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DEVELOPMENT OF A MULTI-TRACER GAS TECHNIQUE FOR OBSERVING AIR MOVEMENT IN BUILDINGS

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Development of a Multi-Tracer Gas Technique for Observing Air Movement in Buildings

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1. INTRODUCTION

A method for following air movement within buildings, which uses several different tracer gases simultaneously, has been developed. The method consists of the following sequence of operations:

- up to four tracer gases are released at various points within the building (see Section 2)
- the mixture of gases is sampled at any number of positions in the building as a function of time since the release (see Section 3)
- the samples are chemically analysed to produce curves showing the concentrations of each gas stepping through time and space (Section 4)
- the variations in gas concentrations are used to evaluate air movement through the space. Specific experiments to illustrate such air movement have been carried out and these are summarised in Section 5.

2. TRACER GASES AND THEIR RELEASE

An extensive survey was carried out to find non-toxic, odourless tracers with a zero background concentration. It was also necessary to find unreactive chemicals whose concentrations were easily measured, and which could be readily separated for analysis. A series of perfluoro hexanes and decalins fit the requirements and the following ones have been used in the prototype development :-

PP1 perfluoro n-hexane
PP2 perfluoro methyl cyclohexane
PP3 perfluoro dimethyl cyclohexane
PP5 perfluoro decalin

These compounds are low boiling liquids which makes for easy transport. They are currently injected into a space (remotely or manually) by evaporating about 1 ml using an electric heater. In some cases the gas is mixed with a desk fan and experiments described later illustrate the effect of the fan.

3. SAMPLING SYSTEM

Mixtures of room air and one or more tracers are sampled by drawing a small fixed volume of air (about 100 mls) through sample tubes packed with an adsorbent. Figure 1 illustrates the system for two sample points. Each sample point shown consists of five removable stainless steel tubes packed with an adsorbent (chromosorb 102). At the front end of each tube a push cap fitting connects it to a solenoid valve which controls the exposure of the tube to the atmosphere. At the back of each tube a similar fitting connects it to a nylon tube which leads to a manifold. From the manifold, a single tube leads to a T-piece adaptor connected to a similar line from the other unit. At present a three port solenoid at the T-piece enables the pump to draw air either through the samplers, or through a needle valve. This arrangement allows the pump to run continuously without the risk of a surge of air occuring when a sample is taken due to the formation of a partial vacuum. It also prevents the packing of any tube being pulled tightly against the retaining gauze (see Figure 2), which would seriously affect its gas flow/adsorption properties. The outlet from the pump passes through a pressure gauge, a needle valve, and a flow meter allowing the volume of air drawn through each tube to be monitored. The pump, flow meter, pressure gauge, needle valve, three port solenoid valve and T-piece are housed on a small trolley. Also included here is the control system (Figure 3) which opens and closes the solenoid valves. The valves are operated so that the tubes are exposed in pairs, one at each sample point. Samples are thus taken simultaneously at each point and in a timed sequence from 1 to 5. The sample tubes are capped for transportation to the automatic desorber where up to 50 tubes may be analysed. In Figure 4 the air movement induced between two adjacent zones on opening an interconnecting door is illustrated. PP1 is released in room A and PP3 in room B with the interconnecting door closed. The air in each zone is stirred with a fan to give a uniform gas distribution. After opening the door, the concentration of PP1 falls in zone A and rises in zone B whilst the concentration of PP3 falls in room B and rises in zone A.

4. SAMPLE ANALYSIS

The tracer gases are desorbed from the sample tubes using a Perkin-Elmer ATD50 automatic thermal desorber and then separated and analysed on a Perkin-Elmer Sigma 3B gas chromatograph fitted with a 4m glass column packed with 5% SE30 on CHROM W.H.P and a flame ionization detector (Figure 5). In the automatic desorber, each sample tube in turn is connected to an inert gas line and then heated. The desorption temperature and time can be programmed by the operator and experiments have been carried out during this work to find the most suitable desorption parameters for the gases. During the heating process N_2 carries the tracers into a cold trap packed with Chromosorb 102 at $-30^{\circ}C$ which decreases the band spread and increases the resolution of the chromatographic column. When the primary desorption is complete, the cold trap is flash heated to $250^{\circ}C$ and the tracer gases liberated and swept directly onto the column of the chromatograph where they are separated before entering the flame ionization detector for analysis. The automatic thermal desorber is connected to the column in the gas chromatograph oven by a heated line.

4.2 Choice of desorption parameters

It is essential to examine the efficiency of the desorption process to make sure that all the tracers adsorbed in the tubes are desorbed as cleanly and quickly as possible. Tests were carried out on PP5 which is the least volatile and the most difficult to desorb from the tubes. A clean adsorber tube was fixed in the gas chromatograph injector in place of the column. With N_2 carrier flowing a 1 ml headspace sample of PP5 was injected on to the tube with a gas tight syringe. The tube was removed and the column replaced in the oven. The tube was then loaded on the automatic desorber and a desorption programme chosen. The tube was reheated (fired) several times to make sure that the sample was completely desorbed. The whole procedure was repeated for different desorption parameters until a suitable set was found such that the whole sample

could be shown to come off at one firing. The aim was to carry out the primary desorption at as low a temperature as possible in order to minimise interference from stray compounds which might also have been adsorbed.

The conditions chosen were:

Primary oven : 200°C, desorption time 15 minutes.

Cold trap temperature, -30°C. Cold trap high temperature, 250°C.

Box surrounding cold trap assembly : 100°C.

4.3. Assessment of optimum sampling volumes

It is important to make sure that the air drawn through each tube in a field test, deposits all its tracer gas on the adsorbent and that none breaks through to the other end of the tube. The optimum sampling volume of an adsorbing tube is the volume of air containing a tracer which may be sampled over a wide variety of concentrations without significant breakthrough.

The optimum sampling volumes of gas were measured using the indirect method of Brown and Purnell (1979), in which the adsorber tube is used as if it were an analytical column. Sampling conditions for this work were chosen as a 100 ml volume to be collected at a rate of 100 ml /minute.

4.4 The Gas Chromatograph

The column and operating conditions for the gas chromatograph were chosen on the advice of ISC Chemicals Ltd., who also provided samples of all tracer gases used. A 4m glass column packed with 5% SE30 on CHROM W.H.P was installed in the oven and used isothermally at 50°C. The injector and ionization detector were heated to 120°C.

The detector was calibrated using standard concentration gas mixtures made up on a glass vacuum line, and serial dilutions of these mixtures.

5. DEMONSTRATION OF THE TECHNIQUE

Four distinct experiments were necessary to evaluate the sampling system, the tracer gases in use and the method as a whole. The first experiment tests for absorption of the tracers by walls and furnishings (Section 5.1). The second investigates the possibility of stratification over a period of time both with and without a mixing fan (Section 5.2). The third observes the degree of mixing of the tracer gases in room air (Section 5.3). Finally, some experiments were carried out to show with one gas and then simultaneously with two, how the air between two adjacent zones moves when a door between them is opened (Section 5.4).

5.1 Tests for absorption into walls and furnishings

Method

An office of volume $33m^3$ with a false panelled wall, carpeted concrete floor, concrete ceiling and large sliding double glazed windows was sealed with tape over joints in the wall, gaps in the ceiling, the window frame and the skirting board.

The tracer release system was set up in the middle of the room with an oscillating desk fan to ensure good mixing. One sampling unit was placed at each end of the room. The trolley with the pump and switching equipment was positioned outside the door. 1 ml of each tracer was evaporated in the room and the door was then closed, sealed from the outside and the oscillating fan switched on. After 27 minutes the fan was switched off. After another 3 minutes the first sample was taken. A further four samples were taken at intervals of 30 minutes (Figure 6). The test was repeated using intervals of one hour (Figure 7) and intervals of one minute (Figure 8) between samples.

Results

Figure 7 illustrates the variation in concentration of one tracer (PP1) up to 5 hours after its release into the sealed room. Between hours 1 and 5 the mean concentration in the room air at the two sampling points falls from 5.7×10^{-5} g/l to $5.0. \times 10^{-5}$ g/l. The very small drift downwards is probably due to residual infiltration occuring in the room, even though it was carefully sealed.

A log linear plot of the data in Figure 7 implies a rate of only 1.7×10^{-2} air changes per hour.

Similar tests were carried out with the other tracer gases and the air change rate obtained by averaging all the results for this 5 hourly period was $(1.7. \pm 0.3) \times 10^{-2} h^{-1}$.

On a different day, an identical set of tests carried out at half hourly intervals (Figure 6) indicated an air change rate in the sealed room of $(0.6 \pm 0.3) \times 10^{-2} h^{-1}$.

Similar experiments were carried out at much shorter intervals of one minute, 30 minutes after the release of the tracers, in order to make sure that the small loss of tracer gas seen above was not

an artifact of the equipment. Figure 8 illustrates that some scatter is present but no firm trend.

5.2 Tests for stratification

Method

Sampling point A was 2.89m above the floor, and point B 1.36m. The ceiling to floor height was 2.95m. 30 minutes after the tracers were released, sampling commenced at 30 minute intervals. In one test a desk fan was left on to mix the room air, and in a second test the fan was not used.

Results

Figure 9 shows the behaviour of PP1 (the lightest tracer, molecular weight 338) with the circulating fan on (top curves) and off (lower curves). There is no discernable stratification which would be seen if PP1 were settling to the bottom of the room. Similarly Figure 10 illustrates the behaviour of PP2,PP3, and PP5 (the heaviest tracer of molecular weight 462), and again there is no stratification when the fan is off.

5.3 Effect of the tracer-release-heater

The tracers are released by sudden evaporation from a small heated surface of about 20 cm^2 at about 160°C. This surface might be thought to set up significant convection currents, prejudicing even distribution of the tracers.

Results

The tracers were released by remote control in the middle of the sealed room and samples taken at the window and the door without any fans running. After about 10 minutes both sample points indicate very similar concentrations, suggesting that the heater is unlikely to provide a skewed tracer distribution.

5.4 Experiments to show air movement between zones

5.4.1 Air exchange between room and corridor : air swept out by opening door

In these tests, PP2 was released into an office which was then sealed for twenty minutes whilst the air was mixed with a fan. The door was opened and samples taken at various intervals ranging from 1 to 10 minutes. Two configurations each with two sample points were used, (a) one inside the room by the window

and the other one just inside the doorway, or (b) one in the room and the second just outside the doorway in the corridor.

a. Both sample points in the room

Figure 11 shows that opening the door causes a large exchange of air, so that the concentration of tracer falls uniformly throughout the room by a factor of 3 within 10 minutes. Similarly, Figure 12 illustrates the same behaviour with higher time-resolution In the first $2\frac{1}{2}$ minutes the mean tracer concentration falls from 5.2×10^{-5} g/l to 3.5×10^{-5} g/l. The plot of log concentration versus time is not linear, due to recirculation of air through the door, but in the first $2\frac{1}{2}$ minutes it appears that opening the door causes roughly 0.4 of the air in the room, or 13 m^3, to be swept out into the corridor.

b. One sample point in the room and one in the corridor

During the daytime, although the room was sealed (apart from its open door) the internal corridor was not. There was some movement of people through the corridor, opening and closing the doors at either end. Figure 13 illustrates the rapid drop in room tracer when the room door is opened, accompanied by a rapid rise in corridor concentration. The two equalise in about $2\frac{1}{4}$ minutes in spite of the fact that the spaces are isothermal. The overall decay is caused by air movement out of the corridor at the rate of 1.5ac h^{-1} (from a log linear plot of the data points on Figure 13). At night, (Figure 14) when no use in made of the corridor, an identical experiment shows an airchange rate very close to zero. Figure 14 also illustrates the rapid equalisation of tracer concentration in room and corridor after only 25 minutes.

5.4.2 Using two tracers to show air movement between zones

Two sampling points were set up, one in the sealed room used in the previous tests and one in the corridor outside the room.
Two gases, PP1 and either PP2 or PP3 were released, one in each zone. Air in each zone was mixed, with the communicating door closed. Samples were taken before opening the door, and at 5 minute intervals after it was opened. Figure 15 shows some of the results. PP1 (full line) is released in the sealed room, and after mixing reaches a concentration of 4.60×10^{-5} g/l (roughly 4 ppm). Its concentration in the corridor is very small (less than 0.2×10^{-5} g/l).

PP3 is released in the corridor and after mixing reaches a concentration of 2.35. x 10^{-5} g/l. Its concentration in the room is zero.

When the door is opened, PP1 is swept into the corridor - leading to a fall in room PP1 and a rise in corridor PP1. Similarly, PP3 is swept into the room, with a concomitant fall in the PP3 concentration in the corridor.

6. FUTURE WORK

The work described in this Report, has established a method for observing air movement in buildings, in which up to four different gases may be used simultaneously. Other gases could be added to the list.

Further sampling points beyond the two presently employed can readily be attached to the system.

The original SERC grant was concerned only with the development of the hardware. Application is being made to continue with the programme, with two objectives :-

1. To develop the mathematical analysis of the curves of tracer concentrations against time, in terms of air volumes.
2. To make specific measurement of air movement in the PCL experimental house at Peterborough.

Reference made:

R.H. Brown and C.J.Purnell, Collection and analysis of trace organic vapour pollutants in ambient atmosphere. The performance of a Tenax GC adsorbent tube, Journal of Chromatography, 178, p 78-90 (1979).

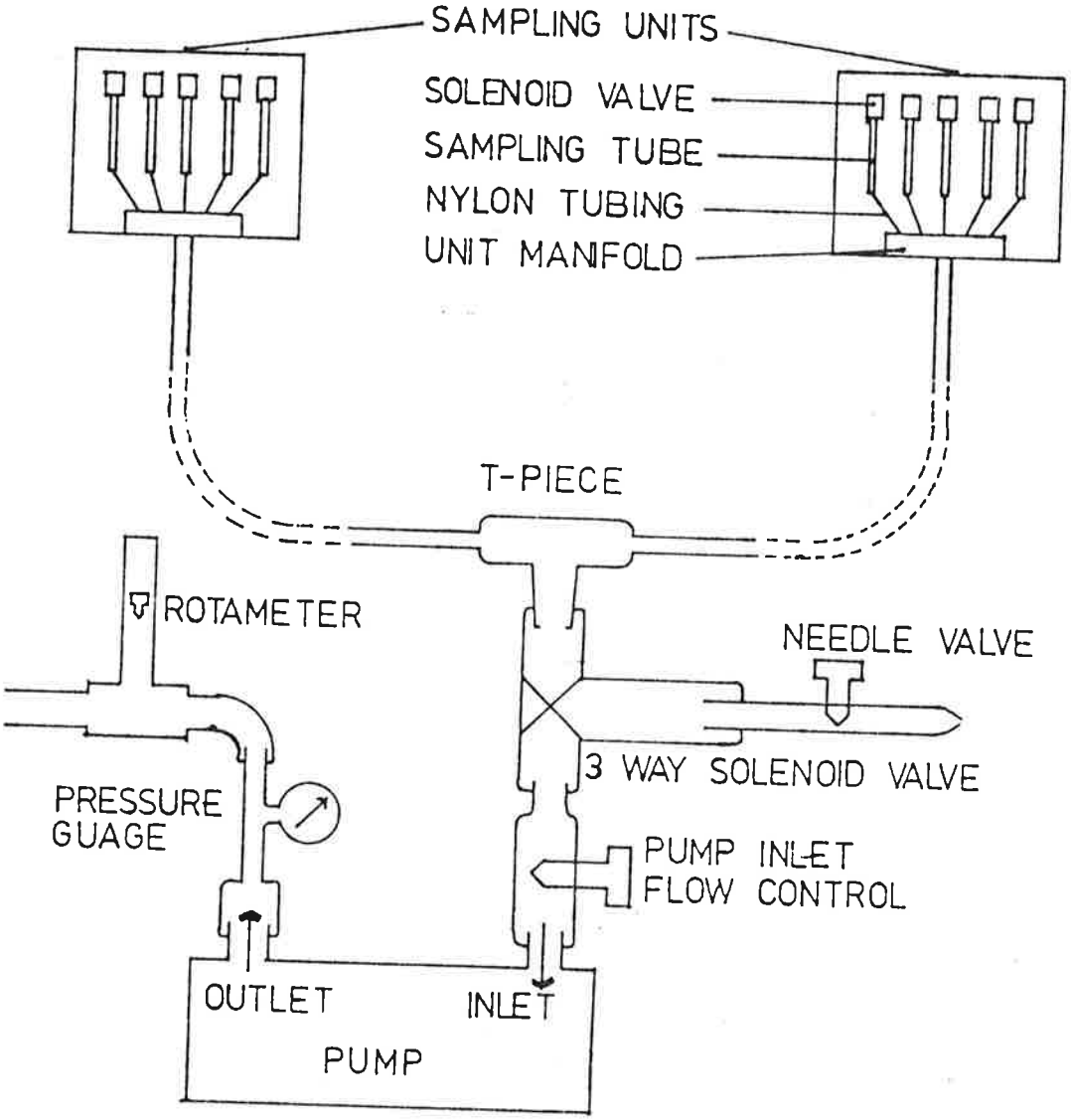


Figure 1. The sampling system.

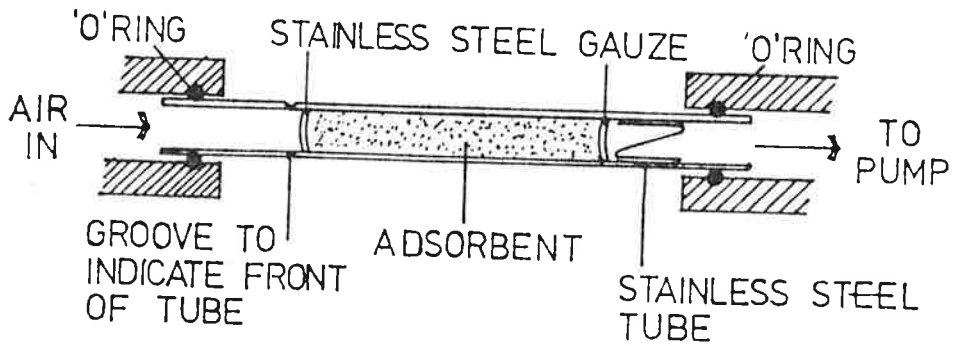


Figure 2. Sample tube.

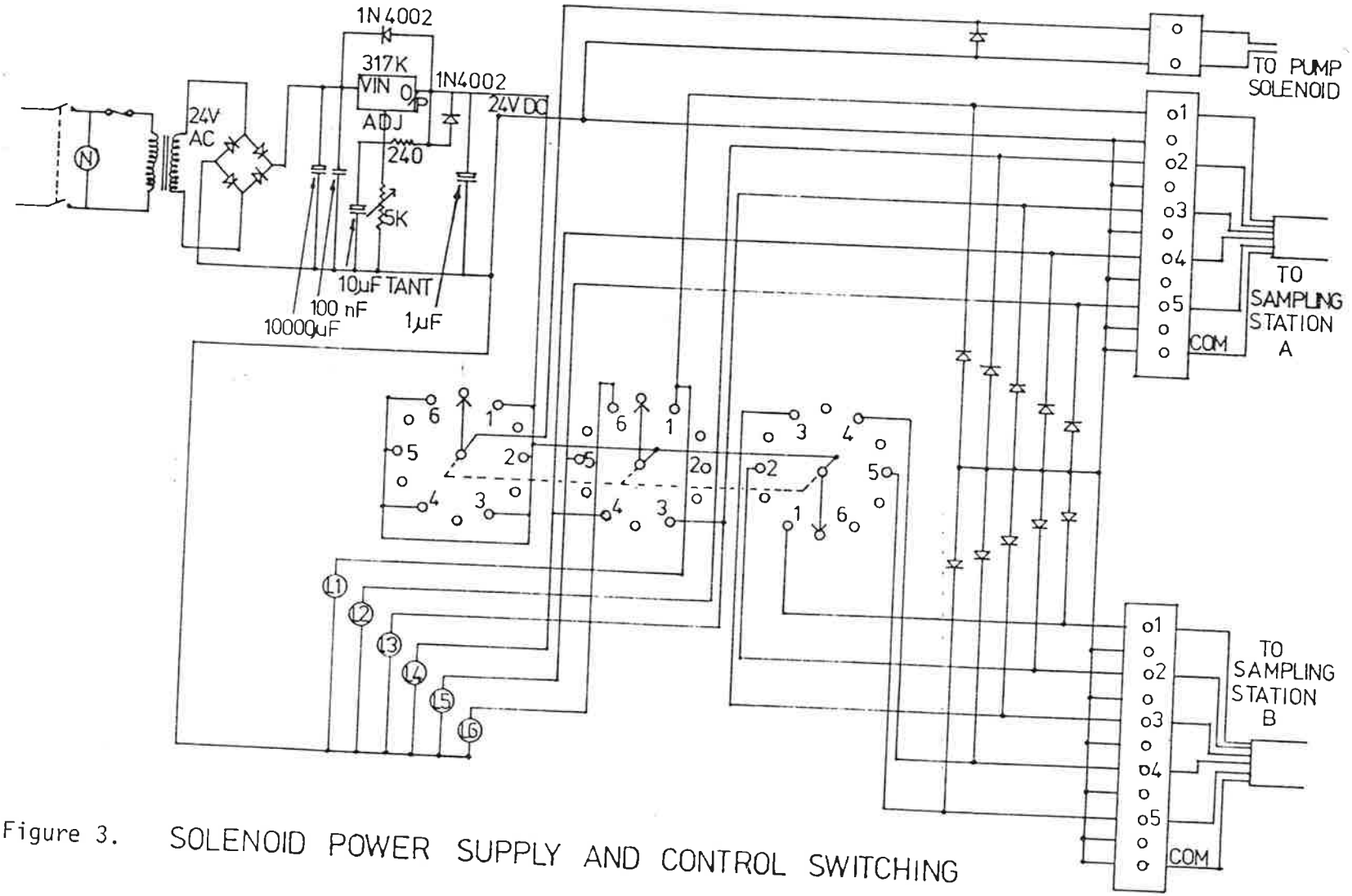


Figure 3. SOLENOID POWER SUPPLY AND CONTROL SWITCHING

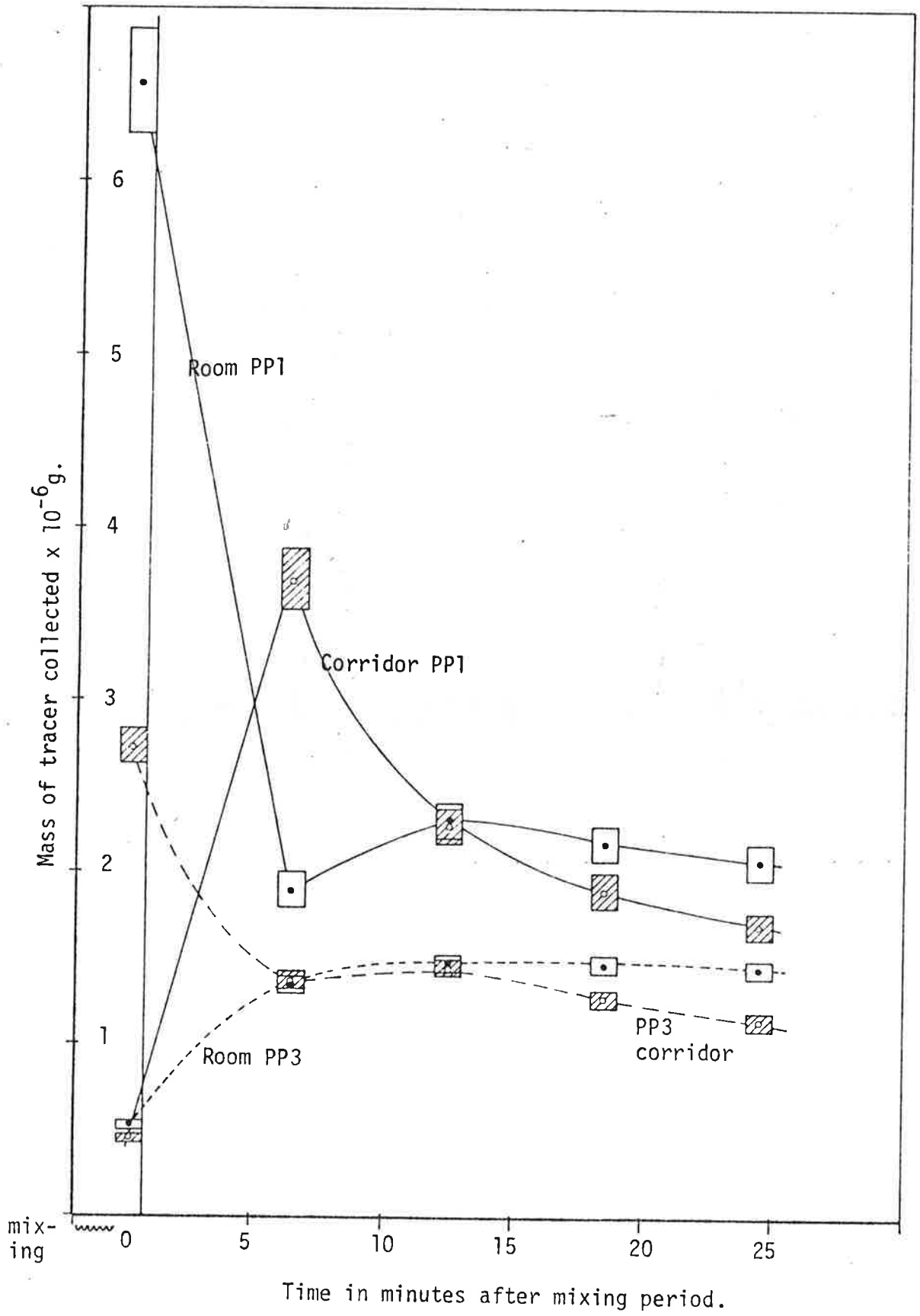
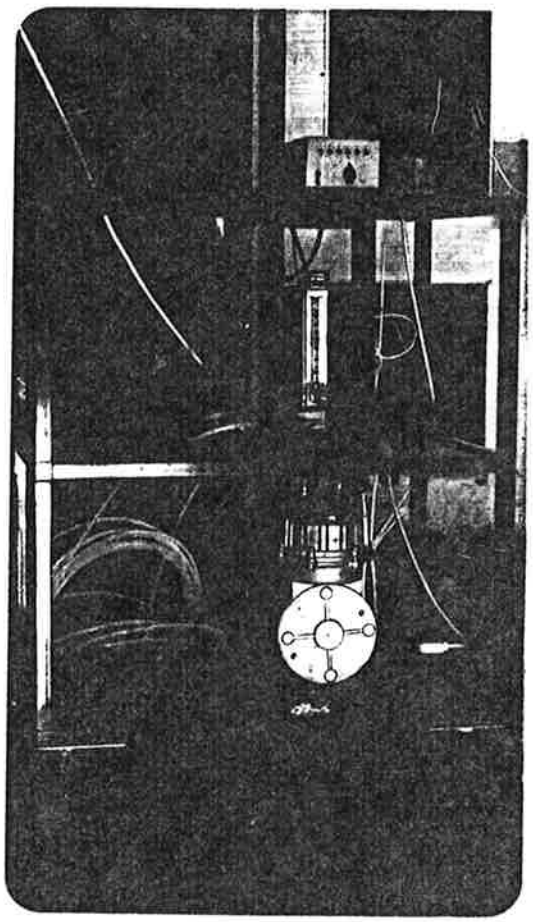
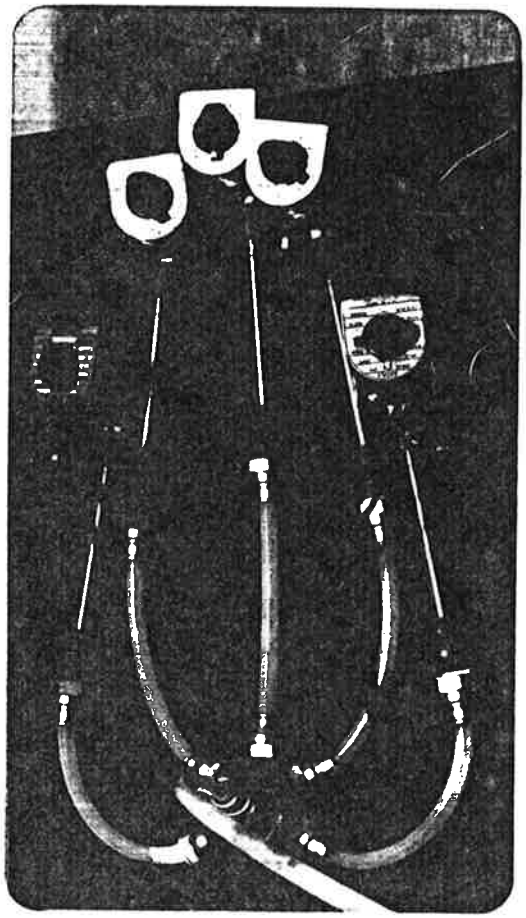
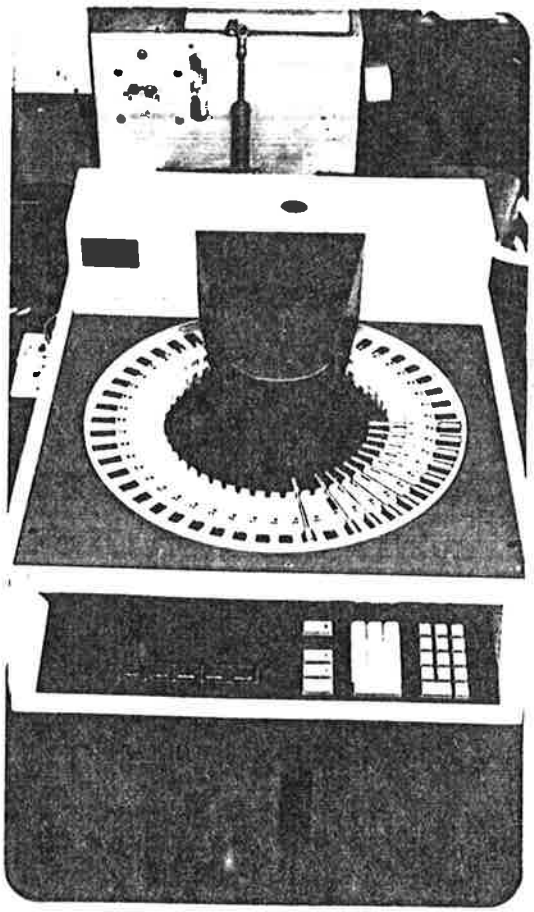


Figure 4. Two-zone, two-tracer test.







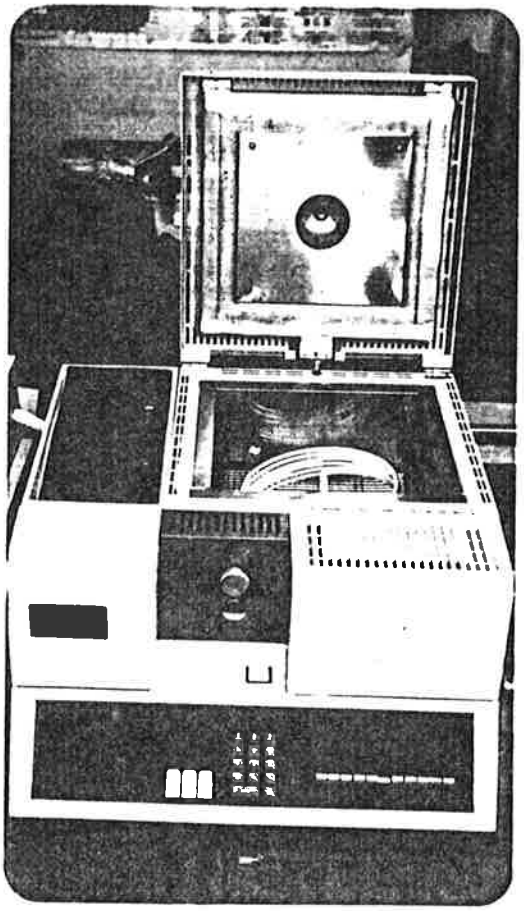


Figure 5.
Top left Pump and controller
Top right One sample point
Lower left Automatic thermal desorber
Lower right Gas Chromatograph

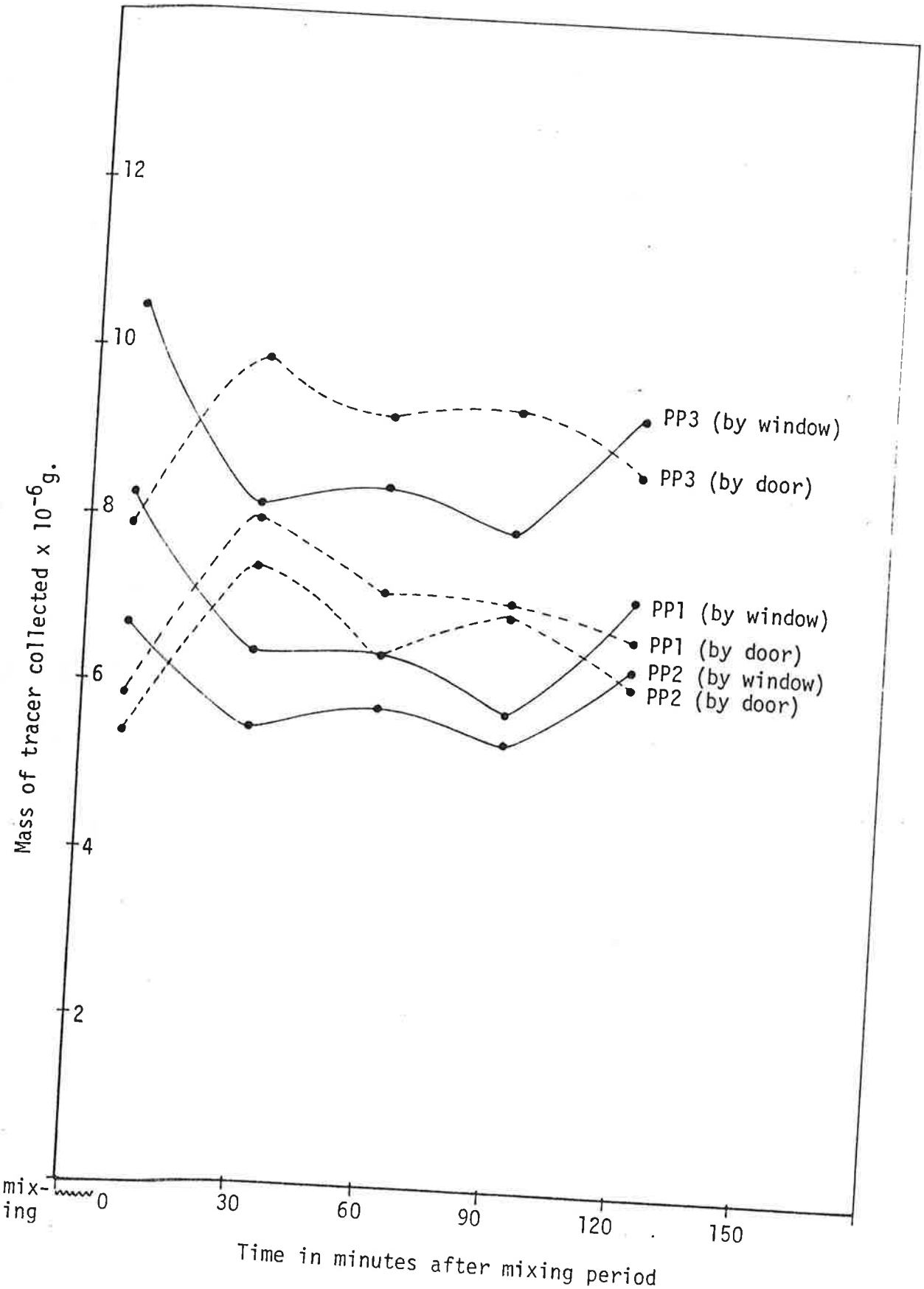


Figure 6. Room absorption test, sample intervals 30 minutes.

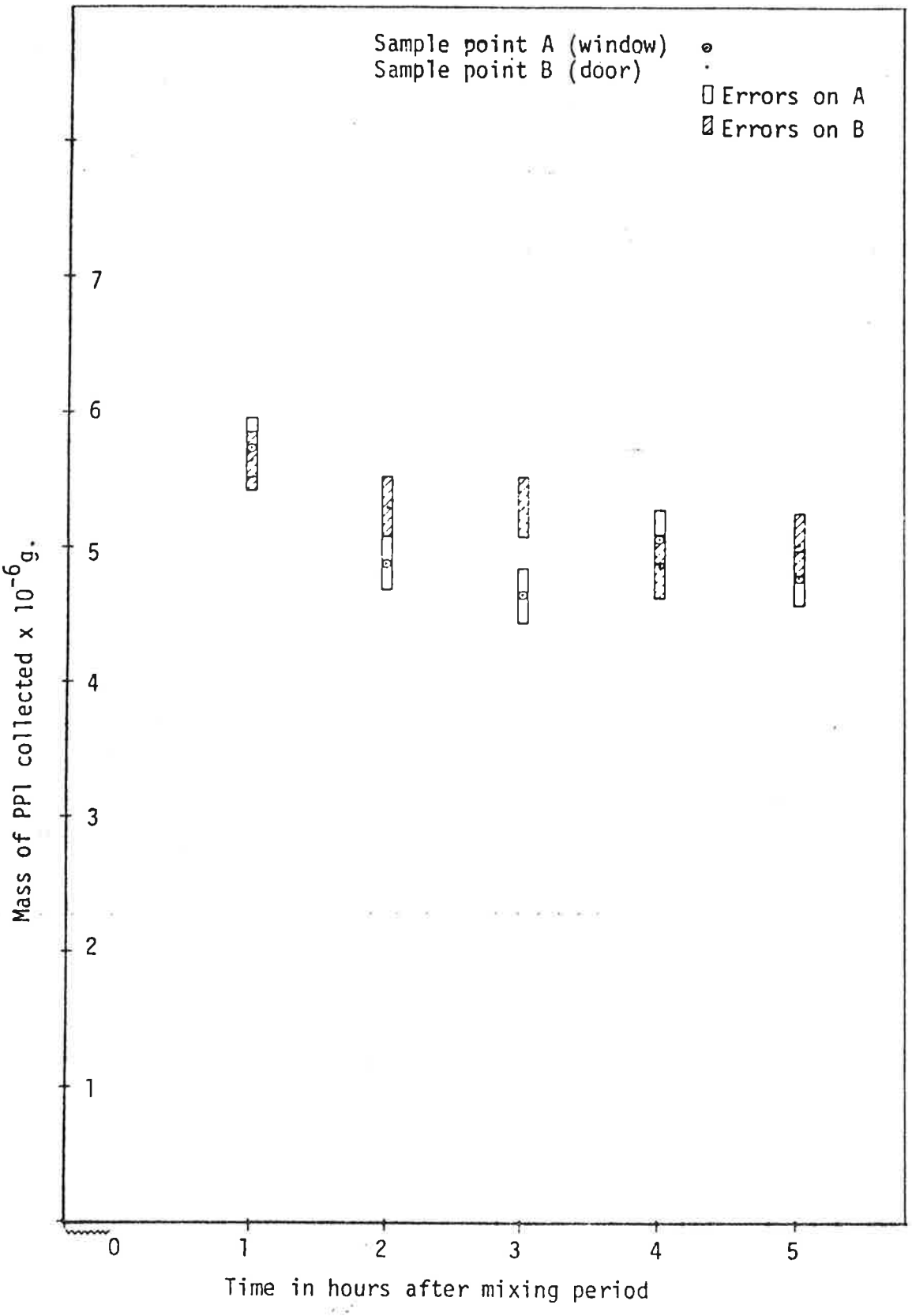


Figure 7. Room surface absorption test with PPl.

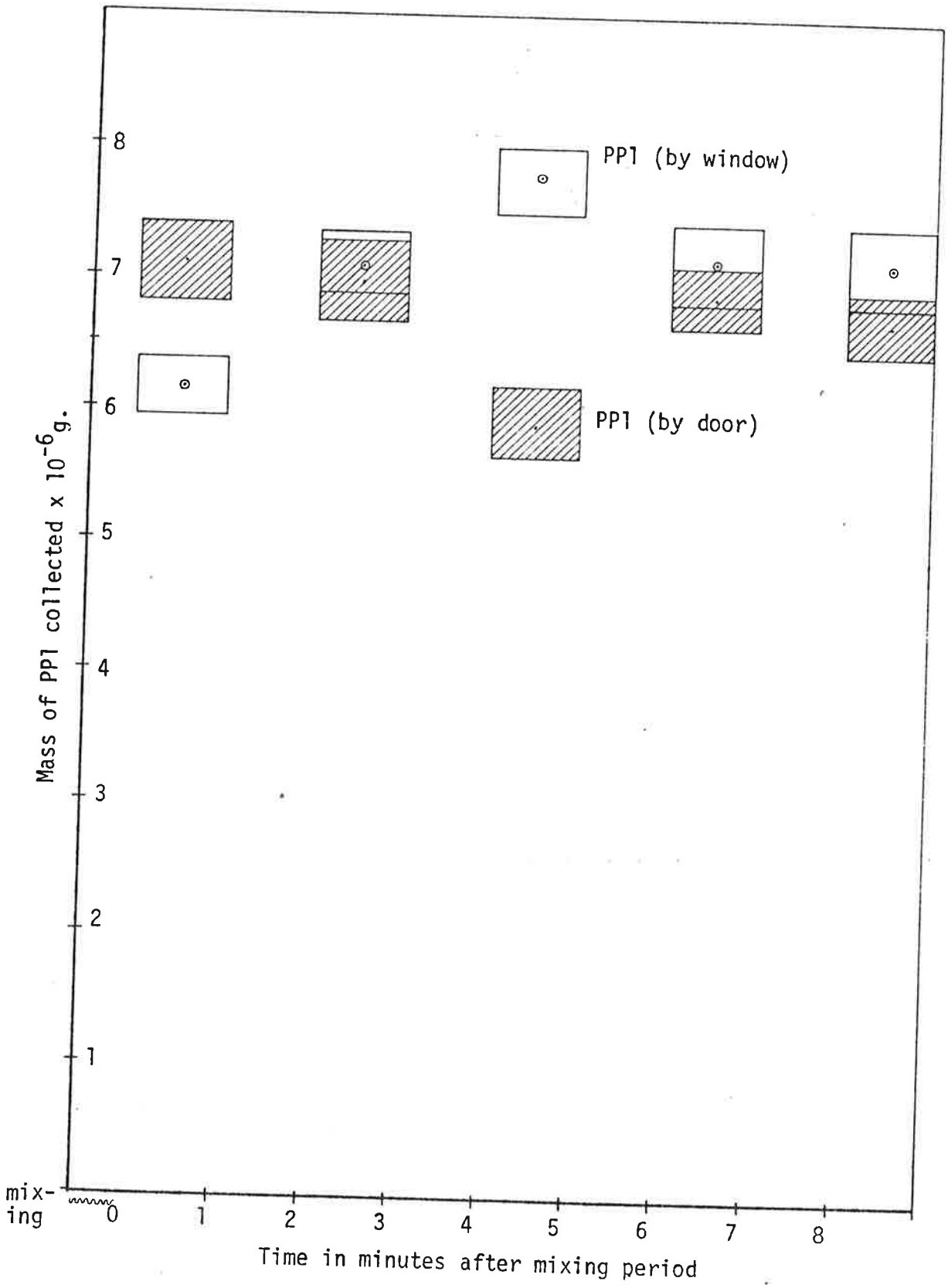


Figure 8. Room absorption test, sample intervals one minute.

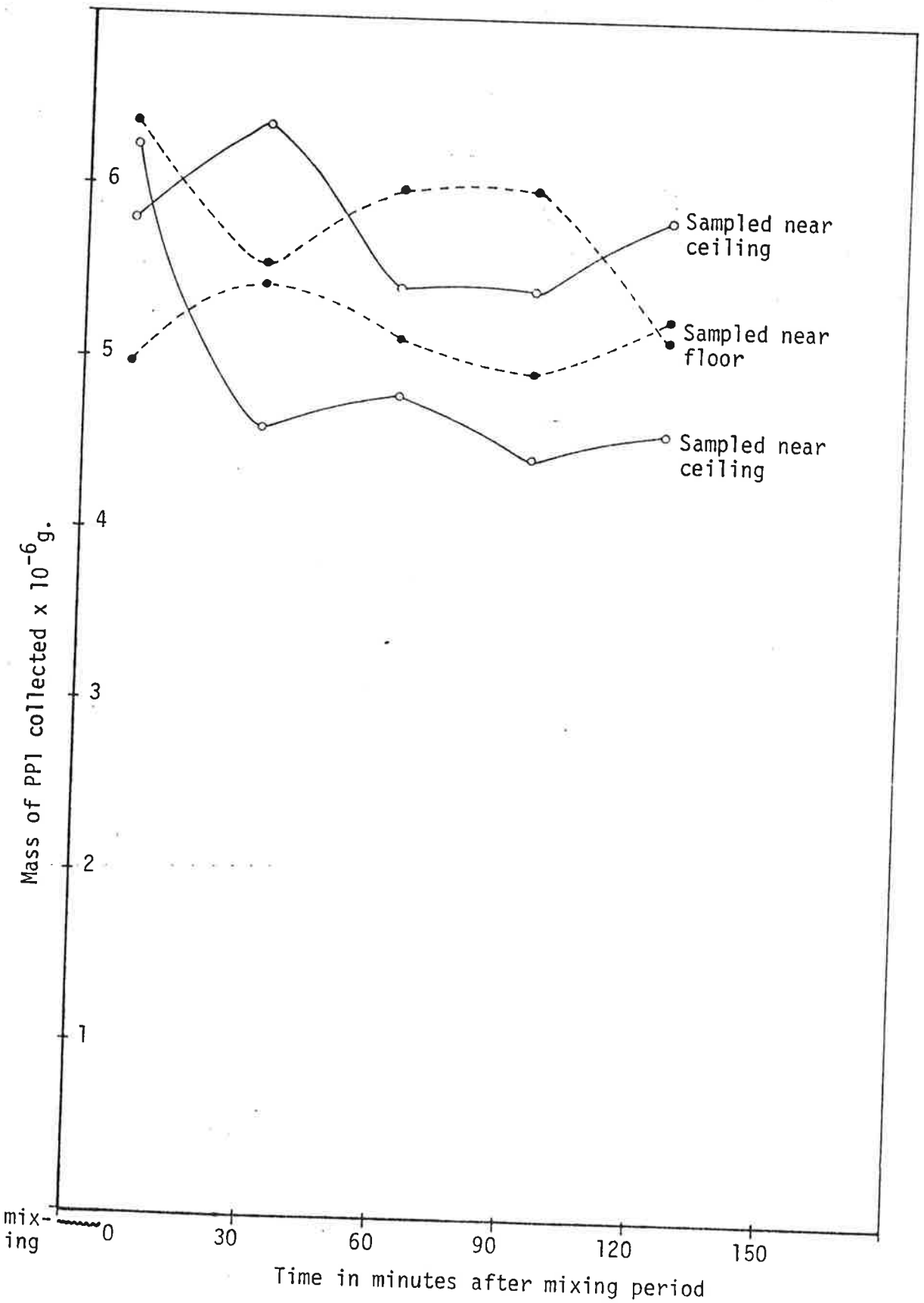


Figure 9. Test to show the absence of stratification: upper curves mixing fan on, lower curves fan off.

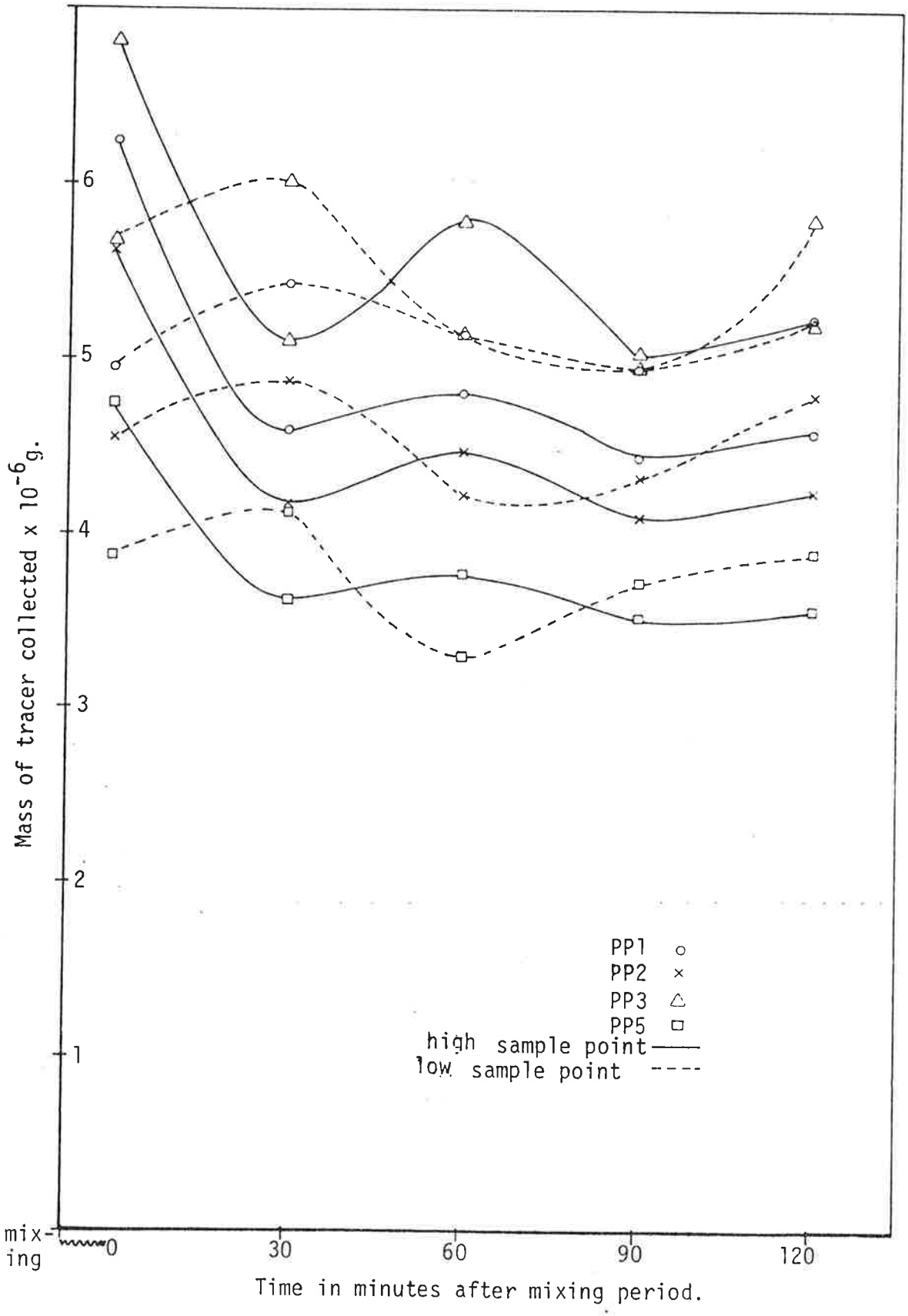


Figure 10. Test to show the absence of stratification with the heavier tracers.

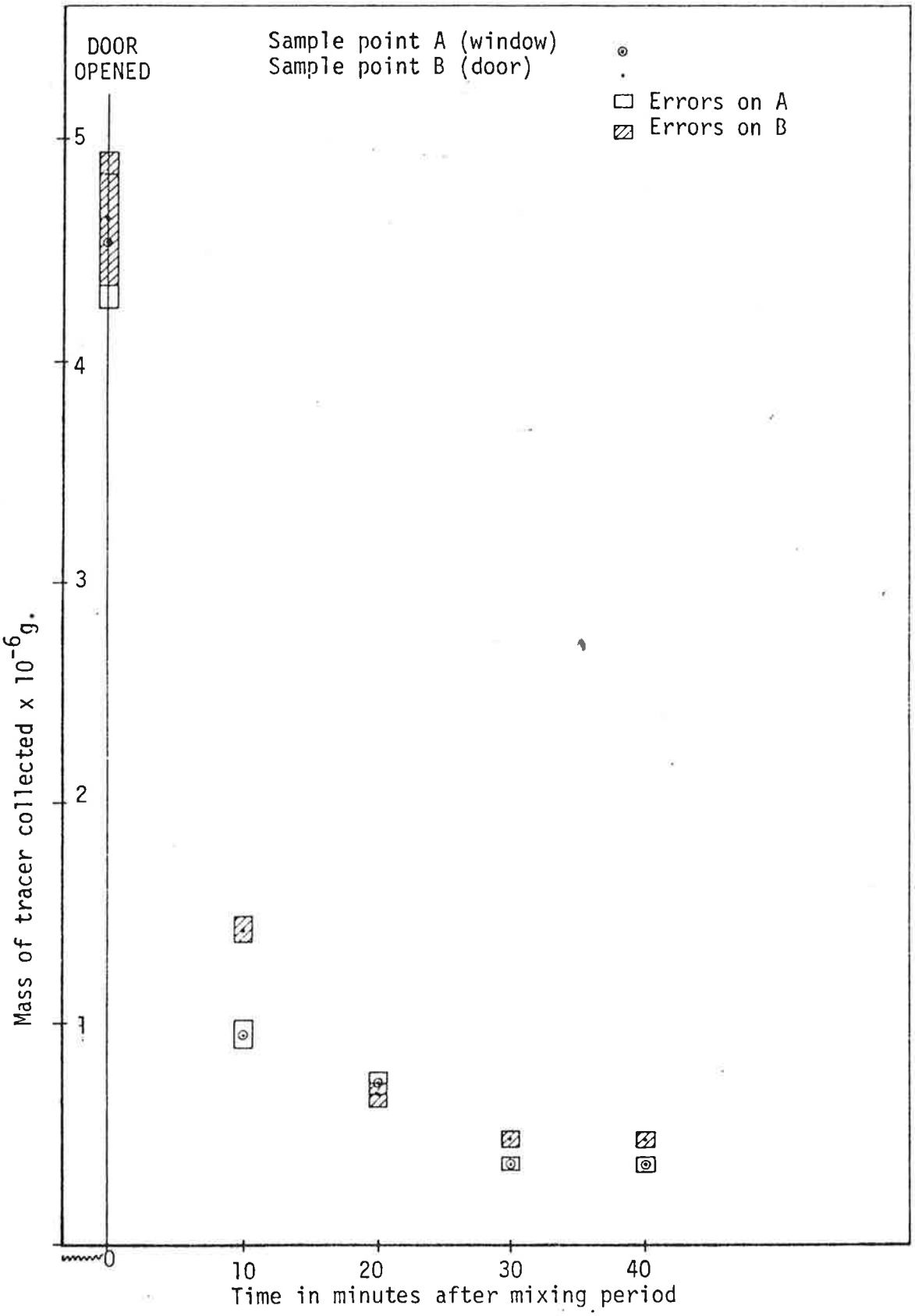


Figure 11. Loss of room air to the corridor on suddenly opening the door. - 10 minute sampling intervals.

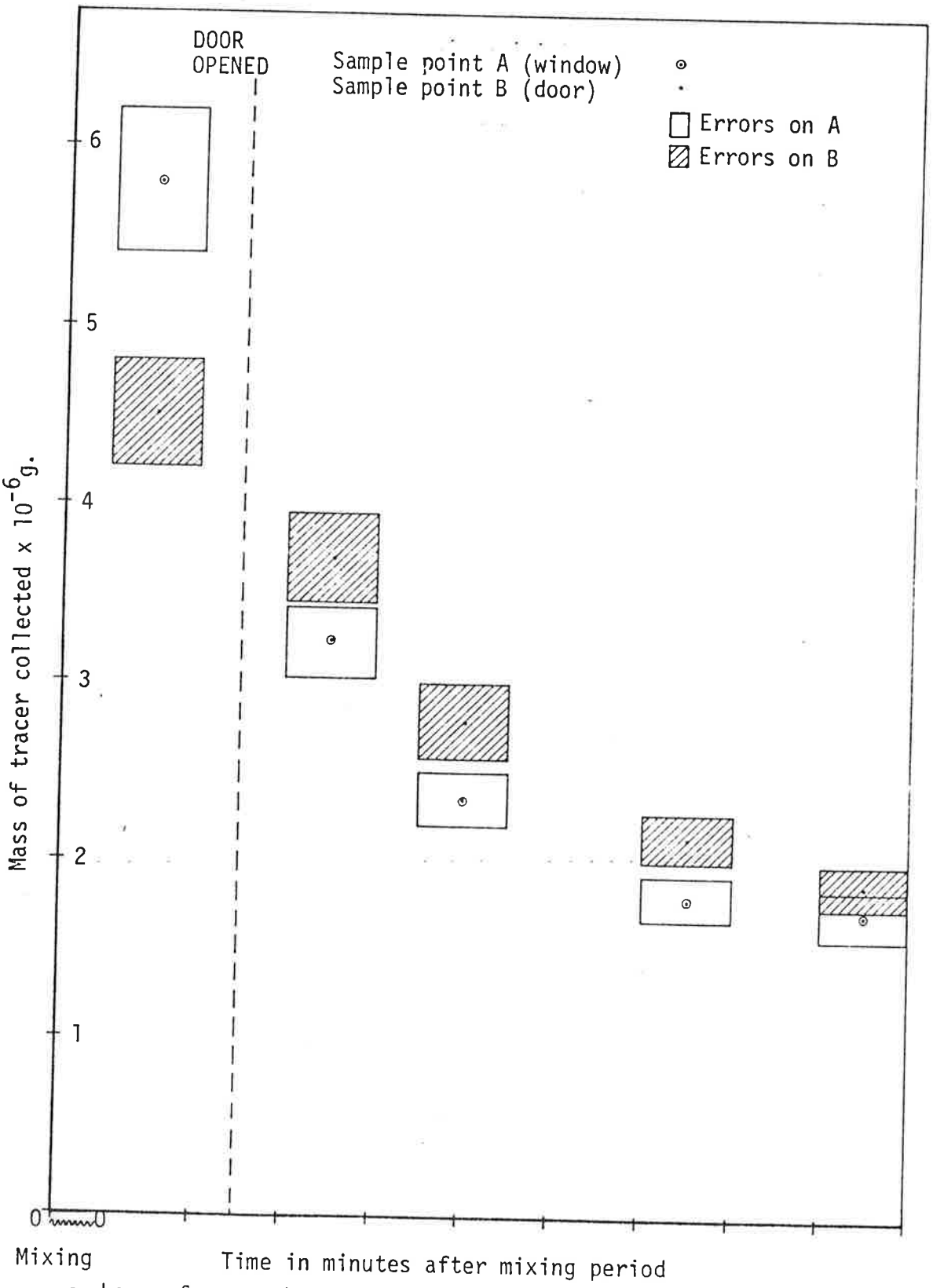


Figure 12. Loss of room air to the corridor on suddenly opening the door.
- sample rate 1 minute intervals

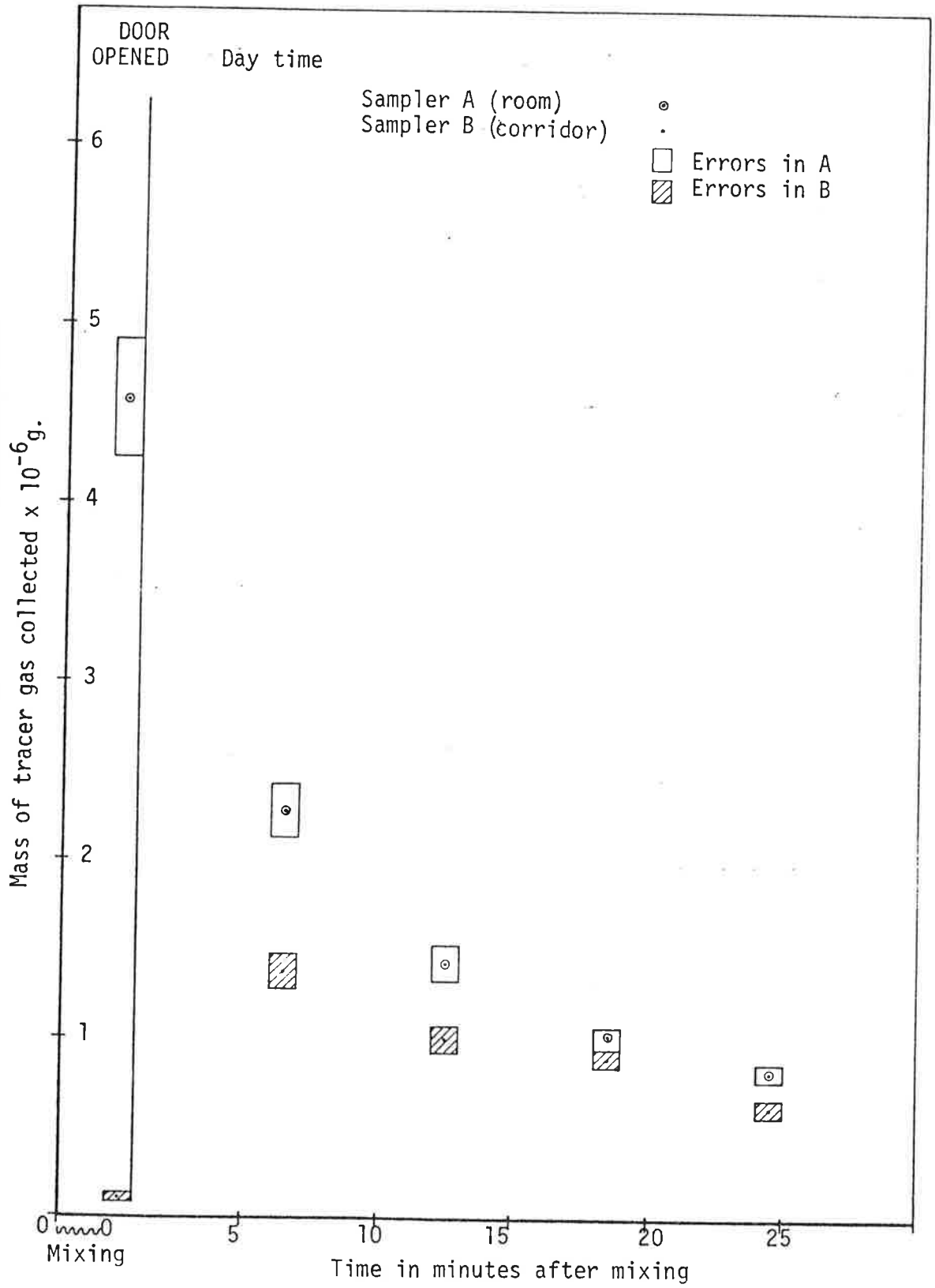


Figure 13. One tracer, two zone test showing air movement between the room and the corridor during the day.

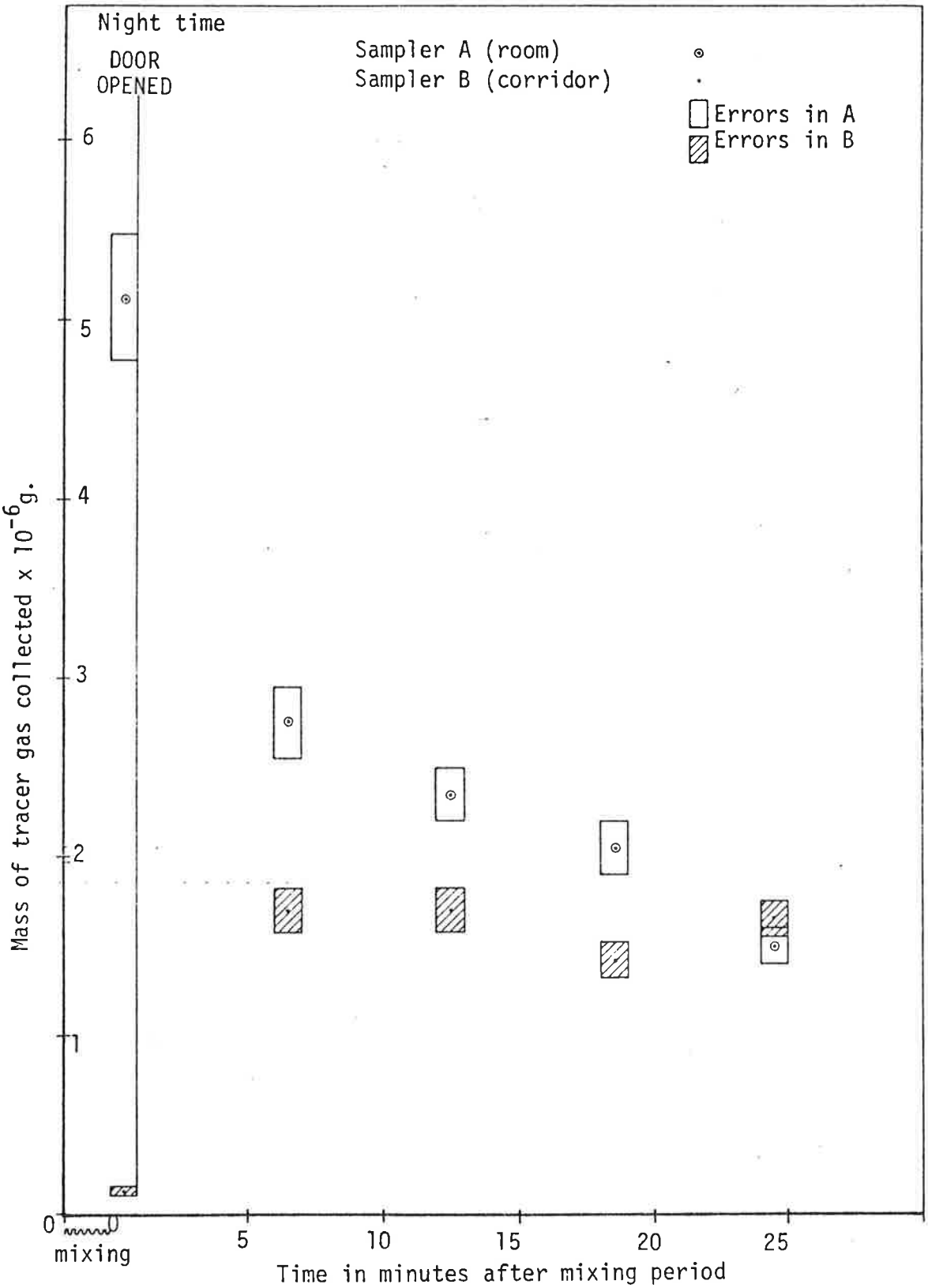


Figure 14. One tracer, two zone test showing air movement between the room and the corridor at night.

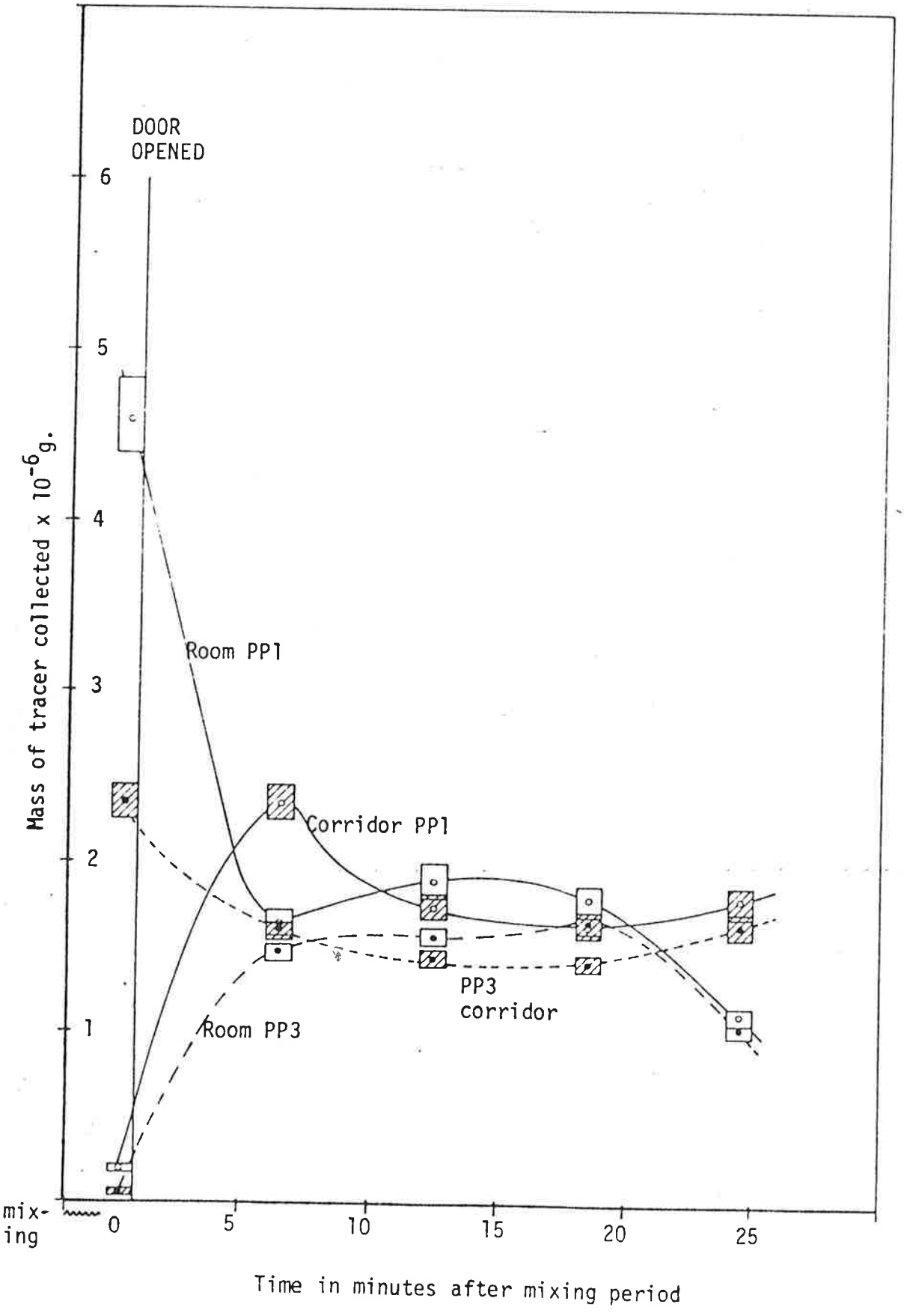


Figure15. Typical curves for a two-zone, two-tracer test.