THE PREVENTION OF EXPLOSION IN LIQUEFIELD PETROLEUM GAS CYLINDERS IN FIRE CONDITIONS

F. W. S. Carver, B. G. P. Freeder
Royal Armament Research and Development Establishment, Fort Halstead, Kent

and

A. J. Taylor
Health and Safety Executive, SMRE Harpur Hill, Buxton, Derbyshire

The behaviour of cylinders containing liquefied petroleum gases when exposed to fire has been investigated. It has been shown that in conditions representative of both industrial and residential fire situations, violent failure of these cylinders was prevented by the incorporation of spring loaded pressure relief devices in the valve assemblies.

INTRODUCTION

During the past seven years, the quantity of liquefied petroleum gases (LPG) supplied to industry and the general public for power generation has more than doubled. Most of this increase has been attributable to increases in the bottled LPG market; for instance the domestic demand for bottle LPG has risen by 300 per cent in this time, mainly as the result of the introduction of prtable, LPG fuelled room heaters.

The increase in the usage of LPG has led to a rise in the number of incidents in which LPG cylinders have become involved in fires. In most cases reported, only a single cylinder has been involved, but on many occasions, these have exploded violently causing severe injury or loss of life as well as considerable damage to property.(1, 2, 3). In all such cases which have been documented, the cylinders involved were not fitted with a recognised pressure relief system.

However, there have been two major incidents in this country in recent years, each of which has involved many cylinders. The first of these was at Mitcham (4) where fire swept through a storage depot and involved several hundred full and part full cylinders of LPG which ranged in size from 1 kg to 47 kg capacity. Many cylinders exploded violently and debris, which included full and empty cylinders, as well as cylinder fragments, was projected up to 600 m over the surrounding residential and industrial area and caused considerable damage. There were times during the progress of the fire when the danger from explosion and debris was such that temporary withdrawal of the fire services was necessary. During the subsequent examinations of the scene, it was noted that the least damaged of the cylinders remaining on the site had been fitted with pressure relief devices.

The other major incident occurred at a propane filling plant at Bargeddie (5, 6). All the propane cylinders which were of 13 kg, 19 kg and 47 kg capacity, were fitted with pressure relief valves. Fire fighting was again hampered by explosions and debris projected by exploding cylinders. The subsequent investigation showed that many complete cylinders were projected up to 30 m and cylinder fragments were recovered at distances in excess of 100 m. A comparison of the debris distribution patterns from the two major incidents showed that although the pressure relief valves fitted to the cylinders involved at Bargeddie did not have the capacity to prevent explosion, they had sufficient capacity to reduce markedly the severity of the explosions.

It was as a result of the Mitcham incident that RARDE became involved, via the Home Office, in studies to assess pressure relief devices as a means of prevention of the violent rupture of LPG cylinders in fire conditions. A limited amount of work had been done to assess the effects of intense heat on propane cylinders. The Post Office had studied the effects of heating small unrelieved cylinders (11 kg capacity) in an oil bath and over a 'Bullfinch' stove (7). At internal temperatures of 110–150°C and internal pressure up to 13 MNm^{-2} (1900 psig), the cylinders burst violently. Cylinder fragments were reported to have been projected up to 300 m. The British Oxygen Company (BOC) exposed two sizes of propane cylinders (23 kg and 47 kg capacity) some with, some without pressure relief valves, to standard wooden crib-type bonfires (8). They reported that cylinders without a relief valve ruptured violently within a few minutes of the start of the fire test, whereas those cylinders fitted with a commercial spring loaded pressure relief valve survived the test without rupture. In these latter tests, the relief valve vented the contents of a 47 kg capacity cylinder in approximately 10 minutes, producing a jet of flame up to 10 m in length.

All the tests that had been carried out involved the effects of heat on isolated cylinders. Hence although the BOC work had demonstrated the ability of a commercial spring loaded pressure relief valve to prevent cylinder rupture under standard fire conditions, the question remained whether or not such a relief system would suffice in a fire at a distribution depot such as Mitcham. The incident at Bargeddie suggests that the depot situation is more dangerous than the single cylinder situation, although the characteristics of the relief valves involved are not known.

In order to answer this question, it was considered necessary to know (a) whether the jet of flame from a venting cylinder, impinging on a neighbouring cylinder, could produce a rate of heating and hence a rate of internal pressure rise greater than that which could be handled by the fitted commercial relief valve, (b) whether the rate of pressure rise in such a situation could lead to cylinder failure.

The first part of the work carried out and described below is an evaluation of commercial pressure relief devices in such a situation.

The advent of the portable cabinet heater, used either as an emergency heat source, or as a convenient main source of space heating that does not require the expense of a fixed installation, is the main reason for the recent rise in the domestic consumption of LPG. These heaters consist of a metal cabinet, normally mounted on wheels, containing a heater unit, a gas supply line, controls and an LPG cylinder. In the UK, this latter is normally a 15 kg capacity butane cylinder, although similar sized propane cylinders can be used. Although these heaters had been tested for functional safety and effectiveness by the Fire Research Station (9) the Home Office became increasingly concerned about possible increases in hazard as a result of their use in residential premises. Hence the second part of the study undertaken was designed to investigate –

i. the relative hazards associated with the use of propane and butane cylinders, with and without pressure relief devices, in residential premises.

ii. the effects produced in a fire situation by the operation of a pressure relief valve fitted to LPG cylinders in close proximity to fire doors and other fire barriers.

INDUSTRIAL SITUATION – EXPERIMENTAL CONSIDERATIONS

Relief Valves

Three basic types of system can be used to relieve the excess pressure generated in a vessel caused by fire involvement, namely a fusible plug, a frangible disc and a spring loaded valve. The first two of these devices have the major disadvantage that once they have operated, the whole of the contents of the vessel are discharged to atmosphere. For a material like LPG, where fire and explosion are the main hazards, total discharge of the contents of a vessel is unacceptable if a suitable alternative exists. Hence the decision was taken to examine carefully the spring loaded pressure relief system. This type of system is designed to discharge only when the pressure in the vessel rises above a present level. Hence in a fire situation, the valve will open to prevent excessive pressures building up within the vessel. When the pressure in the vessel falls as a result of venting or removal of the heat source, the valve will reseat at a predetermined pressure thus preventing further gas escape. In the event of a very intense fire, this type of valve is designed with seatings which will fail in a manner that provides unimpeded venting to atmosphere.

Two sizes of a commercially available pressure relief valve were selected for the tests as representative of the basic valve design. The smaller type (A) was designed to be fitted to 5 and 11 kg capacity cylinders and the larger type (B) to the 47 kg capacity cylinders. Prior to fitting the relief valves to the target cylinder, their operating and discharge characteristics were determined under laboratory conditions using a high flow capacity compressed air plant. The following parameters of the relief valves determined are defined as follows:

(a) Pop Pressure

When the inlet pressure on the valve face is increased at the rate of 1 to 2 MN m^{-2} min^{-1}, the pop pressure is defined as the pressure at which the relief valve opens for the first time sufficiently wide to allow a sudden reduction in the inlet pressure. It should be noted that subsequent operations on the same valve usually produce a lowered, but consistent value for the pop pressure. This reduction in pop pressure was found to vary considerably, and in one or two cases it amounted to 20 per cent.

(b) Free Air Flow

Free air flow rates were determined with air at a steady inlet pressure flowing through the valve. In some cases, flow rates were obtained at several values of inlet pressure up to 4.2 MN m^{-2} (600 psig).

Flame Lance

It was considered that the most realistic way of generating a lance of flame similar to that produced by a relief valve in a fire situation was to use a similar relief valve and force propane vapour through it at a predetermined rate. The equipment designed to do this is shown diagrammatically in FIGURE 1. Liquid propane was forced from a cylinder by nitrogen pressure through the vaporiser coils, which were heated by propane burners, and ignited at the outlet of the relief valve. The burn rate of propane at the valve was standardised at approximately 4.5 kg min^{-1}, this being the average rate of discharge of propane from a 47 kg capacity cylinder fitted with a similar capacity relief valve and subjected to the BOC bonfire test.

Target Cylinders

The target cylinders consisted of 5, 12 and 47 kg capacity propane cylinders fitted with a pressure relief device, and modified in such a way that internal pressure and temperature could be monitored continuously. They were placed 1.25 m away from the nozzle of the flame lance, the whole assembly being housed inside a steel fragment trap. In setting up the test programme, due consideration was paid to the following points which were considered pertinent to the depot situation.

(a) State of Fill. In a distribution depot, the cylinders are normally either full or empty, but it was recognised that cylinders may be returned to a depot in any state of fill.

(b) Cylinder Orientation. It is not unusual to find that cylinders are palletised and stacked several layers high. It is probable, therefore, that in an emergency situation, some cylinders will attain a random orientation and will suffer flame lance attack in these positions. Consequently, the behaviour of cylinders was examined in the three basic orientations namely upright, upright inverted and horizontal.

(c) Position of Flame Impngement. Whereas with the smaller sized cylinders, the brush of flame produced by the lance was sufficient to envelop most of the cylinder, with the 47 kg capacity cylinders, this was not the case. Therefore with this size of cylinder, it was considered necessary to study the effects of the position of flame impingement on cylinder behaviour.

For control purposes, cylinders of each size, fitted with a standard valve, and placed in the upright position, were subjected to the standardised test. Details of the experiments carried out are given in TABLE 1.

TABLE 1 – Details of Flame Lance Tests

Cylinder Details					
Nominal Size (kg)	Wt LPG Used (Kg)	Relief fitted	Cylinder Orientation	Point of Lance Attack	No. Tests
5	4.8	Yes	Vertical	Centre*	3
5	2.4	Yes	Vertical	Centre*	3
5	4.8	Yes	Horizontal	Centre*	3
5	2.4	Yes	Horizontal	Centre*	3
5	4.8	Yes	In Vert. ϕ	Centre*	4
5	2.4	Yes	In Vert. ϕ	Centre*	3
12	11.3	Yes	Vertical	Centre*	4
12	5.7	Yes	Vertical	Centre*	2
12	11.3	Yes	Horizontal	Centre*	2
12	5.7	Yes	Horizontal	Centre*	2
12	11.3	Yes	In Vert. ϕ	Centre*	2
12	5.7	Yes	In Vert. ϕ	Centre*	2
47	47.2	Yes	Vertical	Upper half	2
47	23.6	Yes	Vertical	Upper half	2
47	47.2	Yes	Vertical	Lower half	2
47	23.6	Yes	Vertical	Lower half	2
47	47.2	Yes	Horizontal	Central	2
47	23.6	Yes	Horizontal	Central	2
47	47.2	Yes	In Vert. ϕ	Upper half	2
47	23.6	Yes	In Vert. ϕ	Upper half	2
47	47.2	Yes	In Vert. ϕ	Lower half	2
47	23.6	Yes	In Vert. ϕ	Lower half	2
5	4.8	No	Vertical	Centre	2
12	11.3	No	Vertical	Centre	1
12	5.7	No	Vertical	Centre	1
47	47.2	No	Vertical	Centre	1
47	23.6	No	Vertical	Centre	1

Table Notes: *The cylinder was smaller than the diameter of the flame lance, hence the flame was directed at the cylinder centre
ϕIn Vert – Cylinder inverted and vertical.

Results

All relief valves used has been set by the manufacturer to open fully at a nominal pressure of 2.7 MN m^{-2} (375 psig). The average data obtained experimentally are given in TABLE 2.

TABLE 2 – Operating and Flow Characteristics of Relief Valves

Valve Type	Pop Pressure MN m^{-2}	Flow Rate at Pop Pressure $m^3\ min^{-1}$
A	2.7	4.0
B	2.7	9.2

The test data for full cylinders fitted with a relief valve or a standard valve are summarised in TABLE 3.

TABLE 3 – Average Data for Cylinders exposed to the Flame Lance Test

Cylinder Capacity kg	Relief Valve	Time to vent sec	Time to Explosion sec	Observations
5	A	30	–	Internal pressure did not rise above pop pressure. No visible cylinder damage.
5	Nil	–	65	Both full and half full cylinders explosed violently.
12	A	34	–	Internal pressure rose 800 kN m^{-2} above pop pressure. No visible cylinder damage.
12	Nil	–	75	Both full and half full cylinders exploded violently.
47	B	50	–	In 2 out of 4 tests, internal pressures rose 700 kNm^{-2} above pop pressures. There was distortion and non-violent failure of cylinder shell in one test.
47	Nil	–	100	Both full and half full cylinders exploded violently.

1. Nil refers to a standard valve with no relief mechanism.

The results obtained with cylinders, fitted with relief valves, in the horizontal and upright inverted orientations were in most respects similar to those quoted in TABLE 3. There were no catastrophic failures, of these cylinders, although one or two cylinders did develop a small split, and hence a small fireball, toward the end of the test. In general the peak pressures developed in the target cylinders in the horizontal and inverted positions were approximately 30 per cent higher than those produced in the normal upright position. Consequently distortion of the cylinder shells was more prevalent in these tests.

It was found throughout the whole series of tests that the relief vavles opened at pressures lower than those determined in the laboratory. This is almost certainly due to the effect of heat on the actual relief mechanism.

RESIDENTIAL SITUATION – EXPERIMENTAL CONSIDERATIONS

Experimental work was carried out in collaboration with the Fire Research Station in a test environment based on current fire characteristics of residential premises. The variables examined included the size of the test room, the degree of fire loading in the room, the type of LPG, the state of fill of the cylinder, the presence or absence of a pressure relief valve, the position of the cylinder relative to the fire source, the orientation of the cylinder and the degree of protection afforded by the heater cabinet. The effect of cylinders in fire conditions with and without relief valves on standard 30 min fire check doors was assessed in a few selected experiments.

Test Facility. The facility consisted of a single storey building of stout construction, containing two rooms, 57 m^3 and 27 m^3, each ventilated by a single doorway 2 x 1 m set in one of the long sides. The material for the fires was 50 x 50 mm softwood cut into 1.5 m lengths and built into a rectangular crib, the size of which varied according to the degree of fire loading required. Facilities were available to measure temperature and pressure at various points within the rooms, the radiant heat flux within the open doorway and the total radiation from the test site 25 m from the doorway. The general layout of the facility is shown diagrammatically in FIGURE 2. Target cylinders were modified so that internal temperatures and pressures could be continuously monitored. Three types of relief valves were examined, named A, C and D and the operating and discharge characteristics were determined in a manner similar to that described previously.

Results

Data relating to the determined characteristics of the relief valves are summarised as average values in TABLE 4.

TABLE 4 – Characteristics of Relief Valves

LPG TYPE	VALVE TYPE	Nominal Set Pressure MN m^{-2}	Pop Pressure MN m^{-2}	Flow Rate at Pop Pressure m^3 min^{-1}
Butane	C	1.7	1.7	2.6
Propane	A	2.7	3.2	5.1
Propane	D	2.7	2.6	1.6

The times for relieved and unrelieved cylinders to reach the following states were measured:

i. full venting from the relief valves.

ii. explosion, defined as major mechanical failure accompanied by a local overpressure.

iii. critical pressure defined as an internal pressure at which the same pattern of cylinder had exploded in a similar fire situation.

Average results for full cylinders positioned alongside the wooden crib and not shielded by a heater cabinet are given in TABLE 5.

TABLE 5 – Effects of an Adjacent Fire on Uprotected, full LPG Cylinders

LPG	Relief Valve Type	Time to reach Pop Pressure min	Time to Explosion min	Time Observations
Butane	Nil	–	17 14.5*	6 explosions from 13 experiments ϕ
Butane	C	9.5	–	Cylinder pressure did not exceed pop pressure
Propane	Nil	–	9	5 explosions from 5 experiments
Propane	A	5	–	Cylinder pressure did not exceed pop pressure
Propane	D	3.75	–	In 2 out of 5 experiments cylinder pressure rose 1.4 MN m^{-2} above pop pressure. There was no evidence of cylinder damage.

*Average time for critical internal pressure to be reached.
ϕIn the 7 experiments where no explosion occurred, the internal pressure was relieved either by failure of a coupling or a valve seating.

The protection afforded by heater cabinets to unrelieved cylinders was not sufficient to significantly alter the risk of explosion. The degree of protection afforded varied with the position of the heater within the test room. With the rear of the cabinet facing toward the fire, the shielding effects for butane are such that the time to the attainment of critical pressure was 19 min, and the number of cylinders that exploded was 2 out of five tests (cf TABLE 5).

When relieved cylinders were placed in cabinets, the effect was to increase the average time for full venting by only one minute.

A 30 minute fire check door, when tested under the conditions set out in BS 476 Part 8 (1972) would normally be expected to possess an integrity of not less than 20 min and a stability of 30 min. Average results for such fire doors under the fire conditions used, both with and without LPG cylinder involvement are summarised in TABLE 6.

TABLE 6 – Effects of Fire, with and without LPG Involvement on Standard 30 minute Fire Check Doors

LPG	Integrity Time. min.	Stability Time. min.
Nil	23	30
Butane	19	30

When unrelieved cylinders exploded within the test rooms, overpressures of up to 13 kN m^{-2} were measured, and considerable damage to the fire doors and surrounding brickwork was caused.

DISCUSSION

General

Although the two series of tests were carried out under very different fire conditions, the effect produced by fitting pressure relief valves to cylinders was similar. In all the experiments designed to simulate fire conditions in residential premises, no relieved cylinder failed structurally. In the industrial situation, pressure relief valves prevented violent failure of cylinders, although in 5 of the 20 tests on 47 kg capacity propane cylinders, the cylinder shells ruptured at the site of the lance attack before venting was completed. These failures were caused by internal pressures higher than the relief valve setting acting on cylinder shells weakened by heat, and resulted in small fireball effects which in 2 cases were accompanied by mild explosions. A larger flow rate capacity for the pressure relief valves would have prevented these failures.

The length of the flame jet produced by the relief valve was dependent upon the mass flow of gas through it. Valve type B produced a 10 m flame whereas the lower capacity valves gave a flame length of only 6–7 m. Therefore, the venting cylinder should be capable of being tackled as a fire hazard only, provided that the relief valve has a suitable capacity. Ideally cooling would reduce the internal pressure and allow the relief valve to reseat thus isolating the LPG.

In the early stages of fire involvement of a cylinder, the onset of venting from the relief valve may be considered to constitute an additional hazard to the original fire, especially as an unrelieved cylinder would be quiescent at a comparable fire exposure time. This increased hazard has to be weighed against the ultimate effect of fire on an unrelieved cylinder, ie a violent explosion producing fragmentation of the cylinder shell and a fireball up to 20 m in diameter.

Data supplied by the Fire Research Station suggested that a fire within residential premises would be oxygen deficient by the time that an involved LPG cylinder would start to vent through its pressure relief valve. The fact that the temperature and the fire level within the rest room fell considerably when relief valves opened confirmed this suggestion. As the relief valves were always directed toward the door opening most of the liberated LPG burned outside the room as a 4 m jet of flame.

In those tests where fire doors were fitted to the test rooms, the presence relief valves were directed so that the discharge of LPG impinged on the inner face of the door from a distance of 1.5 m, thus causing some induced gas flow through the gaps between the door and its surround. With the door installed according to BS 459 Part 3 (1951) these gaps were gradually attacked resulting in a 20% reduction in its time of overall integrity. However the stability time was unaffected.

When an unrelieved cylinder exploded in one of the test rooms, with the sudden release of 13–15 kg of LPG, overpressures up to 13 kN m^{-2} were measured. The sudden release of LPG produced a very fuel rich atmosphere which greatly decreased the level of fire for a few seconds, as indicated by a marked fall in temperature. In many such tests, the room fire appeared to extinguish completely with the appearance of a small dark cloud in the doorway. Re-ignition, which usually did not occur for several seconds, was accompanied by a fireball, 12–15 m diameter, outside the test room. When fire doors were exposed to these conditions, they and the surrounding brickwork suffered considerable structural damage. In all these tests, it was not unusual to retrieve debris, including cylinder fragments, 50 m from the rooms.

Characteristics of Pressure Relief Valves

The incident at Bargeddie, where all cylinders were fitted with pressure relief valves similar to type D, clearly demonstrated that the explosion hazard was not removed, although both the incidence and severity of cylinder explosion were less than those experienced in the Mitcham fire. Experimental evidence from the residential fire tests showed that when this type of valve was fitted to 13 kg propane cylinders, it was just adequate to ensure safe venting of the LPG, although in 2 tests, the maximum cylinder pressure recorded exceeded 4.0 m^{-2} (560 psig). Therefore it must be concluded that similar assemblies subjected to the more severe industrial fire situation would result in much higher cylinder pressures and consequently a high incidence of cylinder failure. The use of this valve on propane cylinders with a capacity greater than 13 kg would lead to explosion hazards in most fire situations. It is imperative, therefore, that a pressure relief valve has a venting capacity large enough to protect its cylinder under all practical fire situations.

The main factors that are considered to govern the suitability of an effective relief valve system for a cylinder are:–

i. Size and type of cylinder.
ii. Type of LPG involved.
iii. The fire situation that has to be catered for.
iv. The operational and discharge characteristics of the relief valve itself.

The last of these requires further work to be carried out before it can be discussed adequately, but the first 3 can be discussed in the light of the testing that has been described.

i. Size and type of Cylinder

In the directional flame tests valve type A vented propane from 5 kg capacity cylinders without allowing the cylinder pressure to rise above the valve pop pressure. However, under similar test conditions, the valve behaved less satisfactorily when fitted to 12 kg capacity propane cylinders. It was evident from the internal pressure records that the increases in cylinder capacity required a corresponding increase in the discharge rate of the relief system. This increased discharge rate could not be attained until the internal cylinder pressure had risen above the pop pressure. The effect of valve inlet pressure on the flow rate through the valve is shown in FIGURE 3 for the 4 types of relief valve used. It can be seen that the flow rate is directly proportional to the applied pressure in each case. Hence it is possible to compare the flow rates through valve type A for the 2 sizes of cylinder exposed to similar fire conditions (TABLE 3). The larger valve B was shown to be not completely satisfactory for relieving 47 kg capacity cylinders under similar directional fire conditions. The maximum internal pressures observed and the corresponding computed flow rates are given in Table 7.

TABLE 7 – Effect of Cylinder Size on Flow Requirements for a Relief Valve under Similar Fire Conditions

Valve Type	Pop Pressure $MN\ m^{-2}$	Free Air Flow at Pop Pressure $m^3\ min^{-1}$	Cylinder Capacity Kg	Max. Internal Pressure observed $MN\ m^{-2}$	Calculated Free Air Flow $m^3\ min^{-1}$
A	2.7	3.7	5	2.7	3.7
A	2.7	3.7	12	3.4	5.5
B	2.7	9.0	47	4.1	13.6

ii. Type of LPG

As a result of the difference in vapour pressure between butane and propane, at a particular temperature it would be expected that relief pressure and relief flow rate requirements would be different. Data are given in TABLE 8 for propane and butane cylinders tested under similar conditions, using relief valves type A and C made by the same manufacturer. The flow rate/ pressure curves for these valves were similar (FIGURE 3) but the set relief pressures were different.

TABLE 8 – Relief Requirements under Similar Fire Conditions of Different LPGs

LPG	Valve Type	Pop Pressure of alve $MN\ m^{-2}$	Max. Internal Pressure Observed $MN\ m^{-2}$	Calculated Free Air Flow $m^3\ min^{-1}$
Butane	C	1.7	1.5	2.3
Propane	A	2.7	2.7	3.7

The pop pressure settings for the valves were selected such that the internal temperature of the cylinder would be similar for both butane and propane when the relief valve opened. Although the relief flow rate requirements are very different, the overall capacity of the valve required is practically independent of the LPG considered.

iii. Fire Situation

The effect of varying the heat flux on the efficiency of relief valves to vent excess pressure safely may be seen by comparing the data obtained for 12 kg propane cylinders. Average data for the residential situations and for the industrial situation are given in TABLE 9, together with free air flow rates for valve A computed from FIGURE 3.

TABLE 9 – The Effects of Fire Type on Venting Characteristics of Valve Type A fitted to 12 kg Capacity Propane Cylinders

Type of Fire	Maximum Recorded Pressure $MN\ m^{-2}$	Computed Free Air Flow. $m^3\ min^{-1}$
Room	2.7	3.6
Lance	3.4	5.5

In the worst case, the maximum cylinder pressure recorded in a directional fire experiment was 4.2 $MN\ m^{-2}$ (570 psig) which corresponds to a free air flow of 7.1 $m^3\ min^{-1}$.

As expected, the rate of efflux of LPG is directly dependent upon the heat flux into the cylinder. If the capacity of the valve at the pop pressure is insufficient to handle this flow rate, the internal pressure of the cylinder rises until the flow rate condition is met (see FIGURE 3).

To prevent dangerously high internal pressures occurring, the relief valve should be designed to have a flow rate at its pop pressure sufficient to cope with the severest fire situation that could arise in practice.

Conclusions

1. In all cases, the incorporation of a pressure relief in the valve assembly prevented catastrophic failure of LPG cylinders exposed to fire. The cylinder failures that did occur could have been prevented by a relief valve of a sufficiently high flow capa city.

2. For a given fire situation, the required flow capacity of the relief valve is proportional to the size of the cylinder to which it is to be fitted.

3. In a fire situation, the relief capacity requirement is independent of the type of LPG for a given size of cylinder.

4. The use of pressure relief valves on LPG cylinders for use in residential premises, will, in the event of a fire, reduce the time of integrity of standard fire check doors, but will not effect the overall stability time of these doors.

5. The incorporation of pressure reliefs on LPG cylinder valve assemblies reduces the overall hazard faced by the fire services when dealing with cylinders involved in fires in residential premises.

ACKNOWLEDGEMENTS

The authors wish to thank members of the LPG ITA for assistance with the stores needed for the tests and especially the British Oxygen Company who gave additional help by making available their test site facilities at Charing Kent for the first part of this work. Thanks are also due to Mr A. Moore, Mr L. Sargent and Mr K. Park who assisted with the experimental work and to Mr Z. W. Rogowski of the Fire Research Station for his assistance with experimental design and radiation measurements.

REFERENCES

1. Fire and Explosion in Soho Road, Birmingham; F. W. S. Carver and T. A. Roberts, Unpublished RARDE report (1973).

2. Fire and Explosion in Barber Road, Totton, Southampton; A. J. Taylor, Unpublished report (1973).

3. Fire and Explosion in Lea Bridge Road, London E10; London Fire Brigade Research Report 1976.

4. Report on Her Majesty's Chief Inspector of Explosives for year ended 31 December 1970; HM Stationery Office 1971.

5. Report of HM Inspectorate of Factories, Lanarkshire District; Unpublished Report 1973.

6. Private Communication; D. M. Tooth 1975.

7. Private Communication; Post Office Engineering Department 1970.

8. Private Communication; G. Williams, British Oxygen Company 1971.

9. Fire Research Note, Fire Research Station; Z. W. Rogowski and A. I. Pitt 1973.

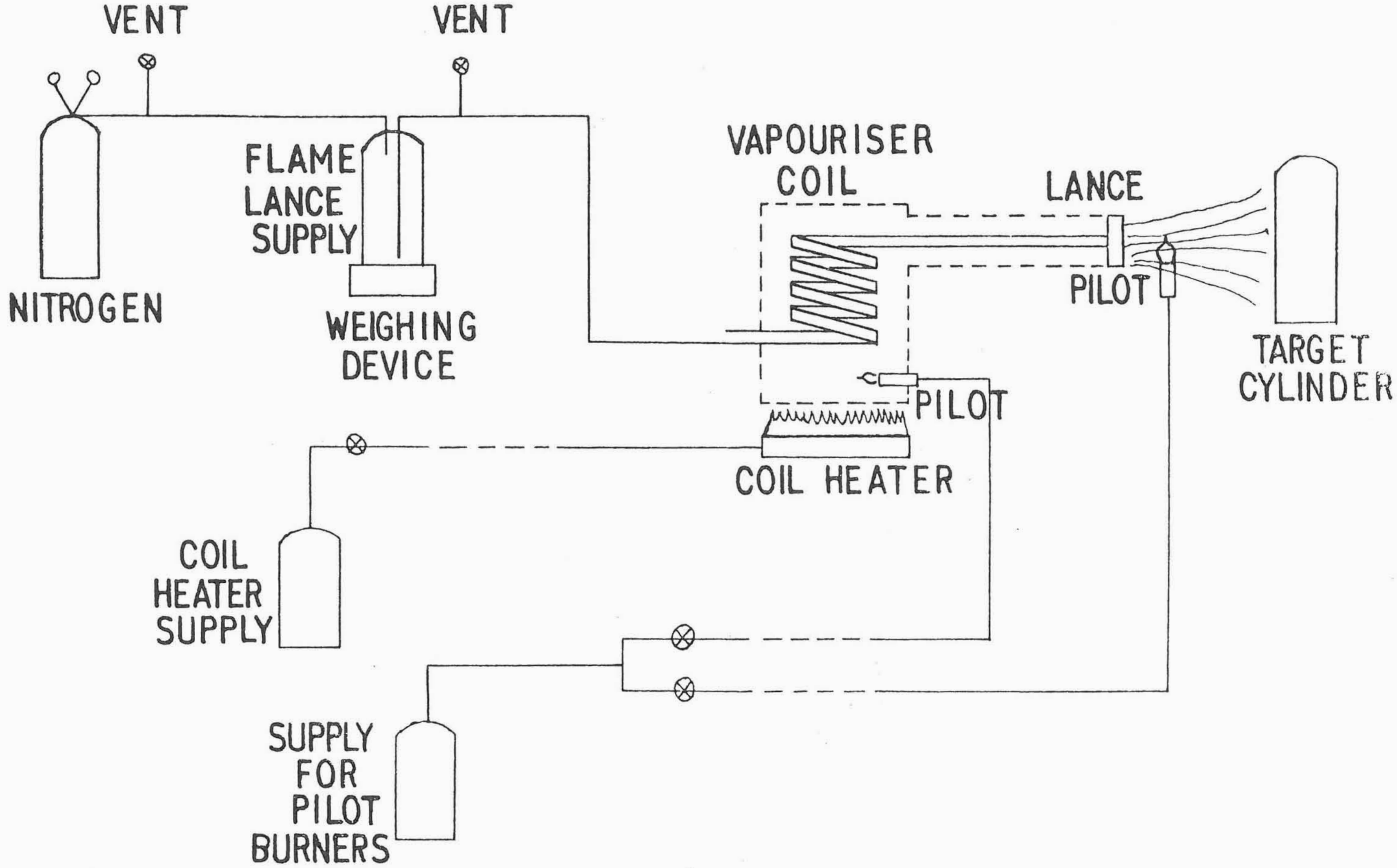

FIG.1. FLAME LANCE EQUIPMENT

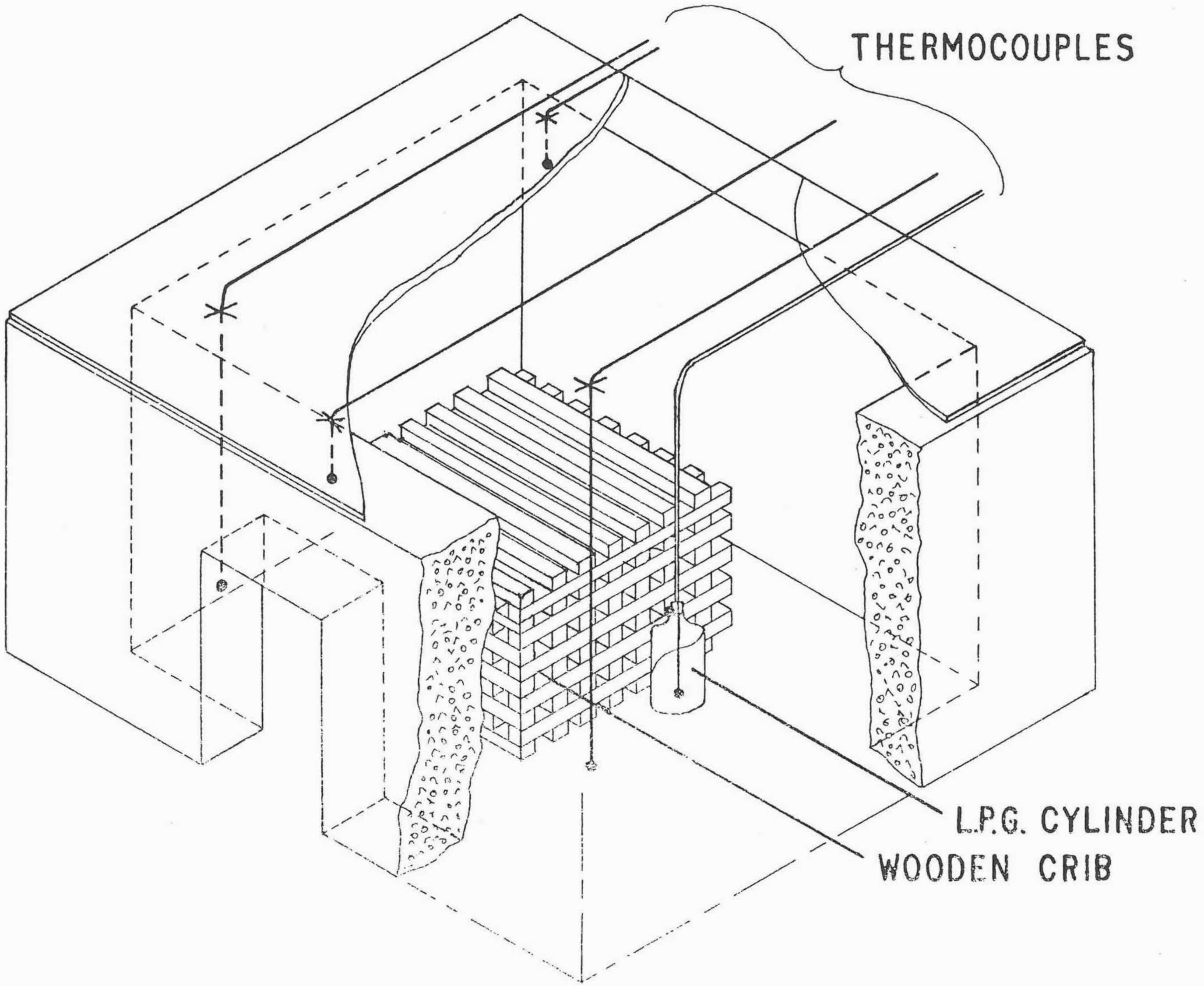

FIG. 2. FIRE TEST ROOM

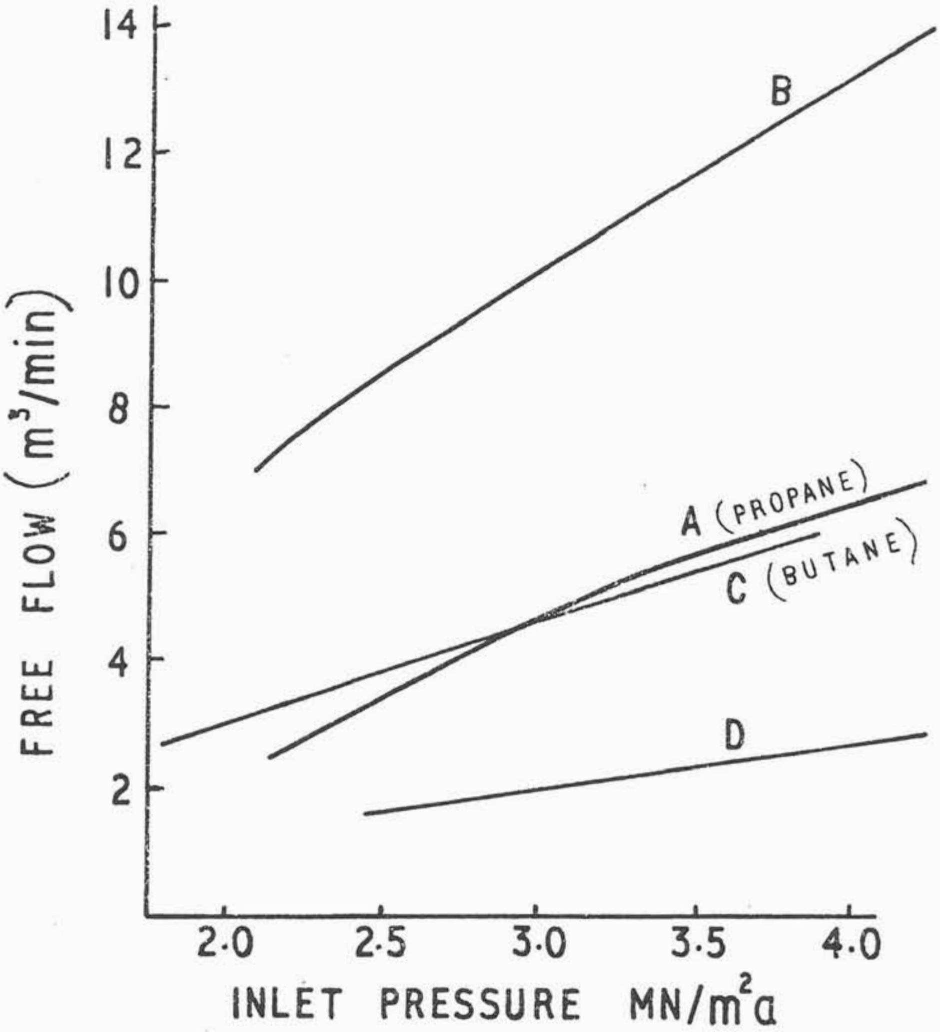

FIG.3. RELATION BETWEEN FREE AIR FLOW AND INLET PRESSURE