Fire Research Note No 996

INVESTIGATION ON SAFE OPERATION OF RADIANT PORTABLE LPG HEATERS

by

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November 1973

FIRE RESEARCH STATION

F.R. Note No. 996
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SUMMARY

Two models of portable domestic butane-fired radiant heaters were tested in accordance with B.S. 2773 and B.S. 1945. The heaters failed to comply with a number of clauses essential for safety.

If the Standards are to accommodate recent changes in domestic heating trends arising from the use of heaters of the kinds examined here, and also take account of some safety features which do not appear to be sufficiently well covered, some amendments will be necessary.

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

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INTRODUCTION

There are two types of liquefied petroleum-fired domestic heating appliances. One, known as the catalytic heater, oxidises the fuel gas on a catalytic bed. With this type there are no flames visible once the heater has been ignited and reached its normal operating conditions; the catalytic bed attains a temperature of approximately 450°C. There is at present no British Standard for such appliances. The other type, known as the radiant panel heater, burns the fuel as flame on various arrangements of perforated ceramic burners giving various proportions of radiant and convective heat. B.S. 1945[1] and B.S. 2773[2] appear to be the British Standards giving constructional and performance specifications most appropriate to these latter appliances.

In recent years a number of imported radiant panel heaters have appeared on the U.K. market, but these are not stated to comply with the relevant British Standards. Two models of such heaters have been examined by the Fire Research Station, at the request of the Home Office, for compliance with B.S. 2773 and B.S. 1945, with some additional measurements considered to give an improved evaluation of their safety. The results of this examination are reported in this Note which, being of some general interest in the field of domestic heating appliances, is being made openly available and cannot therefore identify the heaters by name.

APPARATUS AND MATERIALS

Heaters

Two radiant models were examined. One heater designated in this report as Heater A, was an imported product marketed by U.K. Fuel Distributors. It was purchased from the approved dealer in a carton with the regulator which had a 2 ft tube joined with a clip; there was another loose clip for making a connection to the appliance input pipe. This tube had composite structure and there were no marks indicating its origin or compliance with any standard. No

instructions were received from the shop assistant. Heater A there was a set of operating instructions enclosed; also there were brief operating instructions displayed on the body of the appliance. In addition, a leaflet was enclosed explaining the safe use of L.P.G. cylinders and regulators. The heater had three radiant panels positioned vertically and any number of those could be made to work by pressing an appropriate actuating button which would open a port in the manifold system to give the selected rate of flow of butane. The maximum heat output was stated to be 3.8 kW/h (12970 Btu/h) while using butane at 11 in water gauge pressure. There was a thermocouple flame failure device operating a springloaded relay which isolated the fuel supply when the pilot jet and the radiant panel were extinguished. It was impossible to extinguish either the radiant panel or the pilot jet individually. This device was also claimed to shut down the fuel supply when the CO_2 concentration in ambient air reached 1 per cent. This function of the flame failure device operated as a result of pilot-flame lift off causing the thermocouple to cool down and close off the fuel supply. Preliminary tests with the heater operating at maximum heat output in a closed room of 400 cu ft capacity have shown that this device shut down the fuel supply when the ambient CO_2 concentration reached 2.1 per cent[5]. To start the heater the gas container valve was opened, then the fuel to the burner and the pilot jet was admitted by pressing a springloaded button and the fuel ignited by a repeated pressing of this button, each operation of which produced an electric spark from a piezoelectric device. Once the thermocouple was hot the EMF generated held open a springloaded valve admitting fuel without any further action.

The heater designated B was also an imported product and this was advertised in the national press and sold by mail order. It had the operating instructions stuck to the body of the heater. No other operational leaflets were enclosed. The purchase of the regulator with the heater was optional, but there was a list of fuel suppliers. The heater had horizontal radiant panels and the heat output could be reduced one stage down by turning a knob, which reduced the flow of butane. The maximum heat output was stated to be $2\frac{1}{2}$ kW/h (8530 Btu/h). There was a flame failure device operated by the heat of four pilot flames which distorted a circular snap action diaphragm which in turn either admitted or turned off the fuel (Fig. 1). This device was also claimed to shut down the fuel supply when the concentration of CO_2 in the ambient atmosphere reached a certain unspecified value. Preliminary tests have also been carried out on this heater and it was found that the shut down device operated when the ambient CO_2 concentration reached 1.4 per cent[5]. To initiate the fuel flow

for starting, the heater had a button which had to be depressed before igniting the burners with a flame. When the burners ignited they in turn ignited the pilot flames, but the pilot flame was apparently not in this case designed to ignite the burners. Once the burners and the pilot flames were ignited, the actuating button was held for 15–20 seconds until the pilot flames actuated the fuel entry valve. The 32 lb fuel container was held within the heater body.

Measurement of the temperatures

Surface temperatures at points specified in the Standard were measured with a commercial surface thermometer calibrated against T_1 and T_2 alloy thermocouples.

Measurements in draught

An air flow was produced by a 60 cm (24 in) diameter fan. The heaters were tested in a range of wind speeds obtained by placing the heater at different distances from the fan. Values of the air flow given in the text are extremes measured over the whole exposed area of the heater, at given distance from the fan.

Gas sampling and gas analysis

Combustion products were collected in a hood over the heater terminating in a flue. The flow profile within the flue was modified with the gauze and honeycomb inserts until non-helical and symmetrical flow profile was obtained and the gas flowing through the flue had homogenous composition, in accordance with B.S. 3300[3] (Fig. 2).

Apparatus for measurement of floor and wall temperature

The apparatus and the procedure described in B.S. 3300 were used. The sketch of the apparatus is shown in Fig. 3.

Gas analysis

The carbon monoxide and carbon dioxide concentrations were determined using infra-red gas analysers. The maximum resolution of both CO_2 and CO was 0.001 per cent by volume.

Flannelette test

These tests were carried out in accordance with B.S. 1945[1] using the specified cotton flannelette.

RESULTS

Stability - Clause 20, B.S. 2773

Both heaters complied with this clause. They did not fall when tilted 15° forward and 10° backward.

Flame stability - Clauses 39, 40

The heaters were operated at 96 and 113 per cent of their normal input and the burners and pilot flames observed for stability. This test was also carried out with gas pressures of 10 and 14 in wg. The burners and pilot flames on both heaters remained stable in these tests.

Flame failure device - Clause 30

Both heaters complied with this clause. The flame failure device opened and shut within 90 s.

Portable free standing heater - Clause 33

Both heaters failed to comply with this clause as their output exceeded 1.76 kW/h (6000 Btu/h).

Resistance to draught - Clause 41

The heaters were in turn subjected to draughts within the range of 0.3 - 1.8 m/s (1 - 6 ft/s). Once the main flame had been blown out the heater was removed from the draught and tested to determine whether or not unburnt gas was still flowing.

At all three settings on Heater A the burners, and also the pilot light which heated the thermocouple-operated valve, were blown out by a draught of 0.3 - 0.6 m/s (1 - 2 ft/s) within 15 s. Due to the extinction of the pilot light the gas flow was cut off so that no unburnt gas was released.

At the full heat setting on Heater B a draught of 0.76 - 1.05 m/s (2.5 - 3.5 ft/s) for 5 min was needed to blow out the burner flames. However, the pilot gas flame keeping the valve open remained alight so that unburnt gas was still flowing when the heater was removed from the draught and the pilot flame failed to reignite the burners. The same situation arose with the low heat setting when the burner flames were blown out by a draught of 0.45 - 0.76 m/s (1.5 - 2.5 ft/s).

With both heaters the gas jets flickered before being blown out and this produced wisps of flame several inches long. The flames did not extend outside the guard on Heater A but flames from Heater B extended to about 6 in outside the guard.

Combustion - Clause 43

(i) The heaters were positioned in turn beneath a sampling hood as specified in the Standard and measurements of CO and CO_2 were taken when the appliance had reached thermal equilibrium. The tests were carried out with one, two and three burners ignited on Heater A and at the high and low settings on Heater B.

Results - CO/CO_2 ratio in combustion products

Heater	Setting	CO %	CO_2 %	CO/CO_2 ratio
A	High	0.0015	0.70	0.0021
	Medium	0.001	0.60	0.0017
	Low	0.001	0.40	0.0025
B	High	0.008	0.50	0.016
	Low	0.013	0.41	0.032

The maximum allowable CO/CO_2 ratio is 0.02; therefore Heater B failed at the low setting.

Floor and wall temperatures - Clause 45

The heaters were positioned in the corner of the wooden apparatus shown in Fig. 3 in the manner specified in B.S.3300 and the temperature was measured on the floor, side wall and back wall of the apparatus as required. The Standard requires that the temperature shall not rise above 150°F.

Heater	Maximum floor temp °F	Maximum side wall temp °F	Maximum back wall temp °F
A	163	226	82
B	82	252	82

Both the heaters would fail the test in this respect but, as is suggested below, some modification of this part may be desirable. Even if 100°C (212°F) were to be permitted, the temperature at side wall would still be too high.

Surface temperature of appliances - Clause 46

Surface temperatures were measured of the specified parts of the heaters excluding working surfaces, i.e. refractories, guards etc when the heaters had reached thermal equilibrium at the maximum settings. The table shows the temperatures measured against the maximum allowable temperatures according to the Standard.

Heater	Surface	Measured temperature °F	Maximum allowable temperature °F
A	Metal switches	81	135
	Door handle	72	135
	Carrying handle - metal	82	120
	" " - non-metal	81	150
	Nozzle for flexible inlet	82	130
	Regulator	77	120
	Hose	79	120
	Gas container	75	90
B	Igniter button	126	135
	Control tap - metal	86	135
	" " - non-metal	84	165
	Door handle	77	135
	Nozzle for flexible inlet	115	130
	Regulator	79	120
	Hose	84	120
	Gas container	75	90

Guards

The guards on the heaters were tested according to the B.S. 1945 Standard for 'Fireguards for heating appliances'.

Guards for gas fires - Clause 212

This section deals with openings in the guard. It specifies that no opening in the guard shall have a major dimension exceeding 150 mm and a minor dimension exceeding 35 mm and a diagonal measurement exceeding 154 mm.

The table shows dimensions for each heater:

Heater	Major mm	Minor mm	Diagonal mm
A	120	24	127
B	84	62	100

The measurements on Heater A are within the allowable limits but Heater B fails on the minor dimension.

Clause 213

The heaters were allowed to burn for 30 min at the maximum setting and the guards were then tested for effectiveness against smouldering or ignition. A piece of dry flannelette 100 mm wide was held in close contact with the guard approximately in the centre and in the case of Heater A reaching from top to bottom of the guard, and in the case of Heater B reaching from the back to the front of the guard. The Standard specifies that the flannelette shall not smoulder or ignite within 10 s of being so held.

With both Heater A and Heater B the flannelette smouldered within 5 s and ignited at 25 s and 14 s respectively. The tests were repeated and the flannelette removed at 10 s. The smouldering ceased almost at once and the flannelette did not ignite.

Additional tests

To demonstrate the possibility of an explosion following the extinction of the burners of Heater B the following experiment was carried out. The heater was placed within a 1.2 m x 1.5 m base and 0.76 m high (4 ft x 5 ft x 2 ft 6 in) rectangular vessel. Then the main burners were put out by blowing and the top was sealed with the polyethylene film. The experiment was repeated five times; in all cases mild explosion developed within 20 to 21 min after the burners were extinguished. One minute before the explosion occurred there was combustion of the lean flammable mixture within the heater body above the pilot flame of the flame failure device. A film of one explosion was taken; this showed that the explosion occurred in two stages, there was a blue flash of fast burning mixture, possibly approaching the stoichiometric composition, and then slow blue flame followed consuming the remaining lean mixture. Figure 4 shows the heater in the vessel after the polyethylene had been destroyed by the explosion.

DISCUSSION

Both heaters failed to comply with B.S. 2773 in several respects and one of these failed to comply with one clause of B.S. 1945. The following clauses cover requirements of primary importance to the safe functioning of such appliances:

Clause 30	Flame failure device
" 41	Resistance to draughts
" 43	Combustion
" 45	Floor and wall temperature

B.S. 2773 specifies that the flame failure device shall be fitted to heaters where the effect of the combustion cannot be seen. This assumes that if the heater with flame or glowing radiant panels goes out, there is someone in the vicinity to rectify such fault; such heaters, however, are often expected to work without any attention and should the fuel supply fail for a short time, there would be no protection against possible explosion and fire; thus, it is important that such safety devices are fitted to all portable heaters.

There are two aspects of the reaction of the heaters to draught which require comment. One aspect is the possible ignition of easily ignitable material in the vicinity of Heater B by the displacement of the flame in a draught. The other aspect is the incorrect functioning of the flame failure device which may not stop the flow of fuel in spite of the burners being extinguished. This occurred with Heater B and it is unlikely that conventional testing procedures would detect such fault as the commonly convenient way to test the flame failure device for compliance with the Standard is to shut off the fuel supply for a recommended period and to ascertain that the main flow is interrupted after this period. It is suggested that clause 30 should be strengthened by inclusion of a condition which would stipulate that it is not possible to extinguish the main burner by any means without extinguishing the pilot flame. Such a condition is easily satisfied with the thermocouple type flame failure devices, by always placing the flame very close to the burners so that they will be reignited. It is possible that if the pilot flames of Heater B were placed closer to the main burner, this heater would satisfy such a condition.

Testing in a draught is an important part of the evaluation of the performance of the flame failure device and, indeed, with Heater B, tests in a draught have shown that the flame failure device did not function properly. When both pilot flame and the burners are extinguished by draught and the fuel flow is stopped by the flame failure device, this may inconvenience the user but is not hazardous.

It is considered that the draught test itself should be strengthened; the maximum velocity of 2.25 m/s (7.5 ft/s) goes some way towards obtaining stable performance in many domestic conditions, but by no means represents the most severe conditions possible. B.S. 3300, for Kerosine (paraffin) unflued space heaters, advocates a maximum air speed of 8 m/s (26 ft/s) which is said to be the maximum encountered in dwellings. Since, however, a speed of approximately 4.5 m/s (15 ft/s) was found to produce the most critical conditions, such a value may be acceptable, but several relative positions of the appliance in relation to the direction of air movement should be tested.

B.S. 2773 sets the maximum heat output of such appliance at 1.76 kW/h (6000 Btu/h). Thus both heaters do not comply with this clause. It is, however, questionable whether this upper limit is large enough. The maximum output of most modern heating appliances is about $2\frac{1}{2}$ kW/h (8530 Btu/h); this copes with most of the modern demands for heat comfort. If, however, this value were to be adopted, such heaters need to be redesigned to reduce the radiant heat output to the side of the test wall in order to pass the test for the maximum allowable wall temperature.

A further essential condition of the flame failure device is that it should fail safe. A thermocouple-operated device satisfies this condition in a sense that, if the thermocouple fails to actuate the valve, this stays in a closed position being held down by a coil spring; the sound condition of this spring is essential for fail-safe functioning. This spring, while the heater is working, is at or near ambient temperature.

The flame failure device on Heater B relies on the elasticity of the metal diaphragm to keep the valve in closed position. It is not clear what long term reliability such a device offers. The diaphragm is exposed to atmosphere and it is heated by four small jets all the time the heater is functioning, and only accelerated or long term tests may evaluate the life and the mode of failure of such a device. The burner unit of this heater is positioned horizontally, which may lead to the heater being used as a cooker, consequently creating other hazards.

CONCLUSIONS

The performance and structure standards of new domestic butane fired radiant heaters need to be brought up to date. If the existing B.S. 2773 is to be retained, it is desirable that it should be modified to satisfy modern heat comfort requirements; alternatively, the new standard for larger heat output

appliances could be formulated. Following aspects of safe performance need attention:

a) Flame failure device

b) The temperatures of floors and walls

c) Performance in vitiated atmospheres[5]

d) Installation of shut down devices when CO_2 concentrations exceed acceptable level[5].

REFERENCES

1. British Standard 1945 : 1971. Fireguards for heating appliances.

2. British Standard 2773 : 1965. Domestic single room space heating appliances for use with liquefied petroleum gas.

3. British Standard 3300 : 1963. Kerosine (paraffin) unflued space heaters, cooking and boiling appliances for domestic use.

4. Fire Research 1969. pp 18-19.

5. Work is being carried out at Fire Research Station.

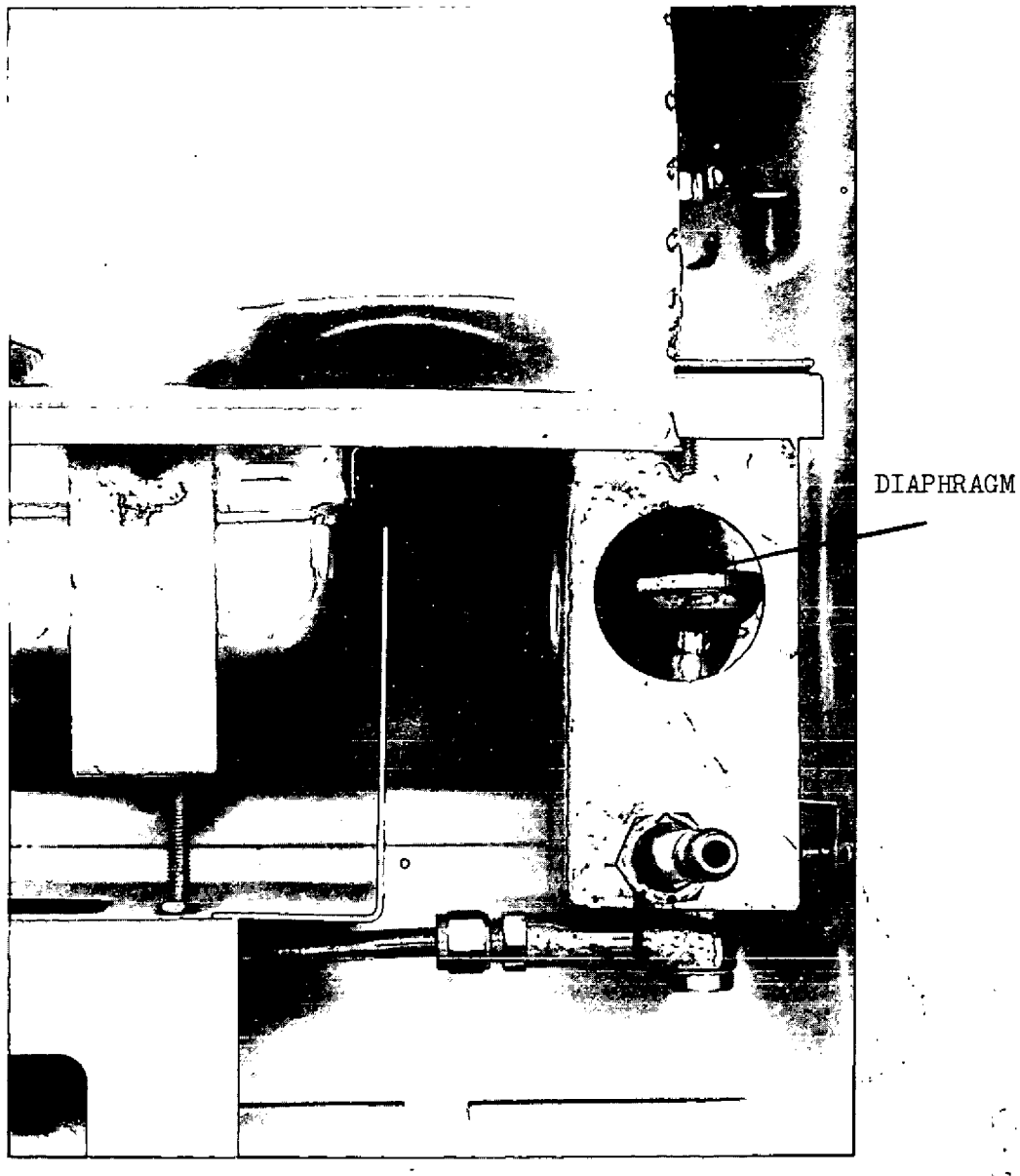

FIG.1. FLAME FAILURE DEVICE FITTED TO HEATER B

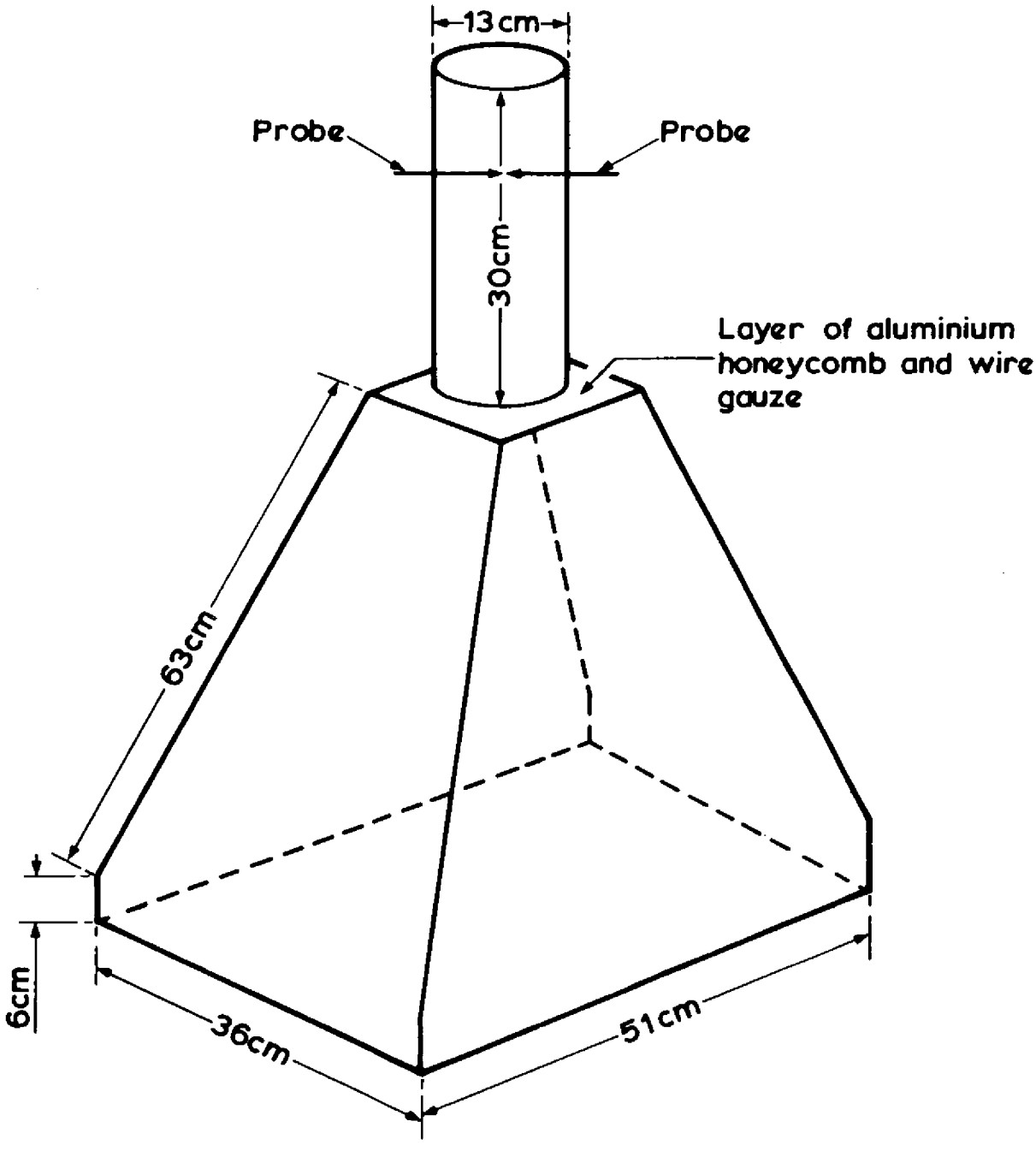

Figure 2 Gas sampling hood

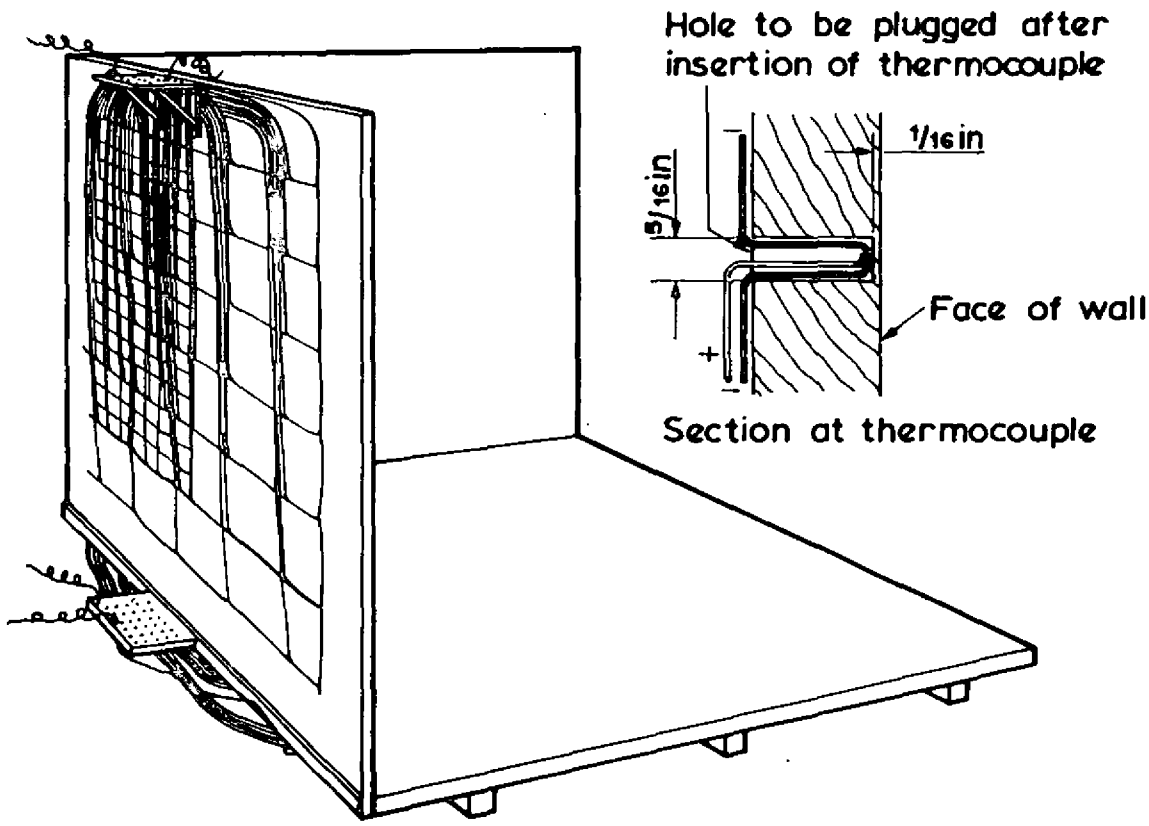

Figure 3 Apparatus for measuring floor and wall temperatures

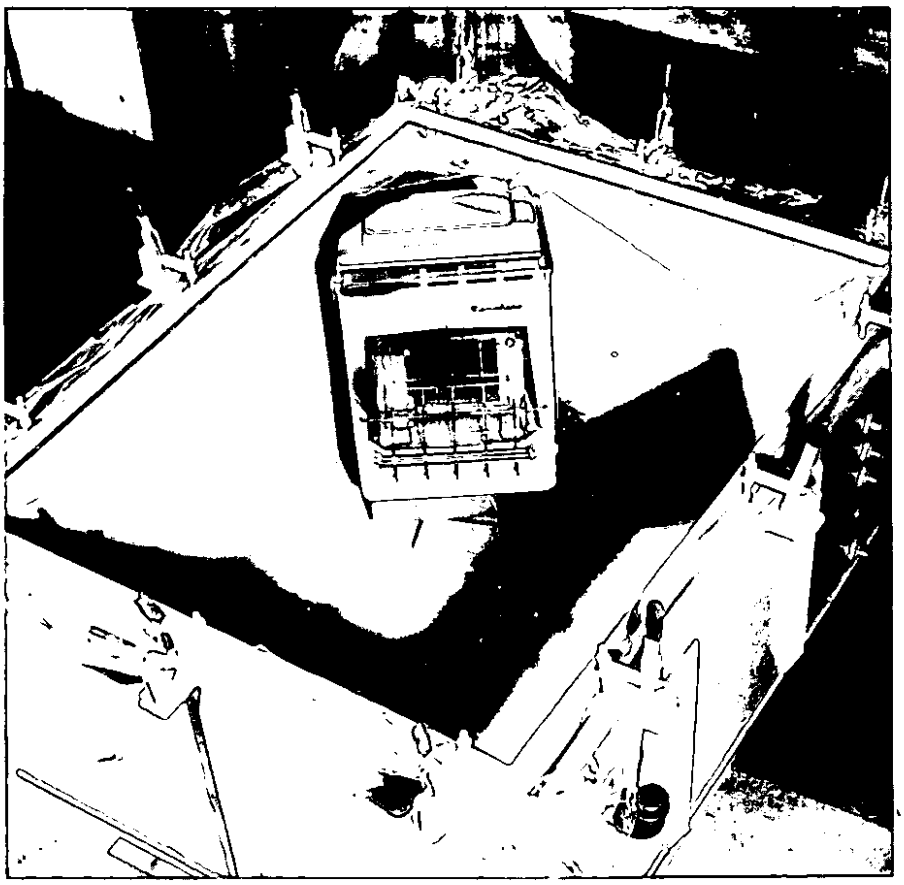

FIG.4. HEATER 'B' WITHIN THE TEST CHAMBER AFTER THE EXPLOSION DESTROYED THE POLYETHYLENE COVERING