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GAS EXPLOSIONS IN BUILDINGS
PART I. EXPERIMENTAL EXPLOSION CHAMBER

by

P S Tonkin and C F J Berlemont

February, 1974.

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SUMMARY

An explosion chamber of volume 28.4 m^3 (1002 ft^3) has been built of 4.8 mm ($^3/16$ in) thick steel plates in which explosions with natural gas/air mixtures can be carried out.

Provision has been made for the measurement of all relevant explosion parameters as necessary to obtain information on the effects of gas explosions in buildings.

Satisfactory operating and safety procedures have been established and used and are described herein.

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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PART I. EXPERIMENTAL EXPLOSION CHAMBER

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FOREWORD

Following the Ronan Point disaster and the report of the Investigating Tribunal, it was decided that the Fire Research Station of the Building Research Establishment would undertake a study of gas explosions in large compartments. In particular, the study would cover the factors affecting the development and severity of the explosions and the extent to which the pressures obtained could be relieved by venting.

In the context of the problem as a whole, the study is intended to provide the basic data on the form and magnitude of the transient stresses likely to be experienced by buildings in the event of gas explosions involving one or more compartments. This information is required as a guide for safe structural design and for any reappraisal of the relevant parts of the Building Regulations 1972, Part D, England, or Building Standards (Scotland) (Consolidation) Regulations, 1971.

Initial studies in this programme are concerned with explosions in a single compartment of realistic dimensions 28 m^3(1000 ft^3) provided with a single opening of simple configuration, the size of which can be varied and which can be closed with panels having a range of bursting pressures.

In view of the progressive change to natural gas, which is lighter than air, and the probable circumstances of the Ronan Point explosion, special emphasis is placed on the explosion of layered gas/air mixtures and the effects of layer depth, composition and point of ignition.

The principal measurements consist of high-resolution pressure-time records at points both inside and outside the compartment. In general, these pressure records are complex, including both positive and negative pressures, and attention is given to the exclusion of spurious effects due to mechanical vibration and transient heat pulses accompanying the explosion.

The study is to be extended to gas explosions in multiple compartments communicating by door openings and corridors. Here, particular attention will be given to the effects of turbulence generated at openings, bends and obstacles and the possibility of pressures increasing as explosion propagates from one compartment to another.

This series of notes comprises detailed accounts of phases of the work as it proceeds. A project of this magnitude necessarily involves a considerable amount of preliminary work in the development of equipment and procedures, all of which needs to be placed on record, but, in isolation, may sometimes appear somewhat remote from the objectives. This foreword is intended to facilitate the presentation of the detailed material with a minimum of introductory matter - no more than is needed to indicate the place of the particular work reported in the project as a whole. Reports of results and conclusions from this study will be included in the series at appropriate stages as the work proceeds and, correspondingly, these will need to contain a minimum of experimental detail.

INTRODUCTION

As a preliminary to the investigation of gas explosions in full-scale structures of several compartments, a single, vented, explosion chamber has been constructed with the objects of firstly, developing satisfactory procedures for the formation and monitoring of layered gas/air mixtures on a large scale and, secondly, to carry out systematic studies of explosions in a single compartment as such.

This note places on record a general description of the explosion chamber and ancillary equipment, and describes the safety procedures designed for the filling of the chamber with flammable mixtures and for carrying out the explosions. Some more detailed descriptions are given in appendices. Later notes in this series describing equipment and procedures will cover pressure measurement, automatic gas sampling and analysis, strain measurements, and the formation of layered gas/air mixtures in the chamber.

GENERAL DESCRIPTION

The explosion chamber

The explosion chamber and all ancillary apparatus is situated at the NNE end of an airship shed at Cardington, Bedfordshire. It stands in an area 39.6 m x 24.4 m (130 ft x 80 ft) which can be cordoned-off from the rest of the shed for safety purposes during experiments.

The explosion chamber is shown in Fig. 1 and, in general terms, consists of three sides and a roof constructed of commercially available standard steel tank sections with an external frame for strengthening. The bottom edges of the sides were bolted to a frame which, in turn, was grouted into concrete which also formed the floor of the explosion chamber. One side of the chamber was left open to act as a vent. The size of the vent could be varied by fitting standard steel tank sections as required. The vent covering material was secured to the flat surface of a heavy steel frame which constituted the front of the explosion chamber.

In the sides and back of the chamber provision was made for the introduction of gas mixtures, for the outflow of displaced air, for attaching measuring devices to the chamber as well as inlets for purging the chamber of combustion products after each explosion. In the roof of the chamber provision was made for fitting gas sampling units to any of seven positions (Fig. 2). Constructional details are given in Appendix A.

For photographic purposes the exterior of the chamber was painted yellow but the outward surfaces of the front frame were chequered black and white to give a scale reference for ciné and other photographic work.

Before the chamber was used and during use it was tested for leaks using smoke from a heated oil smoke generator. Leaks were stopped with a commercially available sealing compound. The atmosphere in the chamber was under a positive pressure of about 0.13 kN/m^2(0.5 in) water gauge when tested in this way.

A control room was sited at a distance of 12.5 m from the side of the explosion chamber.

<u>Apparatus for the production of gas mixtures</u>

The gas used in the experiments was Natural Gas, grade NSEG stated by the suppliers to contain between 92 and 94 per cent by volume of methane. The gas was obtained in steel cylinders containing 8.2 m^3 (290 ft^3) of gas at a pressure of 13,800 kN/m^2 (2000 psi). Air for gas mixtures was supplied by a centrifugal fan capable of delivering up to 1.4 m^3/min (50 ft^3/min) against a head of 4.5 kN/m^2 (18 in WG). The natural gas and the air were metered individually at ambient temperature with float and variable area type flow meters (Fig. 3). At high rates of gas flow in cold weather the pressure regulating valves were heated in a water bath at 50°C (Fig. 4). The natural gas also passed through a dry gas meter to facilitate checking of the gas flow entering the air stream. Figure 4 shows diagrammatically the components of the system used and the flow systems for the gas, air and the gas/air mixtures. The gas flow could be measured at any desired pressure up to 69 kN/m^2 (10 psi) and the air flow could be measured at pressures up to 5.0 kN/m^2 (20 in WG).

The components of the system were so arranged that there was no change in the gas mixture composition on termination of the gas flow to the chamber, there being in the air line a magnetic valve which closed automatically when power to the fan was cut off. Simultaneously with this power cut a magnetic valve in the gas line diverted the gas from entering the air stream. The gas and air mixed by turbulence in the pipeline to the explosion chamber: at a distance of 3.7 m (12 ft) there was a sampling point through which samples of gas/air mixture were withdrawn and analysed chromatographically throughout each experiment. Before entering the explosion chamber the gas mixture passed through a flame arrester, a lever operated gate valve and the diffusers to be described in a later report.

Cable supports

Figure 5 shows one of five 'pylons' used on the site for supporting cables above ground level between the measuring devices on or near the explosion chamber and the instruments and operating devices in the control room.

Closed circuit television

A closed circuit television unit was used during experiments. The camera was focussed to photograph any desired aspects of the experiments and the monitor and video recording unit were installed and operated in the control room.

Safety and operating procedures

In work involving explosions it is imperative that there is a safety system incorporated in the operating procedure and that procedure rigidly followed. This work was therefore carried out within the framework of F.R.S. general safety regulations and with an operating procedure incorporating relatively simple safety methods as applicable to this particular project. The system used was a composite one of procedural and electrical methods. Details of the safety and operating procedures are given in Appendix B.

ACKNOWLEDGMENT

The explosion chamber was designed by the Department of Civil Engineering Development, Department of the Environment, incorporating the requirements of the Fire Research Station.

APPENDIX A

The explosion chamber

The explosion chamber is shown in Fig. 1. Its roof and closed end were made from steel plates with dimensions 1.22 m x 1.22 m (4 ft x 4 ft) and 1.22 m x 0.61 m (4 ft x 2 ft). The two sides of the chamber were constructed of plates 1.22 m x 1.22 m (4 ft x 4 ft). All the steel plates were 4.8 mm ($^3/16$ in) thick and double flanged, one bevelled flange being at an angle of 45 degrees and the other at 90 degrees to the flat area (Fig. 6). All the 90 degree flanges had 16 mm ($\frac{5}{8}$ in) bolt holes drilled at 76 mm (3 in) pitches and the bevelled flanges were drilled with the same diameter holes at 73 mm ($2\frac{7}{8}$ in) pitches as necessary for the construction of the chamber. Plates were bolted together with BSW bolts $^9/16$ in x 1.5 in long. The floor of the chamber was of concrete.

The bottom edges of the sides and back of the chamber were bolted to the top flange of a heavy iron horizontal frame which, in turn, was fixed to the concrete floor by grouted holding down bolts. The top flange of the frame was 76 mm (3 in) above the floor level, the rest of the frame being set in the concrete floor. The roof and back of the explosion chamber were bolted to the sides at the bevelled flanges.

In order to ensure rigidity of the structure under experimental conditions, frames consisting of 152 mm x 152 mm, 37.2 kg/m (6 in x 6 in, 25 lb/ft) universal columns and cross members of the same material were erected around it at two positions, namely 1.22 m (4 ft) from the front and the other the same distance from the back. The explosion chamber was connected to these strengthening frames down both sides and across the roof with bolted angle iron cleats 63 mm x 38 mm x 6.4 mm (2.5 in x 1.5 in x 0.25 in), 152 mm (6 in) long, at 0.6 m (2 ft) intervals. The more forward of these strengthening frames was connected to the front of the explosion chamber and the other frame was connected to the ends of a horizontal length of 152 mm x 152 mm, 37.2 kg/m (6 in x 6 in, 25 lb/ft) universal column spanning the back of the chamber and fixed to it with bolted angle iron cleats of dimensions similar to those described above. The horizontal connecting pieces on both sides of the chamber were of 76 mm x 76 mm x 13 mm (3 in x 3 in x 0.5 in) angle iron with attachments welded to each end through which the pieces were bolted into position.

The front frame at the mouth of the explosion chamber was constructed of two sizes of steel channel and angle iron as shown in Fig. 7. The channel was 152 mm x 76 mm, 17.9 kg/m (6 in x 3 in, 12 lb/ft) and 203 mm x 89 mm, 29.8 kg/m (8 in x 3.5 in, 20 lb/ft). The angle iron was 127 mm x 76 mm x 13 mm

(5 in x 3 in x 0.5 in). The 127 mm (5 in) wide face of the angle iron was lined with 2 mm thick asbestos strip and constituted the flat surface to which the vent closure material (to date polyethylene film) was clamped by the action of toggle clamps (Fig. 8) at intervals of 0.3 m (1 ft) all round a frame made of 51 mm x 25.4 mm (2 in x 1 in) timber.

Loose steel plates for the chamber were provided so that the size of the vent (open end) could be changed as required. Figure 9 shows the lower half of the front of the chamber closed with three of these plates. The number and dimensions of the plates were as follows: two 1.22 m x 1.22 m (4 ft x 4 ft), three 1.22 m x 0.61 m (4 ft x 2 ft) and one 0.61 m x 0.61 m (2 ft x 2 ft). In order to ensure rigidity when these plates were used (Fig. 9) a length of universal column 152 mm x 152 mm, 37.2 kg/m (6 in x 6 in, 25 lb/ft) was fitted across the mouth of the chamber, being bolted at each end to appropriate cleats which were themselves bolted to the inside face of the 203 mm x 89 mm (8 in x 3.5 in) vertical channel. At 0.33 m (13 in) from each end of this length of universal column was situated a lug with a hole 38 mm (1.5 in) diameter to facilitate lifting of the column. The top of the plates was connected to the horizontal length of universal column with bolted angle iron cleats as described above. With this arrangement the plates were fitted inside the front frame and the vent covering material was of constant dimensions as required for the first series of experiments (Fig. 9).

Grooves on the inside walls of the explosion chamber caused by the bevelled flanges, where the plates were bolted on the square flanges, were covered with steel cover plates 102 mm x 6.4 mm thick (4 in wide x 0.25 in thick) and lengths as required. These plates were welded along their entire perimeters.

The explosion chamber therefore was of two sections with differing dimensions, namely 3.7 m x 3 m x 2.4 m (12 ft x 9.8 ft wide x 8.1 ft high) and 229 mm long x 3.1 m wide x 2.5 m high (9 in long x 10.3 ft wide x 8.3 ft high). This gave a volume of 28.4 m^3 (1002 ft^3).

Two inch diameter BSP sockets were situated along each side of the explosion chamber at 76 mm (3 in), 1.8 m (6 ft) and 3.5 m (11 ft 7 in) from the back and 1.1 m (3 ft 9 in) from the top of the chamber. In one side of the chamber and 0.5 m (18 in) from the floor were situated two British Standard pipes 2.5 in diameter, one 0.8 m (2.5 ft) and the other 3.5 m (11.5 ft) respectively from the front of the chamber. On the other side of the explosion chamber similar pipes were situated 0.6 m (2 ft) and 1.8 m (6 ft) from the front and 0.5 m (18 in) from the floor.

The delivery pipe of a centrifugal fan was connected to a 2.5 in diameter BSP inlet situated in one of the sides of the chamber. This fan was used for purging the chamber of combustion products after each explosion.

One of the 2.5 in BSP sockets on each side of the chamber was used as an outlet pipe for the air displaced when gas mixtures were flowing into the chamber. The pipeline contained a lever operated gate valve which could be closed from outside the hazardous area by using a rope and pulley system and kept open by a weight on the lever when in use. The effluent gases were conveyed to atmosphere outside the shed through 152 mm (6 in) diameter polyethylene tubing, the walls of which were 0.05 mm (0.002 in) thick.

Along both sides of the explosion chamber and 0.6 m (2 ft) below the roof were situated holes drilled and tapped standard 14 mm, thread pitch 1.25 mm, to facilitate the fitting of flame detecting ionisation gaps. These holes were 51 mm (2 in), 0.9 m (2.8 ft), 1.8 m (5.8 ft), 2.6 m (8.7 ft) and 3.5 m (11.4 ft) from the back of the explosion chamber.

In both sides of the chamber 0.9 m (3 ft) from the top, 0.6 m (2 ft) and 3 m (10 ft) from the back were situated two glass windows 0.3 m (10 in) diameter. The glass was 13 mm (0.5 in) thick.

In the centre of the closed end (back) of the chamber and 102 mm (4 in) from the roof there was a 2.5 in BSP inlet for the gas mixture supply to the gas diffusers situated inside the chamber (Fig. 10). Below the gas inlet and 0.3 m (12 in) from the chamber roof was a 14 mm hole, tapped 1.25 mm thread pitch, for a flame detection ionisation gap device. Also in the back of the chamber at 0.6 m (24 in) and 1.1 m (42 in) respectively from the roof were a 2 in BSP and a 2.5 in BSP inlet into which could be screwed plugs fitted with electrodes, insulated from the metal of the plugs, for the purpose of conveying electrical energy to an explosion initiating device.

In the roof of the chamber were fitted seven 2 in BSP sockets to facilitate gas sampling as required from any of the seven positions (Fig. 2).

Around the perimeter of the roof of the chamber were safety rails at 0.5 m (18 in) and 0.9 m (3 ft) above the roof. The horizontal components were screwed into sockets on uprights at convenient intervals with breaks for ladderways from the ground on one side and at the back of the chamber.

APPENDIX B

Safety and operating procedure

Safety

Before work commenced all heads of groups and teams working in the airship shed were informed in writing that explosions would take place. The information sheet included a resumé of the warning and safety systems employed.

Before any gas was conveyed to the explosion chamber, the area, as above, was cordoned off with a coloured rope and flag safety barrier, warning notices were posted along each side of the area and flashing lights were put into operation. All personnel were outside this area throughout all experiments. The above situation was maintained throughout the experiments, which were deemed to have finished only when it was ascertained by analysis that the atmosphere in the explosion chamber was safe for persons to enter.

The procedure and firing circuit for initiating the explosion were designed so that they had to be operated by two persons and to ensure that the 'firing' system was completely safe when not in use. Figure 11 shows the electrical circuit used to fire the igniferous fuses which initiated the gas explosions. It shows a circuit breaker consisting of a block with two sets of 'tapped' half collars, one set for each electrical lead, conducting only when the removable circuit breaker was screwed into position. This mechanism was housed in a box which remained locked until the circuit was needed for use. Figure 11 also shows diagrammatically the key operated electrical contact switch in which the circuit remained open until the key was inserted, turned and the contact maker pushed manually. The 'red' firing button and the electrical contact switch were so sited and spaced that they could not be operated by accident or simultaneously by one person.

Operating procedure

The operating procedure for producing an explosion in the chamber was as follows: The officer in charge of safety carried, on his person, the key of the lock on the circuit breaker box, the removable circuit breaker and the key of the electrical contact switch. The commercially available, electrically initiated igniferous fuses were placed in position on the back wall of the chamber, the number and positions depending upon whether a gas mixture or layers of natural gas alone were being used. The whole firing circuit was then tested for continuity with a low current instrument. The vent covering, which was commercially available 0.05 mm (0.002 in) thick polyethylene film, was clamped in position on the front of the cell as described above. The hazardous area was cleared of all personnel, the warning notices were placed in position and the flashing lights system put into operation.

A 'look-out' was posted above ground level with an uninterrupted view of the explosion chamber and the cordoned-off area. He was equipped with a radio receiver/transmitter set with which he was in constant communication with the control room.

The gases were then metered into the pipeline as necessary to form a predetermined mixture and the supply was continued until sufficient gas mixture had been passed into the explosion chamber to form a layer of the required depth. Displaced air left the explosion chamber through the 2.5 in BSP outlet pipes in the sides of the vessels, then through the 152 mm (6 in) diameter polyethylene tubing to the outside of the airship shed.

When sufficient gas mixture had been supplied to the explosion chamber, the gas supply was shut off, and the three levered gate valves were closed by means of ropes, from outside the safety barrier. The firing procedure was then put into operation as follows:

Upon receiving a favourable report from the 'look-out' as to the position of all personnel relative to the cordoned-off area, the circuit breaker box was unlocked and the removable circuit breaker screwed back into the block (Fig. 11) and power applied to the 'Firing' panel in which the green light indicated the 'Safe' condition. The key was then inserted into the electrical contact switch, the explosion imminent warning was indicated by short blasts on the klaxon horn, the television system was set to record and the countdown from ten to zero begun.

At countdown 'zero minus two' the key in the contact switch was turned and pressed, contact being indicated by audible warning and the illumination of the red firing button in the panel. At 'zero' countdown the red button was pressed and the explosion initiated. Following the explosion the chamber was 'purged' of combustion products with air from the fan installed as described above. The 'experiment completed' signal, a continuous note on the klaxon, was sounded at the discretion of the person in charge of safety during experiments, after which explosion research personnel were permitted to enter the previously cordoned-off area.

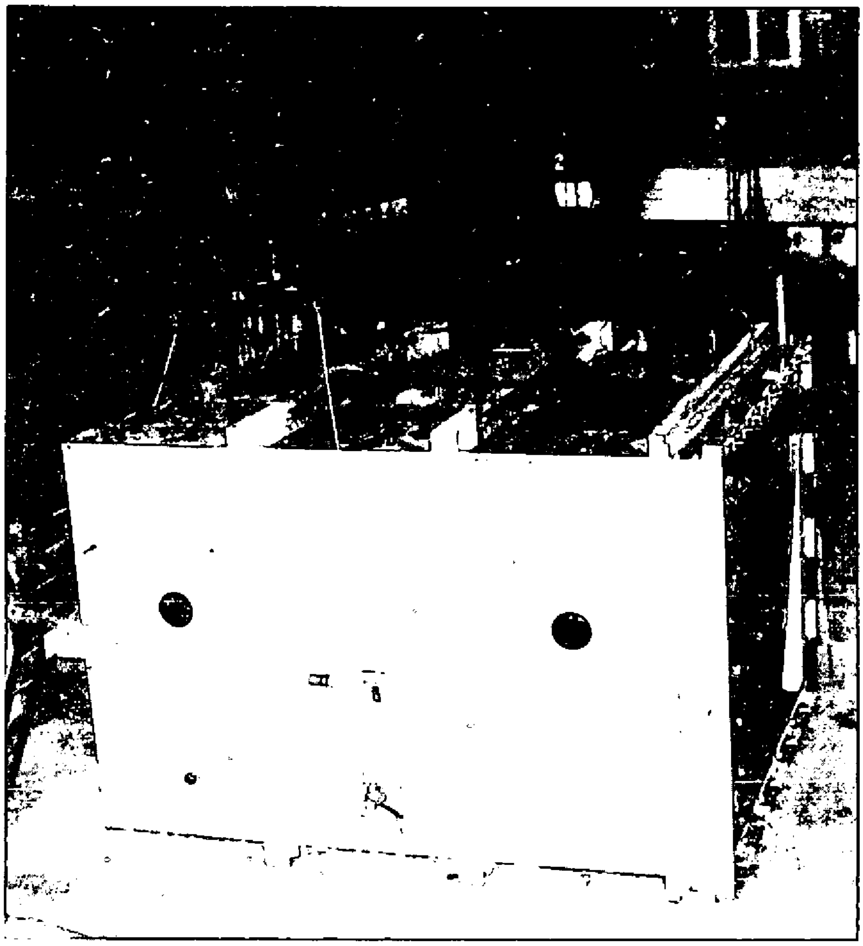

FIG. 1. THE STEEL EXPLOSION CHAMBER
(VENT AT RIGHT HAND SIDE)

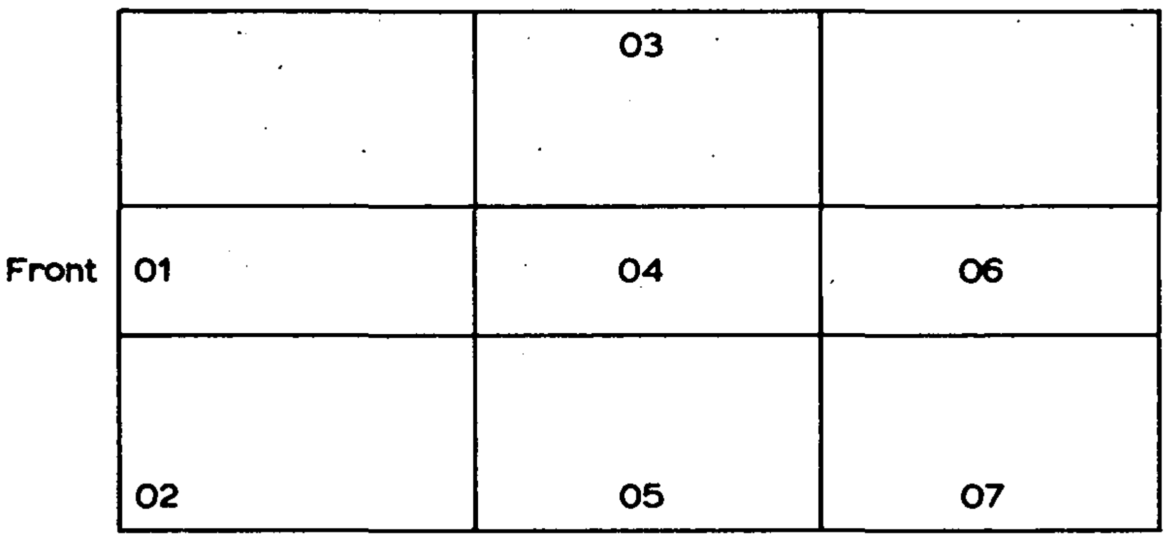

Figure 2 Diagram of roof of the explosion chamber showing gas sampling points

FIG. 3. GAS METERING APPARATUS

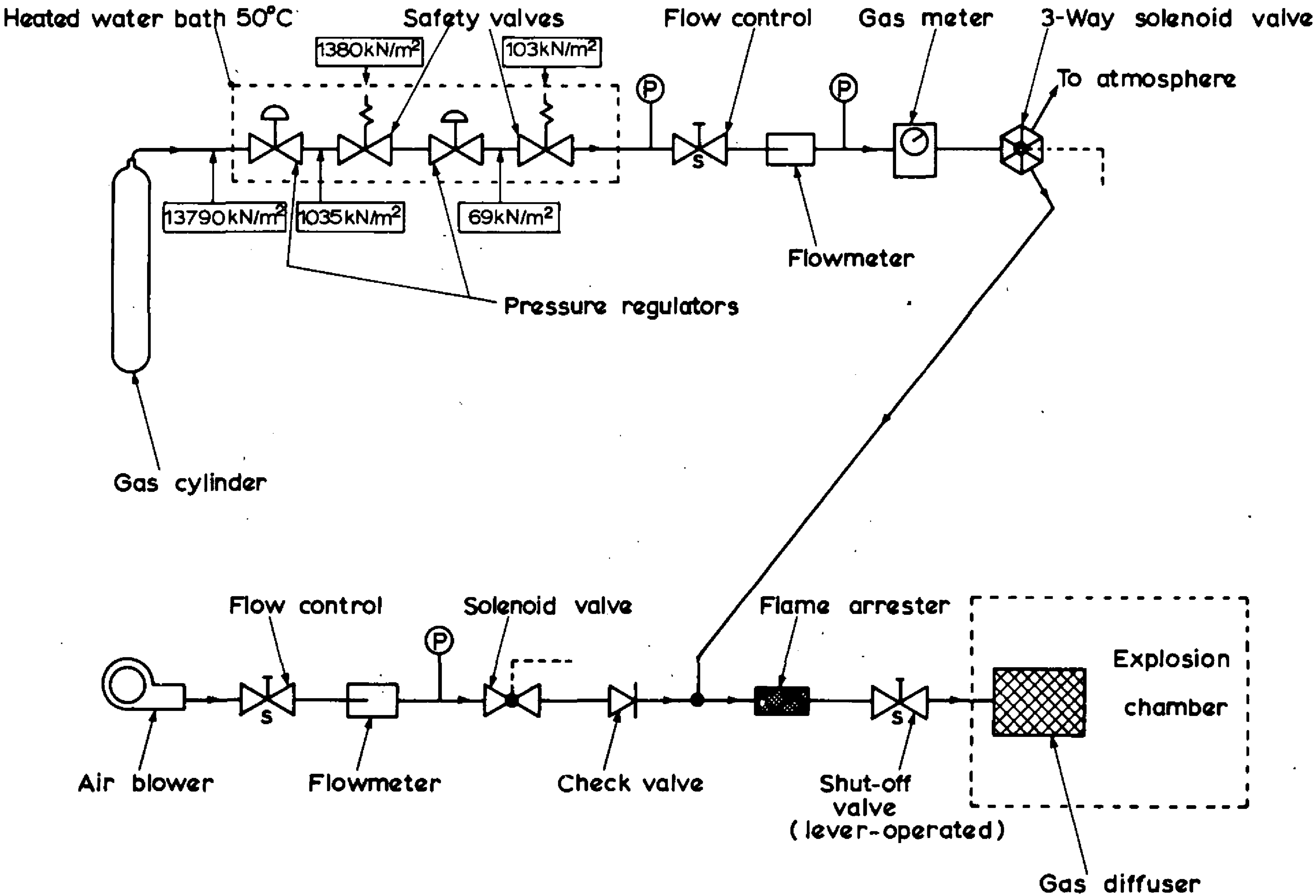

Figure 4 Flow diagram for the supply of gas mixture to the explosion chamber

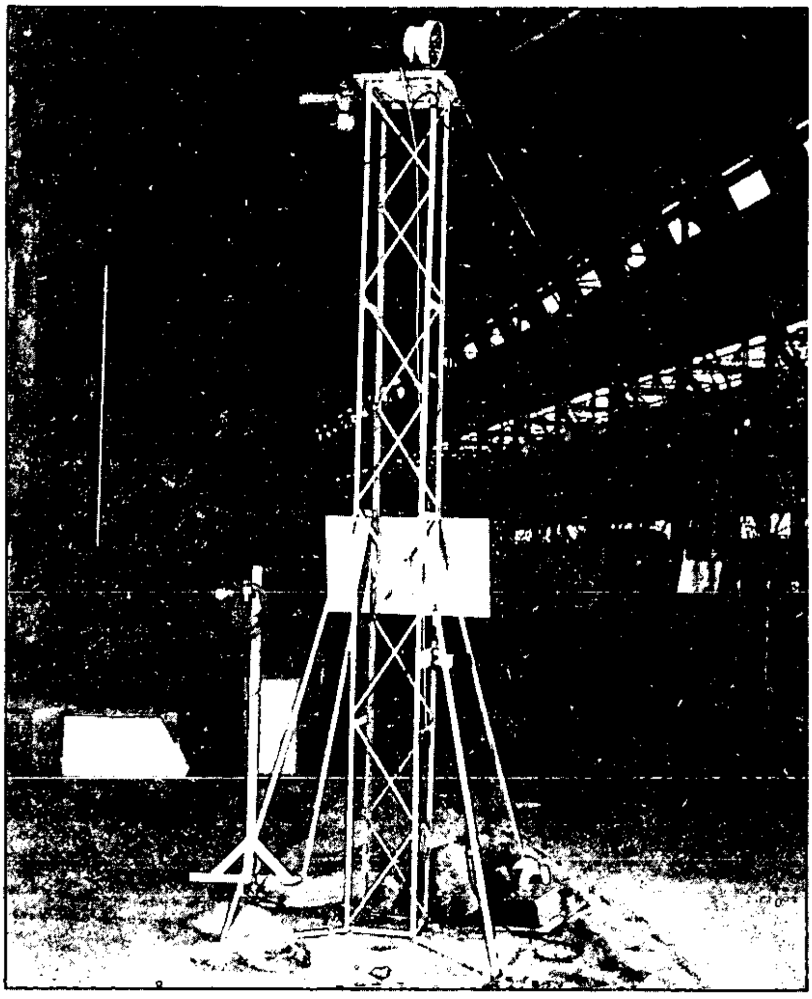

FIG. 5. A PYLON FOR SUPPORTING CABLES AND OTHER EQUIPMENT

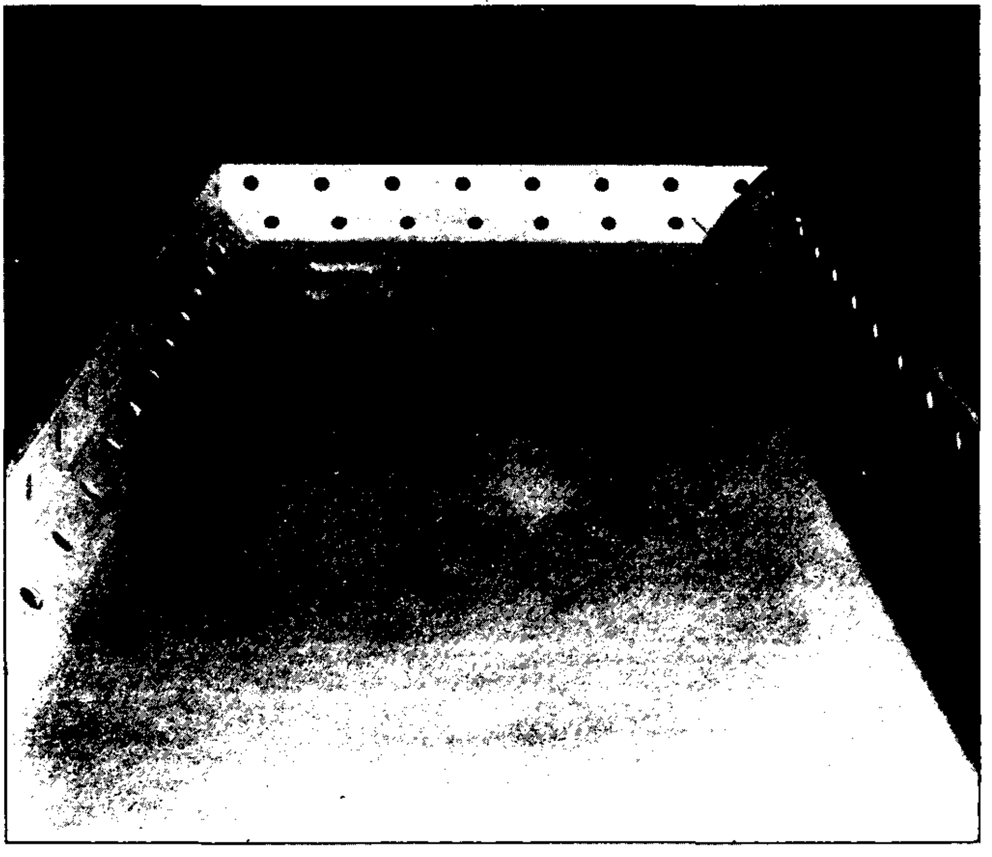

FIG. 6. STEEL PLATE SHOWING BEVELLED AND SQUARE FLANGES

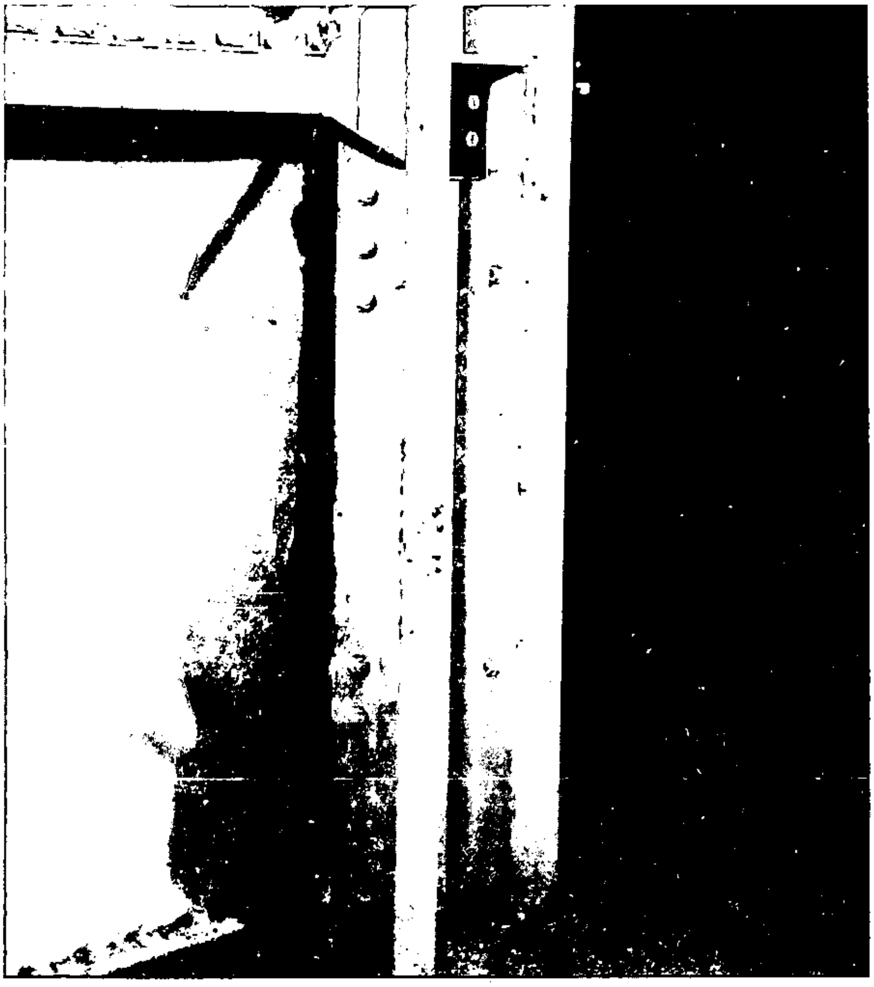

FIG. 7. UNIVERSAL COLUMNS COMPRISING THE FRONT FRAME OF THE EXPLOSION CHAMBER

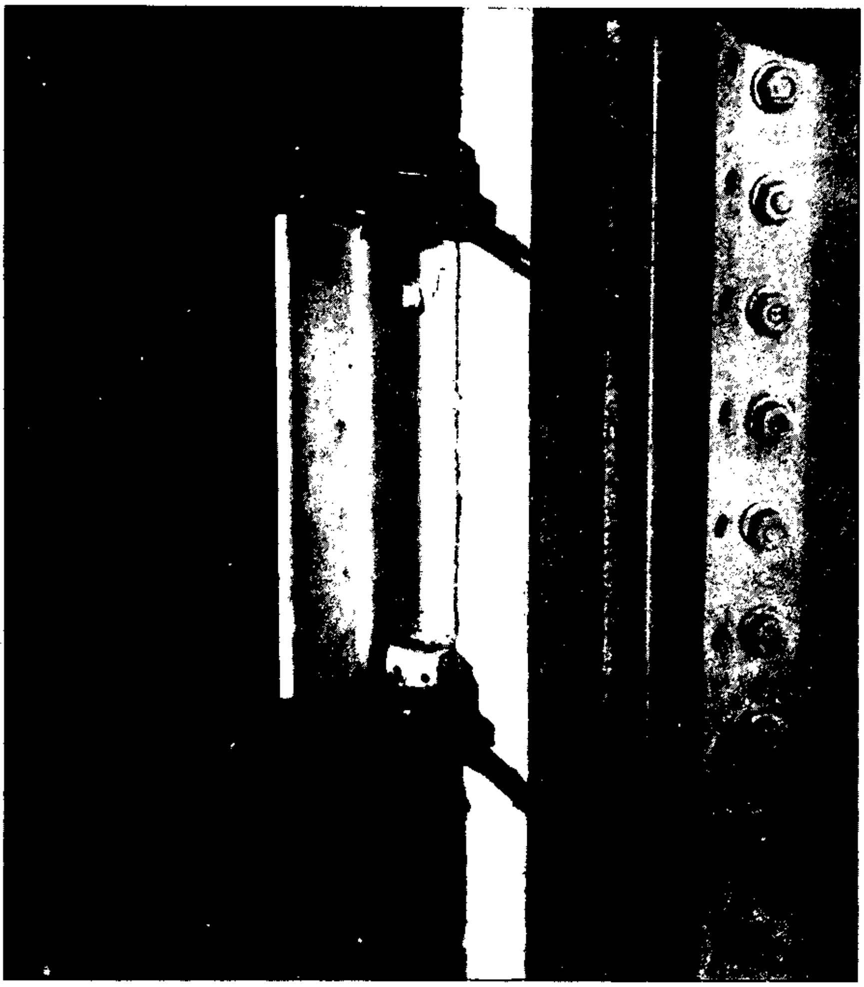

FIG. 8. THE CLAMPS FOR CLAMPING VENT COVERING IN POSITION

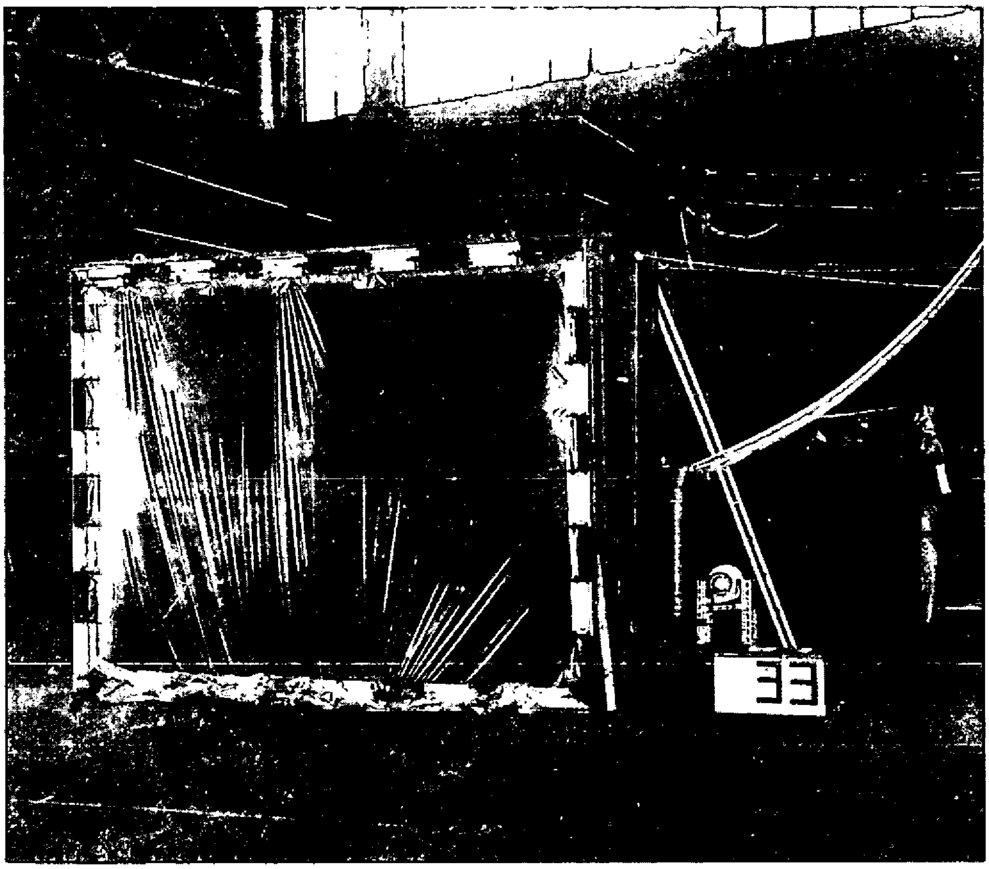

FIG. 9. FRONT OF EXPLOSION CHAMBER PARTIALLY CLOSED WITH STEEL PLATES

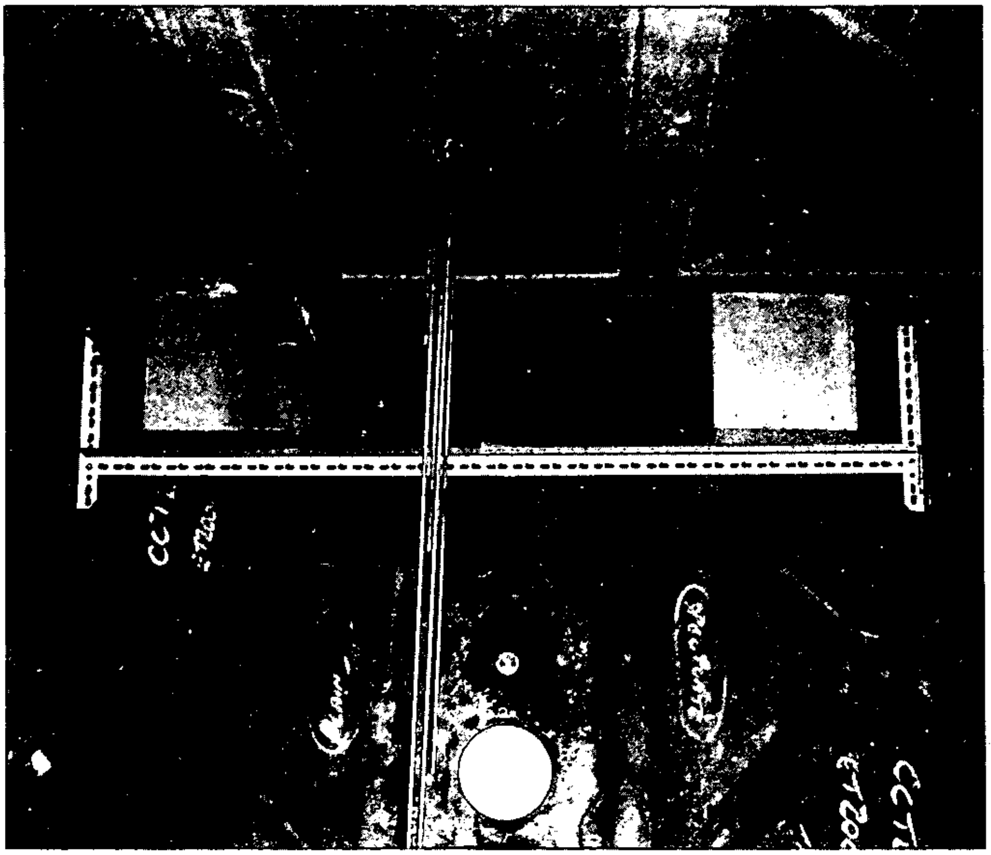

FIG. 10. DIFFUSERS IN THE EXPLOSION CHAMBER

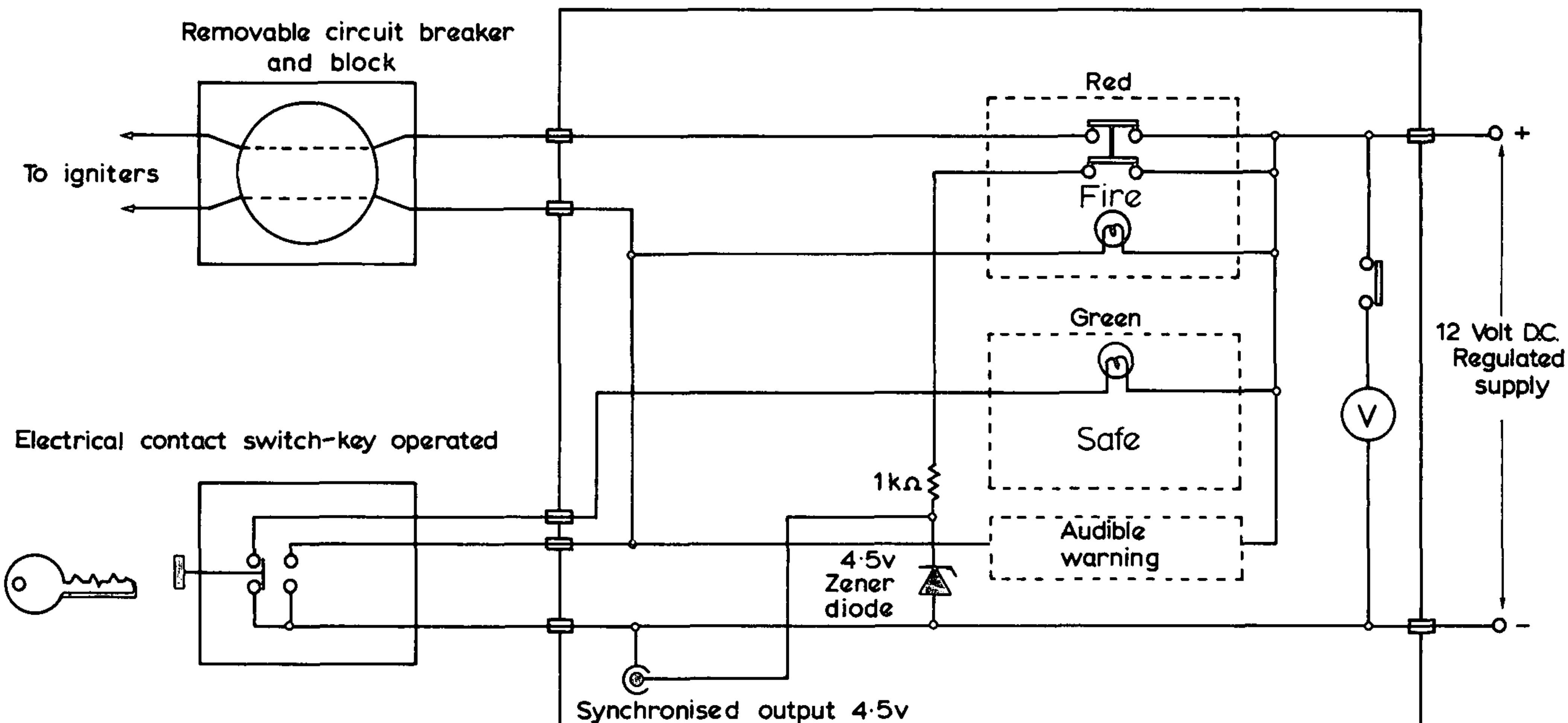

Figure 11 Electrical circuit for initiating explosions in gas/air mixtures
Ignition synchronising at recording instruments