Fire Research Note
No 964

EVALUATION OF ROAD TANKER DIP TUBES AS FLAME BARRIERS

by

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March 1973

FIRE
RESEARCH
STATION

F.R. Note No. 964
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SUMMARY

Dip tubes are used for liquid level measurements in the compartments of road tankers transporting fuel. They are fitted with flame arresters intended to eliminate the hazard of explosion originating outside the tanker from propagating within the tanker compartments. These arresters cover the necessary openings in the wall of the dip tubes and are designed to confine an accidental explosion within the tube. The performance of three dip tubes has been tested. One tube gave a satisfactory performance, the other two failed to stop the transmission of the explosion.

KEY WORDS: flame arrester, tanker, explosion, prevention, test

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

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INTRODUCTION

Road tankers carrying flammable liquids are fitted with mechanical devices for measurement of liquid level. Such a device consists of a vertical tube which is dipped in the liquid; in this tube a graduated dipstick is inserted. The dip tube has a number of holes which ensure uniformity of liquid level in the tube and the tank compartment. The holes are covered with flame arresters to prevent the transmission of accidental explosion flames from within the tube to the tank. 28 mesh stainless steel wire gauze is used as a flame arrester. A request was received to evaluate the performance of dip tubes with these arresters, in the laboratory.

APPARATUS AND MATERIALS

Dip tubes

Three different dip tubes were tested. They were cylindrical and all had a diameter of 7.5 cm (3.5 in); and they are designated A, B and C. Each tube had one open and one closed end. Tube A is shown in Fig. 1. The tube was 191 cm (75 in) long and it was made from drawn aluminium. Four sections of this tube were perforated; there were nineteen holes 25 mm (1 in) diameter in each section. Each perforated section was covered with 28 mesh stainless steel gauze and perforated sheet metal. The gauze and the perforated metal were attached to the tube with jubilee clips. For test purposes the tube was fitted with an igniting source, a pressure measuring transducer, and four flame sensors. Their location and the dimensions of the tube are shown in Fig. 2.

Tube B is shown in Fig. 3. This was also made from drawn aluminium; it was 191 cm (75 in) long and had a 16 mm ($\frac{5}{8}$ in) wide slot along its whole length. This slot was covered with 28 mesh stainless steel gauze and perforated metal. When the tube arrived, the end of the slot near the closed end of the tube had been damaged; this was repaired. The tube was also fitted with the igniting source, the pressure measuring transducer and three flame sensors. Their location and the dimensions of the tube are shown in Fig. 4.

Tube C is shown in Fig. 5. It was 221 cm (7 ft 3 in) long; and it was made from perforated metal, only the end being solid metal sheet. The whole area of the perforated metal was covered with 28 mesh metal gauze. The igniting source was situated 3.8 cm (1.5 in) from the open end on the axis of the tube. No flame detectors or pressure transducer were fitted to this tube.

Test apparatus

The assembled apparatus is shown in Fig. 6. The dip tube assembly withdrawn from the test duct is shown in Fig. 7. The diagram of the apparatus in Fig. 8 illustrates the mode of operation. The dip tube was mounted within a 30 cm (1 ft) diameter flanged duct X. The leads connecting the flame detectors and the pressure transducer were led through the wall of the duct to the oscilloscope Y and the charge amplifier D. The flammable mixture, after being metered by flowmeters H, was fed into the duct through the non return valve and the flame arrester E. The polyethylene sleeve F between the duct and the flame arrester relieved the explosion if the dip tube failed. The flammable gas after penetrating the dip tube was discharged to waste through the polyethylene tube G.

Flammable mixture and ignition

For all tests, a 4.5 per cent propane/air mixture was used. This was ignited by an electric spark, generated by an induction coil, passing between electrodes 2 mm apart.

Pressure measuring transducers and flame detectors

The explosion pressure was measured by a piezo-electric transducer and the time/pressure curves were recorded for most experiments. The flame movement was sensed by three or four ionisation gaps mounted in the wall of the tube. These were screwed in and had ceramic insulated electrodes. Upon contact with the flame, the ionisation gaps caused a DC voltage to be recorded by the oscilloscope and the camera.

PROCEDURE

The apparatus was charged with the 4.5 per cent propane/air mixture by displacement. The flammable mixture was metered until ten changes of the atmosphere within the apparatus were achieved; in a few tests twenty changes of the atmosphere were achieved. Then the flow of the flammable gas was stopped, the polyethylene tube close to the open end of the dip tube was tied up and the flammable gas was ignited. If the explosion penetrated the dip tube, the polyethylene bag at the bottom of the duct X burst.

RESULTS

Ten tests were carried out with the dip tube A having the upper end fully open, and then ten tests with 75 per cent of the cross-sectional area of the open end blocked with an orifice plate. The latter tests were intended to simulate conditions when the dip stick was at least partly inserted into the dip tube. The explosion was contained within the dip tube in all cases. In all tests immediately after ignition the polyethylene covering the open or restricted end of the dip tube was disrupted and a sound was produced within the tube for a period of 43 - 45 sec with the fully open end, and for 43 - 60 sec with the opening restricted. Figure 9 shows the flame movement and the explosion pressure record obtained with the tube having fully open end. The deflections on the top four traces indicate the arrival of the flame front at the appropriate detector. Subsequent oscillations after the initial deflection are caused by flowing combustion products. The lowest detector produced only a single deflection of short duration because at this point the flame front arrived at the closed end of the tube and further propagation ceased. Figure 10 shows the average flame speeds between the sensors plotted against the distance travelled vertically downwards, for the tube with the fully open end. Figure 11 shows the plot of flame speeds obtained while using the tube with the end partially blocked. In both cases the flame front decelerated after the initial acceleration. The last trace at the bottom of Fig. 9 is the time/pressure curve; this shows a number of oscillations about ambient pressure which remains unchanged. When the maximum pressure is quoted, this is the maximum value of the oscillations above ambient pressure. Such pressures averaged from a number of experiments were 0.4 kN/m^2 (0.06 lbf/in^2) and 0.6 kN/m^2 (0.09 lbf/in^2) for the experiments with the open and restricted end respectively.

Eight tests were carried out with the tube B. In two tests the explosion was contained within the tube. The explosion was followed by combustion of the flammable gas on the surface of the gauze within the tube and this was observed for up to 2 min. In four tests the explosion was transmitted to the duct after an interval of 41 to 58 sec after ignition; during that time there was combustion within the tube and this was audible. The pressure/time traces were very similar to those obtained with the tube A, and the average maximum pressure was 0.6 kN/m^2 (0.09 lbf/in^2). This was the average of the highest values of the oscillations as with Tube A. Figure 12 shows the average flame speeds between the two adjacent flame sensors plotted against the distance between the igniting source and the appropriate sensors. No reading was obtained with the sensor situated at the bottom of the tube. In the two other tests the explosion was transmitted immediately after ignition. The pressure record of one test is shown at Fig. 13. This indicates that the explosion was transmitted 60m sec after ignition and at this moment the flame arrived at the first flame sensor after travelling 56 cm (22 in). The transmission is indicated by a rapid rate of rise on the explosion pressure trace. Soon after this event, deflections are registered by all flame sensors as the flame propagated at high speed outside the duct and triggered the sensors when passing round the points where the sensors were connected to the output leads. After completion of the tests, there was no structural damage to the arrester, but there was some discolouration.

Three tests were carried out with the dip tube C; in all tests the explosion was transmitted beyond the tube. After these tests the jubilee clip near the end of the tube was readjusted to improve the seal between the gauze and the tube near the closed end, and a further three tests were carried out. In all tests the explosion was again transmitted beyond the tube to the surrounding flammable mixture.

DISCUSSION

The movement of flame fronts in tubes with ignition near the open end has been widely investigated and it is well documented[1]. Experimental data indicate that initially the flame accelerates and if at a later stage vibrations develop the velocity can fluctuate widely and the mean velocity increases further. The behaviour of the flame in the dip tubes was different; after an initial acceleration there was a steady deceleration during the remaining part of the propagation. Flame propagation was vibratory during the initial stages only. These differences may be caused by the presence of the gauze covered openings in the side wall of the tube. It is very probable that some combustion products were being ejected through these openings, thus reducing the flame speed.

Figure 12 shows that the commencement of the deceleration coincided with the ignition of the gas within the surrounding duct. The transmission resulted from the flame penetrating the gauze, and the flow of unburnt gas through the gauze assisted such a transmission. If the flame failed to ignite the surrounding gas, it continued to travel along the dip tube until all gas was consumed. At this stage, the surrounding gas may have been slightly pressurised, by the transfer of heat from the hot tube and by the hot gases ejected through the arrester. The hot gases within the dip tube would exert a buoyancy force. The overall result was that unburnt mixture could flow into the dip tube and support a stabilised flame. This process could continue until a temperature equilibrium was reached between the surrounding gas and the contents of dip tube. More gas was burnt at the bottom of the dip tube than at a higher position, the buoyancy of hot gas within the dip tube assisting the flow. If, during that period, extensive heating of the gauze occurred, the transmission of flame could result.

REFERENCE

1. MARKSTEIN, G H. Non steady flame propagation. Pergamon Press, 1964.

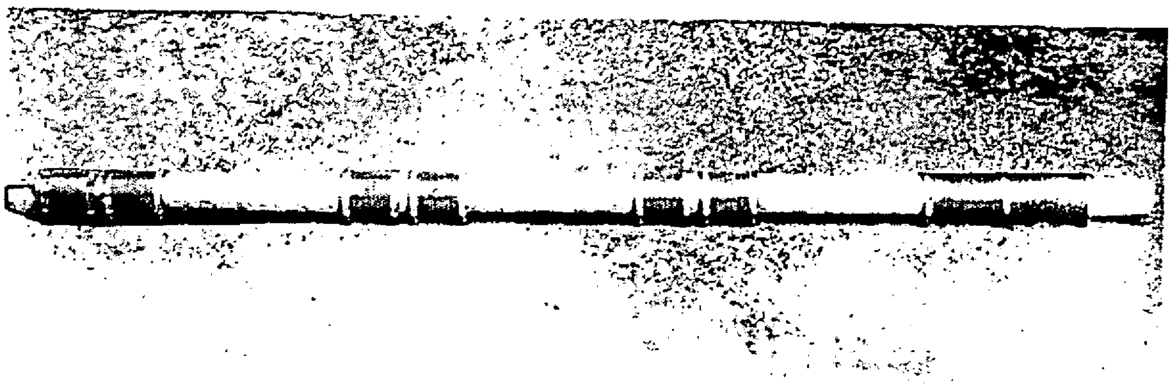

FIG. 1 DIP TUBE A

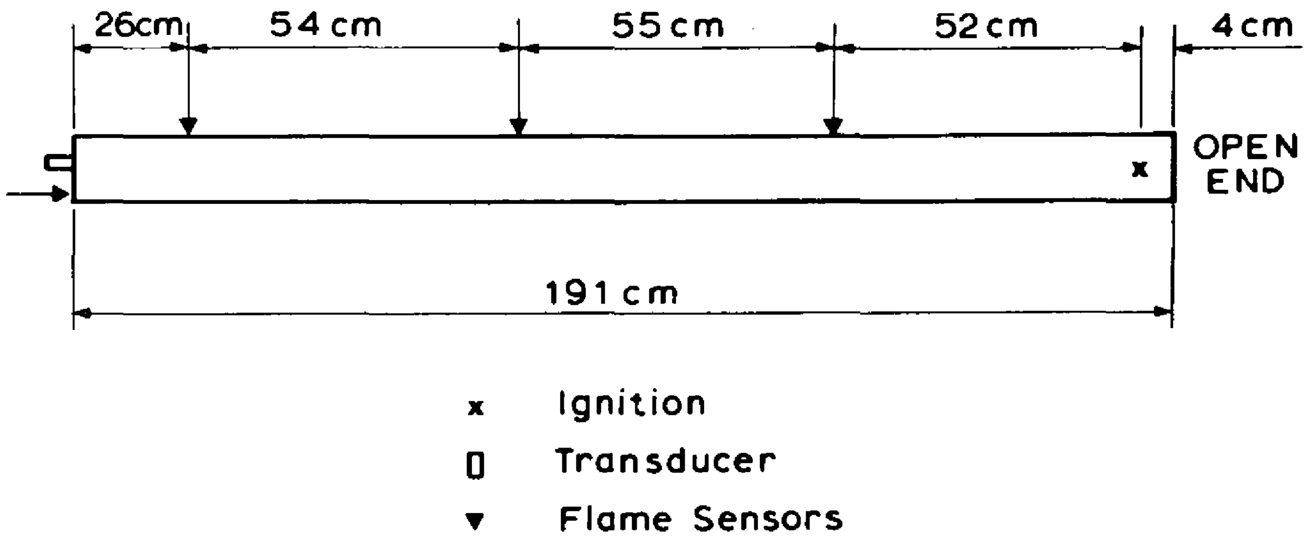

FIG 2. DIMENSIONS AND POSITIONING OF INSTRUMENTATION FOR DIP TUBE A

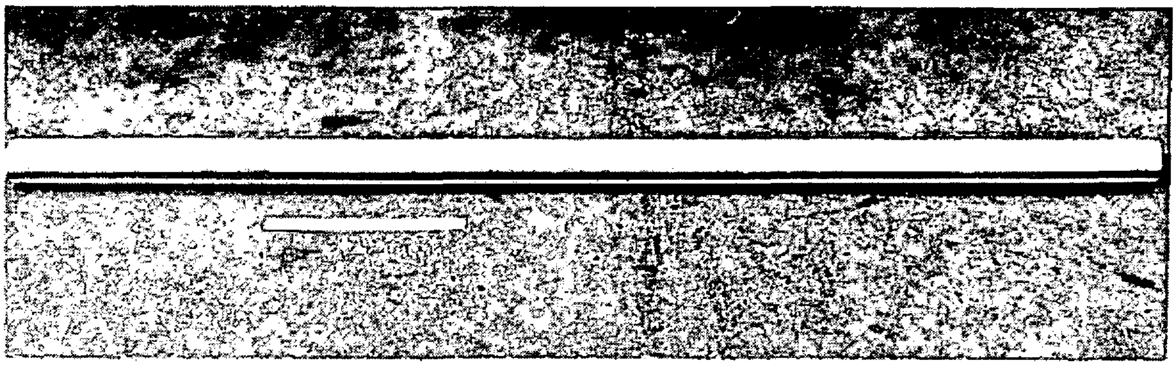

FIG. 3 DIP TUBE B

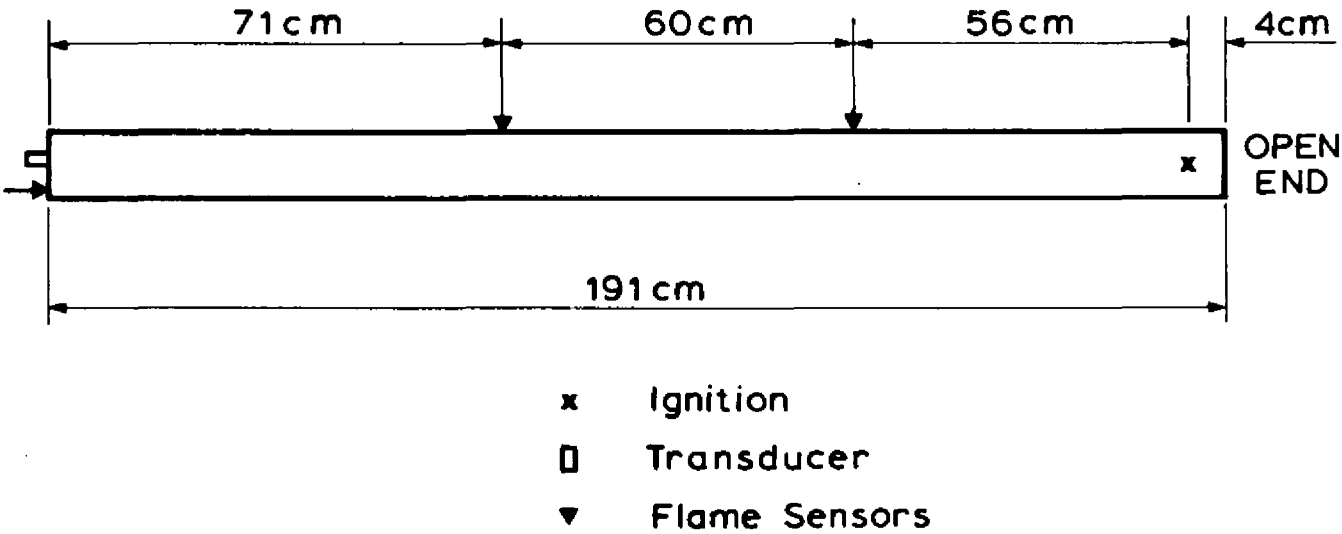

FIG. 4. DIMENSIONS AND POSITIONING OF INSTRUMENTATION FOR DIP TUBE B.

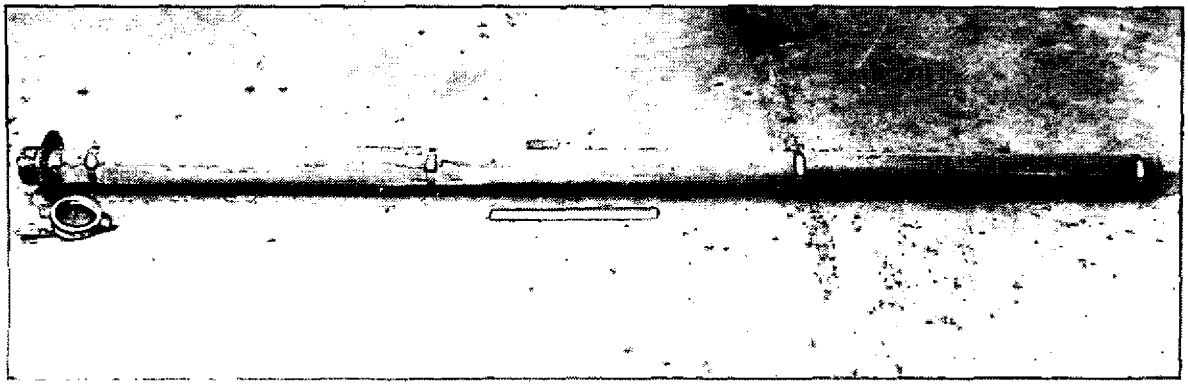

FIG. 5 DIP TUBE C

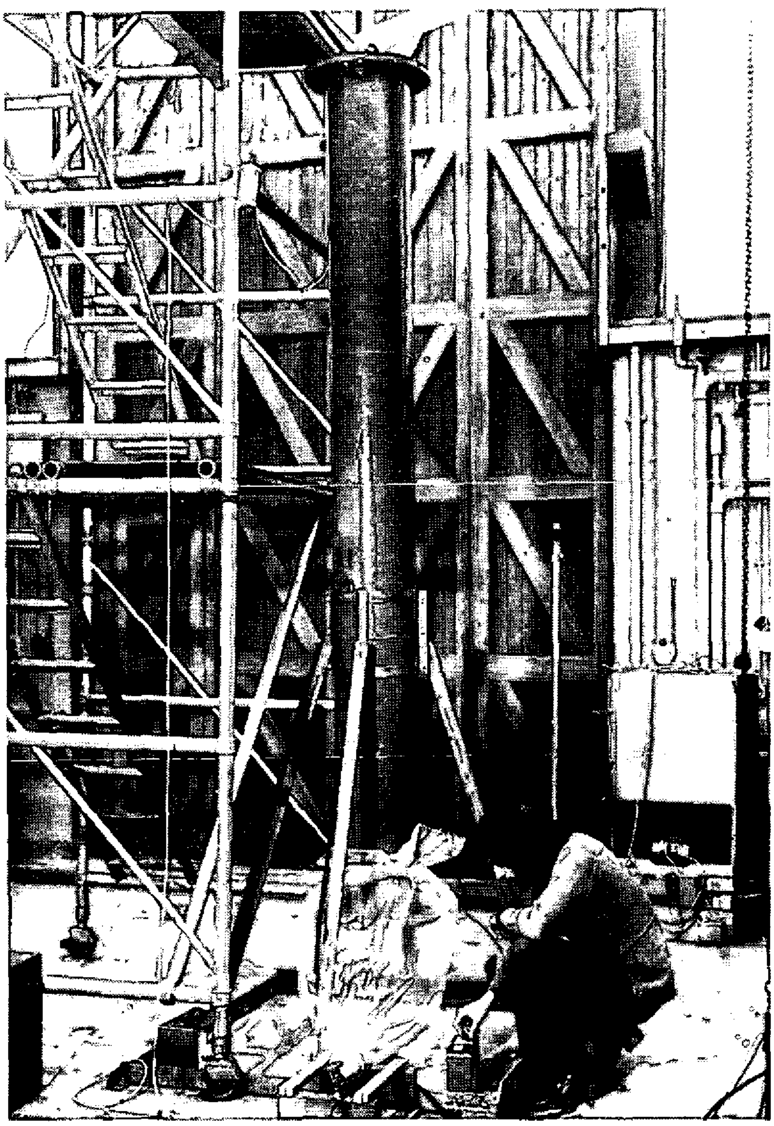

FIG. 6 TEST APPARATUS

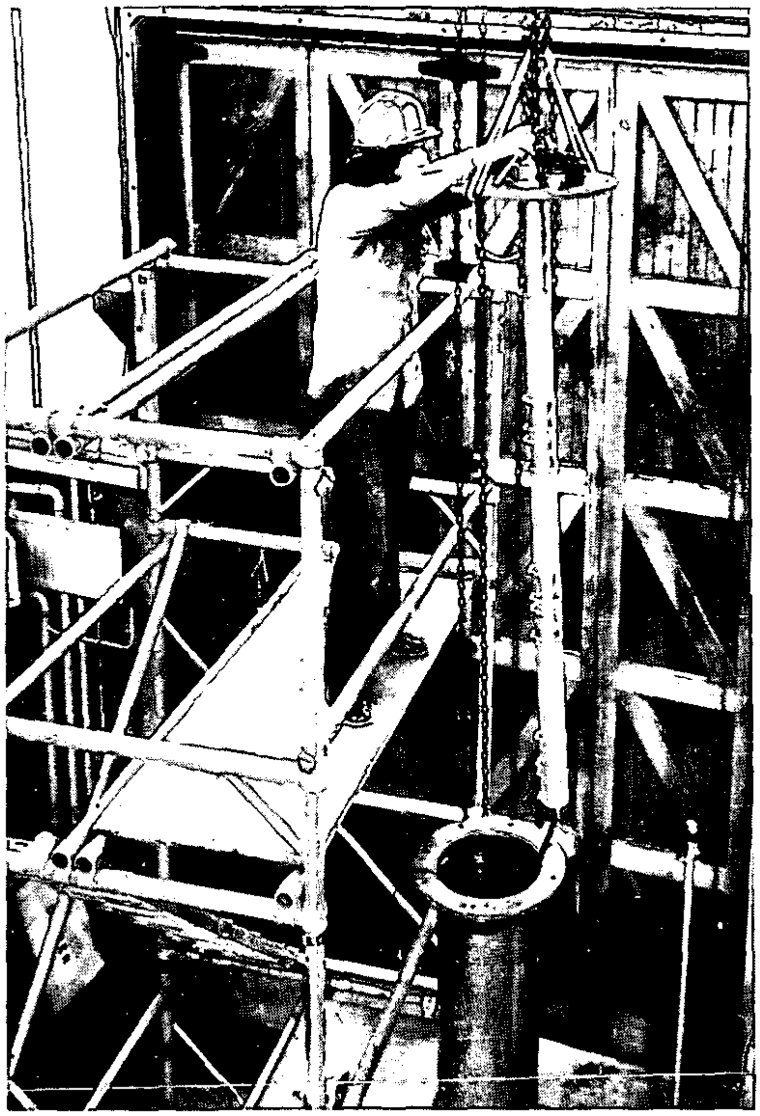

FIG.7 DIP TUBE ASSEMBLY OUTSIDE THE DUCT

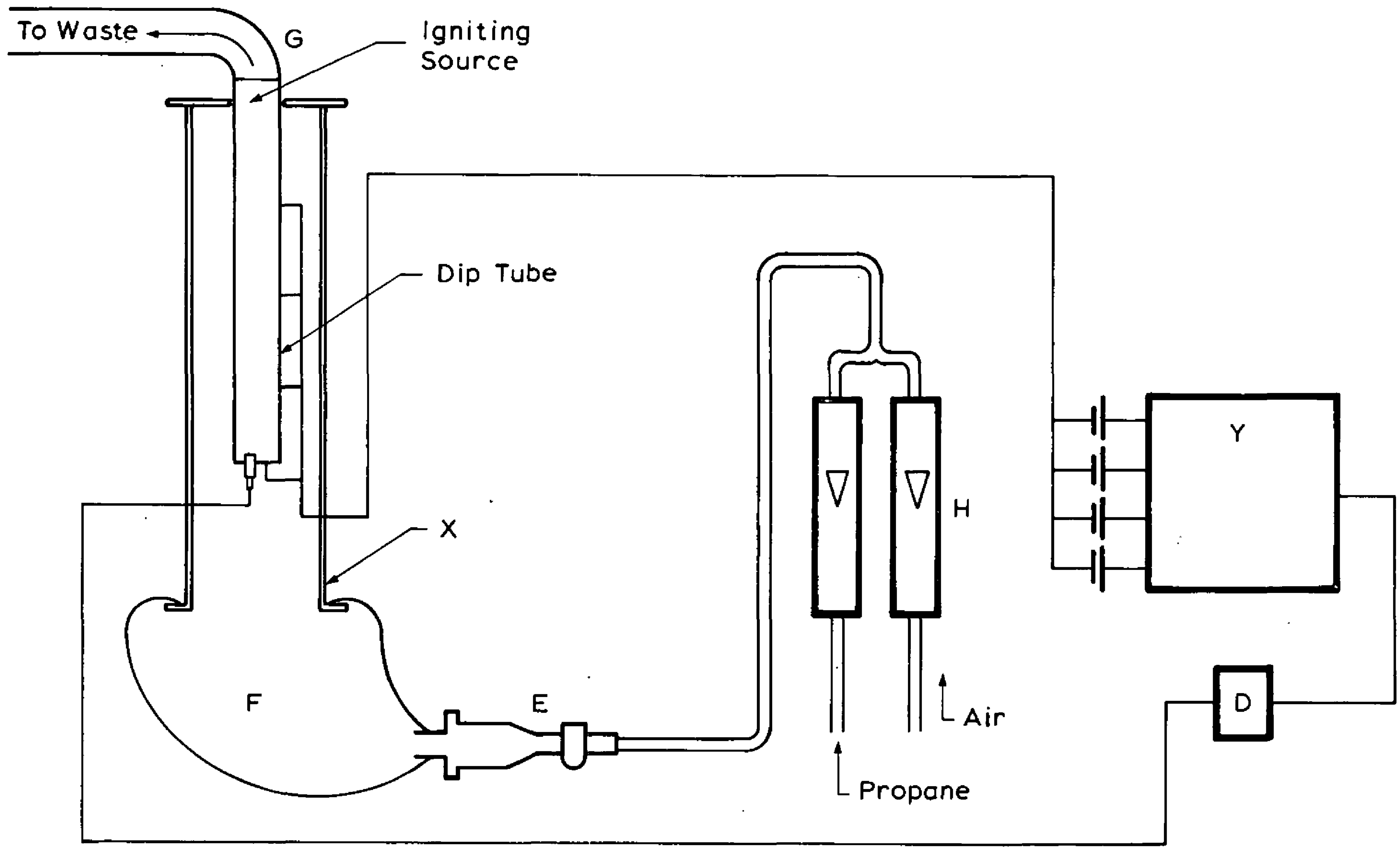

FIG. 8 DIAGRAM OF THE APPARATUS

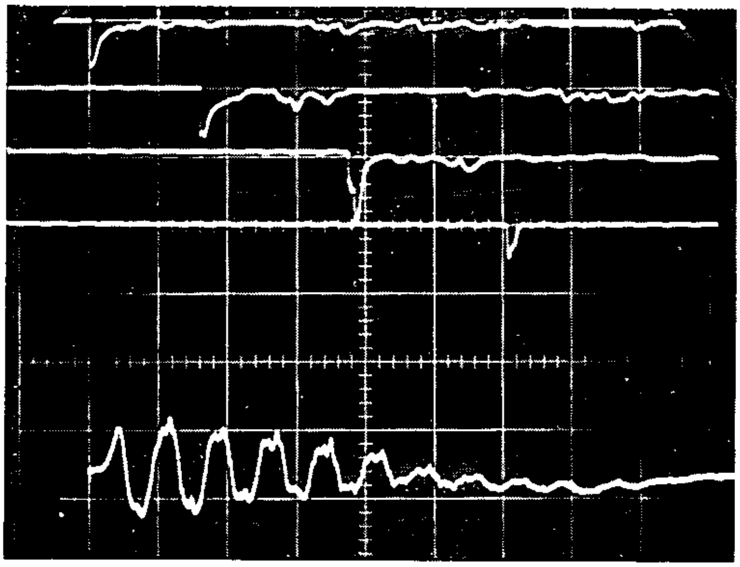

FIG.9 FLAME MOVEMENT AND EXPLOSION PRESSURE RECORD OBTAINED WITH TUBE A

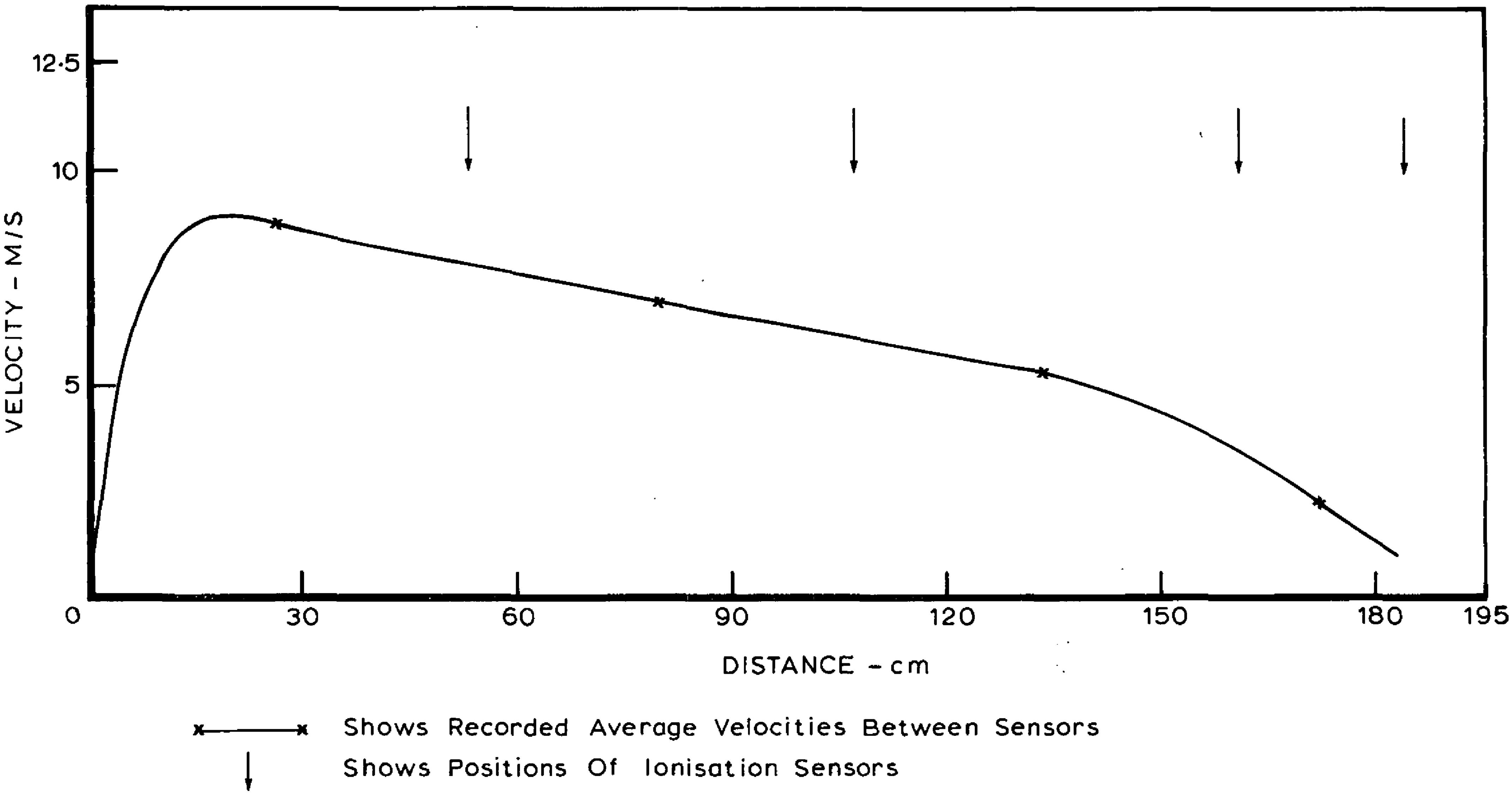

FIG. 10 FLAME SPEED ALONG DIP TUBE A, WITH FULLY OPEN END

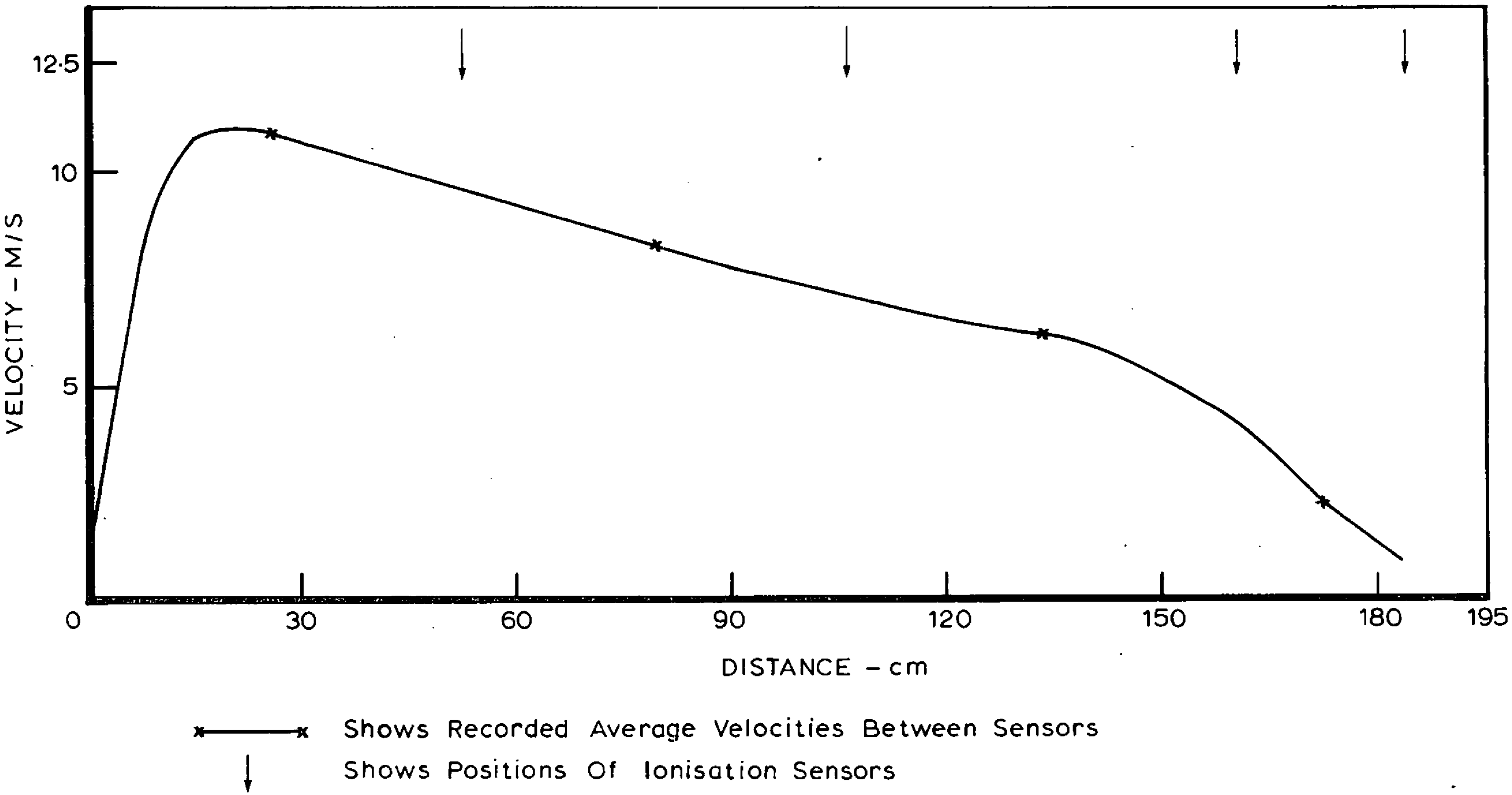

FIG. 11 FLAME SPEED ALONG DIP TUBE A, WITH PARTLY OPEN END

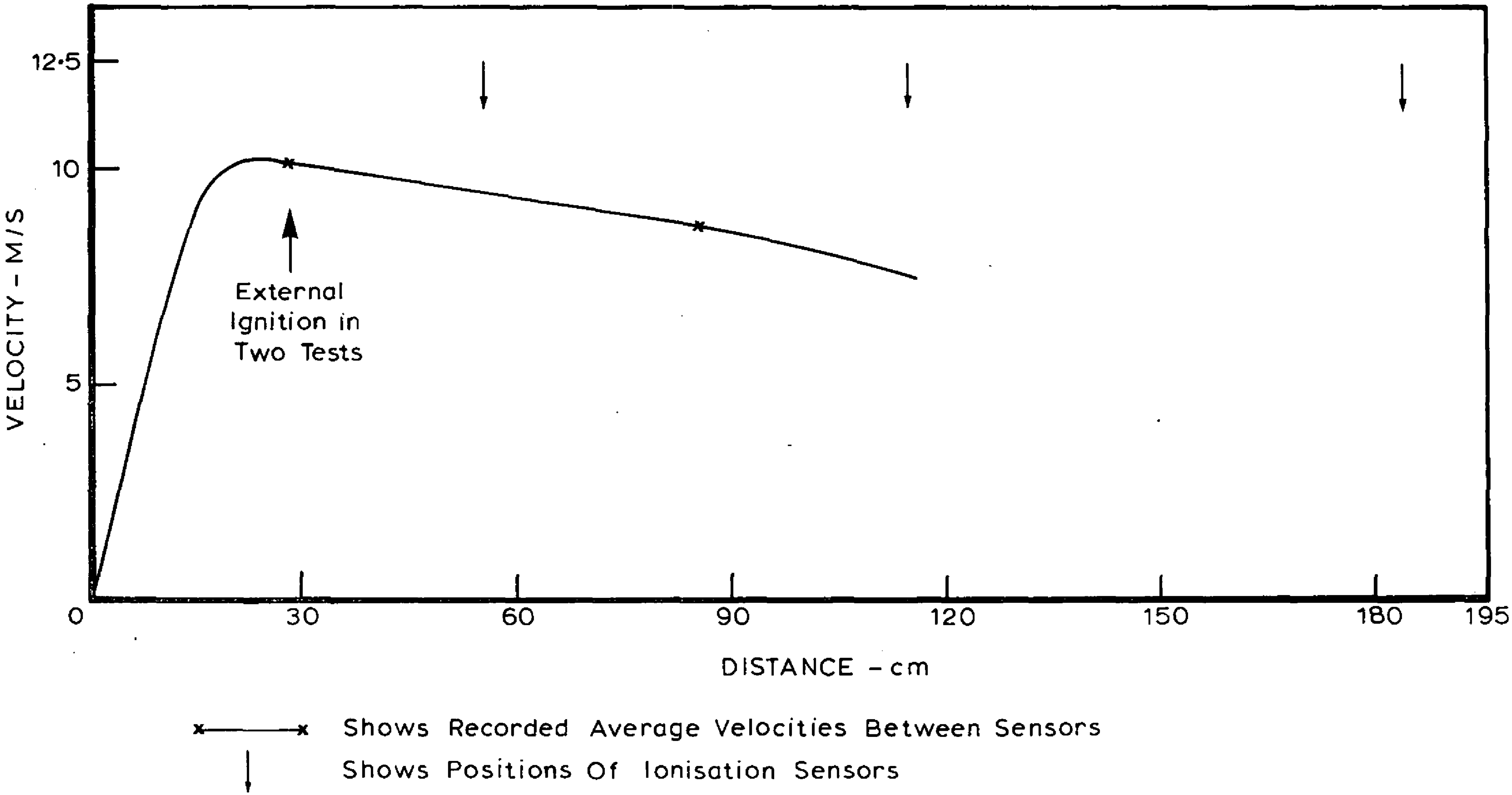

FIG. 12 FLAME SPEED ALONG DIP TUBE B

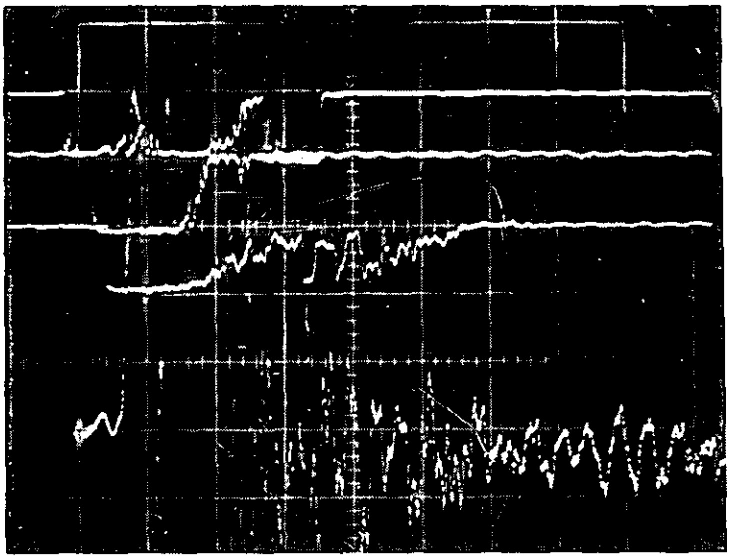

FIG.13 FLAME MOVEMENT AND EXPLOSION PRESSURE RECORD OBTAINED WITH TUBE B