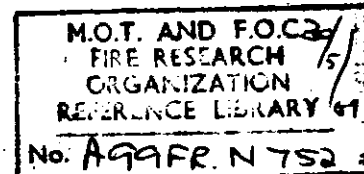


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**TOXIC GASES FROM RIGID POLY (VINYL CHLORIDE)
IN FIRES**

by

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SUMMARY

Tests have been made in a small compartment to examine the effect of the presence of PVC with a cellulosic fuel fire on the toxic gases evolved under different degrees of ventilation.

When the ventilation was small, as might be provided by a fanlight, hydrogen chloride was evolved from the PVC at a low rate, 30 min or more after the evolution of carbon monoxide from the cellulosic fuel, which occurred a few minutes after ignition. When the ventilation was larger, as might be provided by an open door, hydrogen chloride was evolved almost as quickly as carbon monoxide and in comparable amounts. When combustion of the PVC was complete, the hydrogen chloride evolved was equivalent to the chlorine content.

However, the amount of hydrogen chloride produced by the combustion of, say, a PVC wallpaper, would not add much to the toxic risk due to the carbon monoxide formed by the combustion of the cellulosic content of a furnished room.

Further tests are in progress to examine the effect of scale on the combustion processes and to test the feasibility of determining the rate of evolution of hydrogen chloride from the temperatures of surfaces within the compartment on fire.

KEY WORDS: Plastics, poly (vinyl chloride), combustion, toxic gas, ventilation.

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MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

The smoke and toxic gases produced from combustible building materials in a building on fire can reduce the chances of escape of the occupants and put their lives in jeopardy, even if they are far from the fire. Information on casualties for fires attended by the Fire Brigade in the United Kingdom shows that about half the deaths in fires are attributable to smoke and gases. For example, returns for 1966 show that of 780 fatal casualties, 376 were attributable to asphyxiation. Reports received from the Fire Brigades, and experience during fire resistance tests of building components at the Fire Research Station, show that dense smoke and noxious fumes may be released when some plastics are present in a fire.

Although wood and other cellulosic matter at present form the major part of the combustible material in buildings, materials incorporating plastics are being used to an increasing extent, both in the structure and in furnishings¹. In addition cellulosic products are being used that have been treated with compounds to confer special properties, such as flame retardance. It has, therefore, been considered desirable to examine the effect of such changes in combustible materials on the smoke and toxic gases produced in fires, in order to assess the likelihood of any significant changes in hazard.

This note presents the results of tests on the toxic gases evolved from fires in a small scale compartment with mixed fire loads of poly (vinyl chloride) and cellulosic fuels. Three different degrees of ventilation have been studied, ranging from the equivalent of, say, an open fanlight to a fully open door in an otherwise closed room. Two weights of cellulosic fuel were used, one having a volumetric fire load (weight per unit volume) approximating to that of a traditionally furnished room, namely about 9.5 kg/m^3 (0.6 lb/ft^3), and the other twice this value. The poly (vinyl chloride) was present, either as wall linings of thickness 0.5, 1.5, 3 and 6 mm (0.02 , $1/16$, $\frac{1}{8}$ and $\frac{1}{4}$ in) or in strips 3 mm ($\frac{1}{8}$ in) thick incorporated in the cellulosic fire load. A few tests were made also with 0.03 mm ($.001$ in) thick plasticised PVC faced board. The toxic agents which have been considered here are carbon monoxide and hydrogen chloride, which are most likely to be present in significant proportions in the combustion gases. The

results of a similar programme of tests on cellulosic fuels alone, in which the toxic agent considered was carbon monoxide, have already been reported².

EXPERIMENTAL

APPARATUS, MATERIALS AND PROCEDURE

The combustion tests were made in the 0.9 m (35 in) cubical compartment used for tests of cellulosic materials alone². The compartment, constructed of steel lined with 13 mm ($\frac{1}{2}$ in) asbestos mill-board, had a front face which could be opened for introducing the fire load. The front face was also provided with a sliding shutter, which could be lowered to produce a vent of the full width of the compartment and of predetermined height, at the top of the front face. The internal dimensions of the compartment were an 0.9 m cube, and the heights of vent used were 50, 100 and 150 mm (2, 4 and 6 in). The temperature within the compartment was measured by thermocouples, and samples of combustion gases were withdrawn for analysis through tubes, sited as shown in Fig.1. The thermocouples and tubes protruded 20 mm ($\frac{3}{4}$ in) into the compartment from the ceiling or wall. The compartment prepared for test is shown in Fig.2.

A cellulosic fire load of 6.4 or 12.8 kg (14 or 28 lb) of 13 mm square section wood fibre insulating board (WFIB) sticks, 600 mm (2 ft) long, was constructed as a crib by evenly spacing the sticks 13 mm apart on a 600 mm square base, for each test. Most of the tests were made with wall linings of unplasticised poly (vinyl chloride) (UPVC) in four thicknesses, 0.5, 1.5, 3 and 6 mm. The thinnest sheet was supplied calendared on to 4.5 mm ($\frac{3}{16}$ in) hardboard and was erected directly in the asbestos lined compartment. The three remaining thicknesses of sheet were first stuck to 3 mm asbestos millboard, which was then cemented to the walls of the compartment. The remaining tests were made with strips of 3 mm UPVC, 13 mm wide and 600 mm long, which were incorporated in the upper layers of the WFIB crib. In these tests the cellulosic fire load was the same as used in the tests with UPVC wall linings, but the UPVC fire loads used were 2.8 and 5.6 kg (6 and 12 lb), the latter being the same weight as that of the 1.5 mm wall linings.

The cellulosic crib was ignited by an electrically heated coil, dissipating about 50 watts, at the centre of the base of the crib, which first ignited about 2 gm (0.07 oz) of wood wool. The coil was heated for 30 sec to ensure ignition. Records of temperature were taken throughout each test, and samples of gases were withdrawn at intervals for subsequent analysis. The time of origin for each test was taken as the time the electric heating coil was switched on.

The tests were carried out in a large single compartment laboratory measuring 40 x 15 x 12 m (130 x 50 x 40 ft) high, with service rooms opening from it. Personnel were protected from any toxic agents released during the tests by breathing masks supplied with air from a gas cylinder. The temperature of the combustion gases was measured and samples taken throughout each test for as long as possible during the working day. The combustion gases were taken from the chamber by the shortest route, and rapidly reduced in temperature, to minimise changes of composition in the sampling tube. The samples for gas analysis were withdrawn through a series of gas pipettes, the pipettes being isolated from the gas flow at appropriate times. The samples for analysis for hydrogen chloride were withdrawn through silica tubing to a gas bubbler containing sodium bicarbonate solution at a constant rate until a known volume of gas had been passed, this operation being repeated at appropriate times during a test. The temperatures within the compartment were measured by supplying the outputs of the thermocouples to a multipoint potentiometric recorder.

The composition of the emergent gases was calculated on a dry volume basis from gas chromatographic analysis of the permanent gases, oxygen, nitrogen, hydrogen, methane, carbon monoxide and carbon dioxide, and nephelometric determination of hydrogen chloride as silver chloride. Preliminary tests were made to ensure that the analytical techniques were satisfactory. The rate of flow of the combustion gases from the compartment was calculated, using a modified form of the equation presented by Kawagoe³, with a discharge coefficient of 0.9, which had been shown to be the appropriate value for the present tests⁴.

Three important parameters were thus obtained from the test results: the temperature of the combustion gases; the concentration of highly toxic agents, carbon monoxide and hydrogen chloride, and the total quantity of evolved gases, the last being obtained from integration of the rates of evolution during the test period.

RESULTS AND OBSERVATIONS

TEMPERATURE OF EMERGENT GASES

There was a consistent relation in the tests between the ventilation conditions and the temperature of the emergent combustion gases, as is indicated by the mean steady-state temperature of burning presented in Tables 1 to 3. The values were obtained by averaging the gas temperature, omitting the peak

temperatures recorded during the flash ignition of vapours, which occurred after the first few minutes of test. The least reliable mean temperatures are associated with tests at the largest degree of ventilation, because for these tests there was often no period during which the temperature remained substantially constant. For such tests, the temperature was averaged over the estimated period of flaming combustion. The variation of temperature with time of burning for three tests with the same fire load for each of the three ventilation conditions is shown in Fig.3. In this figure, the first peak in temperature in each curve was produced by the flash ignition within the compartment of the combustible gases produced by the initial smouldering of the WFIB fuel. This event was usually followed by continuous smouldering combustion in tests with the 50 mm vent, but smouldering alternated with flash ignition several times in many of the tests with the 100 mm vent; however, in most tests with the 150 mm vent, the initial flash ignition was followed by steady flaming combustion. Each flash ignition was accompanied by a sharp rise in temperature, but the average temperature of the combustion gases after the first flash ignition was fairly consistent until the fire load was largely consumed. The mean temperatures from the above tables for tests with UPVC linings on the walls are about 240°, 350° and 520°C for vents of 50, 100 and 150 mm height and 190° and 425°C for tests with UPVC incorporated in the WFIB crib for vents of 50 and 150 mm depth. The presence of UPVC on the walls had negligible effect on the temperature of emergent gases for tests at 50 mm height but apparently gave a somewhat lower temperature for tests with the larger vent sizes. The presence of UPVC in the crib resulted, however, in lower temperatures at both the vent depths tested.

BEHAVIOUR OF UPVC

The behaviour of UPVC wall linings could be observed through the vent when its height was 100 or 150 mm but only the upper part could be seen when the height of vent was 50 mm. It was not possible to see the crib easily through the vent for any height of vent, and therefore the behaviour of UPVC incorporated in the crib could only be estimated from the appearance of the crib at the end of a test.

The behaviour of the UPVC wall linings appeared to depend on their thickness. The 1.5 mm sheet remained on the walls for long periods of test; the 3 mm sheet peeled away from the top and often fell partially across the crib, but the 6 mm sheet in most tests either stayed in place or fell across the crib as a fairly rigid board. The plastic sheet was usually fully consumed in tests with heights of vent of 100 and 150 mm, but much of the UPVC and some of the WFIB crib

remained in a partly carbonised state at the end of tests with a 50 mm high vent, Figs 4, 5 and 6.

The behaviour of the 0.5 mm thick UPVC calendared on to hardboard was somewhat different. The sheets buckled during tests at high ventilation (150 mm vent) but thereafter the hardboard burnt during the tests and fell in partly consumed pieces, some falling on to the crib. Tests at the lowest degree of ventilation produced neither marked buckling or fracture of the sheet, and the UPVC either remained in place as a blackened glazed mass or as small coils of about 6 mm diameter, Figs 7 and 8.

Both the distribution of the plastic sheet as originally installed and the mode of collapse could be expected to produce a non-uniform distribution of hydrogen chloride gas across the length of the vent. The results of a separate group of tests to examine the distribution of hydrogen chloride are given in Appendix I.

The incorporation of UPVC in the crib resulted in a different behaviour from that of the WFIB crib alone. Whereas in tests with the WFIB crib alone combustion proceeded and the crib was finally reduced to a heap of ash, when UPVC sticks were in the upper layers of the crib, these layers cemented together into a relatively impermeable matrix, supported on the heap of ash produced from the lower part of the crib that was free of plastics, Fig.9. The presence of such a matrix could affect the distribution of gases emerging from the vent: this effect is discussed in Appendix I.

GAS EVOLUTION

The measured evolution of the principal combustion gases during tests is given in Tables 1 and 2 for tests with wall linings of UPVC: results for tests with WFIB alone are included for comparison. The results for tests in which UPVC was incorporated in the WFIB crib are given in Table 3. The yields of carbon monoxide and hydrogen chloride calculated from the composition of the gases emerging from the vent are given in Figs 10 to 22. The percentage of carbon monoxide and hydrogen chloride in the gases emerging from the vent is shown in Figs 23 and 24 for a group of tests at the three vent sizes.

For the tests with UPVC wall linings, Tables 1 and 2, there was no consistent relation between the minimum oxygen concentration or the maximum carbon dioxide concentration of the emergent gases and the degree of ventilation for either WFIB fire load. The concentration of carbon monoxide in the

emergent gases was invariably least for the largest vent size. It was also probably true that the total amount of carbon monoxide evolved was largest for the smallest vent size, but the long time of burning for these tests precluded definite measurements of the amount evolved. The time after ignition when the maximum concentration of carbon monoxide was found was usually shorter than that for the maximum concentration of hydrogen chloride, although the differences were marginal for the largest vent.

The effect of vent size on the above concentrations of gas in the combustion products was more consistent when UPVC was incorporated in the WFIB crib, Table 3. Minimum oxygen concentration and maximum carbon dioxide concentration were usually smaller for the smaller vent size, and the carbon monoxide concentration was larger. The times to reach maximum concentration of carbon monoxide were, as in the tests with UPVC wall linings, usually shorter than those for hydrogen chloride.

The curves for evolution of hydrogen chloride and carbon monoxide with time, Figs 10-12 and 15-17, show that for the smallest vent size, 50 mm high, significant amounts of hydrogen chloride were not evolved until about 90 min after ignition, but significant amounts of carbon monoxide were evolved in less than 20 min. The rate of evolution of carbon monoxide rose rapidly after ignition to a fairly steady value (see the slopes of the curves, Figs 15-17 and 20-22) and then decayed over a long period of time to zero. This behaviour was consistent for tests of WFIB alone, Figs 20-22, but some disturbance occurred when UPVC wall linings were present, Figs 15-17. This may have been occasioned by the collapse of the linings affecting the combustion of the crib. Figures 15 and 20 (50 mm vent) show a similarity in slope, which would imply that the presence of UPVC wall linings does not have much effect on the evolution of carbon monoxide from the cellulosic fire load. Combustion was too rapid in tests with 100 and 150 mm high vents for the slopes to be compared so readily but some similarity can be seen (Figs 16, 17, 21 and 22).

The curves for tests with UPVC incorporated in the WFIB crib (Figs 13, 14, 18, 19) portray differing behaviour. Hydrogen chloride was evolved earlier than when UPVC was present as wall linings although it was still evolved later than carbon monoxide. The rate of evolution of the carbon monoxide was also lower than in comparable tests with wall linings except for the largest cellulosic fire load and the smallest UPVC load at a vent height of 50 mm.

The variation of carbon monoxide and hydrogen chloride concentration with time is given in Figs 23 and 24 for the same group of tests for which emergent gas temperatures were plotted in Fig.3. Figure 23 indicates that peaks in carbon monoxide concentration occurred at about the same time as peaks in temperature, although there was no quantitative relation between the two. However, the peak concentrations of hydrogen chloride followed a different pattern than the peaks of temperature. A possible explanation is that the high concentrations of hydrogen chloride occurred when the UPVC sheet was subjected to a higher temperature environment than that of the upper part of the compartment where the temperatures were measured; this could arise if the UPVC fell on to the burning crib (see Appendix I).

The above figures and tables give data for the complete duration of the tests. In applying the findings to actual fires, and considering the escape of occupants from the building involved, escape should occur in shorter times. Table 4 therefore presents the volumes of the toxic agents, hydrogen chloride and carbon monoxide, evolved during the first hour of the present tests, which has been assumed to be the maximum period of exposure before escape or rescue of occupants. Such agents may escape and contaminate the atmosphere in communicating parts of the building; because of this, the table also includes the volumes of atmosphere that could be contaminated to irrespirability for hydrogen chloride⁵, and to present a lethal hazard in 30 min for carbon monoxide^{6,7}.

A previous examination of the results of tests on the evolution of carbon monoxide from fires in compartments, has suggested that the concentration of carbon monoxide in the evolved combustion gases may be related to the cellulosic fuel load and ventilation conditions in compartments by the factor AH^{2W-1} (Ref.2). This relation is reproduced as a curve in Fig.25. The volume rate of escape of combustion gases from compartments in which the amount of ventilation is equivalent to the three amounts used in the present tests is given in Fig.26. The data is given for rooms 3.05 m (10 ft) high, making the assumption that the temperature of the gases is in excess of 200°C and hence that K is constant in the equation given below.

The values are calculated from the equation

$$R = CKAH^{\frac{1}{2}} \text{ m}^3/\text{min}$$

where R is the volume rate of flow of gases in or out of the vent at ambient temperature

C is the discharge coefficient (value 0.9 for the present tests)

and K is a buoyancy factor, increasing with temperature to about 200°C, but nearly constant thereafter at a value of 33.3.

Thus, estimates of carbon monoxide concentration for given ventilation conditions derived from Fig.25 may be used to calculate rates of contamination of atmosphere in a building by the escape of combustion gases from a burning compartment, the rate of escape being found from Fig.26. Points for the average concentrations of carbon monoxide from the present tests have been plotted in Fig.25. In deriving the fuel load that could produce carbon monoxide in fires, the weight of the carbon and hydrogen in UPVC has been added to the weight of the cellulosic fuel. These show sufficiently good agreement for this approach to be justified, although there is an indication that the slope of the curve may be steeper for fire loads in which cellulosic matter and PVC are combined.

No such relation was found to exist for the evolution of hydrogen chloride. However, the concentration increased with increasing ventilation factor, AH^2 ; as the temperature of the gases also increased with increased ventilation some form of kinetic process is indicated. The relation between small scale laboratory decomposition rates, and those in the present tests is presented in Appendix II, and the relation is plotted in Fig.29. It is not possible at this stage of the programme to present the results in a way that permits extrapolation to buildings of other sizes and geometries.

EFFECT OF SMALL LOADS OF PVC (WALLPAPER)

A few exploratory tests were made with an asbestos board coated with a thin layer of paper coated with plasticised PVC. Only slight odours of hydrogen chloride were detected when the compartment was approached at intervals during these tests.

Calculation of the amount of hydrogen chloride that could be evolved from the complete combustion in the compartment of a 0.1 mm (0.004 in) thick layer of PVC, i.e. approximately the thickness of the coating on the above-mentioned board, gave a value of 0.1 m^3 (3.5 ft^3). Under the higher conditions of ventilation used, 12.8 kg of wood fibre insulation board would produce about $1-3 \text{ m}^3$ ($35-105 \text{ ft}^3$) of carbon monoxide during the first hour of burning, estimated as producing as much atmosphere contaminated to the toxic level adopted for consideration as the hydrogen chloride would produce of atmosphere contaminated to irrespirability (see Discussion).

DISCUSSION

The introduction of combustible materials into buildings other than the traditional cellulosic materials may alter the decomposition products from existing cellulosic fuels and may also produce additional toxic agents. The problems presented by toxic agents from a fire in a compartment in a building are manifold. These include the risk within the compartment, the risk in the approach routes to the compartment, and the risk in other parts of the building containing the compartment. Provided that the findings of the present tests can be applied to larger scale compartments, the conclusions from the present tests may be applied to buildings at risk.

Taking 9.6 kg/m^3 as the average volumetric load of cellulosic matter in a furnished compartment, the test fire load of 6.4 kg of WFIB is about the same volumetric load, 9.2 kg/m^3 (0.58 lb/ft^3). Published data on the hazard of toxic agents in air suggest concentrations of 0.3 per cent of carbon monoxide, 0.15 per cent of hydrogen chloride and 10 per cent of carbon dioxide as presenting a lethal risk after 30 min exposure and a reduction to 10 per cent of oxygen in the atmosphere as presenting a similar risk^{6,7}. However, because atmospheres containing hydrogen chloride become intolerable to breathe if its concentration exceeds 0.01 per cent⁵, this lower concentration would seem more appropriate than the toxic concentration for estimating the effect of hydrogen chloride on escape. It is unlikely that either the presence of carbon dioxide or the depletion of oxygen are significant hazards, except in the compartment on fire, provided there has been no spread of fire beyond the compartment. Under the latter condition occupants of the building other than those fighting the fire would have escaped or retreated to more remote parts of the building, where dilution of the combustion gases with air would rapidly produce safer atmospheres.

The atmosphere in a room with an average content of combustible materials would rapidly become lethal if a fire occurred (Fig.24). If, however, the combustion gases from such a fire are vented solely into the remainder of the building, then the important parameters affecting the well-being of occupants are: the rate of evolution of toxic gases from the compartment on fire, and the total volume evolved in the period up to the evacuation of the occupants.

Escape should take place shortly after the time of discovery of a flaming fire, because of the possibility of rapid spread of fire and the high rates of evolution of toxic gases, and times for escape of up to 15 mins have been assumed. However, the time between ignition and escape could be longer if a fire occurred under conditions of low ventilation, so that it might smoulder for a long period.

It is also likely that a flaming fire would be detected more quickly than a smouldering fire. In the following discussion, it has been assumed that exposure of up to one hour could occur in the case of a smouldering fire.

Data, as presented in Figs 10-24 may be used to calculate the concentration of toxic agents, in the corridors and parts of a building through which combustion gases are dispersed, at different times after ignition.

For the condition where combustion gases escaping from a burning compartment enter, say a corridor where they mix turbulently with the air therein, and the mixed gases and air escape through another opening in the corridor without there being any recirculation of the mixed gases to the fire, the proportion of combustion gas in the atmosphere in the corridor at a given time is given by

$$C_t = 1 - \exp. -Rt/V \quad (1)$$

where C_t is the proportion of combustion gases in the atmosphere of the corridor after discharge of the combustion gases for time t

R is the rate of discharge of the combustion gases into the corridor

and V is the volume of the corridor.

This condition, which depends on the complete mixing of combustion gases and air, is not likely to be met in practice because the buoyancy of the hot combustion gases and their rate of discharge would both encourage stratification, with the combustion gases forming an upper layer. However, the calculation would permit the estimation of the relative hazard of different fuels and different compositions and rates of discharge of combustion gases.

Thus for example, if combustion gases containing 5 per cent of hydrogen chloride were escaping at $5 \text{ m}^3/\text{min}$ ($165 \text{ ft}^3/\text{min}$) into a corridor of 200 m^3 (7000 ft^3) volume, mixing turbulently with the air, then the concentration of hydrogen chloride in the corridor would reach the intolerable level of 0.01 per cent (0.2 per cent of the combustion gases) in about 5 sec. This implies an impractically high mixing rate, and it is therefore likely that there would be a condition in the corridor approaching the plug flow of the combustion products towards the escape vent. If the combustion gases contained 0.1 per cent hydrochloric acid, then the intolerable level would be reached in 4 min 12 sec when the atmosphere in the corridor would contain 10 per cent of combustion gases. Full mixing could well occur under these conditions.

For the condition of a corridor ventilated at a known rate R_v and combustion gases escaping from a burning compartment at a rate R_c , the

concentration of the combustion gases swept along the corridor, assuming turbulent mixing, would be approximately

$$C = \frac{R_C}{R_V + R_C} \quad (2)$$

Thus, for example, using the same combustion gas conditions as in the previous calculations, and assuming a corridor of cross section of 6 m^2 (65 ft^2) ventilated at a speed of 30 m/min (100 ft/min), the concentrations of hydrochloric acid downwind of the escaping gases would be 0.135 per cent and 0.0027 per cent respectively. These concentrations indicate that the atmosphere would be lethal for short exposure for the first condition and irritant but not unbreathable for the second. Therefore, an assessment can be made of the degree of risk to persons entering the corridor, and by the combined use of equations 1 and 2, the times at which remote communicating parts of the building become affected by the combustion gases to an extent affecting persons therein, can be estimated.

If it can be assumed that there is no restriction to gas flow into all other parts of the building from the compartment on fire, the building may be considered as one simple volume V and equation (1) applied.

As is shown in the above examples, the toxicity of the mixed atmospheres estimated from the above equation may be assessed by determining the concentrations of toxic agents, obtained by multiplying the concentration of combustion gases in the atmosphere C by the concentration p of the toxic agent in the combustion gases. If the value of p varies appreciably with time, as is usually the case, stepwise calculation would be needed.

However, simple comparison of the toxic hazard presented by different combustibles and conditions of ventilation can be made from estimates of the amount of toxic gases that would be formed in the maximum period during which escape could be effected after ignition of a given fire. Such periods would be dependent primarily on the degree of ventilation. For example, if a smouldering fire started in a room ventilated only by a fanlight, a considerable time could elapse before the fire burnt through barriers, such as doors, or the products of combustion were detected by a passing occupant. For this condition, a maximum time for detection and escape of one hour has been assumed. For fires occurring in compartments with higher degrees of ventilation, such as that provided by an open door, when flaming combustion could be expected, the shorter time of 15 min has been assumed.

Table 4 shows that the hazard due to carbon monoxide from fires of cellulosic fuels did not vary much between the three sizes of vent tests, but increased with increasing load of fuel, and was greater when some of the fuel was present as a wall lining. However, when UPVC was present, differences between the two loads of cellulosic fuel were less but the amount of carbon monoxide produced was greater than for the cellulosic fuel alone. These results can be brought together when the contribution of the carbonaceous matter in the plastic is taken into account, together with any cellulosic content of backing material (Fig.25). The results for tests with UPVC wall linings show similar behaviour to the tests of cellulosic fuel alone, from which the curve in Fig.25 was constructed. The results for the tests with UPVC incorporated in the crib, however, show a marked deviation, the values of average carbon monoxide concentration relating to a steeper curve than the one given, higher concentrations of carbon monoxide being obtained at lower values of $AH^{1/2}W^{-1}$. This difference may be associated with the observed presence of a matrix of cemented UPVC and cellulosic combustion products on top of the crib. Such a barrier to the supply of oxygen bearing gas could mean that the crib fire was burning in a less well ventilated environment than that presented by the compartment as a whole. The lower values of carbon monoxide concentration at higher values of $AH^{1/2}W^{-1}$ may be explained if the escape of combustible gases at high temperatures is such that better mixing with oxygen bearing gas and hence more efficient combustion is obtained because of the matrix.

The evolution of hydrogen chloride increased with increased ventilation and hence temperature (Appendix II). No significant amounts were produced in the first hour in tests with the 50 mm high vent, except for those tests with UPVC in the crib and test I20. At the larger vent sizes, the volumes of harassing gas were invariably larger than the volumes of toxic atmosphere due to carbon monoxide. The observed large scatter in the measured recoveries of the chlorine content of the UPVC as hydrogen chloride is probably due to the softening and collapse of the sheets as the fires developed with consequent uneven release and irregular distribution of hydrogen chloride particularly if the wall linings encroached on the crib fire. A test was conducted by the Rubber and Plastics Research Association, in which the adhesion of the sheets of plastic to the walls was superior to that in the present tests.¹⁰ The plastic sheets remained attached to the walls for the duration of the test and no sharp peaks in hydrogen chloride concentration were noted for the period when measurements were made (about 30 min). In other respects, the test at RAPRA broadly confirmed the

results reported here.

The low recovery of available chlorine as hydrogen chloride, obtained when UPVC sticks were incorporated in the upper layers of the crib, was probably brought about by the cemented matrix formed on top of the crib during combustion. Such a matrix would deflect the combustion gas and could therefore alter the distribution across the vent.

Application of the present results to the behaviour of PVC in a room or compartment involved in a fire presents some difficulties. The attachment of wall linings could be either by locking strips, which would be the only attachment to the wall, or the linings could be more securely fixed to the wall or a substrate. For the first condition, collapse would occur earlier than in the tests, and for the latter, much later if at all. Spacing of the wall linings from the sources of fire could be greater or less than the 135 mm ($5\frac{1}{4}$ in) in the tests. The cellulosic combustibles in the room could behave differently after ignition. Indeed some preliminary tests in a large compartment, in which the bulk of the cellulose was 50 mm (2 in) square section timber, ignited by a small amount of more readily ignitable combustible cellulose, it was found that smouldering combustion, as obtained in the present tests at low degrees of ventilation, did not become established. However, earlier tests on cellulosic fuels alone in the same large compartment² did not indicate different behaviour with scale for flaming fires. However, the data in Table 4, and Figs 25 and 28, indicate that when the ventilation/fire load ratio is small, the risk due to carbon monoxide far outweighs the risk due to hydrogen chloride, but that the reverse applies when the ventilation/fire load ratio is larger, when the amount of hydrogen chloride evolved would become more dependent upon the amount of PVC in the compartment. For high ventilation it may be assumed that all the chlorine content of the PVC present could be released as hydrogen chloride during a fire.

The most promising approach to the problem of estimation of evolution of hydrogen chloride in full scale compartments would appear to be presented by a study of the temperature gradients set up in layers of PVC subjected to thermal environments produced by fires. Ample data are available on the thermal environments, but more information is required on the temperature gradients existing in exposed PVC. This is being sought.

CONCLUSIONS

The results of the tests reported herein suggest that, when a fire starts in a compartment of a building, the risk due to the evolution of carbon monoxide is an immediate one, but the delay in the evolution of hydrogen chloride from a compartment containing both cellulosic materials and poly (vinyl chloride) is significant only if the ventilation is low, for example, that provided by an open fanlight. If the ventilation is higher, for example, an open door, then the risk due to hydrogen chloride evolved from the plastic occurs soon after the emission of carbon monoxide, and the total quantity released is a proportion of the weight of the plastic present. For amounts of poly (vinyl chloride) as may be presented by a coated wallpaper, the amount of hydrogen chloride released should not materially increase the risk above that already presented by the carbon monoxide produced from the cellulosic contents of the compartment.

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APPENDIX I

The evolution and distribution of combustion gases

Effect of sampling position

The usefulness of the values obtained for the quantities of toxic gases evolved depends upon whether the composition of the samples of gas collected, which could differ for different sampling positions, is representative of the average composition of the gases evolved at the time of sampling. It was shown, from a series of tests in which propane was burnt effeciently in a manner simulating the cellulosic crib fire, that the sampling position invariably used in the present tests, namely, at the middle of the vent and 20 mm below the ceiling of the compartment, gave a gas composition in accordance with the average composition of the emergent gases⁴.

However, if the fuel distribution were different from that of the crib fire, for example, if wall linings of UPVC were present, the above sampling position might not be equally representative. This may be examined simply for UPVC, because it has been shown that, under a wide variety of conditions of combustion or pyrolysis, the chlorine content of the plastic is evolved very nearly quantitatively as hydrogen chloride^{8,9}. Thus, the calculated value for the hydrogen chloride in the emergent gases can be compared with the expected yield of hydrogen chloride from the chlorine content of the plastic, for those tests in which the plastic is totally decomposed. The results for appropriate tests in the present series is given in Table 5; these show that the recovery of hydrogen chloride was erratic. Table 6 shows also that the recovery varied between different sampling positions.

Some tests made with heat provided by the propane burner mentioned above, and with wall linings of UPVC, indicated that erratic distribution of hydrogen chloride was obtained also with this system (Tables 7 and 8). There was a rapid collapse and combustion of the UPVC wall linings in these tests, because the temperature within the combustion compartment rose rapidly to the steady state value which was well above the softening point of the UPVC, and this restricted the number of samples that could be collected. Although some of the variation could have been due to the position of the UPVC on the walls, some was due to the softening and collapse of the thermoplastic UPVC, (Figs 27 and 28), which, in the case of the thicker, 3 mm sheet tested, extinguished the propane flames.

An estimate of the significance of these variations on the recovery of hydrogen chloride was made for those tests in which combustion of the UPVC sheet

was complete or nearly so. The mean values of the percentage recovery, and the standard deviation for comparable groups of these tests are given in Table 9. If the first two groups in the Table are considered to be from a single population, application of Student's t-test shows that the population could have a true mean of 100 per cent recovery.

The actual concentration of hydrogen chloride in the combustion gases at any particular time would, however, be affected by the position of the wall linings. If the wall linings remained on the walls, they would then be in an environment at the gas temperature within the compartment. However, if the wall linings collapsed and fell on to the crib fire, then the heat transfer to the sheet resulting in decomposition would be at a much higher rate, due both to better conditions of heat transfer, and to an environment at higher temperature than the gas temperature within the compartment. Under these conditions, increased values of evolution of hydrogen chloride would be expected. This could well be the explanation of the sudden increase in hydrogen chloride shown in Fig.24 for the test with a 50mm vent.

The recovery of hydrogen chloride for tests in which UPVC was incorporated in the WFIB crib was shown by application of Student's t-test to be significantly less than 100 per cent. It is considered that as the decomposition of plastic appeared to be complete, the lower than theoretical yield was brought about by the impermeable matrix of carbonised UPVC and WFIB at the top of the crib deflecting the combustion gases sideways, so producing an enhanced content of hydrogen chloride at the edges of the vent. This contention is supported by the yields of carbon monoxide, which would be expected to be similarly affected, recorded in Tables 1-3 of the main report.

APPENDIX II

Temperature dependence of the evolution of hydrogen chloride from UPVC

The relation between the evolution of hydrogen chloride and the uniform temperature of small samples of UPVC has been studied in the laboratory⁹. The time for the evolution of half of the available hydrogen chloride and the uniform temperature of the UPVC extrapolated from the results of these studies is given in Fig.29. For such data to be applied to the compartment tests reported herein, the temperature of the decomposing surface of the plastic is required. This was not measured in the tests; however, in two tests in the same compartment, lined only with the 13 mm asbestos board, the temperature of the exposed surface of the board was measured as well as the emergent gas temperature. An estimate of the temperature of the exposed surface of the asbestos board was made for differing emergent gas temperatures by assuming a logarithmic relation between these two temperatures between the limits: ambient temperature, when the temperature of the exposed surface and the gas in the compartment would be the same, and the emergent gas temperatures in the two experiments, Fig.30. To apply these data to the compartment tests in this report, the further assumptions were made that the temperature of the exposed surface of the UPVC wall lining would be the same as that of the asbestos sheet, Fig.30, and that the softening and collapse of the sheet plastic, and the presence of carbonised matter on its surface did not alter the temperature of the decomposing surface of the plastic.

The times for the release of half the available hydrogen chloride at the estimated wall temperature were then plotted against the times for the release of half the total yield of hydrogen chloride for those tests in which decomposition was complete, Fig.31. These results show that the time for evolution of hydrogen chloride in the compartment tests is much slower than in the laboratory tests, and that, although there is a correlation between the rates of evolution, the correlation is different for different amounts of cellulosic fuel. Because only one face of the plastic sheet was exposed in the compartment tests, and all surfaces of the plastic were at the same temperature in the laboratory tests, the release of hydrogen chloride in the compartment tests under otherwise equivalent conditions would be expected to take about twice as long as in the laboratory tests. Also the compartment tests started with a low rate of combustion and a rising gas temperature, whereas the laboratory tests were made at a constant temperature, which would result for the first part of the tests, in a lower wall

temperature than that estimated for steady state conditions, Fig.30. Also, the presence of a layer of expanded carbonaceous matter over the surface of the decomposing plastic, and the temperature gradient from cool incoming air at the bottom of the compartment to hot combustion gases in the upper part of the compartment would both result in lower average surface temperatures of the plastic than those of the escaping combustion gases. The difference between tests at the two loads of cellulosic matter is more difficult to explain. One important difference in behaviour which may have a bearing was the longer time taken during tests at the higher cellulosic load to attain maximum or steady state temperatures; this could result in the surface temperature of the plastic sheet rising at a lower rate and hence prolonging the time for release of hydrogen chloride.

TABLE 1

Gaseous combustion products from 0.9 m cubic chamber
lined with rigid poly (vinyl chloride) sheet.
Crib fire load of 6.4 kg wood fibre insulation board

Test No.	I14	I13	I3 & I12	I6	I8	I25	I11	I10	I9	G3	G2	G1
PVC load, kg	5.6	5.6	5.6	10.7	10.7	10.7	21.9	21.9	21.9	Nil	Nil	Nil
PVC thickness, mm	1.5	1.5	1.5	3	3	3	6	6	6	"	"	"
Vent height, mm	50	100	150	50	100	150	50	100	150	50	100	150
Time of burning, min	>205	±210	±105	±210	>210	±150	±300	>390	±210	±160	>60	±60
Mean temp. of burning, °C	225	320	500	210	275	605	230	300	500	210	500	600
Min. O ₂ content, %	5.9	8.8	2.3	8.7	6.8	4.6	8.4	3.4	6.0	6.6	5.2	2.6
Time of min. O ₂ , min	60	15	10	10	5	10	60	15	20	51	10	10
Max. CO ₂ content, %	11.4	9.8	15.7	10.2	13.6	12.6	9.7	14.5	12.8	12.5	15.2	18.2
Time of max. CO ₂ , min	60	15	10	10	5	10	20	15	10	51	10	10
Max. CO content, %	5.72	3.8	3.1	7.4	3.5	3.8	4.8	4.1	2.4	4.9	2.8	2.7
Time of max. CO, min	15	30	10	10	10	10	75	20	25	15	10	10
Max. HCl content, %	0.14	1.81	1.88	5.5	1.66	3.46	4.16	5.17	12.1	-	-	-
Time of max. HCl, min	90	25	15	180	90	25	105	75	20	-	-	-
Total CO evolved, m ³	> 2.1	> 2.38	> 1.19	± 1.13	> 2.46	± 2.03	± 1.92	± 2.83	1.57	> 0.68	> 0.53	± 0.54
Total HCl evolved, m ³	> 0.04	> 0.71	> 0.54	> 0.81	± 0.85	> 1.95	± 1.88	± 4.84	3.74	-	-	-
HCl % of original chlorine	> 2.2	> 38.2	> 29.4	> 22.3	± 24.1	> 55.1	± 25.2	± 66.7	52.8	-	-	-

TABLE 2

Gaseous composition products from 0.9 m cubic chamber
lined with rigid poly (vinyl chloride) sheet.
Crib fire load of 12.8 kg wood fibre insulation board

Test No.	I20	I19	I18	I17	I16	I24	I23	I22	I21	G13	G5	G6
PVC load, kg	5.6	5.6	5.6	10.7	10.7	10.7	21.9	21.9	21.9	N11	N11	N11
PVC thickness, mm	1.5	1.5	1.5	3	3	3	6	6	6	-	-	-
Vent height, mm	5	10	15	5	10	15	5	10	15	5	10	15
Time of burning, min	> 360	> 240	± 200	> 360	> 360	200	> 360	> 330	± 300	± 398	> 90	> 60
Mean temp. of burning, °C	270	380	520	230	400	520	260	370	460	210	450	610
Min. O ₂ content, %	6.9	8.0	3.3	4.9	4.4	8.0	6.1	9.3	9.2	6.6	7.2	8.6
Time of min. O ₂ , min	210	15	20	75	20	15	247	10	105	180	15	15
Max. CO ₂ content, %	11.5	12.1	15.9	13.3	14.4	12.1	10.2	10.9	11.1	12.0	13.8	11.6
Time of max. CO ₂ , min	25	15	25	75	20	15	60	10	15	30	15	15
Max. CO content, %	6.0	3.7	4.0	11.4	6.2	3.5	6.3	4.6	2.5	9.7	3.7	3.2
Time of max. CO, min	105	15	30	20	30	25	25	20	20	25	30	25
Max. HCl content, %	1.04	0.2	0.68	6.0	6.58	6.35	7.65	10.4	3.02	-	-	-
Time of max. HCl, min	180	100	65	210	105	75	240	105	150	-	-	-
Total CO evolved, m ³	> 4.04	> 2.08	> 3.34	> 4.75	> 6.69	> 2.43	> 5.15	> 4.46	> 3.14	4.11	1.67	0.90
Total HCl evolved, m ³	± 0.42	> 0.24	> 0.61	> 2.72	> 4.64	± 4.21	> 3.29	> 9.65	> 4.88	-	-	-
HCl % of original chlorine	± 23.2	> 13.1	> 33.7	> 76.6	> 130	± 119	> 45.4	> 133	> 67.4	-	-	-

TABLE 3

Gaseous combustion products from 0.9 m cubic chamber.
Crib fire load of wood fibre insulation board incorporating
3 mm x 12 mm sticks of rigid poly (vinyl chloride)

Test No.	I40	I38	I41	I39	I44	I42	I45	I43
PVC load, kg	5.6	5.6	5.6	5.6	2.8	2.8	2.8	2.8
Wt. WEIB crib fire load, kg	6.4	6.4	12.8	12.8	6.4	6.4	12.8	12.8
Vent height, mm	50	150	50	150	50	150	50	150
Time of burning, min	> 375	> 120	> 360	> 240	> 360	> 120	> 360	> 180
Mean temp. of burning, °C	170	420	200	450	190	400	200	400
Min. O ₂ content, %	6.9	8.7	8.9	9.1	9.1	14.4	5.5	3.5
Time of min. O ₂ , min	45	30	25	45	20	10	25	45
Max. CO ₂ content, %	7.1	9.9	11.4	10.2	7.5	6.1	11.3	14.3
Time of max. CO ₂ , min	45	30	25	45	20	5	30	45
Max. CO content, %	5.2	2.04	7.5	0.92	8.2	0.54	11.7	2.7
Time of max. CO, min	45	5	20	25	15	10	25	45
Max. HCl content, %	1.41	0.98	0.17	0.21	0.36	0.26	0.21	0.29
Time of max. HCl, min	60	30	90	75	15	20	30	45
Total CO evolved, m ³	> 2.16	> 1.1	> 1.32	> 0.91	> 1.49	0.17	> 4.95	> 2.61
Total HCl evolved, m ³	> 0.67	> 0.75	> 0.10	> 0.46	> 0.20	0.20	> 0.11	> 0.42
HCl % of original chlorine	> 36	> 40	> 5.6	> 25	> 22	21	> 12	> 45

TABLE 4

Toxic gases after burning for one hour

Test No.	Cellulose kg		UPVC kg		Height of vent mm	Hydrogen chloride		Carbon monoxide	
	Crib	Wall	Crib	Wall		Vol. m ³	Contaminated air m ³	Vol. m ³	Contaminated air m ³
G3	6.4	Nil	Nil	Nil	50	NA	NA	0.68	230
G13	12.8	"	"	"	"	"	"	0.95	320
G10	5.8	7.0	"	"	"	"	"	0.76	250
I35	6.4	10.9	"	1.9	"	ND	0	0.35	120
I14	"	Nil	"	5.1	"	"	0	0.58	190
I6	"	"	"	11.0	"	0.001	10	0.63	210
I11	"	"	"	22.5	"	0.004	40	0.69	230
I44	"	"	2.8	Nil	"	0.036	360	0.64	210
I40	"	"	5.6	"	"	0.11	1100	0.63	210
I36	12.8	10.9	Nil	1.9	"	ND	0	1.05	350
I20	"	Nil	"	5.5	"	0.010	100	0.61	200
I17	"	"	"	10.7	"	ND	0	1.07	360
I23	"	"	"	21.9	"	"	0	0.75	250
I45	"	"	2.8	Nil	"	0.021	210	1.31	440
I41	"	"	5.6	"	"	ND	0	0.61	200
G2	6.4	12.8	Nil	1.9	100	NA	NA	0.52	170
G5	12.8	"	"	"	"	"	"	1.36	450
G11	5.8	7.0	"	"	"	"	"	1.67	560
I13	6.4	Nil	"	5.6	"	0.48	4800	1.21	400
I8	"	"	"	10.6	"	0.15	1500	1.17	390
I10	"	"	"	21.9	"	0.56	5600	1.61	540
I19	12.8	"	"	5.5	"	0.041	410	0.92	310
I16	"	"	"	10.7	"	0.18	1800	2.17	720
I22	"	"	"	21.9	"	0.13	1300	1.31	440
G1	6.4	"	"	Nil	150	NA	NA	0.53	180
G6	12.8	"	"	"	"	"	"	0.90	300
G12	5.8	7.0	"	"	"	"	"	2.20	730
I34	6.4	10.9	"	1.9	"	0.094	940	1.40	470
I12	"	Nil	"	5.5	"	0.43	4300	0.90	300
I25	"	"	"	10.7	"	1.17	11700	1.38	460
I9	"	"	"	21.4	"	2.75	27500	1.23	410
I42	"	"	2.8	Nil	"	0.13	1300	1.23	410
I38	"	"	5.6	"	"	0.58	5800	0.66	220
I37	12.8	10.9	Nil	1.9	"	0.16	1600	2.82	940
I18	"	"	"	5.5	"	0.21	2100	1.01	340
I24	"	"	"	10.7	"	0.61	6100	1.47	490
I21	"	"	"	21.9	"	1.32	13200	1.07	360
I43	"	"	2.8	Nil	"	0.15	1500	1.67	560
I39	"	"	5.6	"	"	0.069	690	0.59	200

NA = Not applicable

ND = Not detectable

TABLE 5

Recovery of hydrogen chloride from rigid poly (vinyl chloride)
in fires in which plastic was fully consumed

Test No.	UPVC		WFIB wt. kg	Height of vent mm	Time of burning min	Mean temp. of gas °C	HCl in emergent gas	
	wt. kg	thick mm					m ³	% of available
I12	5.5	1.5*	6.4	150	± 105	500	± 0.54	± 29.4
I13	5.6	1.5	6.4	100	± 210	320	± 0.71	± 38.2
I9	21.4	6	6.4	150	295	500	3.74	52.8
I16	10.8	3	12.8	100	> 345	400	± 4.64	± 130
I24	10.7	3	12.8	150	210	520	4.27	119
I22	21.9	6	12.8	100	> 300	370	± 9.65	± 133
I21	21.9	6	12.8	150	> 220	460	± 4.88	± 67.4
I34	1.9	0.5	6.4	150	± 120	600	± 0.11	± 17.5
I37	1.9	0.5	12.8	150	> 210	650	0.54	88.0
I38	5.6	in crib	6.4	150	> 120	420	± 0.75	± 40.3
I39	5.6	"	12.8	150	> 240	450	0.46	24.7
I42	2.8	"	6.4	150	± 120	400	± 0.20	± 21.4
I43	2.8	"	12.8	150	± 210	400	± 0.42	± 45.2

Note * - Thickness of wall linings

TABLE 6

Effect of sampling position on recovery
of hydrogen chloride

Test No.	Combustible material load kg		Height of vent mm	Per cent available HCl in emergent gases								Time of collapse of lining min
				15 min		30 min		60 min		Total		
				Centre	Side	Centre	Side	Centre	Side	Centre	Side	
	UPVC	WFIB										
I25	10.7	6.4	150	1.23	0.30	15.2	5.6	32.9	21.4	55.1	44.3	8
I20	5.5	12.8	50	0.09	NM	0.27	NM	0.53	1.07	23.2	35.5	20
I24	10.7	12.8	150	NM	NM	0.22	4.1	17.1	29.9	119.2	74.8	10
I23	21.9	12.8	50	NM	NM	NM	NM	NM	NM	45.4	38.5	67
I22	21.9	12.8	NM	0.68	0.23	1.65	1.83	3.1	13.3	133	120	23
I21	21.9	12.8	150	0.28	2.12	0.93	29.8	18.3	90.0	67.4	130	13
I35*	1.9	6.4	50	NM	NM	NM	NM	NM	NM	NM	NM	No collapse
I34*	1.9	6.4	150	5.5	2.0	10.7	5.76	15.3	11.5	17.5	13.7	21
I36*	1.9	12.8	50	NM	NM	NM	NM	NM	NM	11.5	26.0	No collapse
I37*	1.9	12.8	150	2.7	2.7	8.1	8.1	23.2	26.7	88.2	91.2	> 201

* UPVC laminated on hardboard

NM = Not measurable

TABLE 7

Effect of sampling position on
hydrogen chloride in emergent gas

1.5 mm rigid poly (vinyl chloride) sheet as wall lining
propane burner consuming 20 l/min, 150 mm high vent

Distance from edge of vent mm	60		290		430	
Distance from top of vent mm	Per cent HCl	Time min	Per cent HCl	Time min	Per cent HCl	Time min
0	0.12	7	3.30	8	3.30	9
	0.14	10	0.21	11	0.40	12
20	1.44	14	1.30	15	3.10	16
	1.10	17	2.22	18	1.13	19
40	2.08	21	0.71	22	1.93	33
	0.75	24	0.33	25	0.31	26
60	0.57	29	0.24	30	0.26	31
	0.24	32	0.14	33	0.07	34
80	0.19	38	0.12	39	0.12	40
	0.19	41	0.19	42	0.12	43

Note: Plastic sheeting fully consumed at about 24 min.

TABLE 8

Effect of sampling position on
hydrogen chloride in emergent gas

3.0 mm rigid poly (vinyl chloride) sheet as wall lining
propane burner consuming 20 l/min, 150 mm high vent

Distance from edge of vent mm	60		290		430	
Distance from top of vent mm	Per cent HCl	Time min	Per cent HCl	Time min	Per cent HCl	Time min
0	0.14	10	0.19	11	0.31	12
	1.03	13	1.13	14	1.68	15
20	6.30	23	8.55	21	6.70	22
			3.16	24	4.03	25

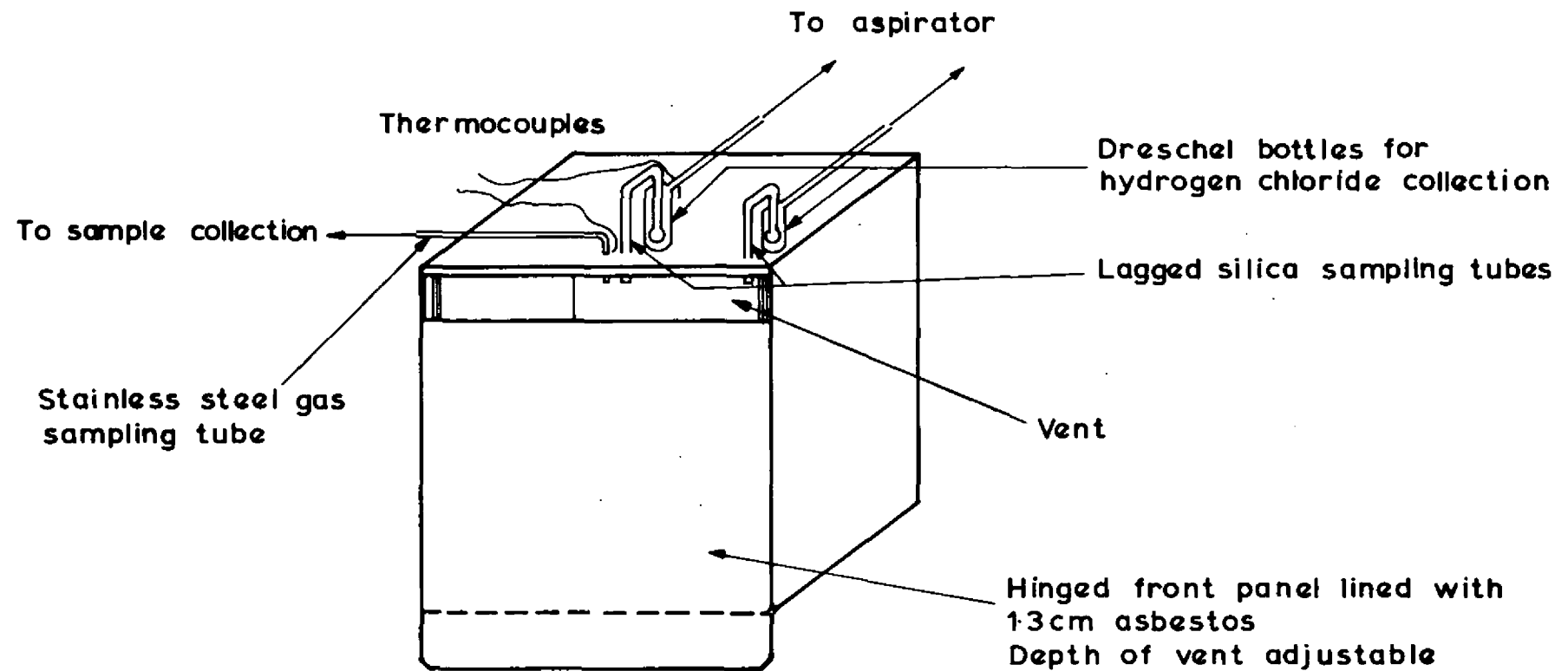
Note: Plastic sheet fell. Flame extinguished at about 20 min.

TABLE 9

Deviation in the recovery of hydrogen chloride

(Based on data in Table 5)

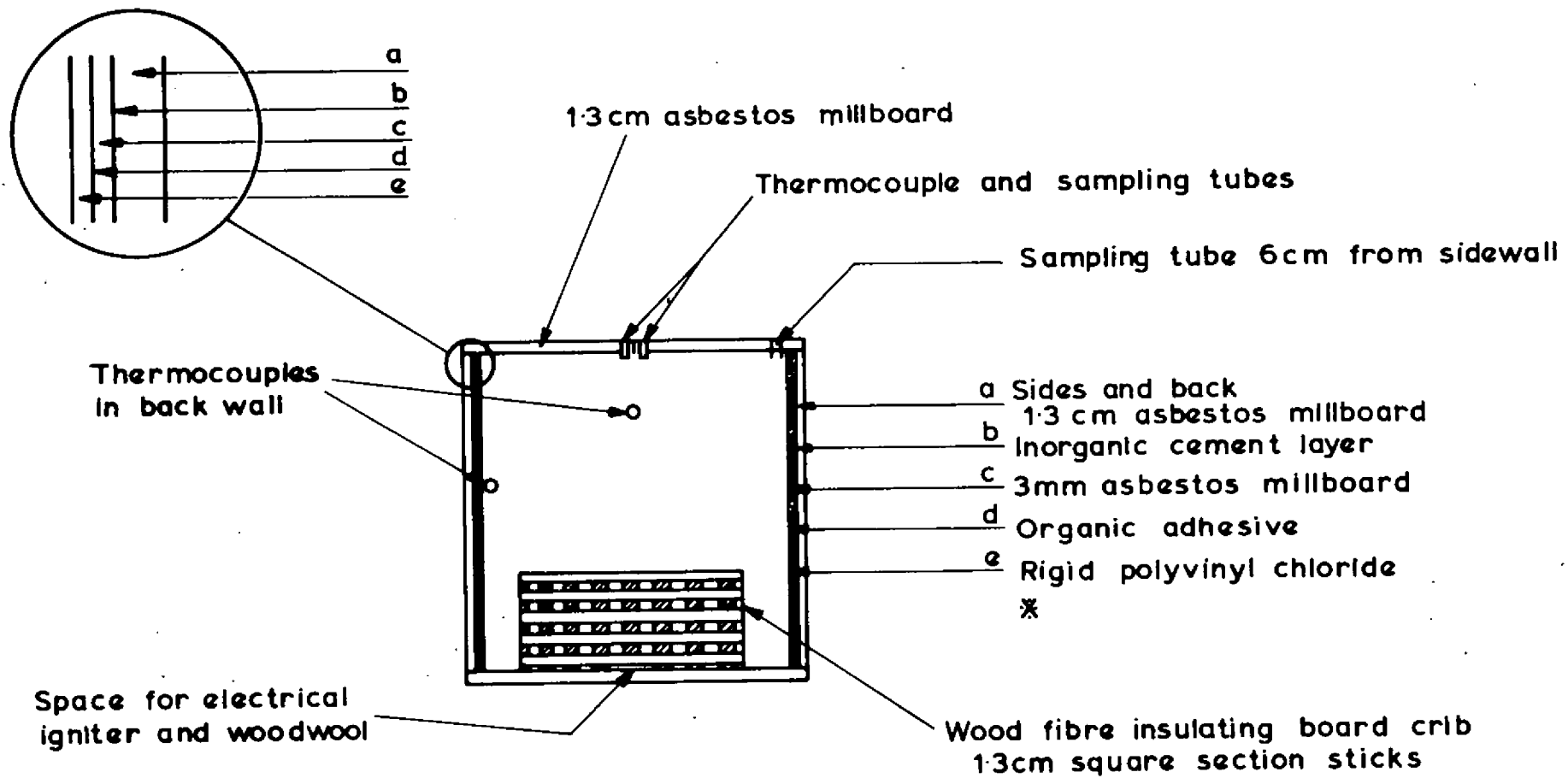
Group of tests	Mean per cent	Standard deviation per cent
Tests with wall linings of UPVC only	81.3	45 (7 tests)
Tests with wall linings of UPVC including UPVC on hardboard	75	44 (9 tests)
Tests with UPVC in crib	33	11.7 (4 tests)



N.B. Sampling tubes and thermocouples placed 2cm below ceiling

CLOSED COMPARTMENT SHOWING SAMPLING ARRANGEMENTS

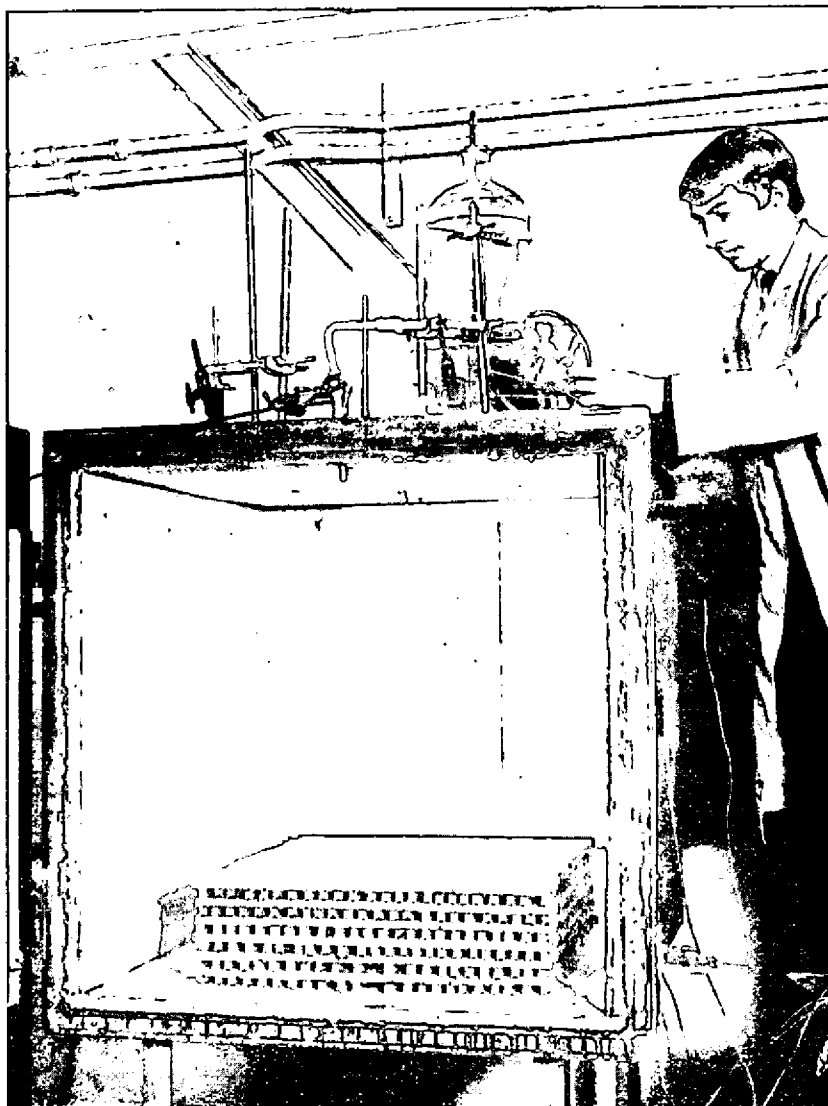
FIG. 1a. COMBUSTION COMPARTMENT FOR TESTS WITH PLASTICS



* Note: 13cm asbestos millboard only on all walls for tests with plastics in crib

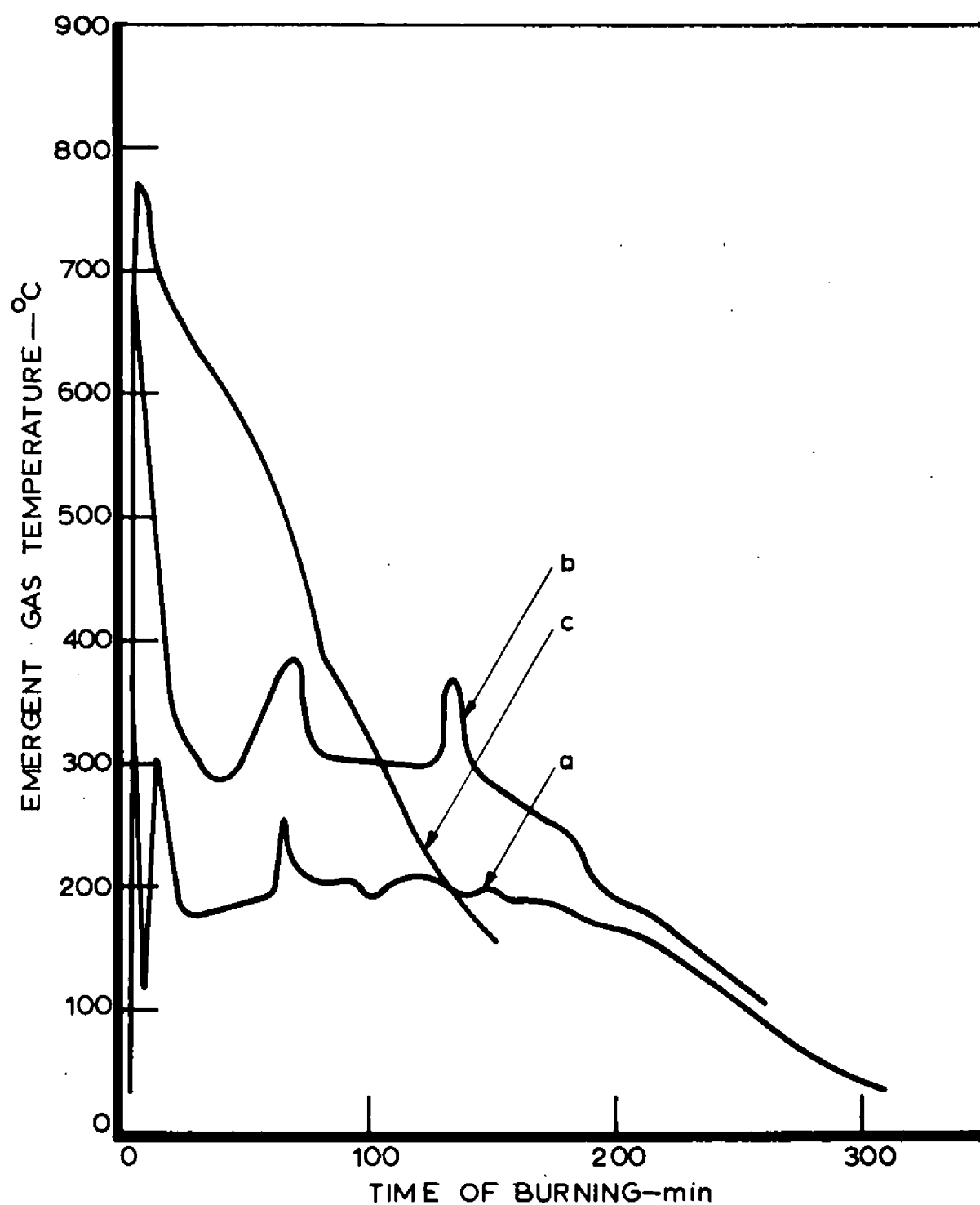
COMPARTMENT WITH FRONT REMOVED SHOWING FIRE LOAD

FIG. 1b. COMBUSTION COMPARTMENT FOR TESTS WITH PLASTICS



COMBUSTION COMPARTMENT PREPARED FOR TEST
WITH 1.5 mm RIGID POLY(VINYL CHLORIDE) WALL
LINING (5.5 kg) AND 6.4 kg CRIB OF WOOD FIBRE
INSULATING BOARD STICKS, 100 mm VENT (TEST I4)

FIG. 2.



Nomenclature

a = Depth of vent 5cm

b = Depth of vent 10cm

c = Depth of vent 15cm

Fuel: 6.4 kg W.F. I.B. crib
3mm U.P. V.C. wall lining

FIG.3. EFFECT OF VENT SIZE ON EMERGENT GAS TEMPERATURE



1.5 m U.P.V.C. SHEET AFTER TEST
6.4 kg W.F.I.B. CRIB
50 mm VENT

FIG. 4.



3 mm U.P.V.C. SHEET AFTER TEST
6.4 kg W.F.I.B. CRIB
50 mm VENT

FIG. 5.



6 mm U.P.V.C. SHEET AFTER TEST. INVERTED
PANEL REMOVED FROM COMPARTMENT
6.4 kg W.F.I.B. CRIB
50 mm VENT

FIG. 6.



0.5 mm U.P.V.C. ON HARDBOARD AFTER TEST
6.4 kg W.F.I. B. CRIB
50 mm VENT

FIG. 7.



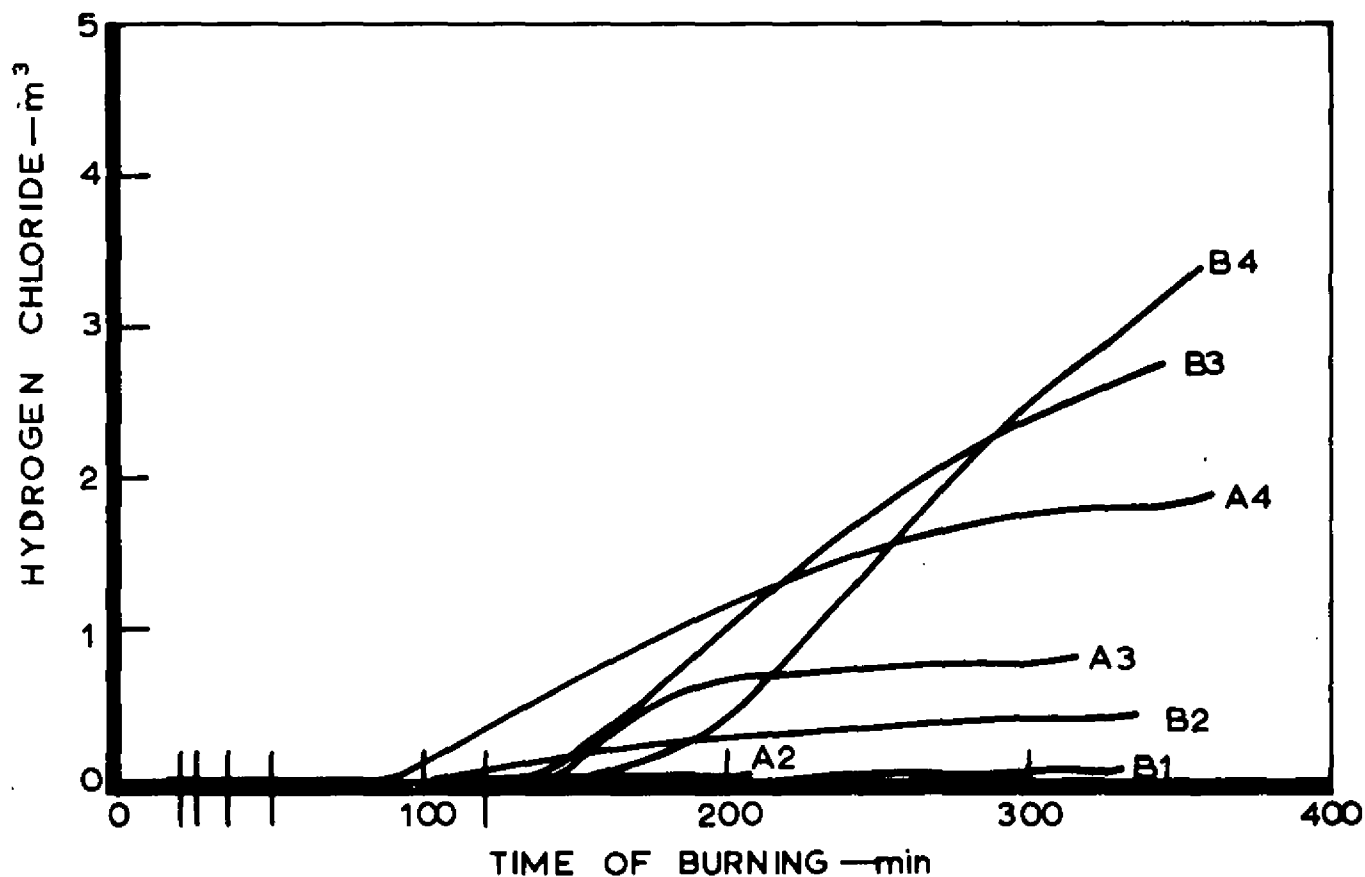
0.5 mm U.P.V.C. ON HARDBOARD AFTER TEST
12.8 kg W.F.I. B. CRIB
50 mm VENT

FIG. 8.



U.P.V.C. STICKS IN W.F.I.B. CRIB AFTER TEST
6.4 kg W.F.I.B. CRIB
5.6 kg U.P.V.C. STICKS
150 mm VENT

FIG. 9.



Nomenclature

A = 6.4 kg W.F.I.B.

B = 12.8 kg W.F.I.B.

1 = 0.5mm U.P.V.C. sheet

2 = 1.5mm U.P.V.C. sheet

3 = 3.0mm U.P.V.C. sheet

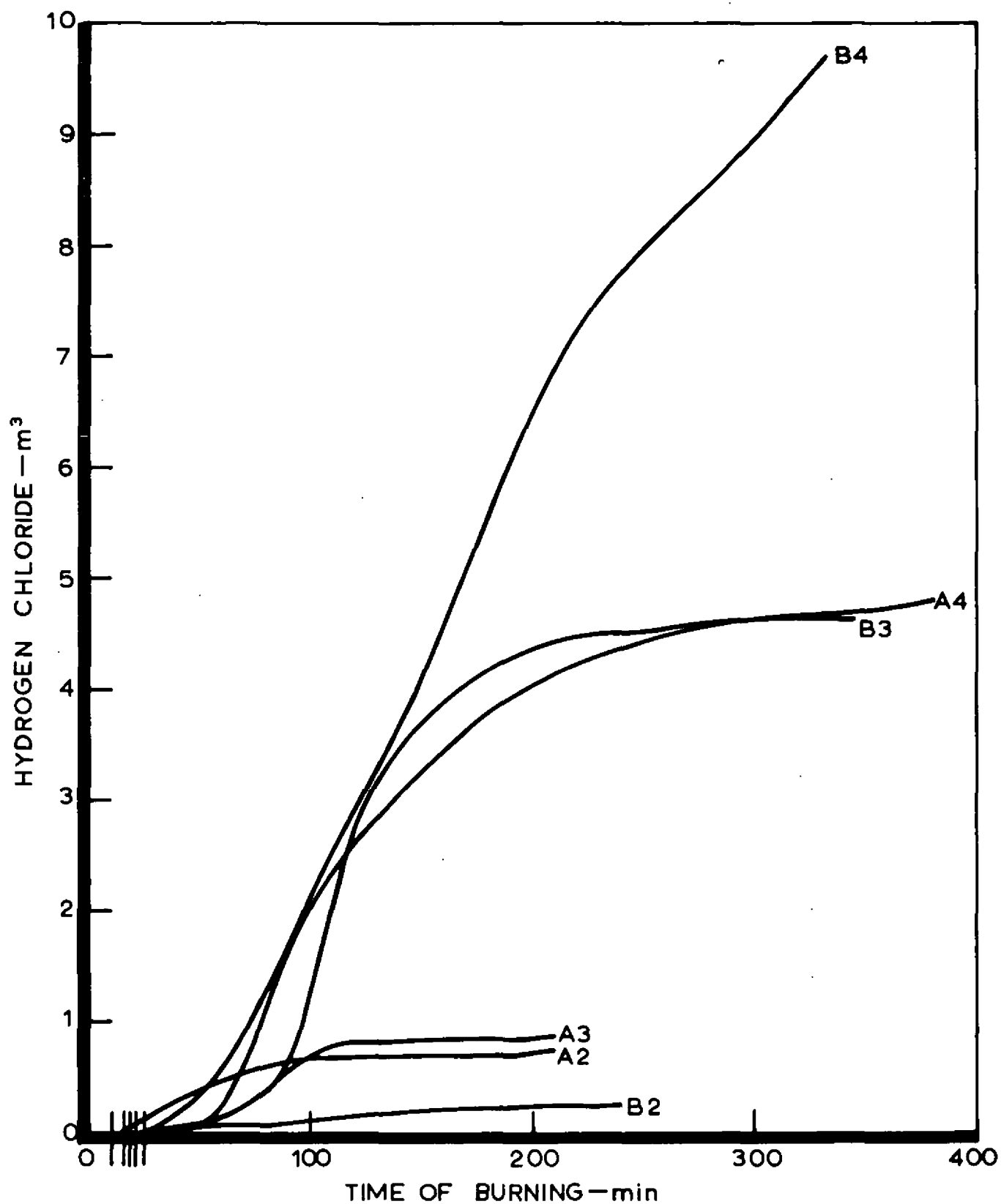
4 = 6.0mm U.P.V.C. sheet

| = Collapse of wall lining

Tests with U.P.V.C. wall lining

Depth of vent 5cm

FIG.10. EVOLUTION OF HYDROGEN CHLORIDE



Nomenclature

A = 6.4 kg W.F.I.B.

B = 128 kg W.F.I.B.

2 = 1.5mm U.P.V.C. sheet

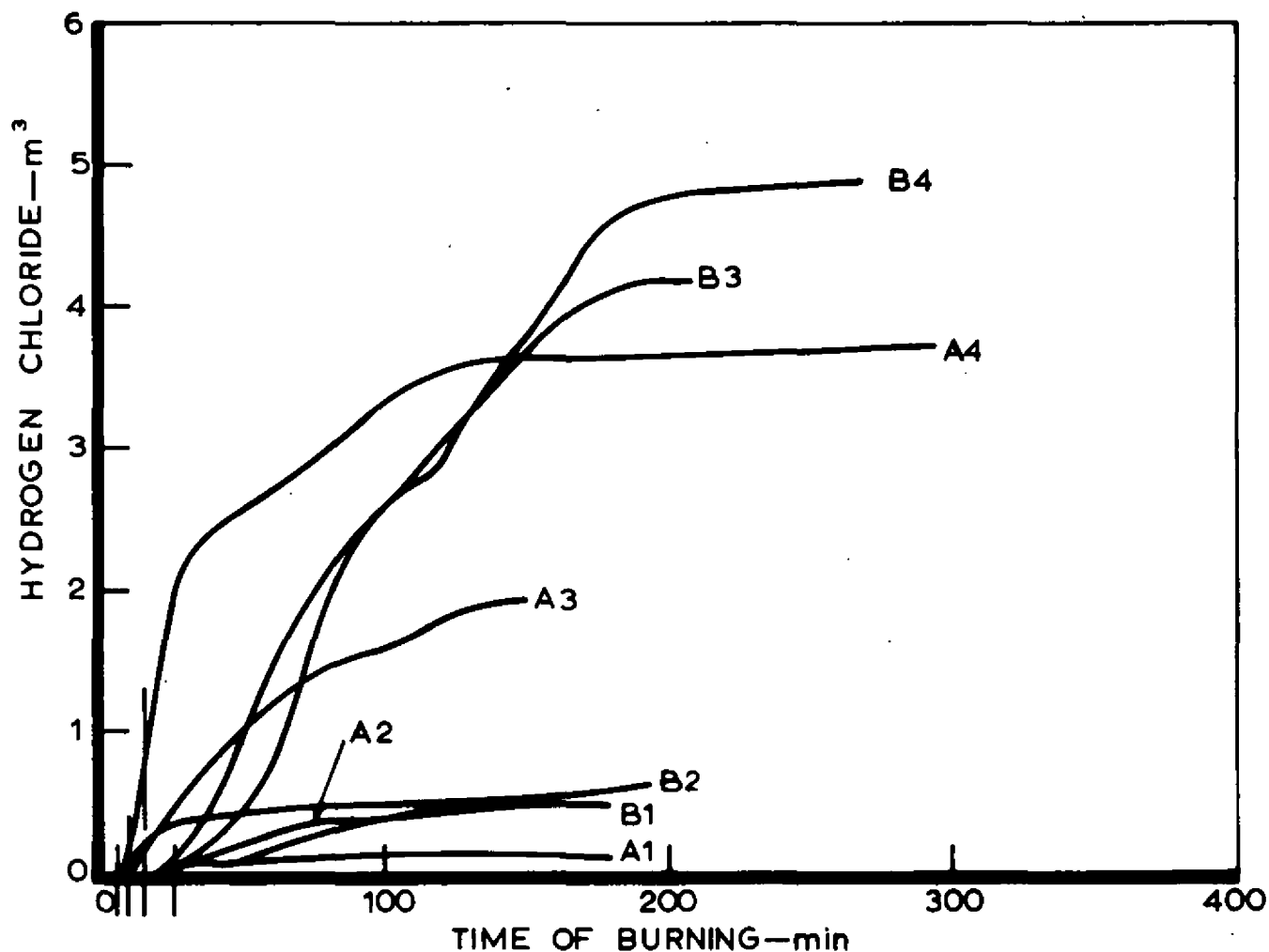
3 = 3.0mm U.P.V.C. sheet

4 = 6.0mm U.P.V.C. sheet

| = Collapse of wall lining

Tests with U.P.V.C. wall linings
Depth of vent 10cm

FIG. 11. EVOLUTION OF HYDROGEN CHLORIDE

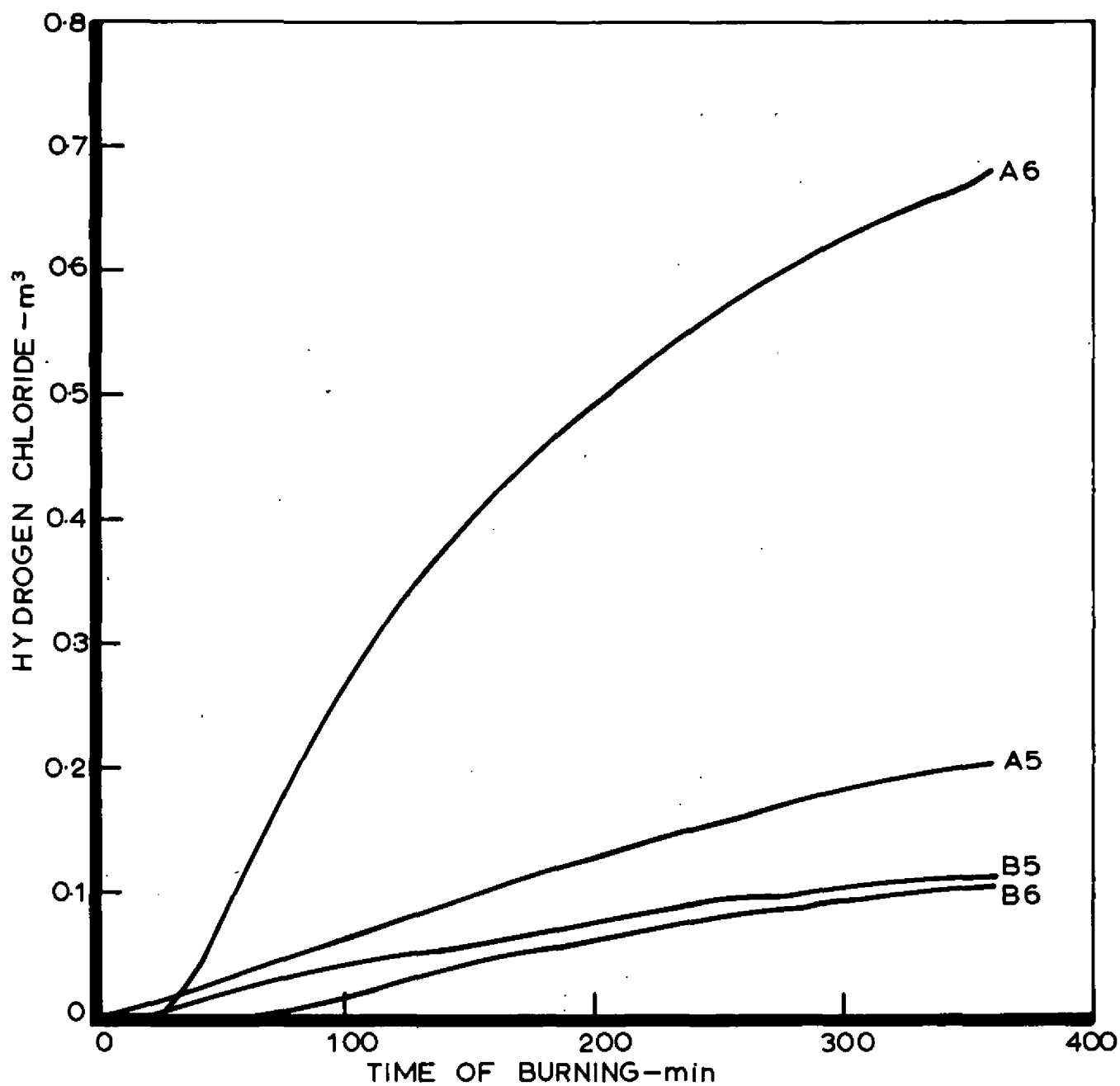


Nomenclatures

- A = 6.4 kg W.F.I.B.
 B = 12.8 kg W.F.I.B.
 1 = 0.5mm U.P.V.C. sheet
 2 = 1.5mm U.P.V.C. sheet
 3 = 3.0mm U.P.V.C. sheet
 4 = 6.0mm U.P.V.C. sheet
 | = Collapse of wall lining

Tests with U.P.V.C. wall lining
 Depth of vent 15cm

FIG. 12. EVOLUTION OF HYDROGEN CHLORIDE



Nomenclature

A = 6.4 kg W.F.I.B.

B = 12.8 kg W.F.I.B.

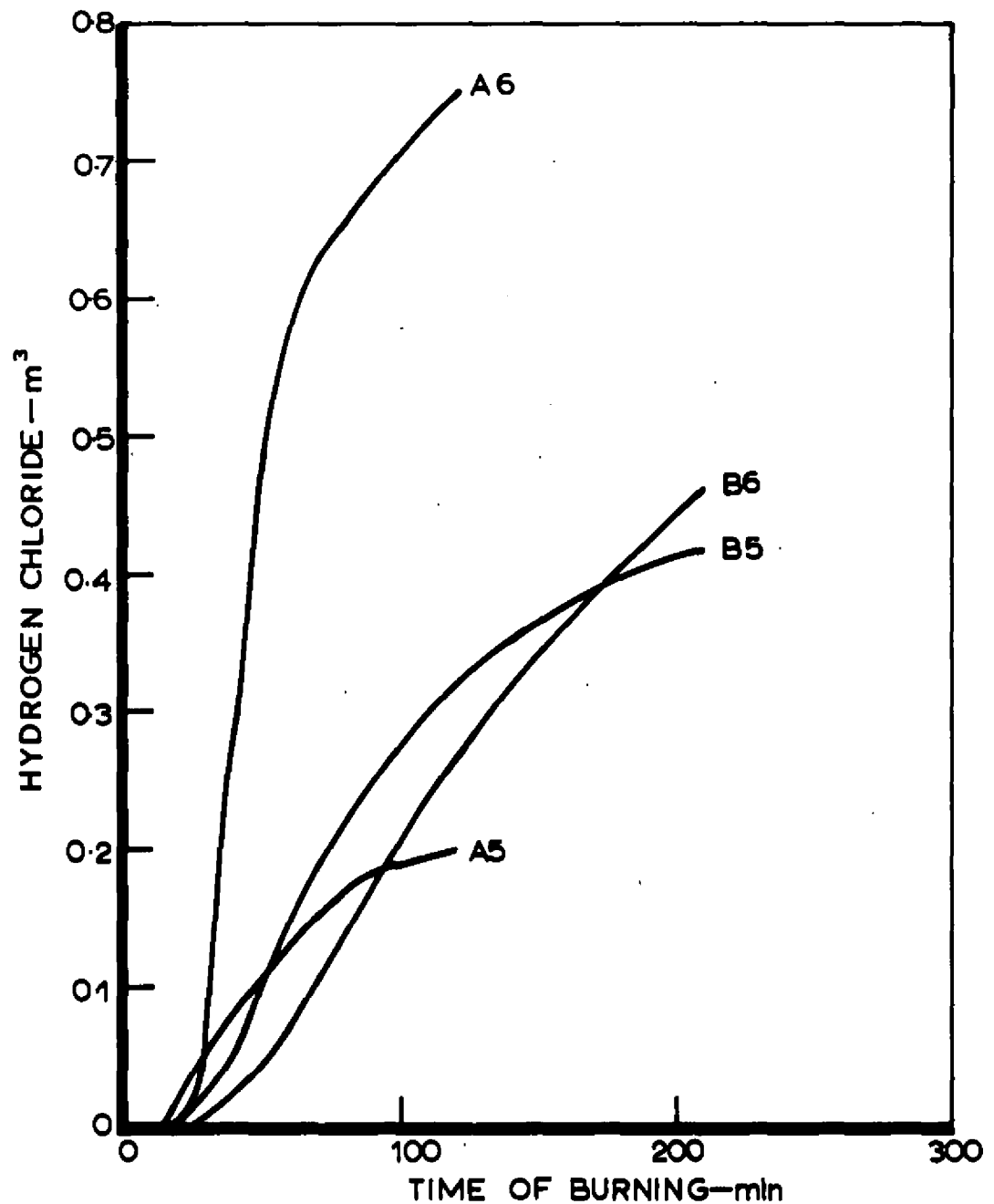
5 = 2.8 kg U.P.V.C.

6 = 5.6 kg U.P.V.C.

Tests with U.P.V.C. sticks in crib

Depth of vent 5 cm

FIG.13. EVOLUTION OF HYDROGEN CHLORIDE



Nomenclature

A = 6.4 kg W.F.I.B.

B = 12.8 kg W.F.I.B.

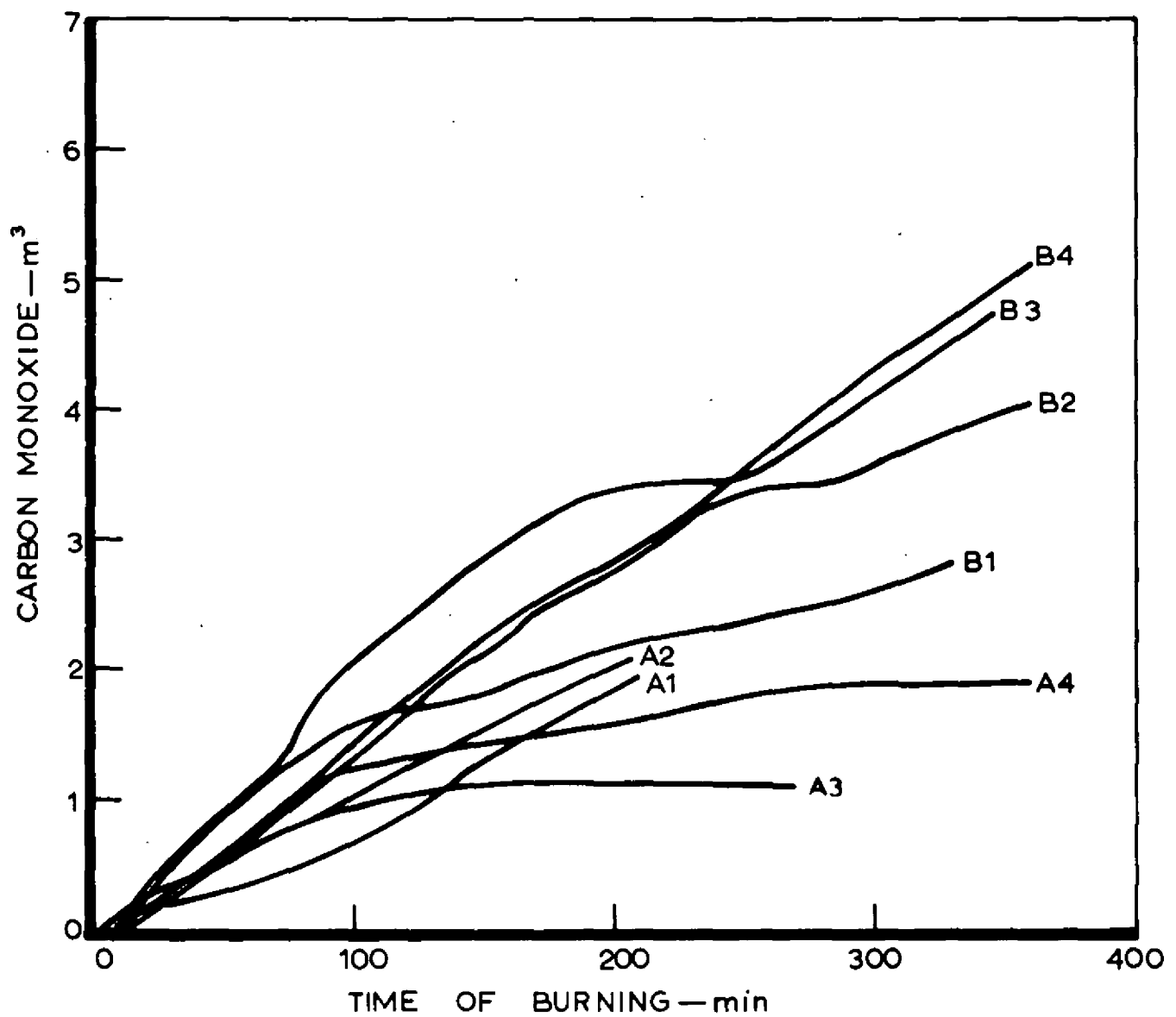
5 = 2.8 kg U.P.V.C. in crib

6 = 5.6 kg U.P.V.C. in crib

Tests with U.P.V.C. sticks

Depth of vent 15 cm

FIG. 14. EVOLUTION OF HYDROGEN CHLORIDE

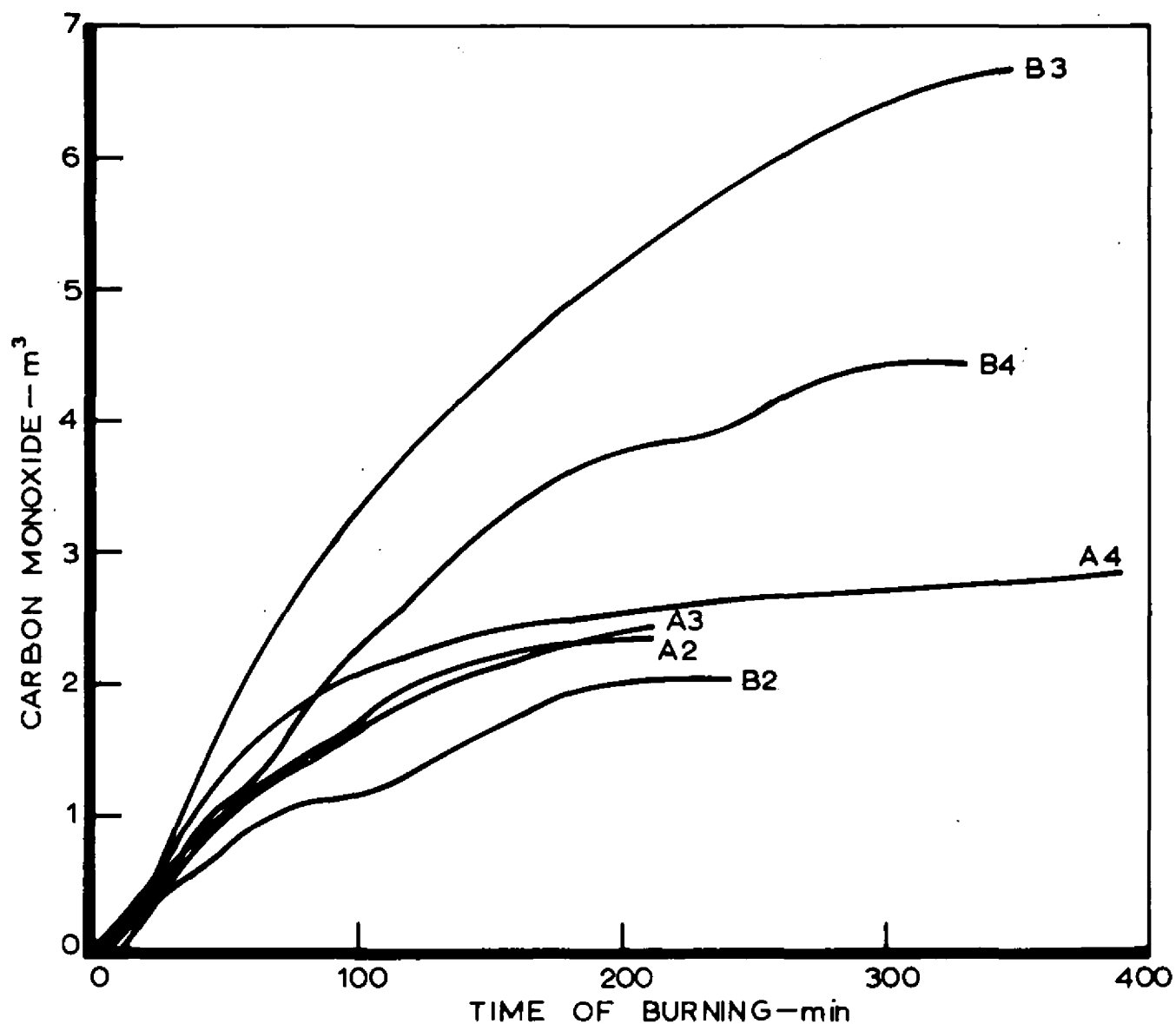


Nomenclature

- A = 6.4 kg W.F.I.B.
- B = 12.8 kg W.F.I.B.
- 1 = 0.5 mm U.P.V.C. sheet
- 2 = 1.5 mm U.P.V.C. sheet
- 3 = 3.0 mm U.P.V.C. sheet
- 4 = 6.0 mm U.P.V.C. sheet

Tests with U.P.V.C. wall lining
Depth of vent 5cm

FIG.15. EVOLUTION OF CARBON MONOXIDE

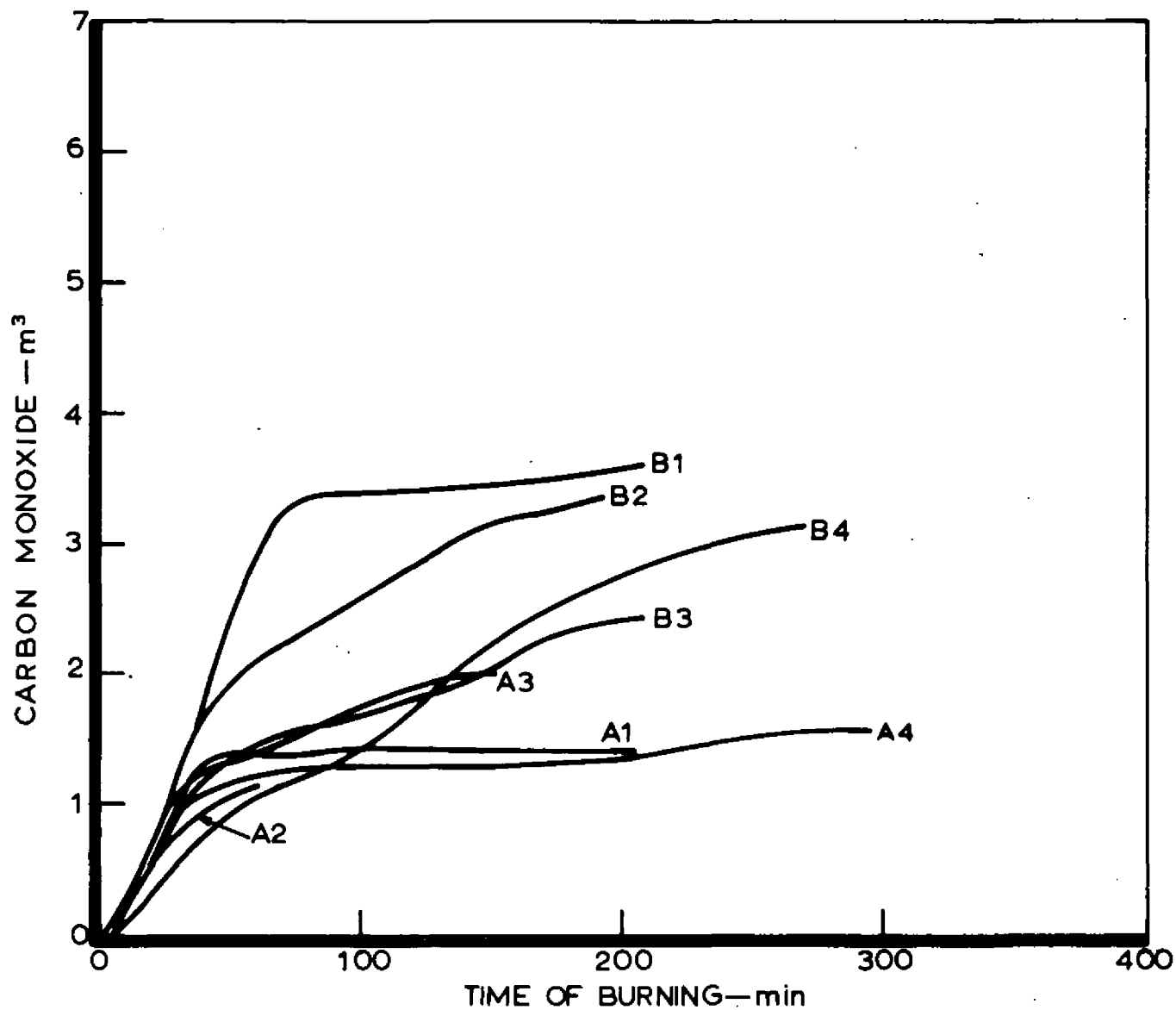


Nomenclature

- A = 6.4 kg W.F.I.B.
- B = 12.8 kg W.F.I.B.
- 2 = 1.5mm U.P.V.C. sheet
- 3 = 3.0mm U.P.V.C. sheet
- 4 = 6.0mm U.P.V.C. sheet

Tests with U.P.V.C. wall lining
Depth of vent 10cm

FIG. 16. EVOLUTION OF CARBON MONOXIDE

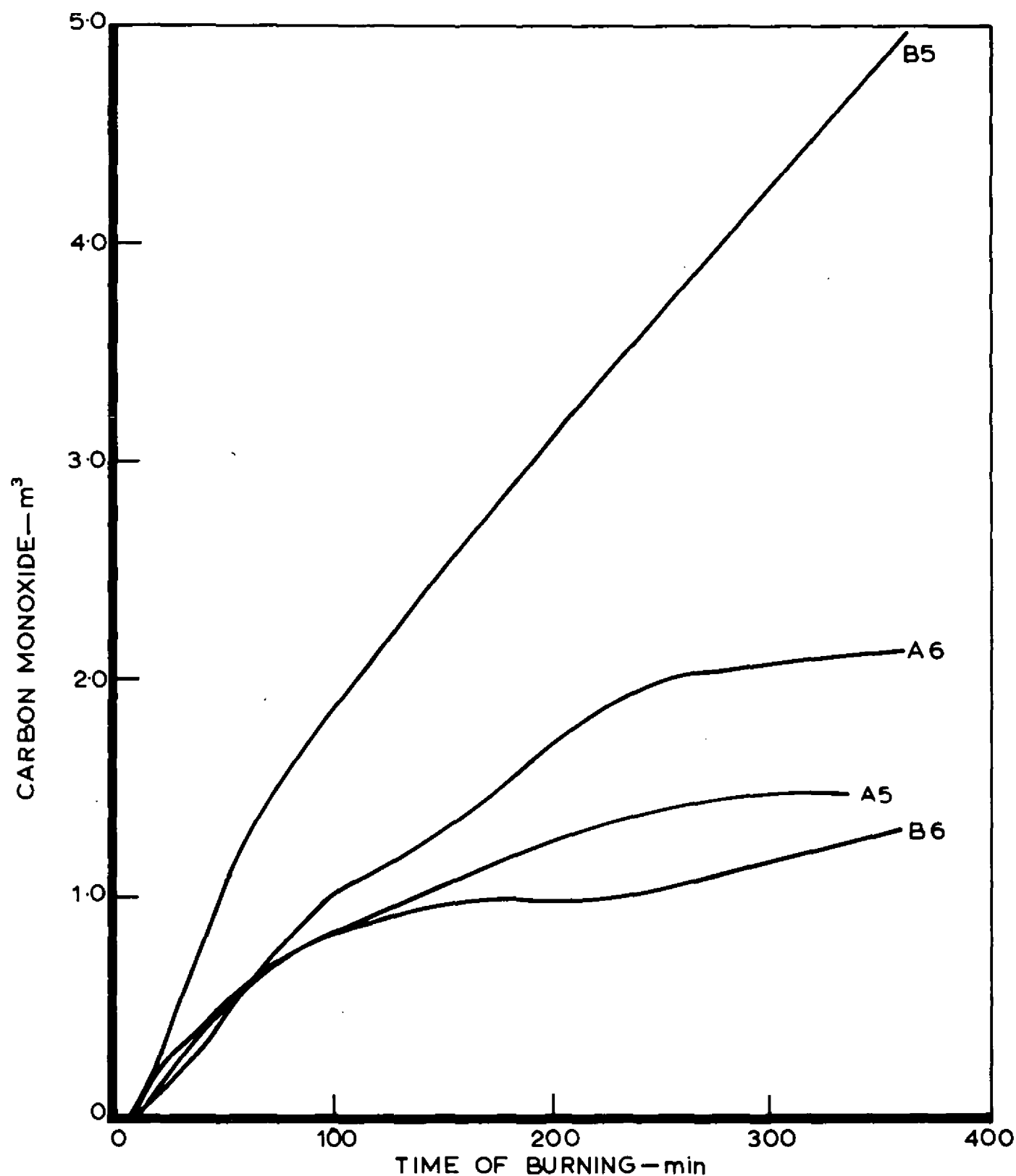


Nomenclature

- A = 6.4 kg W.F.I.B.
- B = 12.8 kg W.F.I.B.
- 1 = 0.5 mm U.P.V.C. sheet
- 2 = 1.5 mm U.P.V.C. sheet
- 3 = 3 mm U.P.V.C. sheet
- 4 = 6 mm U.P.V.C. sheet

Tests with U.P.V.C. wall lining
Depth of vent 15 cm

FIG. 17. EVOLUTION OF CARBON MONOXIDE

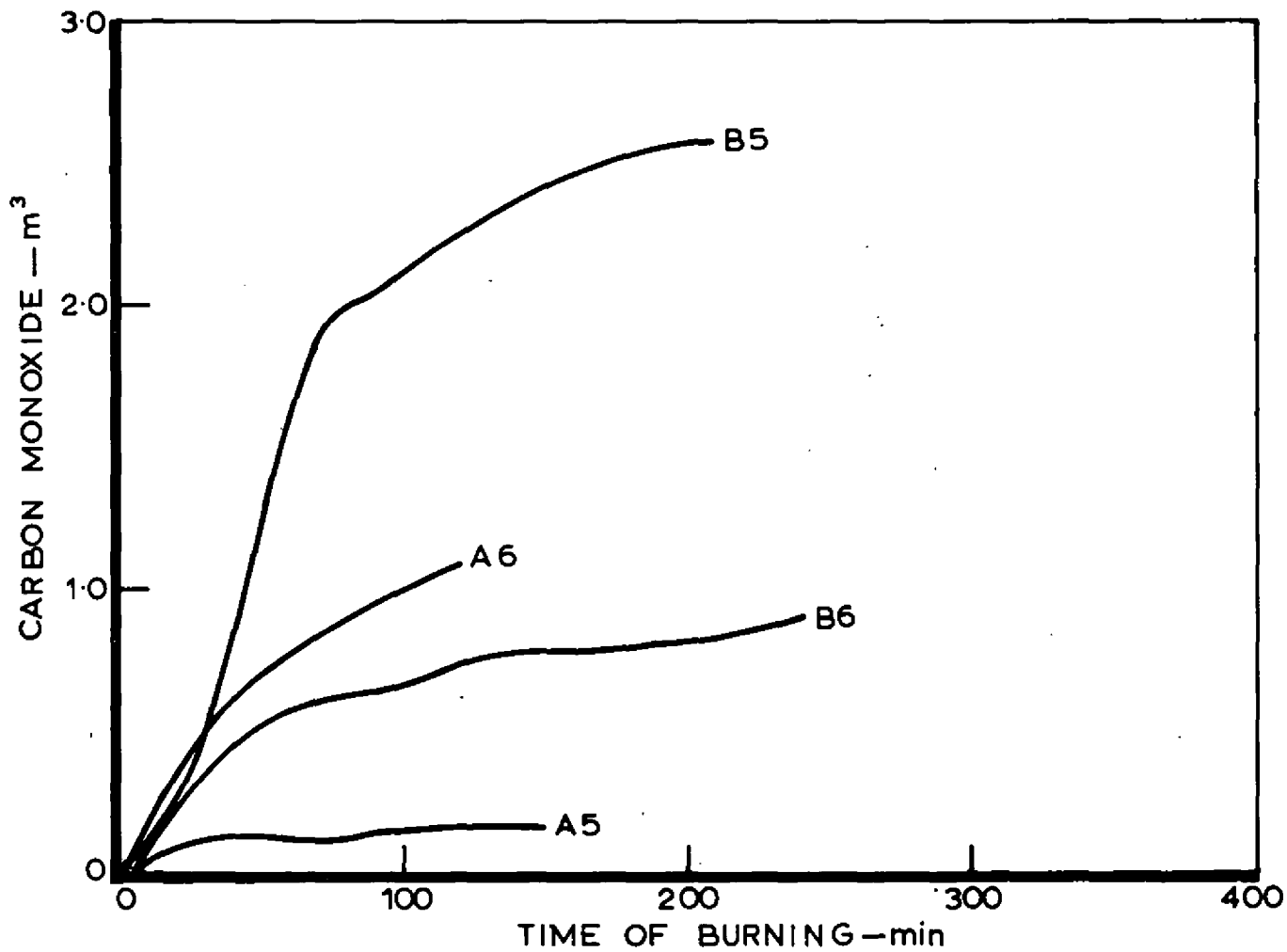


Nomenclature

- A = 6.4 kg W.F.I.B.
- B = 12.8 kg W.F.I.B.
- 5 = 2.8 kg U.P.V.C. in crib
- 6 = 5.6 kg U.P.V.C. in crib

Tests with U.P.V.C. sticks in crib
Depth of vent 5cm

FIG. 18. EVOLUTION OF CARBON MONOXIDE.

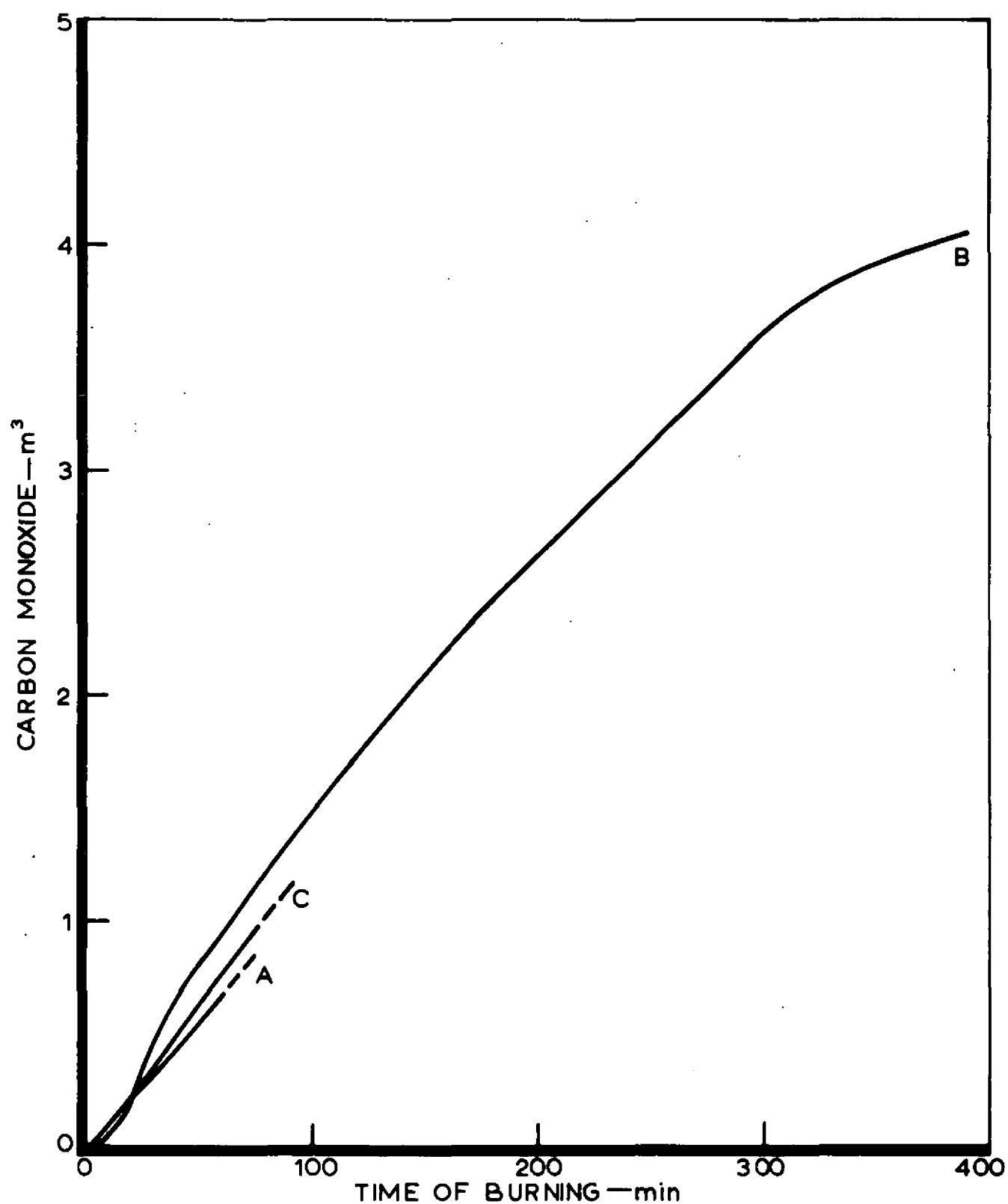


Nomenclature

- A = 6.4 kg W.F.I. B.
- B = 12.8 kg W.F.I. B.
- 5 = 2.8 kg U.P.V.C. in crib
- 6 = 5.6 kg U.P.V.C. in crib

Tests with U.P.V.C. in crib
Depth of vent 15cm

FIG. 19. EVOLUTION OF CARBON MONOXIDE



Nomenclature

A = 6.4 kg W.F.I.B. crib

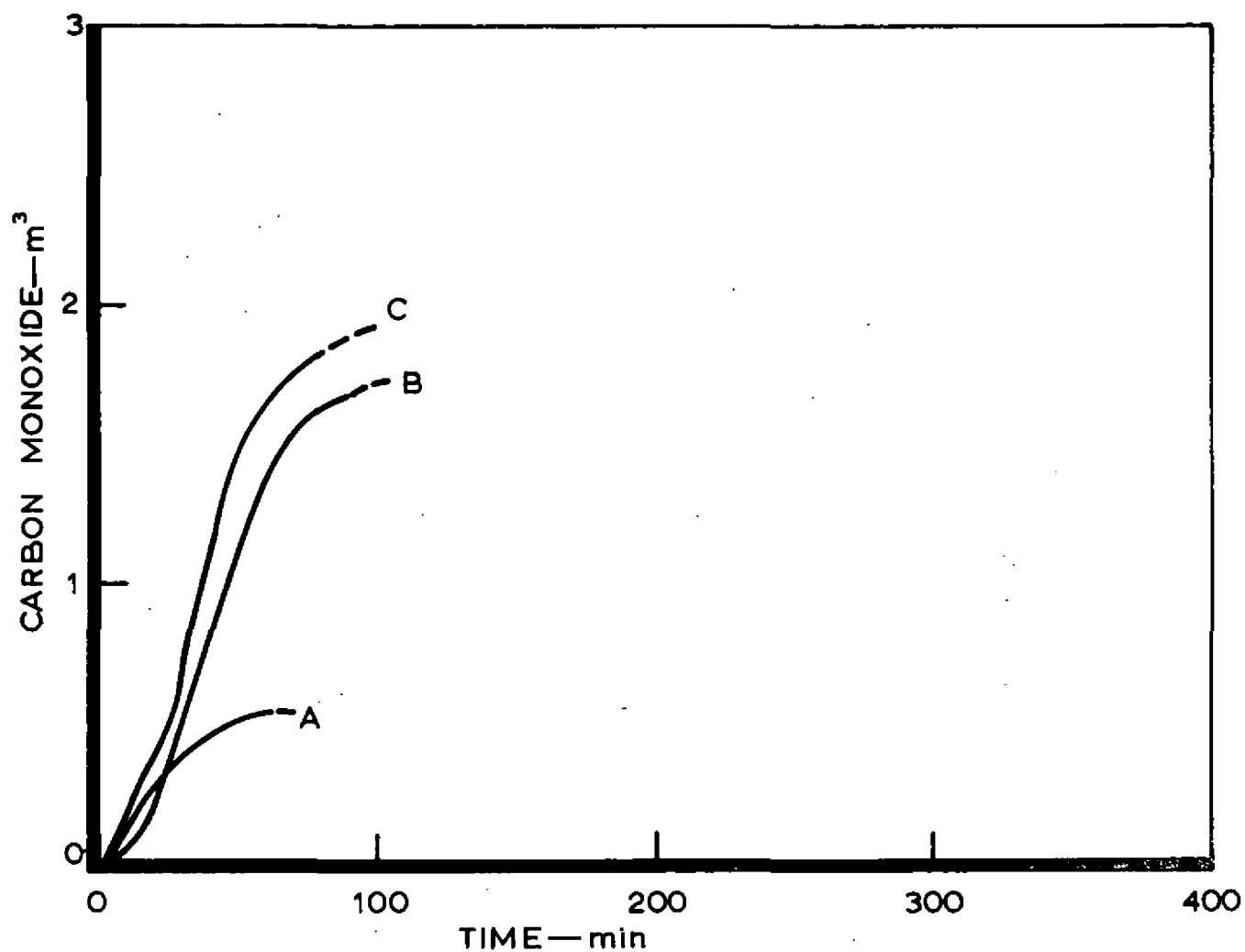
B = 12.8 kg W.F.I.B. crib

C = 12.8 kg W.F.I.B. crib and wall lining

Tests with crib, and crib and wall lining, of W.F.I.B.

Depth of vent 5cm

FIG. 20. EVOLUTION OF CARBON MONOXIDE



Nomenclature

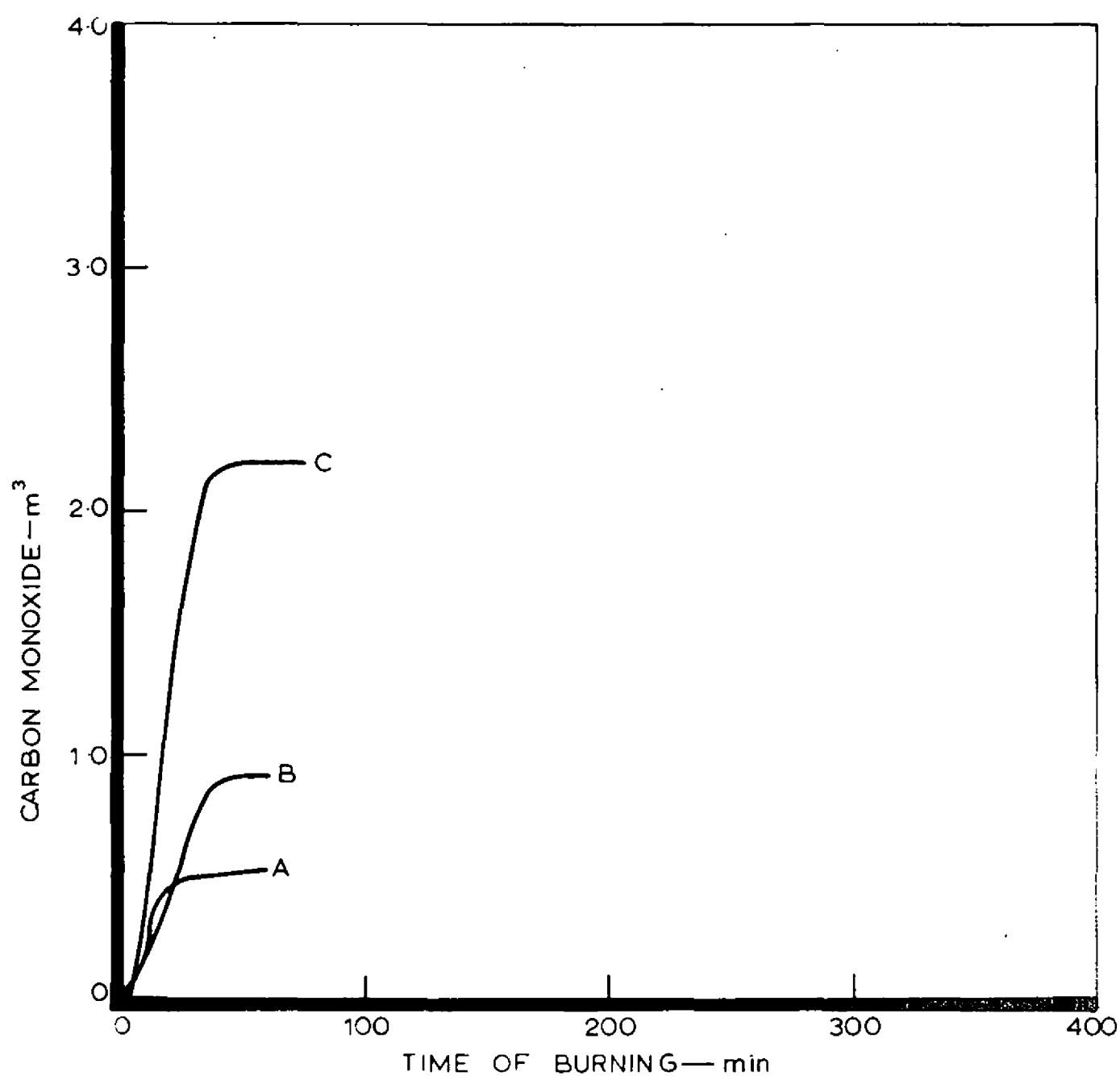
A = 6.4 kg W.F.I.B. crib

B = 12.8 kg W.F.I.B. crib

C = 12.8 kg W.F.I.B. crib and wall lining

Tests with crib and crib and wall lining of W.F.I.B.
Depth of vent 10cm

FIG. 21. EVOLUTION OF CARBON MONOXIDE



Nomenclature

A = 6.4 kg W.F.I.B. crib

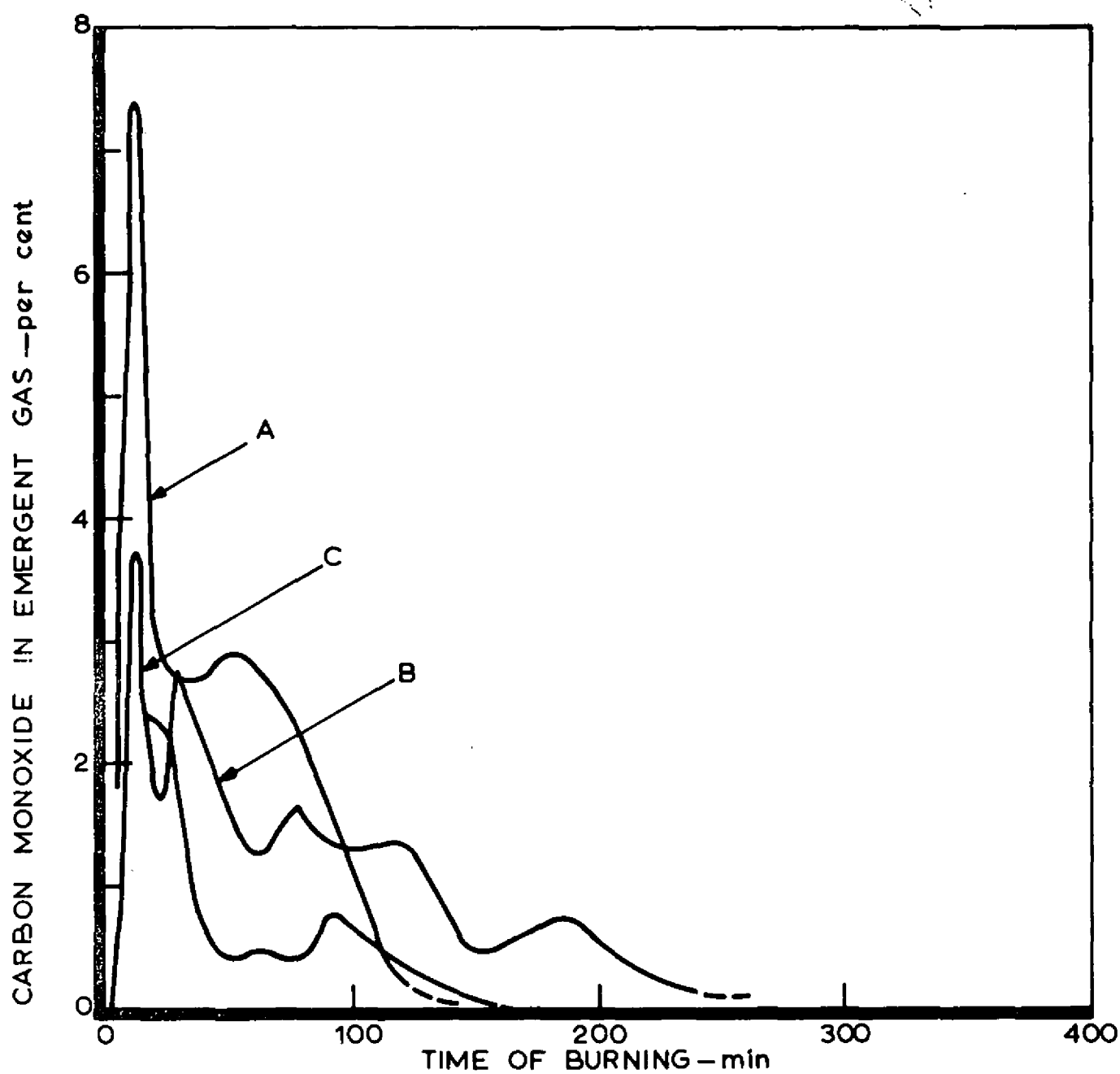
B = 12.8 kg W.F.I.B. crib

C = 12.8 kg W.F.I.B. crib and wall lining

Tests with crib, and crib and wall linings of W.F.I.B.

Depth of vent 15 cm

FIG. 22. EVOLUTION OF CARBON MONOXIDE



Nomenclature

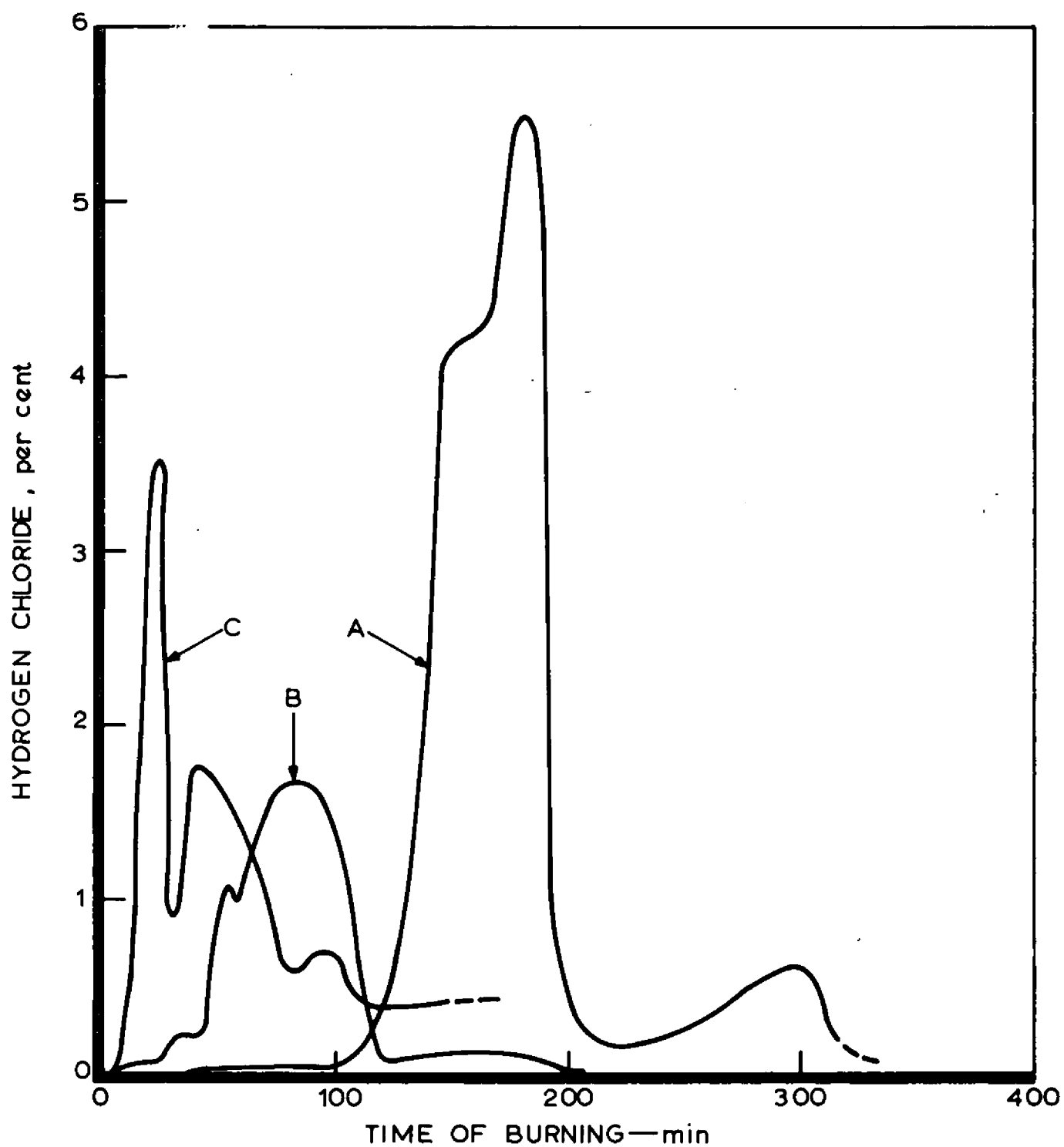
A = Depth of vent 5cm

B = Depth of vent 10cm

C = Depth of vent 15cm

Fuel: 6.4kg W.F.I.B. crib
3mm U.P.V.C. wall lining

FIG. 23. CARBON MONOXIDE IN EMERGENT GASES



Nomenclature

A = Depth of vent 5 cm

B = Depth of vent 10cm

C = Depth of vent 15cm

Fuel: 6.4 kg W.F.I.B. crib

3mm U.P.V.C. wall lining

FIG.24. HYDROGEN CHLORIDE IN EMERGENT GAS

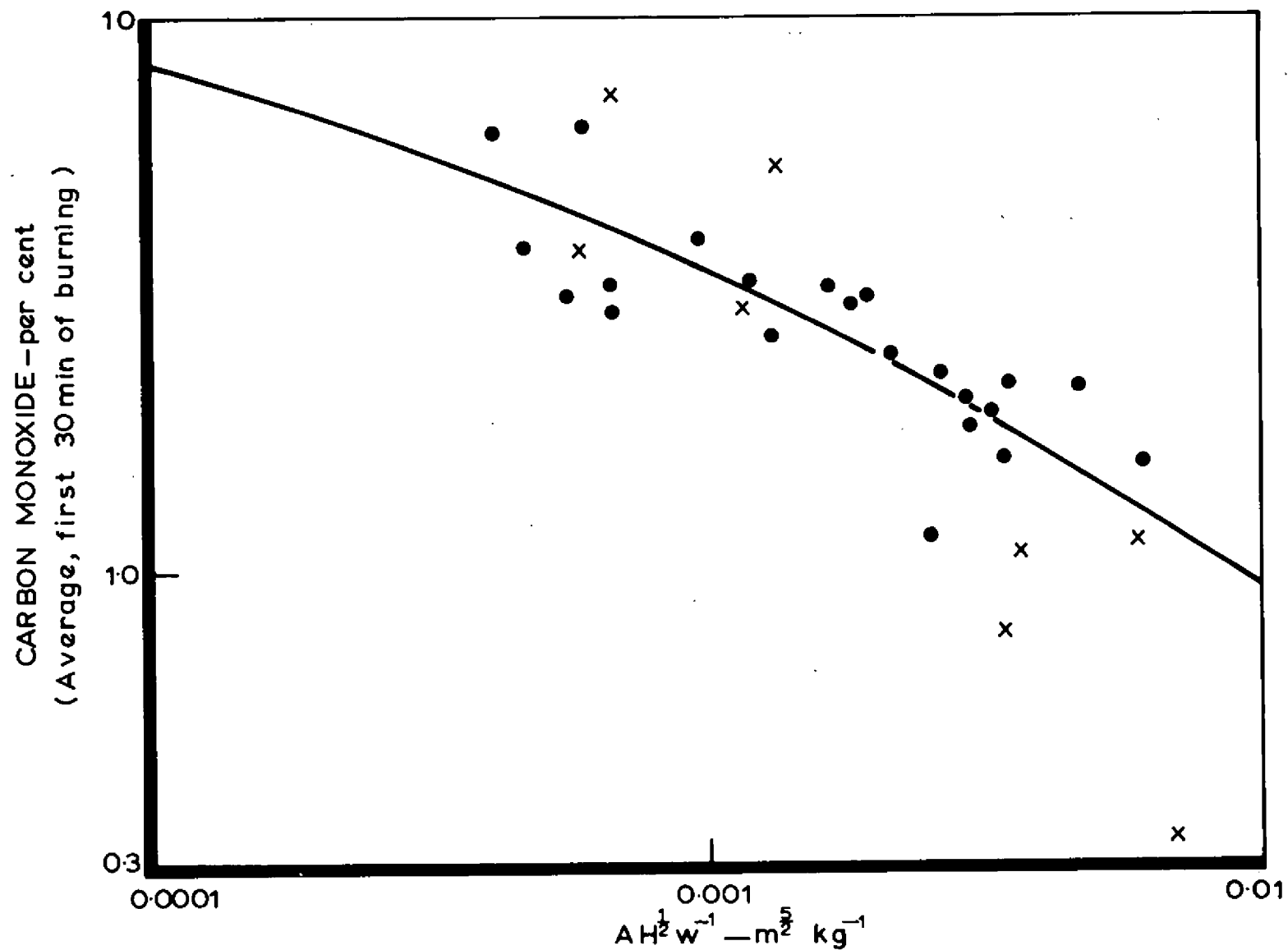


FIG. 25. EFFECT OF CELLULOSE LOAD AND VENTILATION ON CARBON MONOXIDE IN EVOLVED GASES

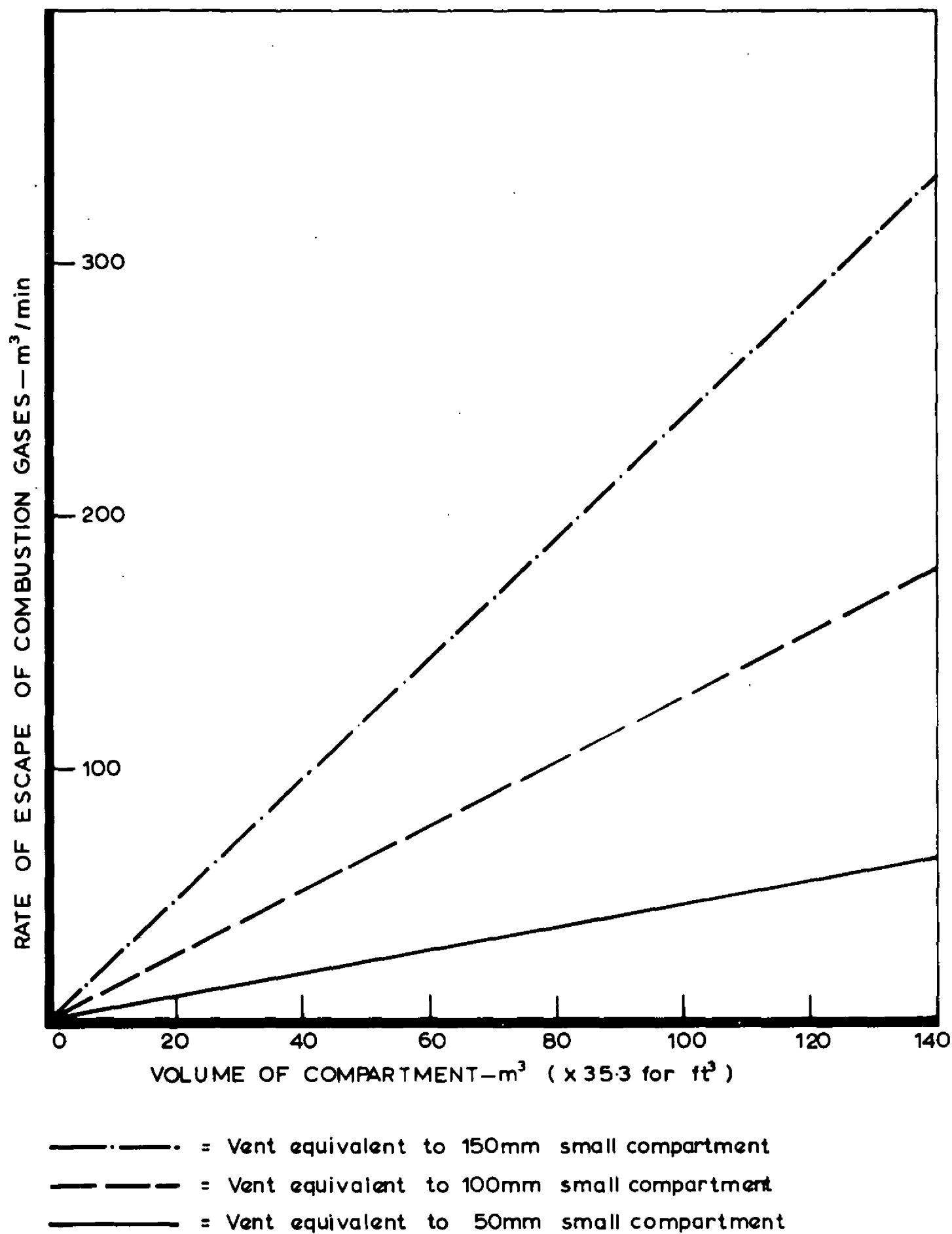


FIG. 26. ESCAPE OF COMBUSTION GASES FROM COMPARTMENTS
EFFECT OF HIGH LEVEL VENTILATION



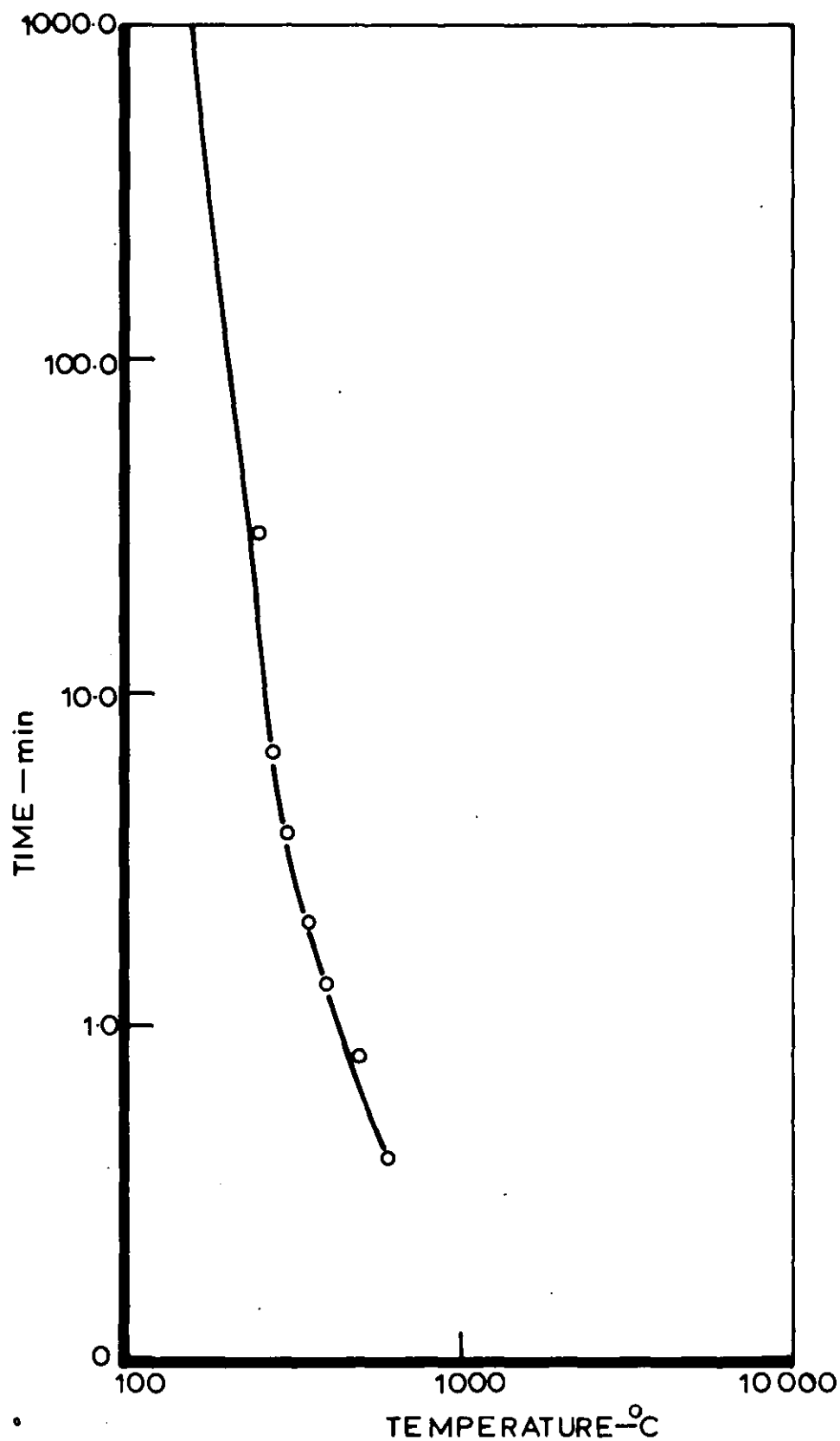
RESIDUE OF 1.5 mm U. P. V. C. WALL LINING
TEST WITH PROPANE FUEL, 20 l/min
150 mm VENT

FIG. 27



RESIDUE OF 3 mm U.P.V.C. WALL LINING
TEST WITH PROPANE FUEL, 20 l/min
150 mm VENT

FIG. 28



Rate of release of hydrogen chloride from
polyvinyl chloride

FIG. 29. TIME FOR EVOLUTION OF HALF THE
AVAILABLE HYDROGEN CHLORIDE FROM
UNPLASTICISED POLYVINYL CHLORIDE
LABORATORY TESTS

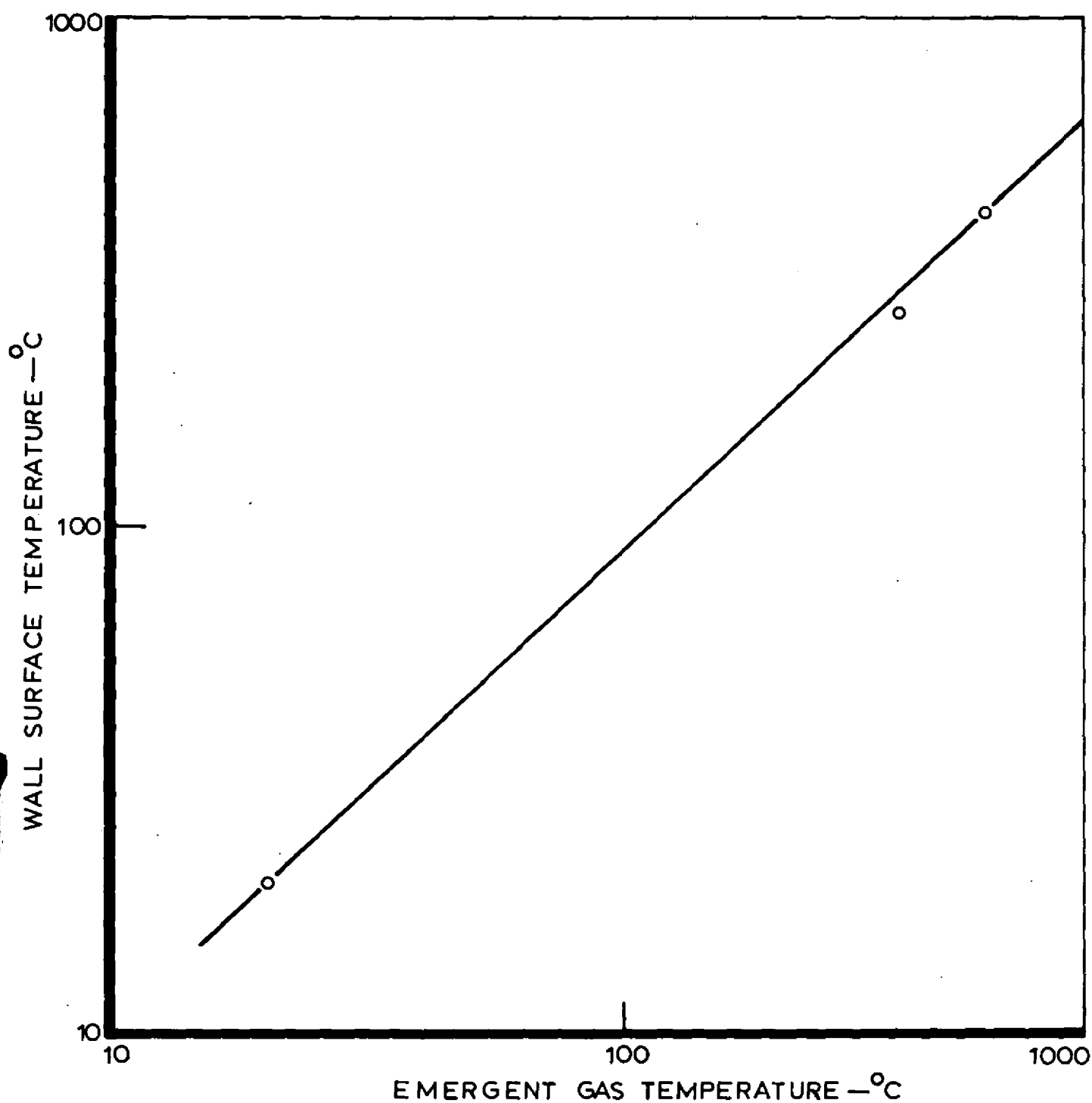
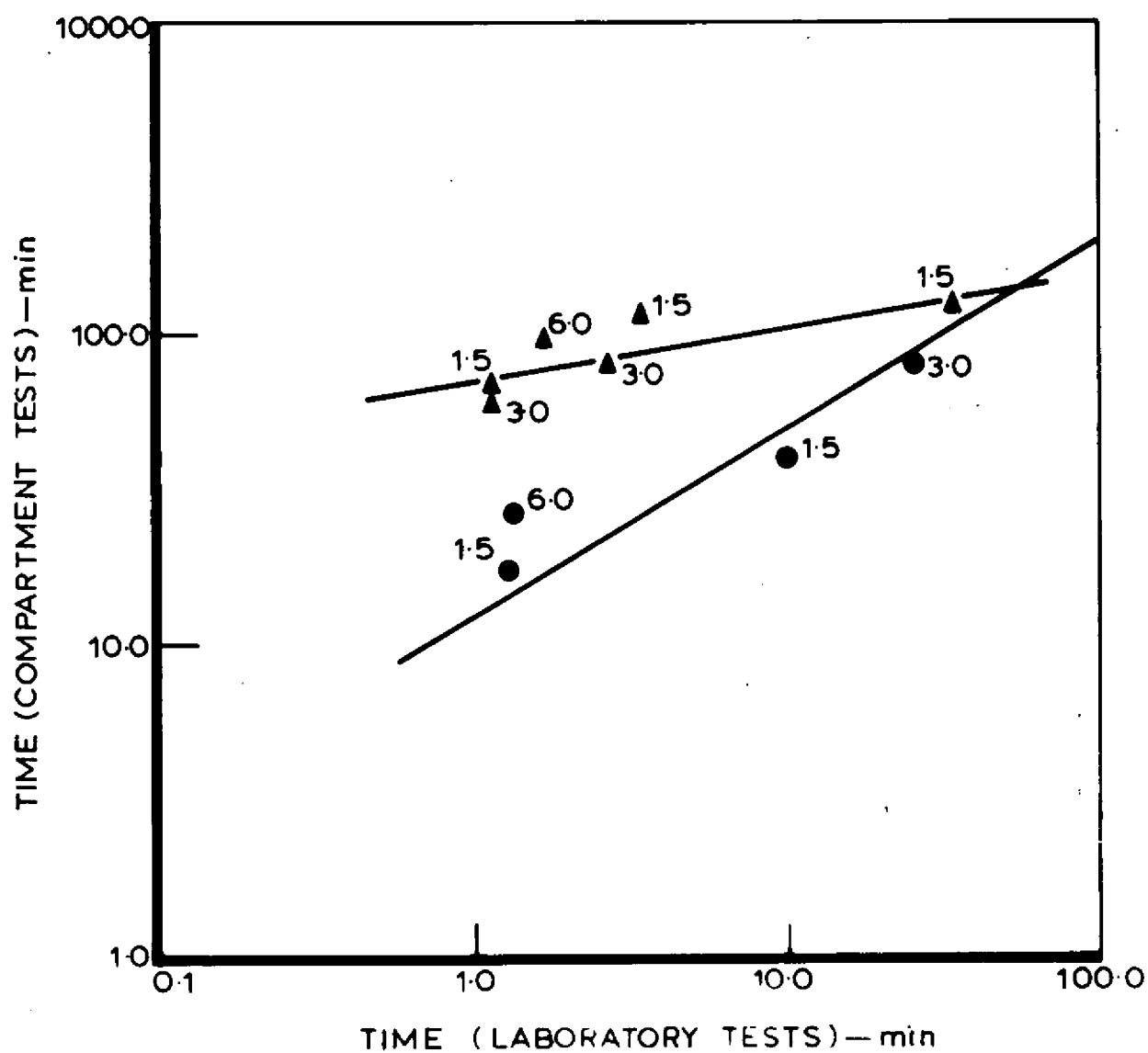


FIG. 30. RELATION BETWEEN WALL SURFACE TEMPERATURE AND EMERGENT GAS TEMPERATURE



- 6.4kg W.F.I.B.
- ▲ 12.8kg W.F.I.B.

FIG.31. TIME FOR RELEASE OF 50 PER CENT AVAILABLE HYDROGEN CHLORIDE IN LABORATORY AND COMPARTMENT TESTS

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