled. On the usefulness side, the radiation from minute amounts can be easily detected by a Geiger-Mueller counter, and its half-life (10.8 years) is long enough that supplies can be bought and stored until needed without a significant decrease in activity.

M. Gerrard is with the Isotopes Information Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., operated for the U. S. Atomic Energy Commission's Div of Isotopes Development by Union Carbide Corp, Nuclear Div. *The article presented here is a modified version of one that appeared originally in Isotopes and Radiation Technology, Vol. 5, No. 4 (1968).*

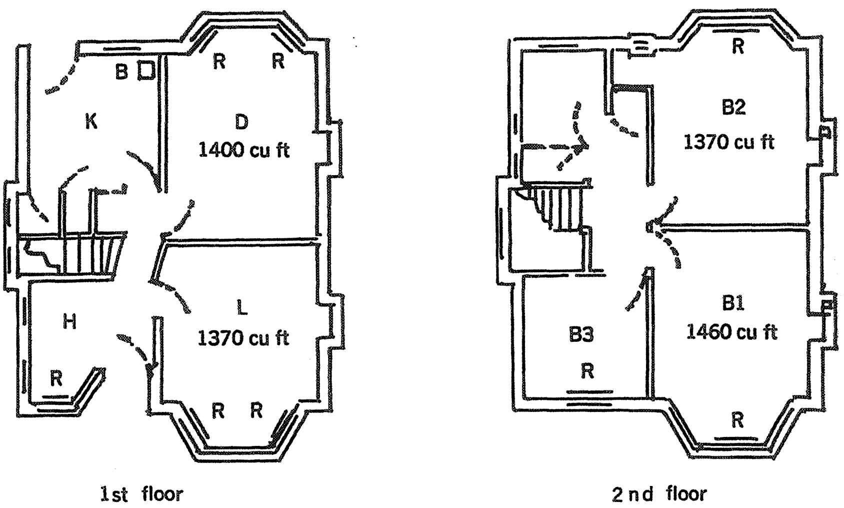

Fig. 1 Plan of experimental house used in ventilation experiments of Howland et al.[11] B, boiler; R, radiator

Probably the best summary of the situation with regard to safety in the use of krypton-85 is that given in a French publication,[2a] which states that there is nothing to fear from the use of krypton-85 in testing the ventilation in a room. The room can be used as soon as the test is finished, and the radiation hazard to an operator who remains outside the test room is nil. The amounts of tracer used are no more than 15 times the maximum permissible concentrations for a permanent exposure, and even this amount decreases rapidly. The temporary excess over the maximum permissible amount is not a hazard because maximum permissible concentration values given by the health physics experts are those for permanent exposure rather than for the very temporary conditions of the test. The air released from the test enclosure is contaminated only very slightly, and even this amount is dissipated rapidly.

Two other inert gases—xenon-133 and argon-41—have found some application. However, their half-lives (5.3 days and 1.83 hrs, respectively) are so short that they can be used only in tests made near a source of supply. The inert gases radon and thoron are not even considered here as possible tracers because they are not usually added to an atmosphere intentionally. Where they are already present, as in a uranium mine, their decay products, which are solid and collect on filters in the mines, have been determined[3] to show whether the mine is being ventilated sufficiently. However, the determination of such solid products is difficult, and every attempt should be made to keep the concentration of these gases as low as possible in a mine.[4]

Some other radioactive elements have also been used, for ventilation studies. For example, bromine-82 was being used[5] in England as early as 1950 and has been reported[6] used in the form of methyl bromide for studying airborne dusts in a coal mine and a tunnel. However, a radionuclide-labeled chemical tracer has many of the same disadvantages as non-radioactive chemical tracers. Labeled or not, methyl bromide, for example, is absorbed on walls,[1] and carbon dioxide dissolves readily in any moisture present.[7] However, methane labeled with either carbon-14 or tritium is of interest for studying removal of methane from coal mines.[8]

SPECIFIC TESTS

Early studies using radioisotope tracers to determine ventilation rates in rooms were made in both France and England. Gueron[9a] (with Cadiergues) reported, at the Oxford conference on radioisotope techniques in 1951 on air-change measurements made in a very leaky laboratory with xenon-133. An unknown amount of xenon was mixed with the laboratory atmosphere by means of a fan, which was operated for 5 min. After the fan was stopped, the radioactivity was measured continuously for 35 min, using an ionization chamber. The decrease in activity with time followed a first-order law, with a clearly marked irregularity at the time that fume hood fans were turned on. (Cadiergues and Leveque subsequently reported this work in French journals.[10]) Also, at the Oxford conference, Seligman[9b] reported on determination of air-change rates with argon-41. He stated that the measurements would have been difficult and cumbersome by any other method. Collins and Smith[1] successfully used argon-41 to measure the ventilation rate in a specially constructed experimental house, after unsuccessfully trying to use methyl bromide labeled with bromine-82.

The rapid response of the krypton-85 detectors, and thus the immediate availability of results, made it possible for Howland et al.[11] to evaluate the immediate effect of changing conditions—e.g., closing doors or opening windows. They used a typical two-story detached house (Fig. 1) with a total floor area of 1150 sq ft. The walls were of brick cavity construction; the roof was tiles on boards; and the upstairs ceiling was insulated with 3 in. of mineral wool. The floors, of tongued and grooved boards, were covered with Kraft building paper, sealed at the joints and edges to simulate linoleum. The wooden window frames held leaded glass. The two downstairs

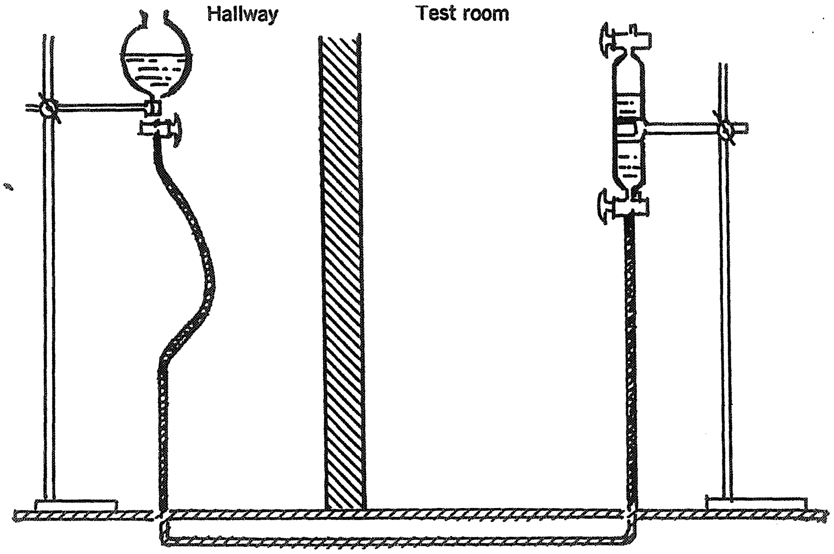

Fig. 2 Apparatus for releasing krypton-85 into a room

rooms and the two large bedrooms upstairs had open fireplaces with the flues running up the outside walls and ending well above roof-ridge level.

The amount of krypton-85, even in these large-scale experiments, was well within the established safe limits. The equipment for introducing the tracer into the room after the operator had gone out is shown in Fig. 2. To release the gas in the room, the water-filled reservoir in the hallway was held below the water level in the gas-sample tube in the room. The tap was then opened but only after the reservoir in the hall was raised did any tracer enter the room. The gas was mixed with the air by a large, slow-speed fan when the room was heated by an open fire. The fan was operated for 45 sec after release of the gas. When a radiator was used for heating, the gas was released in front of the radiator, and it mixed simply by convection currents. The Geiger-Mueller tubes by which the gas was detected were located in the center of the room for convenience. Preliminary experiments had shown the detection point to be unimportant.

The rate of air change in a single room was measured for fireplace heating as well as for radiator heating with various combinations of open and closed windows, doors, transoms, and chimneys. Air movements from room to room with the doors open and a ducted warm-air system in operation were also investigated, and the effects of outside temperature and wind conditions were studied. Comparison of the results of single-room tests with those of similar tests made with carbon dioxide showed good agreement, with reproducibility possibly slightly better with the krypton. Carbon dioxide or other chemical tracer probably could not have been used for the whole-house experiments because of the great dilutions and the number of sampling points that would have been needed.

In homes where gas is used, ventilation problems may be particularly serious. The French gas industry[12] used xenon-133 to measure the ventilation rate on a cross-ventilated test room of 280 cu ft volume. Measurements were made easily and precisely, both of the over-all air change with normal ventilation and of in-leakage rates with all ventilation cut off. The gamma radiation was measured with a scintillation detector and the beta with a Geiger-Mueller counter.

Although the majority of ventilation tests with radioactive tracers have been reported for domestic dwellings, such tests have also been made on a number of other types of enclosures. In Sweden, for example, krypton-85 was used to measure the airflow in a hayloft,[13] and in Germany, argon-41 was used to determine the airflow pattern through a hay ventilator.[14] Krypton-85 is useful for studying air currents in a coal mine.[7]

Both krypton-85 and xenon-133 were used[15] in investigating the leakage and air-change rates in a facility designed to simulate a railway car moving at 0 to 75 mph. From the data, factors contributing to heat loss, as well as the speed and direction of air movement inside the car, were identified. The Australians,[16] in trying to find the point of leakage of CO from the engine into the cabin of an airplane, used krypton-85 to trace the flow of air and concluded that the information would have been difficult, if not impossible, to obtain by other methods.

In a metal heat-treating plant, krypton-85 was used to determine the minimum purging rate of a furnace.[17] The tracer was injected into the furnace through the purging-gas line, and a continuous stream of gas was drawn out through the thermocouple ports. The exit streams were passed over a scintillation counter to measure the krypton-85 removed. Not only was the gas flow inside the furnace determined, but also the amount of the original atmosphere remaining after the purge.

The above examples show that the radioactive inert gases, particularly krypton-85, are quite useful for determining ventilation rates in various kinds of enclosed spaces. The uses have not been fully exploited, and consideration might well be given to the radioactive-tracer technique by anyone interested in ventilation problems.

GENERAL INFORMATION

Although the radioactive tracer technique is not difficult to apply, the user must, of course, receive some basic instruction before starting out in this field. The services of trained personnel to conduct radiotracer tests are available from at least one commercial firm. The do-it-yourself ventilation engineer may take a course in radioisotope techniques at Oak Ridge Associated Universities (P.O. Box 117, Oak Ridge, Tenn. 3783, Attention: Special Training Div).

Krypton-85 can be bought from several suppliers listed in the 1967 Isotope Index (Scientific Equipment Co, Publications Dept, P.O. Box 19086, Indianapolis, Ind. 46219, $10) or from Oak Ridge National Laboratory (P.O. Box X, Oak Ridge, Tenn. 37830, Attention: Isotope Sales Dept) for $100 per curie, more or less, depending on size of order, packaging, and other factors. (Howland et all.[11] used 0.0025 curie for a test.) Detectors and other equipment may be obtained from standard equipment supply houses. A license to use radioisotopes is required for the amounts of krypton-85 involved, and application for same should be made to the State Regulatory Agency in Alabama, Arizona, Arkansas, California, Colorado, Florida, Kansas, Kentucky, Louisiana, Mississippi, Nebraska, New Hampshire, New York, North Carolina, Oregon, Tennessee, Texas, and Washington: in other states, licenses are handled by the Div of Materials Licensing, U.S. Atomic Energy Commission, Washington, D.C. 20545.

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INTERNATIONAL ENGINEERING CONFERENCE TO BE SPONSORED

The University of Pittsburgh will sponsor an international conference beginning October 20 on the topic of how the proper application of engineering technology can help the developing nations industrialize. Some 60 experts from around the world will discuss such topics as the role of the engineer in the industrialization of the developing countries, as well as the roles of international organizations and the governments of developed countries, private industries, universities and national governments. Dr. Detlev Bronk, president of Rockefeller University, will deliver the keynote address at a dinner the first evening of the meeting. Among the principal participants in the small discussion sessions to follow will be K. T. Li, Minister of Economic Affairs for the Government of Taiwan and winner of this year's Magsaysay Award for his guidance of the Nationalist Chinese economy following the government's flight from the mainland. (The Magsaysay Awards of Asia correspond to the Nobel Prize.) The discussions will be concerned with the amount of involvement engineers have with other professions and the problem of understanding the interface between the technical and non-technical aspects of any country's process and then to provide an optimum working relationship between engineers and non-engineers so that the technological base of all nations and their economic stability and standard of living may improve.