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GAS EXPLOSIONS IN MULTIPLE COMPARTMENTS

by

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SUMMARY

Explosions have been carried out in mixtures of town gas and natural gas in air, in a bunker containing two partitions each with large openings. One end of the bunker contained a large opening which almost filled the bunker cross-section. The layout of the bunker was designed to simulate the conditions that might occur when explosions pass from room to room in domestic premises before explosion relief to the outside. The gas was present in the form of a layer 0.9 m (3.0 ft) thick. Pressures substantially larger were obtained than those which might have been expected if no partitions were present and if the bunker were completely filled with most explosible mixtures of gas and air. However, the enhanced explosion pressures took place over a narrow range of gas mixtures and it was important to control the composition of the gas layer accurately to obtain these high pressures.

KEY WORDS: Explosion; Compartment; Gas explosion; Pressure.

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INTRODUCTION

Following the publication of the report of the enquiry into the collapse of flats at Ronan Point, advice was sought from the Fire Research Station on the pressures that might occur in domestic structures during explosions[1]. This advice indicated that the presence of windows, doors, etc, in the outside walls may reduce considerably the pressures that may develop, and under a wide range of conditions such windows and doors could provide explosion relief sufficient to keep pressures down to quite low values. However, certain conditions were specified in which the explosion might pass from one room to another, which could produce severe turbulence in the gas ahead of the flame, and consequently result in substantially higher pressures. These could be of the order 35 kN/m^2 (5 lbf/in^2) with propane and even higher with town gas. Certain special explosion relief facilities were suggested to mitigate the development of these pressures.

During 1969 a series of full-scale tests on gas explosions in domestic premises was carried out for the Building Development Agency by The British Ceramics Research Association (BCRA) in conjunction with The Gas Council and The Atomic Energy Authority[2]. These tests confirmed that windows could act as useful explosion relief for gas explosions in buildings. However, experiments in which gas explosions moved from one room to another did not indicate that any especially high pressures were obtained. Thus the highest pressure obtained for town gas was 23 kN/m^2 (3.3 lbf/in^2).

The postulated increase in violence caused by severe turbulence in an explosion considerably complicates the design of reliable explosion relief. It is, therefore, important to establish the conditions under which this may occur, or indeed, whether it can occur at all. The advice on the conditions of severe turbulence given by the Fire Research Station was based almost entirely on small-scale tests in spaces with a mean linear dimension of 0.5 metres, and it is possible to advance reasons that this effect might not extrapolate to much larger dimensions. To clarify this point the Ministry of Public Building and Works asked the Fire Research Station to design a test which would indicate whether a substantial increase in the violence of an explosion could occur as it moved from room to room in a dwelling, and to co-operate with the Gas Council and the BCRA in carrying out the test.

EXPERIMENTAL

The tests were carried out on the 9, 10 and 11 June 1970 in the BCRA bunker[2]. This was divided by brick partitions in a manner which simulated the consecutive rooms in a dwelling.

In the experiments carried out by the BCRA in their main building in 1969 in which the explosion moved from one room to another there were two factors which may have prevented the development of high pressures:

(1) The room in which the gas was ignited was provided with good explosion relief, and this explosion relief was greater than explosion relief in the room into which the flames travelled. These are conditions where the increase in violence might not be very marked, since the good explosion relief in the room of ignition could provide "back relief"[1]. One would expect that the most violent effects occur when an explosion is relieved almost entirely through the door of a room into another room and not through the window of the room of ignition to outside.

(2) Although the gas was introduced into the rooms in a manner which might occur in practice, this precluded sufficient control of the gas flow to allow definition of the precise quantities and concentrations of the gas mixtures present. Small-scale tests on ducts have suggested[3] that a large increase in the pressure in explosions due to severe turbulence might occur only over a narrow range of fuel gas concentrations. It is quite possible that in a comparatively small number of experiments where special control had not been exercised the relevant concentration range might have been missed.

The experiments were set-up to take into account particularly the above two points.

SUB-DIVISION OF THE BUNKER

Figure 1 shows a diagram of the bunker. It was 5.5 m (18 ft) long, 3.05 m (10 ft) wide and had one open end. The height of the bunker varied since portions of the roof were arched and other portions were flat. The mean height was approximately 2.1 m (7 ft). The bunker was divided into three compartments by two walls, W_1 and W_2. W_1 was 0.22 m (8.75 in) thick and its inside was 2.14 m (7 ft) from the closed end of the bunker. This wall contained two openings, V_1 and V_2 rising from the floor, each opening measuring 1.53 m (5 ft) high and 0.61m(2 ft) wide. The inside edges of these two openings were 0.61 m (2 ft) apart.

W_2 was 0.34 m (13.5 in) thick and its inner face was placed 1.53 m (5 ft) from the outside face of W_1. W_2 was built as a pillar straddling the centre line of the bunker, was 1.53 m (5 ft) long and reached from ceiling to the floor of the bunker. This left spaces V_3 and V_4 in the wall 2.14 m (7 ft) high and 0.76 m (2.5 ft) wide on either side. Into the front end of the bunker a wooden frame F was fixed to contain an opening V_5 measuring 1.60 m (5.25 ft) high by 2.86 m (9.33 ft) wide. This wooden frame contained provision for clamping a polythene sheet to close the opening. The walls thus divided the bunker into three compartments, A, B and C, and the design allowed a study of the effect of movement of the explosion from an enclosed volume A through spaces V_1 and V_2 which simulated doorways, into another space B which could simulate a corridor, and thence into a third space, C, which could be regarded as simulating a room with a large explosion relief. The open area in the walls, W_1 and W_2 was in two parts to allow the partial blocking off of this area if deemed to be necessary. The total area of the two openings in W_1 was approximately the same as the area of a normal doorway. The total area of opening in W_2 was substantially greater than the area of a normal doorway. V_5 was the size of a large window.

METHOD OF INTRODUCING THE GAS MIXTURE

When town or natural gas flows into a room due to some fault or leak it tends to accumulate under the ceiling. However, according to the conditions of entry of the gas into the room or rooms, it is possible to visualize a wide range of mixtures of the gas with air. It was important, therefore, to introduce the fuel into the bunker in a way which would give a layer of known thickness and controlled concentration. It has been shown[4] that to introduce a gas into a room or a compartment in a way which would allow reasonably controlled layering of the gas with respect to the air in the rest of the compartment, requires certain entry conditions, as follows:

(1) The gas if lighter than air needs to be introduced near the ceiling.

(2) The dimensionless number N_1, given by equation 1, at the point of introduction should be greater than unity:

$$N_1 = \frac{gL \Delta\rho}{v^2 \rho_i} \qquad \ldots\ldots\ (1)$$

where L = vertical dimension of the entry duct

v = velocity of the gas as it leaves the duct

ρ_i = density of injected gas

$\Delta\rho$ = difference between the density of the gas present and the injected gas

and g = acceleration due to gravity.

N_1 may be regarded as a local Froude number at the entry point, and is the ratio of the buoyancy forces which promote layering and the gas momentum forces which would stir the contents of the bunker and promote turbulence. The investigation referred to showed that reasonable layering could be achieved by passing the gas through diffusers at the point of entry into the compartments; the effect of these diffusers was mainly to reduce the velocity v.

On the basis of this work it was estimated that to produce good layering in the bunker the gas should be introduced at a point under the ceiling of each of the compartments A, B and C through cylindrical diffusers measuring 0.45 m (18 in) long x 0.076 m (3 in) diameter. The diffusers were constructed to these dimensions from 30 mesh metal gauge; one of them is shown in Fig. 2.

The objective in the experiment was to set up layers of town gas and natural gas of different controlled concentration and constant thickness. This would give information on the range of conditions under which the pressure of the explosion might be increased. The development of the controlled gas layer in the bunker was monitored by taking frequent samples from six sampling points, two in each chamber. One of these two sampling points was 0.61 m (2 ft) below the ceiling, and the other was 0.92 m (3 ft) below the ceiling in compartments A and C; in most tests the second sampling point was 1.22 m (4 ft) below the ceiling in compartment B.

The experiments were carried out in the following order and with the following gas layers, all nominally 0.92 m (3 ft) thick:

(1) 100 per cent town gas
(2) 40 per cent mixture of town gas in air
(3) 20 per cent mixture of town gas in air } nominally stoichiometric
(4) 20 per cent mixture of town gas in air }
(5) 15 per cent mixture of town gas in air
(6) 30 per cent mixture of town gas in air
(7) 10 per cent mixture of natural gas in air } nominally stoichiometric
(8) 10 per cent mixture of natural gas in air }

The town gas had the following composition:

Hydrogen	39.8 per cent
Oxygen	3.57 per cent
Nitrogen	19.3 per cent
Methane	28.6 per cent
Carbon monoxide	0.75 per cent
Carbon dioxide	7.13 per cent
Ethane	0.91 per cent

The natural gas consisted of 87 per cent methane and approximately 13 per cent ethane. It was estimated that the stoichiometric mixture of town gas contained 21.4 per cent of gas and the stoichiometric mixture of the natural gas 9.1 per cent. Normally the most violent mixture in explosions is slightly richer than the stoichiometric mixture. It will be noted that in experiments 3 and 4 and experiments 7 and 8 concentrations of fuel gas were approximately stoichiometric.

The gas was introduced into the bunker over a time varying between 15 to 25 minutes. Criteria for a good layer were as follows:

(a) For the first five minutes or so only a very small fuel concentration was to be registered at any of the sampling points.

(b) Thereafter and for the rest of the time the concentration of the gas at the three sampling points 0.61 m (2 ft) below the ceiling should be approximately the same, and all substantially greater than the concentration at the other sampling points. It might be noted here that under conditions of perfect mixing the gas concentration would build up uniformly at all the sampling points soon after the introduction of the gas.

The layer was taken to be established when the concentration 0.61 m (2 ft) below the ceiling was 90 per cent or more of concentration of the injected gas, and at the sampling points 0.92 m (3 ft) below the ceiling, 50 per cent or more. The total theoretical quantity of gas required to produce a layer 0.92 m (3 ft) thick was 13.3 m^3 (470 ft^3). In general it was found that the quantity of gas that had to be injected to produce the above layer was somewhat greater than this, the flow rate of gas in most of the tests being 51 m^3/h (1,800 ft^3/h). The reason for this is that although the cracks in the bunker were sealed up as far as practicable, there was still some seepage of gas out of the bunker. There was also, of course, still a certain amount of diffusion of gas to the lower part of the bunker.

With all the experiments with town gas it was found practicable to establish a good layer of the injected gas, although in experiment 1, because of fluctuations in the flow, and in experiment 5, it was not possible to quite reach the standard set by the above criteria. However, in the first experiment with natural gas (experiment 7), it was clear from the beginning that a good layer was not being obtained. An attempt was made to retrieve the situation during the last 5 minutes of the injection period by increasing the concentration of the injected gas by 80 per cent. This gave concentrations at the sampling points which approximated to those required. It had been noted earlier that only about 20 per cent of the area of the diffusers were effective in reducing the gas velocity, and owing to the very small pressure differential (see equation 1) associated with a 10 per cent natural gas mixture, the value of N_1 may well have been reduced to below the critical value for layering. Following experiment 7 the whole area of the diffuser was made effective by wrapping a plastic foam mat round it (Fig. 3). This had the effect of producing very good layering in experiment 8, the second experiment with natural gas.

During the introduction of the gas, and in the following period up to the explosion the large vent V_5 at the end of the bunker was sealed with a double layer of polythene 0.13 mm (0.005 in) thick (Fig. 4).

MEASUREMENTS OF PRESSURE AND FLAME MOVEMENT

The pressures developed by the explosion in the bunker were monitored by 5 piezo electric gauges with a natural frequency of 40 kc/s situated 0.61 m (2 ft) from the ground at the points marked **P** in Figure 1. (P1 and P2 for compartment A, P3 for compartment B and P4 and P5 for compartment C).

The gauges were insulated from the effects of the gas flame by wrapping the body of the gauge with several layers of insulating glass cloth, and smearing a silicon grease on the front face of the gauge. This precaution reduced the possibility of spurious readings which might occur when the gas flames impinged on the gauges. An ionization gap G was installed just inside the centre of vent V_5 to allow a measurement of mean flame velocity between the point of ignition and this vent. A cine record was also obtained in many experiments using a camera focussed on the mouth of the bunker. The speed of the camera varied between 400 and 750 frames/second. The direction from which the record was taken is shown in Fig. 1.

IGNITION

The gas was ignited in a region 0.15 m (6 in) in front of the back face of compartment A. Three Nobel safety fuses were provided and these were suspended at intervals of 0.15 m (6 in) straddling the interface of the layer approximately 1 m (3 ft) below the roof of the bunker. The duration between establishing the layer and igniting the gas was kept as short as possible and in general was approximately one minute.

RESULTS

PRESSURE AND IONISATION GAP RECORDS

Table 1 shows the maximum pressure obtained in six of the eight experiments, and also the times taken for the flame to travel between the ignition point and ionization gap at V_5. Pressures reached several pounds per square inch in each of the three compartments in the experiments with 10 per cent natural gas and 20 per cent and 30 per cent with town gas. In the other tests listed in Table 1 the maximum pressures were very much lower. In the experiment with

20 per cent town gas, the explosion was violent. The wooden framework F holding the polythene vent was ripped off and parts of this frame blown a considerable distance. The hut in which the pressure measuring equipment was housed and which was situated at a distance of about 16 m (50 ft) from the bunker, was also bodily moved a distance of 0.15 m (6 in). In the experiment with 10 per cent natural gas, the wooden frame was also completely ripped off. In the experiment with 30 per cent town gas this frame was partly ripped off, and in the other experiments listed in Table 1, it was not affected.

In experiment 3 which was the first of the two experiments carried out with 20 per cent town gas, the pressure records were spoiled, firstly, because some of the records went off the scale as the pressures were unexpectedly high, and secondly, because the heat from the flames spoiled some of the other pressure records. The explosion, however, was of a similar violence to that in experiment 4 which followed.

In experiment 7 with nominally 10 per cent natural gas, the pressures reached were 3.1 kN/m^2 (0.45 lbf/in^2) in compartment A, 2.8 kN/m^2 (0.4 lbf/in^2) in compartment B, and 2.1 kN/m^2 (0.3 lbf/in^2) in compartment C. It will be seen that these pressures are very much less than those given for test 8 in Table 1. However, the development of the layer in experiment 7 was poor, and there was uncertainty as to what actually was the composition of the layer.

In all tests in which pressures greater than 7 kN/m^2 (1 lbf/in^2 were measured, the pressure records at all measuring points were characterized by sharp rises in pressure lasting 20-30 ms occuring at the same time, which was also about the time that the flame arrived at the outside explosion relief V_5. Figures 5 and 6 show sets of pressure records for experiments 4 and 8 respectively.

It will be noted that the pressure records P1 in Fig. 2, and P3, P4, P5 in Fig. 6, fell away rapidly after the peak. Experience with these gauges has shown that these are not due to any pressure changes but to the effect of heat caused by the flame and suggests that the heat insulation of the gauge needs to be still further improved.

CINE RECORDS

All cine records taken in the tests showed the following sequence of events. This sequence is illustrated in Fig. 7a to 7f which are shots taken from the cine record of test 8.

(1) The first sign of explosion was bulging of the polythene cover. This bulging was shown by the reflection of sunlight from the top part of the polythene; the latter effect should not be confused with the presence of flame in the vicinity (Fig. 7a).

(2) The polythene then burst. The tear began usually near the lower edge of the polythene (Fig. 7b).

(3) Flame then appeared in compartment B. The camera was angled in such a way that the flame first appeared at a point which was probably near the top V_2 one of the openings between A and B. A substantial opening existed in the polythene vent at this point of time (Fig. 7c).

(4) The flame then proceeded to fill compartments B and C (Fig. 7d) and to progress beyond the remnants of the polythene into the open air and to fill the whole field of view (Fig. 7e).

(5) In tests where the timber structure blew out this occurred after the field of view was filled with flame (Fig. 7f).

Table 2 shows the time sequence of these events for tests Nos. 3, 4, 6 and 8. The moment of ignition was not recorded on the cine record. However, by equating the time for the flame to reach the ionisation gap as given in Table 1 with the time required to reach the front of the bunker in the cine records, it was possible to relate the times relative to the moment of ignition, and they have been recorded as such in Table 2. What stands out in Table 2 is the very much longer time taken in all tests for the flame to travel from the ignition source to the back of compartment B, a distance of 2.4 m, than it took to travel from the latter point to the front of the bunker, a distance of about 3.2 m. Using the times in Table 2 mean velocities in compartment A and in compartments B and C were estimated and are also shown in Table 2. The speed of approximately 9.5 m/s in compartment A for a 20 per cent town gas experiment is what might be expected for a stoichiometric town gas air mixture under low turbulence conditions.[5] This flame speed indicates that the irregularity in the ceiling of compartment A and the minor items in the compartment, did not have a substantial effect on the flame speed. The mean flame speeds in compartments B and C were some 10-20 times higher than the mean flame speed in compartment A, although comparison between tests 3 and 4 indicates that repeatability of the estimate was not good.

DISCUSSION

INCREASED PRESSURE CAUSED BY HIGH TURBULENCE

The object of the experiment was to find whether the interposition of obstacles in the form of walls containing doorways could substantially increase the violence of a gas explosion. To assess this it is necessary to have an estimate of the pressures that might be developed under similar conditions in the compartments A, B and C by themselves, or in the whole of the bunker in the absence of any partitions. It was not possible to carry out experiments on this, but as an alternative, estimates may be made of the pressures that may be obtained under the worst possible conditions of what has been called "low turbulence"[1]. These are the pressures which would have developed if individual rooms or the bunker as a whole, had been furnished like domestic rooms, had been filled with the most explosive mixture of the particular gas used. For propane/air mixtures under these conditions equation 2 has been put forward[1] as giving the maximum pressures that are developed:-

$$P_m = 1.5\ P_v + 3.5\ K\ (kN/m^2)^{*}$$

$$P_m = 1.5\ P_v + 0.5\ K\ (lbf/in^2) \qquad \ldots\ldots\ldots (2)$$

In the present experiments the gases used were natural gas and town gas and equation 2 needs to be modified to take this into account. It is suggested that this might be done by making the coefficient of K in equation (2) proportional to the fundamental burning velocity of the gas. It may be assumed that natural gas had a fundamental burning velocity of 0.36 m/s as compared with that of propane of 0.46 m/s. This would result in the equation for natural gas being:-

$$P_m = 1.5\ P_v + 2.8\ K\ (kN/m^2)$$

$$P_m = 1.5\ P_v + 0.4\ K\ (lbf/in^2) \qquad \ldots\ldots\ldots (3)$$

where P_m = maximum pressure reached in the explosion (kN/m^2 or lbf/in^2)

P_v = the pressure at which the relief vent opens (kN/m^2 or lbf/in^2)

and K = the ratio of minimum cross-section of compartment to the area of the vent.

In the present experiments the vent was covered by polythene. Experiments on the same thickness of polythene used on one wall of a 0.6 m (2 ft) cubical box containing stoichiometric propane/air mixtures showed that the maximum explosion pressure obtained under these conditions due to the bursting of the polythene was 7 kN/m^2 (1.0 lbf/in^2). Making the necessary correction for the linear dimension of the vent gives a value of P_v of 2 kN/m^2 (0.3 lbf/in^2). The value of K for

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*N.B. The coefficient of P_v in this equation was erroneously given as 10 in ref. 1.

compartments A, B and C respectively was 2.5, 1.0 and 0.6. However, taking the bunker as a whole, the value of K was 1.3; this is smaller than the value for the individual compartment A, but larger than the values for the individual compartments B and C. It is, therefore, appropriate to take 1.3 as the value of K for the latter two compartments. Substituting in equation 3, one obtains maximum pressures under the worst conditions of low turbulence for natural gas of 10 kN/m^2 (1.45 lb/in^2) for compartment A, and 7 kN/m^2 (1.2 lb/in^2) for compartments B and C. If these figures are compared with that obtained for test 8 shown in Table 1, it will be seen that the pressures actually reached in experiment with natural gas were 2 to 2.5 times larger than the pressure expected with the most violent of low turbulence conditions for the same gas and for the same arrangement of vents. This may be ascribed to the introduction of a substantial high turbulence factor due to the presence of partitions; this effect is confirmed by the very much higher flame speeds in compartments B and C as compared with compartment A. It should be noted that if the bunker had been completely filled with the gas/air mixture, or if the bunker had contained obstacles in the form of furniture, higher pressures still might have been expected.

It was not possible to carry out calculations in the same way for town gas because of the uncertainty of the burning velocity of the town gas used and the effect it might have on the coefficient of K. In their original experiments on explosions in gas ovens, Cubbage and Simmonds[5] ascribe a burning velocity of 120 cm/s (3.9 ft/s) to the town gas they used, whereas the Morton Report[6] indicates a maximum burning velocity of 80 cm/s for traditional town gas. On the basis of information provided by Scholte and Vaags[7] one might estimate a maximum burning velocity of 70 cm/s (2.3 ft/s) for the town gas used in the present experiments. However, even taking the highest burning velocity (120 cm/s) and applying the same approach as was used for natural gas above, one can estimate a value of 15 kN/m^2 (2.1 lbf/in^2) for the worst low turbulence condition in the bunker, i.e. the bunker completely filled with the most explosive mixture of town gas and air and containing furniture but not containing partitions. Again Table 1 shows that in test 4 the maximum pressure in compartment B was twice as great, indicating a high turbulence effect. Moreover, this occurred when the concentration of the town gas used was somewhat less than stoichiometric; almost invariably maximum pressures tend to occur with concentrations somewhat greater than stoichiometric.

The only other experiment in which pressures comparable to that which could be obtained under the worst conditions for a low turbulence situation, was test No. 6 for 30 per cent town gas. The tests with 15 per cent, 40 per cent and 100 per cent town gas gave negligible pressures. Thus, it is clear that the enhancement of the pressure takes place only under a narrow part of the conditions in which explosive effects may be obtained. One of the factors on which there was some doubt before these experiments were carried out, was that a layer rich in the fuel gas may give as bad or even worse an explosion under highly turbulent conditions as a layer of the most explosive gas, the reason being that the turbulence caused by the explosion might spread a rich gas of a limited volume to form a gas mixture with the most explosive concentration over a large volume. There is no evidence in these results that this might happen in domestic premises. This may be a consequence of the scale of turbulence which would be related to the dimension of the open doorway through which the explosion passed. This scale may have been too large to cause a sufficiently uniform mixing of rich gas with air, which is the factor that governs the achievement of a high pressure. However it would be desirable to carry out more experiments to confirm this.

CONDITIONS UNDER WHICH HIGH PRESSURES MAY BE OBTAINED

The experiments were designed to estimate the increase in the violence of the explosion caused by the turbulence that might occur as an explosion passes through doors from one room to another. They were not specifically designed to measure the maximum possible explosion pressures that might be obtained in domestic premises. Higher pressures than those obtained in Table 1 might be expected if

(1) the whole bunker were filled with the most explosive mixture of gas and air rather than the top 0.9 m (3 ft) of the bunker,

(2) the size of the opening in the walls W_1 and W_2 were reduced,

(3) the size of the vent V_5 were reduced,

(4) there were a more substantial cover on the vent V_5 than the polythene sheet used in the present experiments,

(5) there were a closed door in the openings in W_1 and W_2,

(6) a town gas concentration slightly richer than stoichiometric were used,

(7) there was furniture in the bunker.

Apart from the first of the above possibilities, all the others might reasonably occur in domestic premises. One might therefore conclude that the experiments suggest that with town gas as fuel pressures substantially higher than 35 kN/m^2 (5 lbf/in^2) might occur in a severe turbulence condition which could be set up in domestic premises. However, the experiments also indicate that the range of gas mixtures under which this would happen is a narrow part of the total range of gas mixtures which, in the form of a layer, could give explosive effects. It should also be emphasized that the experiments were carried out under conditions where no measures were taken to reduce the development of severe turbulence - in particular there was no "back relief". To elucidate the effect of these measures a further substantial programme of research is required and it is advisable that this is carried out in compartments specially built for the purpose.

EFFECTIVENESS OF CONTROL OF LAYERING

The sharpness of the effect of the concentration range emphasizes the importance of obtaining good control over the composition of the gas mixture and the layering in experiments of this kind. The control of the layering in experiment 5 with 15 per cent town gas was not quite as good as the control in the other experiments and the very low pressures obtained with this mixture may have been partly due to this factor. In experiments 1-7 the gas was delivered mostly through the last 0.076 m (3 in) of the gauze diffuser. If it is assumed that the gas was being evolved with an even velocity over this area, then the value of the dimensionless group N_1 may be estimated as between 1 to 1.3 in experiment 5, and between 0.8 and 1 in experiment 7. In experiment 7 the layering was poor and in spite of attempts to retrieve the situation, explosion pressures were much less than those obtained in experiment 8. The results confirm that there is a critical value of N_1 at approximately unity above which good layering is obtained. However, it would be recommended that if further experiments were to be carried out, then in all the experiments the diffuser should be wrapped with a cloth or porous plastic foam layer, to allow the gas to enter the compartment evenly over the whole length of the diffuser. With a flow rate of approximately 17 m^3/h (600 ft^3/h) through each diffuser this would give a value of N_1 very much in excess of unity for any flammable mixture of town gas or natural gas and air.

CONCLUSIONS

(1) The maximum pressures measured in the tests were 5 lb/in^2 for town gas-air mixtures and 3 lb/in^2 for natural gas-air mixtures.

(2) It may be possible to establish conditions in domestic premises in which higher pressures than these might be obtained.

(3) Large increases in pressures and flame speeds may occur in explosions from layers of fuel gas-air mixtures if the explosion moves through door openings between compartments of the size which occurs in domestic premises.

(4) The conditions in which this enhancement of the explosion violence takes place is only a small part of the total range of conditions that can give explosive effects.

ACKNOWLEDGMENT

The tests were carried out in conjunction with the BCRA and the Gas Council. The BCRA were responsible for the bunker and site facilities, and they also provided Figs. 3 and 4 in this report. The Gas Council provided the fuel gas and were responsible also for the monitoring and analysis of the gas. The JFRO designed the experiment, provided the gas diffusers and monitored the explosions. Acknowledgment is also due to the Ministry of Public Building and Works who provided part of the pressure measuring equipment.

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Table 1

Maximum pressures reached in the explosions
kN/m² (lbf/in²)

Test No.	Designated composition of layer	Compartment A P1	Compartment A P2	Compartment B P3	Compartment C P4	Compartment C P5	Time from ignition to V5 ms
1	100% Town gas (4.7S)	1.4 (0.2)	1.4 (0.2)	1.05 (0.15)	0.7 (0.1)	0.7 (0.1)	360
2	40% Town gas (1.9S)	*	3.5 (0.5)	2.1 (0.3)	1.4 (0.2)	*	500
6	30% Town gas (1.4S)	*	21 (3.0)	16 (2.3)	14 (2.0)	13 (1.8)	330
4	20% Town gas (0.93S)	35 (5.0)	35 (5.0)	29 (4.2)	24 (3.5)	21 (3.0)	270
5	15% Town gas (0.70S)	---------- Less than 0.7 (0.1) ----------					> 950
8	10% Natural gas (1.1S)	21 (3.0)	21 (3.0)	17 (2.5)	14 (2.0)	14 (2.0)	400

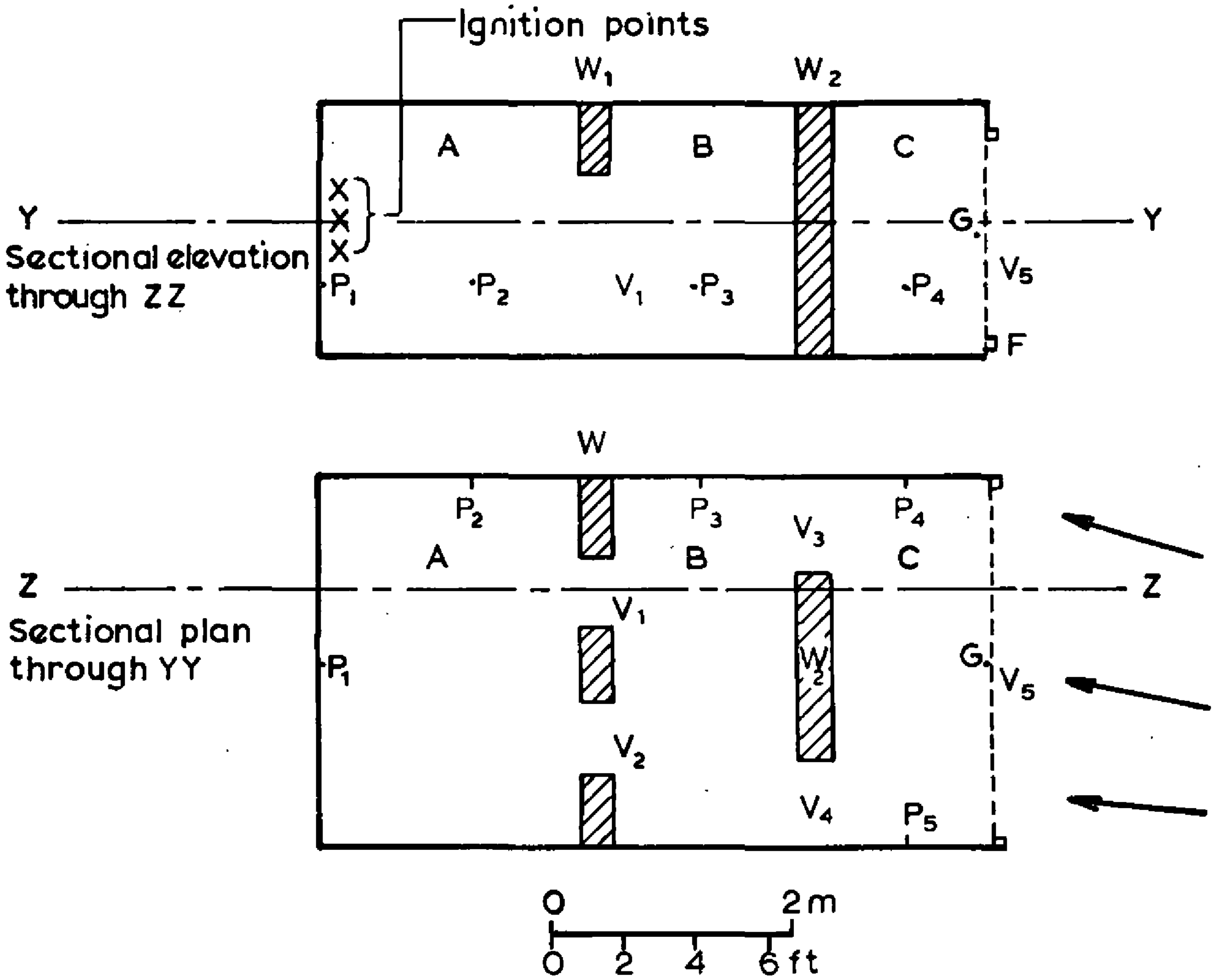
*Not recorded

S = Stoichiometric concentration of fuel gas in layer.

Table 2

The sequence of events in explosions (obtained from cine records).
Times after ignition given in milliseconds

Experiment No.	3 (20% town gas)	4 (20% town gas)	6 (30% town gas)	8 (10% natural gas)
First sign of polythene bulging	83	117	115	122
Polythene splits	203	230	224	347
First sight of flame at back of chamber.	256	248	301	362
Flame reaches front of bunker	270	270	330	400
Flame fills field of view	292	282	344	414
Blow out of timber structure	320	295	409	522
Mean flame speed in compartment A (m/s)	9.4	9.6	8.0	6.6
Mean flame speed in compartments B and C (m/s)	229	145	110	89



F	Wooden frame for holding polythene sheets
W_1 W_2	Brick partitions
V_1 to V_5	Openings or vents
P_1 to P_5	Position of pressure gauges
G	Position of ionisation gap
A B C	Compartments
⟶	Direction from which ciné record was taken

n.b. Alternative flat and arched portions of ceiling not shown

FIG.1 LAYOUT OF BUNKER FOR EXPERIMENT

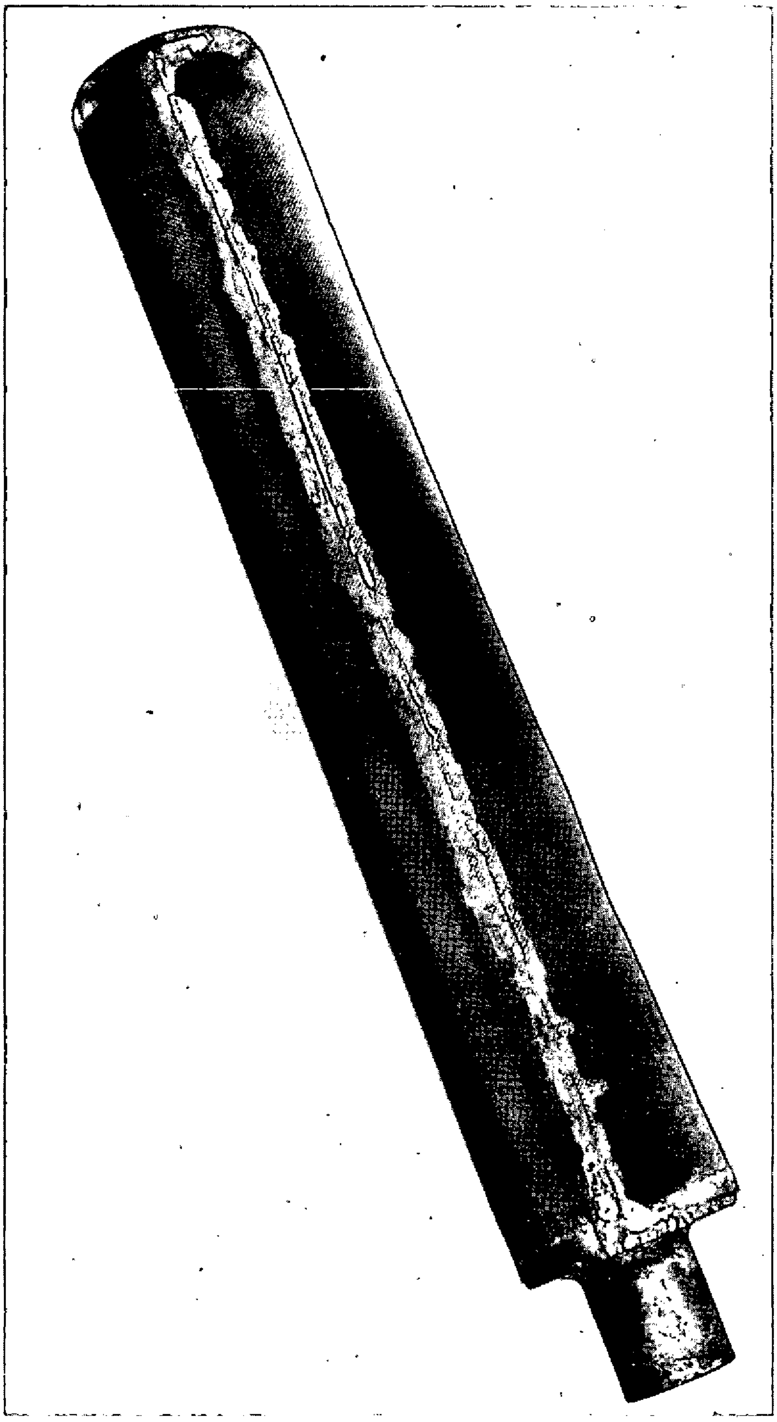


FIG. 2. GAUZE GAS DIFFUSER

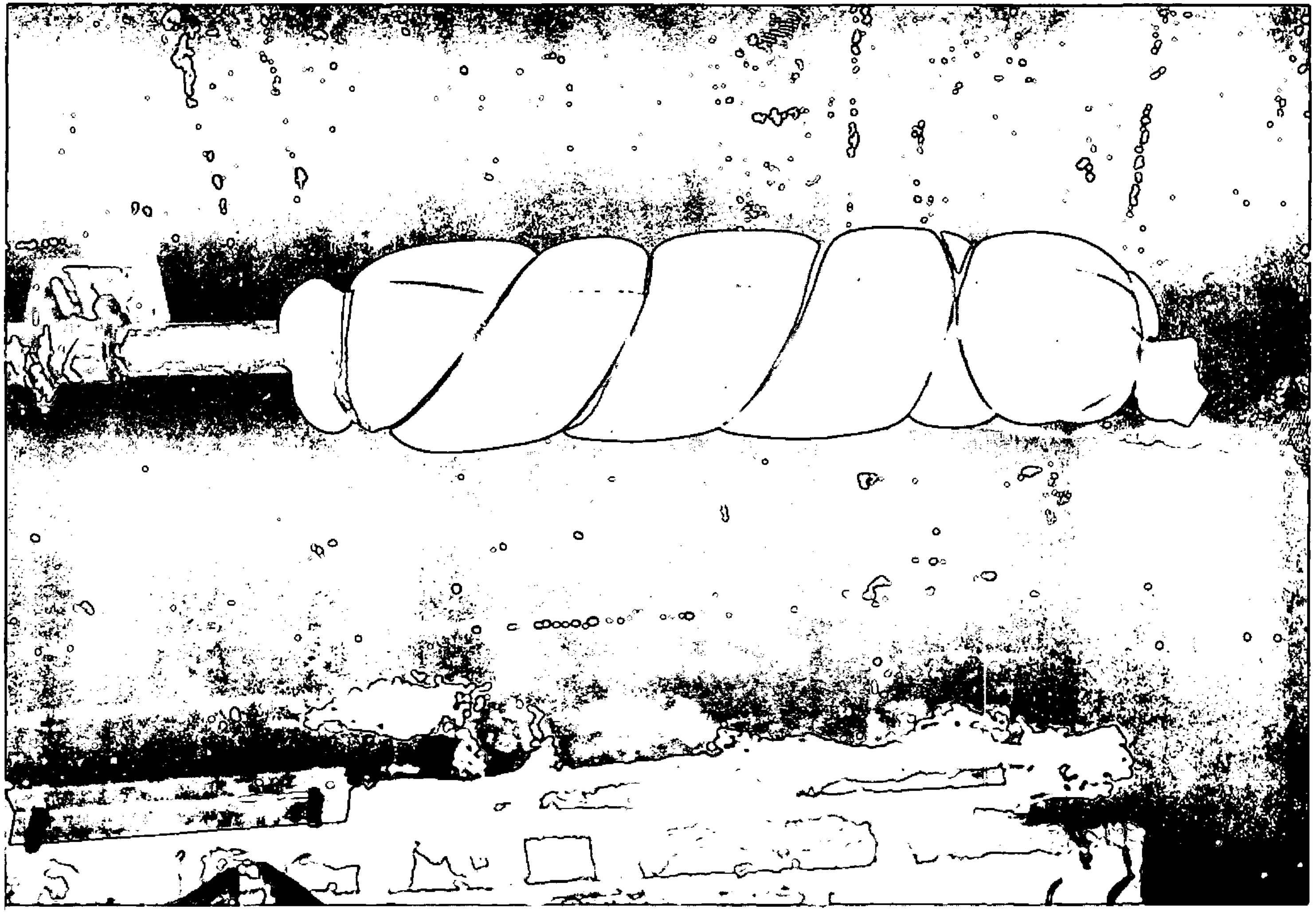


FIG. 3. GAS DIFFUSER WRAPPED WITH POROUS PLASTIC AS FOR TEST

FIG. 4. POLYTHENE SHEET IN PLACE DURING PERIOD OF CHARGING OF BUNKER WITH FUEL GAS-AIR MIXTURE

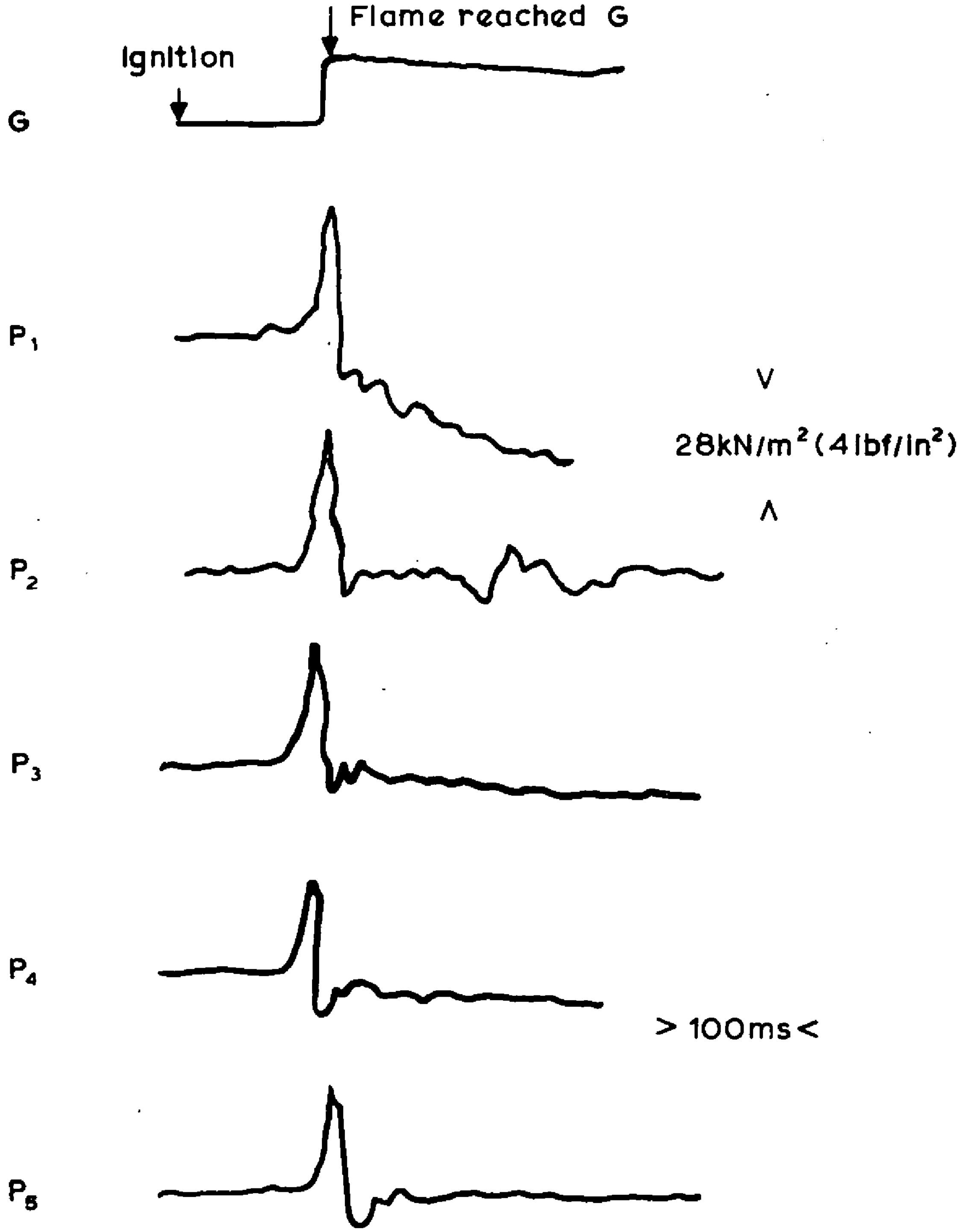


FIG.5. PRESSURE AND IONISATION GAP RECORDS, EXPERIMENT 4, 20 PER CENT TOWN GAS – AIR

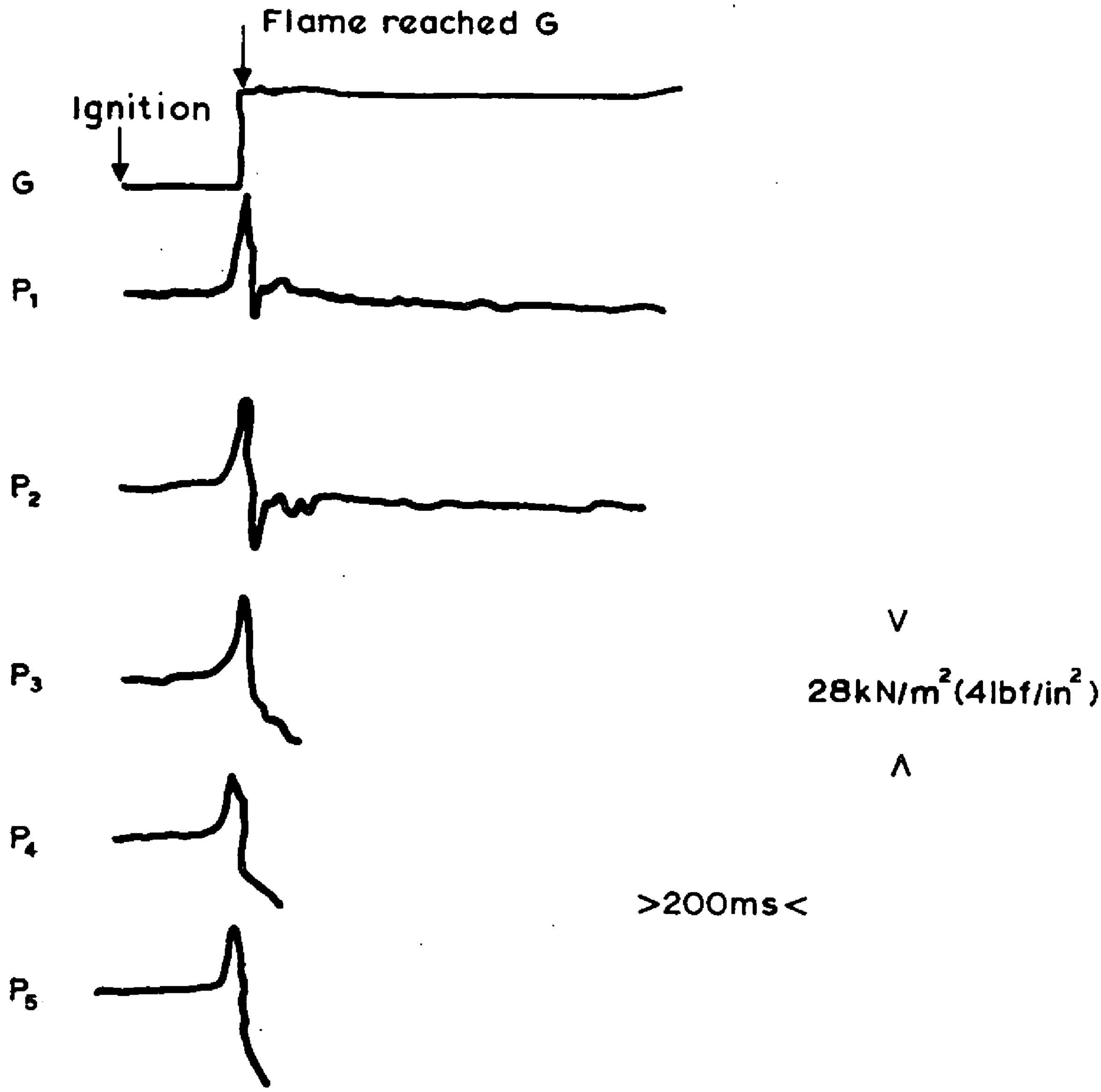
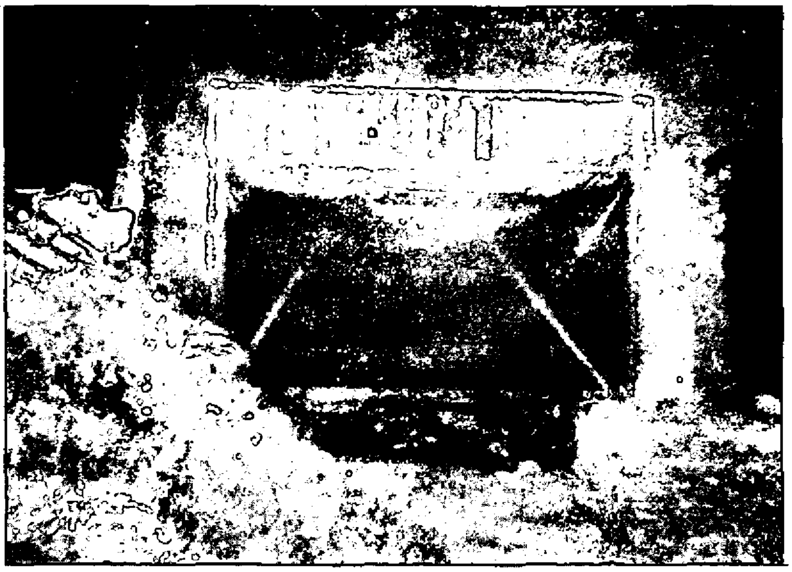


FIG.6. PRESSURE AND IONISATION GAP RECORDS, EXPERIMENT 8, 10 PER CENT NATURAL GAS – AIR

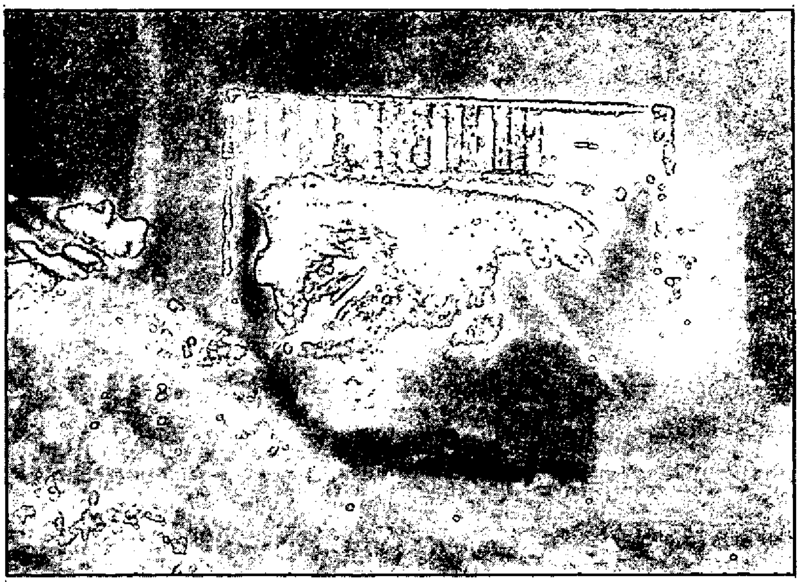


(a) Polythene sheet begins to bulge

(b) Polythene sheet begins to split at bottom.

(N. B. Luminosity is due to reflection of sunlight from polythene and not flame)

FIG. 7. SEQUENCE OF EVENTS IN AN EXPLOSION TEST 8 TAKEN FROM CINE RECORD



(c) Flame appearing in compartment B.
Large opening present in lower part of polythene

(d) Flame reaches front of bunker

FIG. 7 (cont'd)

(e) Flame progressing outside bunker to fill field of view

(f) Wooden frame becoming dislodged

FIG. 7 (cont'd)