DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

AND

FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

FIRE RESEARCH NOTE

NO. 527

CONTROL OF FIRES IN LARGE SPACES WITH INERT GAS AND FOAM PRODUCED BY A TURBO-JET ENGINE

PART 6. TRIALS IN COLLABORATION WITH THE LONDON FIRE BRIGADE AT DISUSED BASEMENT PREMISES

by

D. J. RASBASH, G. W. V. STARK, G. H. J. ELKINS and B. LANGFORD

AUGUST, 1963.

Fire Research Station.
Boreham Wood.
Herts.
('phone ELStree 1341)

F.R. Note No.527.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

CONTROL OF FIRES IN LARGE SPACES WITH INERT GAS AND FOAM PRODUCED BY A TURBO-JET ENGINE

PART 6. TRIALS IN COLLABORATION WITH THE LONDON FIRE BRIGADE AT DISUSED BASEMENT PREMISES

by

D. J. Rasbash, G. W. V. Stark, G. H. J. Elkins and B. Langford

SUMMARY

Tests on the control of fires by inert gas or foam generated by the experimental inert gas generator based on a jet engine have been made in the basement of a disused London brewery. The tests, made in collaboration with the London Fire Brigade, showed that inert gas penetrated throughout the basement system, and that all compositions of gas used, with a range of 6 to 16 per cent oxygen content, cleared smoke and controlled flaming combustion. Gases with low oxygen, and high water content suppressed flaming combustion, but resulted in a hot misty atmosphere remote from the point of injection. Gases with high oxygen and low water content reduced flaming only, but the atmosphere remained warm and clear. High expansion foam penetrated the basement system and suppressed flaming combustion and was found comfortable to work in. The flexible wire helix supported ducting used to convey the inert gas was found to withstand the conditions of usage well. The cotton material used for foam generation was unsatisfactory.

Firemen wearing breathing apparatus who entered the basements during the injection of gas found the high oxygen, low water content gases gave clear atmospheres in which they could work. The firemen found conditions in the low oxygen content gases more onerous, because the atmospheres were either very warm with poor visibility or too hot to bear if the visibility was improved.

CONTROL OF FIRES IN LARGE SPACES WITH INERT GAS AND FOAM PRODUCED BY A TURBO-JET ENGINE

PART 6. TRIALS IN COLLABORATION WITH THE LONDON FIRE BRIGADE AT DISUSED BASEMENT PREMISES

by

D. J. Rasbash, G. W. V. Stark, G. H. J. Elkins and B. Langford

Introduction

Tests at the Fire Research Station with the experimental inert gas generator based on a jet engine(1) have shown that the generator produced inert gas in sufficient quantity and of such composition as to extinguish liquid fuel fires, to reduce solid fuel fires to smouldering, and to clear the atmosphere of smoke when introduced into the Models Laboratory, a building about 130 ft long, 50 ft wide, and 40 ft high of about 250,000 ft^3 volume(2). Other tests in the same building in collaboration with the Herts Fire Brigade have shown that men wearing compressed air breathing apparatus and fire service uniform can enter and work for a reasonable period in an atmosphere at 60-65°C containing about 14 per cent oxygen and 15-20 per cent water vapour. Further tests have shown that high expansion foam can be generated with an efficiency of 60 per cent conversion of gas to foam(3).

The present note describes a series of tests carried out (with the collaboration of the London Fire Brigade) in the basements and a store room of a disused brewery. The tests were designed to examine (i) the feasibility of replacing the atmosphere in a system of intercommunicating basements connected by narrow doorways, (ii) the control afforded by gases of differing oxygen and water vapour content of solid fuel fires remote from the point of injection, (iii) the ability of firemen, wearing standard Fire Service clothing and breathing apparatus, to work in the different atmospheres, (iv) the feasibility of conveying the inert gas through flexible ducting (v) the ability of high expansion foam produced by the generator to progress to locations remote from the point of generation and (vi) the ability of the high expansion foam to extinguish solid fires.

Experimental

Premises.

A sketch plan of the premises used in the trials is shown in Fig.1, on which spaces and openings relevant to the trials are indicated. A staircase at W led through a corridor into compartment A. A doorway, T, fitted with a heavy insulated door, separated compartment A from the series of intercommunicating compartments L, M and N. From compartment L a stairwell led up to ground level at X, and a pair of air lock heavy insulated doors, Y, gave access to the floor of compartment S. A corridor ran from L, alongside compartment B through a door, V, to compartment P; about half way along this corridor a door, R, gave access to compartment B. From compartment B, a door Q gave access to compartment N, and a door U gave access to a ramp into compartment C. Compartment P communicated directly to a staircase to the higher levels of the building and door Z_2 gave access from compartment C into compartment P. From compartment C a doorway Z_1 led to a staircase to street level, and the higher levels of the building; alongside this doorway was a lift shaft opening with a roller shutter. Small openable stall board lights just below ceiling level in compartment C communicated with the street outside the building. Views of the compartments are shown in Plate 1.

Points of Injection.

For all tests but one the experimental generator was placed so that gas could be introduced into the stairwell at X. The gas was introduced through an open ended metal duct, 2 ft 6 in diameter, which protruded a few inches into the stairwell through a hardboard closure (Plate 2). The generator was prepared for the production of foam by connecting a 25 ft length of flexible ducting to the open end of the metal duct, and coupling a foam-making sock to the other end in basement L, Plate 3. Two foam socks were used, Mk.I, a simple sock 5 ft 6 in diameter and 8 ft 6 in long and Mk.II, a sock of the same dimensions, but incorporating internal cloth baffles to improve the distribution of gas over the surface of the sock.

In the remaining test the experimental generator was moved and placed so that gas could be introduced, through 50 ft of flexible ducting, up a stairwell and into compartment S at doorway H Plate 4. The open end of the duct pointed downwards into S /at an angle of about 30° to the horizontal/.

Points of Entry.

The points of entry of firemen and observers for a particular test depended on the parts of the premises being filled with gas or foam, and on the temperature of the gas. Entry was made at one or more of points W, H, V, Z_1 and Z_2 in Fig.1. Plate 5, shows firemen and observers at entry point Z_1 during a test.

Gas Outlets.

The outlets for gas from the building for a particular test depended on the parts of the premises being filled. The outlets were one or more of the points W, H, V, Z, and Z_2, and the stall board lights and lift shaft in compartment C, Fig.1. The area of the opening to the lift shaft could be varied by means of a roller-shutter; except where stated otherwise, a 2 ft opening was used. There were also a number of other small leaks from the basement system. These were sealed, in so far as it was possible, after the first test.

Position of Fires.

Two positions were used for fires, consisting of broken furniture and mattresses. These are shown as hatched areas in Fig.1. Typical fires are shown in Plate 6.

Instrumentation.

Lamps burning gas-oil, thermocouples and wet-and-dry-bulb differential thermopiles, Plates 1 and 7, were installed at the positions indicated in Fig.1. Gas sampling lines were introduced into compartment C for the measurement of moisture content, and gas composition. Lamps and thermocouples were installed at 2, 6 and 9 ft above the floor in compartment C, and the wet and dry bulb thermopile at 6 ft above the floor. In all other locations lamps and thermocouples were installed at 2 ft and 6 ft, and the wet and dry bulb thermopiles at about 6 ft above the floor.

Test Programme.

Tests were made with gases of different composition from the generator, falling broadly into three classes. The method of producing these gases, their temperature and their composition calculated from the fuel-air ratio of the generator and the thermal properties of the gases[1] are given below.

Class 1. Cool gases, produced by running the generator without reheat, and introducing air into the gas stream. Temperature of the gas on leaving the generator not more than 90°C*, water content 15 to 17 per cent by volume and oxygen content 15.7 to 16.3 per cent by volume. The gas temperature was calculated from the thermal properties of the generated gas and entrained air.

Class 2. Warm gases, produced by running the generator without reheat, but with no air entrainment. Temperature of the gas on leaving the generator not more than 110°C*, water content 18 to 19 per cent by volume and oxygen content 14.9 to 15.1 per cent by volume.

Class 3. Hot gases, produced by running the generator with reheat, but with no air entrainment. Temperature of the gas on leaving the generator not more than 120°C*, water content 34 to 48 per cent by volume, oxygen content 6.1 to 10.4 per cent by volume.

Tests were also made with high expansion foam of initial expansion ratio 1000 : 1. A gas of Class 2 was used as the gaseous phase.

Results

The results are presented in the order of the main classes of gas given above followed by the results of tests with high expansion foam. The test numbers are in the chronological order in which the tests were performed. Code letters refer to openings, doors and spaces in Fig.1.

A. Class I Gas

Test No.9 31.10.62.

Gas was produced at 36000 ft^3/min by running the jet engine unit without reheat and entraining air into the exhaust stream. The temperature, on leaving the appliance was 76.5°C and the gas, containing 15 per cent water vapour and 16.2 per cent oxygen (vol.) was introduced into compartments L, M, N and A only, all other parts of the basement system being sealed off. The gas escaped through W.

The temperatures measured in compartment A, and in the corridor from A to W are given in Fig.2. Mist formed in the corridor to W after a minute or so. The range of visibility in the corridor increased with time and was about 30 ft 5 min after gas was introduced at X, and had increased to about 60 ft in a further 2 minutes. Nine min after the introduction of the gas it was observed that visibility was good across the width of A and nearly complete along its length (147 ft). Firemen were then instructed to enter A from W and approach as close to the point of introduction of the gas through C as was possible. The firemen entered A through W, 15 min after introduction of the gas, and returned 10 min later. They reported that visibility was good, that the atmosphere in A was warm but not uncomfortable and could be worked in. Four lamps in compartment A only were burning, the remainder being extinguished. Temperatures in compartment L were appreciably hotter than in compartment A, but were tenable. The test was stopped after 35 min injection of gas.

Test No.13 1.11.62.

In this test, two gases of Class 1 and one of Class 2 were used in succession. At the beginning of the test the gas was allowed to pass through all basements, but compartment S was shut off. The basements were vented at W and the stall board lights and lift shaft in C. A fire of broken furniture

*The measured temperatures of the gases leaving the generator were about 15 per cent less than the temperatures measured in compartment L. Possible explanations of this discrepancy are discussed later.

and mattresses, 20 ft long and 5 ft 6 in wide and 6 ft 6 in high was lit in C, and smoke bombs were ignited in B and A, 14 min before injecting the gas at X.

The first Class 1 gas, injected at 36000 ft^3/min and 79°C, contained 16.3 per cent oxygen and 15 per cent water vapour. After 4 min injection, firemen wearing breathing apparatus entered the basement system at W, and proceeded to the fire in C and back, taking 18 min. The temperature in A during this period was 35° - 50°C and in C was 60° - 100°C, the higher temperature in C being at head level close to the fire. They reported that smoke from the smoke bombs had cleared and that they could work in the warm atmosphere. Observers at ground level said the smoke emerging from W had become very thin 19 mins after injection started. During this period, the fire in C, which at the start of injection was producing a column of flame from the whole of its area impinging on the ceiling, was reduced in size and luminosity. After 6 min injection, flames impinged on the ceiling at three points only and the flame height over the remainder of the fire was between 2 and 3 feet. Also the flames had died out completely over about 3 to 4 feet of the fire closest to the stall board lights. The firemen mentioned above, reported that the fire was still burning brightly at about 15 min after injection.

In the second stage of the test, 23 min after injection started, the gas composition was changed by reducing the air entrainment holes to half maximum area. Calculated gas composition was 15.7 per cent oxygen and 17 per cent water vapour, delivered at 32000 ft^3/min at 91°C. The size of the flames from the fire were reduced to 1 to 2 ft high at 27 to 37 min after injection started, and were semi-transparent, although there was a great deal of glowing combustion in the mass of the fire. Compartment A was shut off by firemen at 39 min after injection, by closing T. The fire continued burning with small flames and glowing combustion until 47 min after the start of injection when gas injection was stopped for 5 min.

During this 5 min period air entered C through the stall board lights and the fire spread to that part of the fire that had not been involved since the early stages of the test. The remainder of the fire did not alter appreciably. Gas of type 2 was then introduced, 52 minutes after starting injection of gas. The gas, containing 14.9 per cent oxygen and 19 per cent water vapour was introduced at 98°C at a rate of 28000 ft^3/min for 10 minutes. Only a slight reduction in the flames was observed.

Temperatures measured during the test are given in Fig.3 and 4. The thermocouple in L was registering faultily in the test, and indicated an impossibly high temperature.

B. Class 2 Gas.

Test No.1 29.10.62.

Gas was introduced at X, at 27000 ft^3/min at 97°C. The gas contained 15.0 per cent oxygen and 18 per cent water vapour. The gas was allowed to flow through the whole of the basement system except compartment S, and to escape from W, Z_2, the stall board lights, and the lift shaft in compartment C. Measurement was made of the velocity of gas flowing into C from B as soon as gas flow was started. The velocity, 10 ft per second, indicated a gas flow of 12,000 ft^3/min into C. The expected flow was 18000 ft^3/min. The basement system was examined for major leaks, and these were plugged after the test.

The atmosphere in C was misty and visibility restricted after about 7 min injection. After 20 min injection door Z_2 was shut and after 30 min the lift door was shut completely but no appreciable improvement in visibility was obtained. Thirty-five min after injection, a team of firemen wearing Breathing Apparatus entered A and closed Door T, isolating A from the gas flow. The firemen reported good visibility in A, improving as compartment L was approached. Visibility in L was good, but the gas passing through T was very hot. During the five minutes after compartment A was isolated no improvement in visibility was observed in compartment C. The injection of gas was stopped 40 min from the start of injection and gas of Class 3 was introduced about 2 min later. The gas containing 9 per cent oxygen and 37 per cent water vapour, was delivered at 42000 ft^3/min at 118°C. This gas was injected for 20 min, but little difference was observed in the opacity in C. Temperature records for this test are presented in Figs.5, 6 and 7.

The lamps in general could not be seen until the end of the test, except in compartment C during the first half of the test. The middle lamp on the mast in C closest to the site for fires was extinguished 25 minutes after starting injection. At the end of the test all lamps throughout the basement system were out, except for one in the middle of compartment A, and one in the corridor from A to W. Both these lamps were 2 ft above floor level.

The gas in compartment C was analysed at intervals during the test, and a mean value of water content of the atmosphere was measured. The results are given in Table 1 below.

TABLE 1

Composition of Gas in Compartments

Time after injection, min:- Temperature °C:-	Dry gas, as measured			Moist gas		
	19 21	34 23	49 32.5	19 21	34 23	49 32.5
Per cent vol. Nitrogen	80.3	80.1	80.8	78.14	77.6	76.67
" " " Oxygen	18.4	18.5	15.9	17.9	18.0	15.10
" " " Carbon dioxide	1.3	1.4	3.3	1.27	1.36	3.14
" " " " monoxide*				0.015	0.02	0.14
" " " Water vapour ø				2.47	2.78	4.85

øAtmosphere taken as saturated.

*Figures presented are those from an infra-red analyser. The carbon monoxide content is less than the limit of accuracy of Orsat Analysis, the method used for the other gases.
The total water content of the atmosphere at 28 min measured by passing a known volume of gas over a desiccant was 11.5 per cent volume.

The temperature in compartment A, Fig.5, indicated a leak into the compartment although door T was closed. This was discovered and sealed for Test 8 and subsequently.

C. Class 3 Gas

Test No.2 29.10.62.

A fire of broken furniture and mattresses and small wood, about 15 ft long, 5 ft wide and 4 ft high was lit in compartment C. Compartments A and S were shut off from the basement system. Gas containing 9 per cent oxygen and 37 per cent of water vapour at 120°C was injected through X at 41000 ft^3/min, 13 min after lighting the fire. At this time the flames were about 8 ft high. No apparent change in the flame was observed for about 7 min after injection; at 10 min the flames were reduced to about 2 ft height, and flames were no longer visible at 12 min. Steam escaped through the stall board lights and other openings in the building, Plate 4. At this time the temperature in the lower half of compartment C was reported as about 65°C and a team of firemen, wearing oxygen demand Breathing Apparatus, were instructed to enter C via Z_1 with a hose line to extinguish any remaining fire if possible. The leader of the team entered C, but the remaining members of the team found the gases emerging at Z_1 too hot to bear. Divisional Officer Watts wearing compressed air breathing apparatus observed that entry was possible at after 20 to 25 min gas injection, and entered C via Z_1 at 30 min of gas injection. Almost as soon as he entered, the gas duct parted from the seal at X, and gas injection was stopped. As this happened, air was drawn into C via the door Z_1 and the stall board lights. The team of firemen was then able to enter with comparative ease and extinguish the fire. Divisional Officer Watts reported that, when he entered, there was a small amount of flame deep seated in the centre of the fire, the flames being about 6 in high. The visibility in C was said to be very poor. The leader of the first mentioned team reported that the atmosphere felt much hotter at the entrance Z_1 than it did when inside compartment C.

Temperatures of the basements during this test are given in Fig.8 and 9. The temperature in compartment C increased rapidly and began falling close to the fire at about 8 min after gas injection started at X; the temperature further from the fire began falling about 3 min later. Although the temperature records were incomplete from the upper thermocouples in C, because the temperature exceeded the range of the recorder and possibly also because the thermocouples or leads were damaged by heat, there was evidence that the temperature close to the fire was higher at the middle level than at ceiling level. The recorded relative humidity in C was in excess of 80 per cent from 20 min after injection of gas until the end of the test. Compositions of the atmosphere in C measured during the test are given in Table 2 below.

TABLE 2

Composition of Gas in Compartment C

Time after injection, min Temperature °C	Dry gas, as measured		Moist gas	
	14 76	44 66	14* 76	44 66
Per cent vol. Nitrogen	79.9	81.1	72.7	60.0
" " " Oxygen	16.9	14.6	15.7	11.0
" " " Carbon dioxide	3.1	4.1	2.8	3.0
" " " Carbon monoxide	0.1	0.2	0.1	0.2
" " " Water vapour*			8.7	25.8

*N.B. The water vapour content given above was calculated from relative humidity measurements, viz., 22 per cent at 14 min and 100 per cent at 44 min. Saturation at 76°C (14 min) is 39.6 per cent water vapour, which would give an atmosphere at 14 min containing 10 per cent oxygen.

Test 8 31.10.62.

This test was a repeat of Test No.2. A fire of similar size was ignited and was slower to reach full burning than in Test 2. The fire was fully involved in flames, and the gas injected at X into the basement systems, excluding A and S, 22 min after ignition. After 6 min injection, the flames were reduced to about 2 ft high. As gas of Class 2, (15.1 per cent oxygen, 18 per cent water vapour at 29000 ft^3/min at 109°C) had been injected in error, injection was stopped for 2 min after which gas of Class 3 was injected, i.e., 8 min after injection started. The gas containing 8.9 per cent oxygen, 38 per cent water vapour was delivered at 39000 ft^3/min at 112°C. Thirteen minutes after injection started, the fire was under control, with no flames visible. A group of firemen wearing oxygen demand breathing apparatus entered through Z_2 at 13 min, and another group through Z_1 at 17 min after injection where the mean temperature below 6 ft was about 60°C. The men emerged 5 minutes later, having extinguished the fire. They reported the conditions to be hot but tenable, and the visibility poor, about 4 ft. After 21 min injection, the gas was changed to Class 1 for 5 minutes to see if this gas was more comfortable, but no apparent difference was observed in this time. The test was then stopped.

Temperatures in compartment C were somewhat higher than in Test 2. The temperature in the upper part of C close to the fire exceeded 200°C before gas injection started (18 to 20 minutes after ignition). The temperature 6 ft above the floor was 176°C close to the fire after 3 min injection, 25 min after ignition, and 107°C at the other location. After 25 min injection the temperature at this level was less than 50°C. The relative humidity in C was in excess of 80 per cent 18 min after injection (40 min after ignition) to the end of the test.

The composition of the gas in compartment C during the test is given in Table 3.

TABLE 3

Composition of Gas in Compartment C Test 8

Time after injection, min. Temperature °C	Dry gas, as measured			Moist gas		
	3 107	14 92	23 55	3 107	14 92	23 55
Per cent vol. Nitrogen	79.9	79.3	80.2	59.7	57.4	67.6
" " " Oxygen	14.2	18.4	16.8	10.7ø	13.5	14.4
" " " Carbon dioxide	5.9	2.3	2.9	4.4	1.7	2.4
" " " Carbon monoxide	0.03	0.03	0.09	0.03	0.03	0.09
" " " Water vapour*				25.2	27.4	15.5

N.B. *Relative humidities as measured, 19.5 per cent at 3 min, 41 per cent at 14 min and 100 per cent at 23 min, were used to calculate moisture in atmosphere.

øThe low oxygen content was not expected, and may be due to the collection of a sample containing a large proportion of combustion products from the fire.

Test No.10 1.11.62.

In this test, a Class 3 gas was injected at X into the basement system, excluding compartments A and S. Gas containing 10.4 per cent oxygen and 35 per cent water vapour was injected at 38000 ft^3/min at 109°C. A fire, similar to those in Tests 2 and 8, was lit in C, 15 min before injection of gas. At this time the fire was fully involved, with flames impinging on the ceiling over the whole fire area. After 3 min injection the flames were reducing in size and becoming more transparent. After 7 min injection no flames were visible. After 11 min injection the gas was changed to Class 1; 4 min later the flames had reappeared and were up to 3 ft in length, and in a further 2 min had increased to between 5 and 6 ft in length. The flames were reddish in colour and somewhat transparent and involved the whole of the fire. Injection of gas was then stopped at a total time of injection of 17 min, immediately air was drawn in through the opening into compartment C and the flames over the whole of the fire formed a column impinging on the ceiling. Firemen entered compartment C at this stage and extinguished the fire.

During this test the fire in compartment C developed rapidly. The temperature recorded close to the fire at 6 ft or more above the floor exceeded 200°C, 10 min after ignition; 20 min after ignition, when gas had been injected for 5 min, the temperature at the 6 ft level was higher than at ceiling level. Records ceased after 15 min injection, when the temperatures in the upper half of C were still falling.

The recorded temperatures in C are given in Figs. 10 and 11. The composition of gas measured during the test is given in Table 4.

TABLE 4

Gas Composition in Compartment C - Test 10

Time after injection, min. Temperature °C.	Dry Gas, as measured	Moist Gas
	14 76	14 76
Per cent vol. Nitrogen	80.6	48.9
" " " Oxygen	14.1	8.25
" " " Carbon Dioxide	4.9	3.0
" " " Carbon Monoxide	0.4	0.25
" " " Water Vapour		39.6

N.B. Carbon monoxide from Orsat. Relative humidity assumed 100 per cent. The relative humidity as measured exceeded 80 per cent throughout the period of injection.

Test No.14 2.11.62.

A Class 3 gas of low oxygen content was used for this test. A fire as in previous tests was lit in compartment C and 20 min later, when the fire was fully involved in flames, which were impinging on the ceiling, inert gas was injected at X, compartments A and S being sealed off. The gas containing 6.2 per cent oxygen and 48 per cent water vapour, was injected at 47000 ft^3/min at 98°C. Four minutes after the start of injection the fire was reduced considerably and 5 min after, only a few reddish flames were present. These flames disappeared leaving a dull red glow only, which disappeared 7 min after the start of injection. For the next 10 minutes no burning was visible, but crackling could be heard occasionally. Divisional Office Watts entered compartment C, about 20 min after injection started, for a short time and reported that the atmosphere was translucent but very hot and that he could discern the shape of the fire (from about 20 ft). At this time a faint reddish glow could be seen in the region of the fire through a 4 in dia. hole in the floor above the fire.

Thirty-one minutes after start of injection, an attempt was made to change to Class 1 gas by turning off reheat and entraining air by injecting the gas stream into the large opening of about 28 ft^2 of the stairwell at X. This largely failed because of a wall a few feet inside the opening which deflected most of the gas into the open air. Within 6 minutes of the gas flow diminishing, the fire rekindled over all its surface to give flames impinging on the ceiling in compartment C.

The top and centre thermocouple close to the fire in C failed to register correctly during this test, but the temperatures recorded at the other location in C indicated a similar level of temperature during the development of the fire as in previous tests. The temperature in compartment C was reduced rapidly when the inert gas was injected, and from 5 minutes after injection started, to the end of the test, the mean temperature was about 74°C, the variation with height between the three levels of the thermocouples not exceeding 5°C. The relative humidity in C exceeded 80 per cent from 10 minutes after injection started until the end of the test.

The composition of the gas in compartment C during the test is given in Table 5.

TABLE 5

Gas Composition in Compartment C - Test 14

Time after injection, min. Temperature °C	Dry Gas, as measured			Moist Gas		
	10 72.5	20 74	30 74	10 72.5	20 74	30 74
Per cent vol. Nitrogen	81.0	82.5	82.1	60.0	53.9	52.9
" " " Oxygen	12.8	11.2	11.3	9.5	7.4	7.2
" " " Carbon Dioxide	6.0	6.2	6.5	4.4	4.1	4.2
" " " Carbon Monoxide∅	0.2	0.1	0.1	0.15	0.05	0.05
" " " Water Vapour*				26.0	34.6	35.7

N.B. Carbon monoxide from Orsat. Water vapour content from the measured relative humidity, 76, 95 and 98 per cent at 72.5°, 74° and 74°C respectively.

Test No.15 2.11.62.

A Class 3 gas was injected through 50 ft of flexible ducting 2 ft 6 in dia., into the uppermost level of compartment S through opening H. The opening was 25 to 30 ft above ground level. The ducting passed up the centre of a stairwell and was restrained by guy ropes tied to the balustrades.

The inert gas generator produced gas containing 6.8 per cent oxygen and 46 per cent water vapour at a total flow of 42,000 ft^3/min at 70°C.

A fire about 10 ft diameter and 7 ft high was lit on the floor of S. After 15 minutes, when the fire was completely involved in flames, a proportion of about 4,000 ft^3/min of the inert gas was passed through the ducting into S, the remainder of the gas being exhausted to air. The ducting withstood the gas flow satisfactorily and therefore the flow of gas into S was increased to about 20,000 ft^3/min 3 minutes after injection started. The ducting withstood the increased flow satisfactorily and 5 minutes after injection started, gas flow was increased to about 35,000 ft^3/min. At this time it was observed that the fire was under control and subdued. Eight minutes after the start of injection, an attempt was made to change the gas to Class 1 by stopping reheat and opening the air induction ports. Back pressure in the ducting prevented this, and gas escaped from the air entrainment ports, indicating that a reduced flow of Class 2 gas was being injected. Firemen wearing oxygen demand breathing apparatus entered S through door Y in the basement and reported conditions too hot to bear and visibility poor. Injection was stopped after 15 min from the start and immediately cool air was drawn into S through the door Y. The firemen entered in this stream of cool air a few minutes later, and found the fire burning strongly. They were able to reach the fire easily and extinguish it.

No temperature records were taken in S during this test. The ducting behaved satisfactorily, becoming somewhat distended on the full flow of the gas. The 25 ft section of ducting that had been used for foam generation showed slight porosity, some water percolating through the material of the duct.

High expansion foam tests.

Foam was generated by supplying gas to a sock of cotton mesh fabric supported just above the floor in compartment L and coupled to the jet engine inert gas generator by a 25 ft length of 2 ft 6 in dia. flexible ducting. A solution of foaming agent containing 1 per cent active matter was pumped to a spray nozzle manifold within the mesh sock at 1/1000 of the rate of gas delivery.

Test No.3 30.10.62.

Proprietary Foam Compound A, Mk.II Foam Sock. This test was performed to check the foam making capability of this system. Gas of Class 2 was supplied at 25,000 ft^3/min at 55°C. The test showed that foam could be produced satisfactorily, and that the flexible ducting withstood the conditions of test.

Test No.4 30.10.62.

Proprietary Foam Compound A, Mk.II Foam Sock. Class 2 gas supplied at 25,000 ft^3/min at 55°C was used to make foam.

Compartments A, M, N, B and C and the corridor alongside B were sealed off, and the door Y to compartment S was fully opened. A fire was laid in S and lit. Five minutes later, foam was generated with gas supplied at 55°C and 25,000 ft^3/min. The fire was stated to be out 2 minutes later. Foam was delivered for a further two minutes and then turned off. Six minutes later flames broke through the foam from the fire. After the apparent extinction of the fire a team of firemen wearing breathing apparatus entered the foam and tested communication by field telephone. The production of foam was started again 11 minutes after it had been stopped, but no foam entered S, because the door Y had closed inadvertently. The generation of foam was stopped 7 minutes later.

It was then found that foam had entered compartments M, N and B and had penetrated half way across the floor of B.

Test No.5 30.10.62.

Proprietary Foam Compound A. Mk.II Foam Sock. Foam was made with Class 2 inert gas supplied at 25,000 ft^3/min at 55°C.

Compartments S and A were sealed off and foam generated in L for 9 min only. Foam was observed through a port in the ceiling to be moving along in a plug about 5 ft high. The foam did not reach compartment C during the test. Divisional Officer Watts, who entered the foam during the test reported that the foam was warm, but movement in it was easy. Visibility above the foam was said to be about 4 ft. The foam broke down rapidly, particularly on the floor of compartment M which was dusty.

The foam sock was examined after the test and was found to have moved from its support and to have collapsed on the floor.

Test No.6 30.10.62.

Proprietary Foam Compound B.

The conditions for this test were as for test 4. Foam was made with Class 2 inert gas at 25,000 ft^3/min at 59°C. A fire was lit in S and foam made in L five minutes later, when the fire was burning more fiercely than in Test 4. The fire was stated to be out after 12 minutes of foam generation, but foam generation was continued for a total time of 19½ minutes. Twelve and a half minutes later flames broke through the foam from the fire.

At the end of foam generation the height of foam in S was 15 ft. The volume of foam in the basement was commensurate with a rate of delivery, neglecting collapse of foam, of 7000 ft^3/min. Firemen who entered the foam said it was warm but comfortable to work in. Sound travelled well in the foam, and speech between men wearing compressed air breathing apparatus was clear over a distance of 42 ft. Examination of the foam generating bag showed that it had again collapsed to the floor.

Test No.7 30.10.62.

Proprietary Foam Compound B. Mk.II Foam Sock.

The conditions of this test were as for test No.5. Gas was supplied at 25,000 ft^3/min at 59°C. The foam generating sock was suspended from the ceiling for this test, to avoid collapse of the sock during the test.

After 3 minutes of injection, foam entered the stairwell P through door V, which was then closed. Nine minutes after injection foam was entering C in quantity through door U. The delivery of foam was stopped 1 min later.

The volume of foam in the compartments at the end of this test was about 120,000 ft^3 giving a mean rate of production, neglecting collapse, of 12,000 ft^3/min. Examination of the sock at the end of the test showed the suspension was in place and the bag supported above the ground

Test No.11 1.11.62.

Proprietary Foam Compound B. Mk.I Foam Sock.

The Mk.II bag was found to be ruptured in places on the 31 October and was replaced, before the test, with the Mk.1 Foam Sock. Otherwise the conditions of this test were as for test 4. Gas was supplied at 17000 ft^3/min at 63°C.

Foam was generated in L, and entered S through Y, for 10 min. The foam rose to a height of about 15 ft in S. Measurement of the total volume of foam produced, and the rate of rise in S each gave an estimated rate of production, neglecting collapse of foam, of 7000 ft^3/min.

Test No.12 1.11.62.

Proprietary Foam Compound B. Mk.I Foam Sock.

The conditions for this test were as for Test 5. (Compartments A and S isolated). The gas was supplied at 19,000 ft^3/min at 63°C.

After injection for 15 minutes, a small amount of foam entered compartment C. The supply of gas was increased to 26,000 ft^3/min after 20 min injection. Injection ceased after a total time of 25 min when the solution of foam compound was exhausted.

The foam sock was examined at the end of the test and was found to have ruptured severely. Plate 8.

Discussion

Inert Gas Injection

Temperatures and Humidity in Basement.

The conditions under which firemen can work in basements through which the inert gas is passing can be assessed from the firemen's observations on their vision and comfort in the atmosphere, and from temperature and humidity measurements. As the firemen would be wearing breathing apparatus, the composition of the atmosphere would have little influence on their performance. The reliability of temperature and humidity measurements in the present tests could be decreased by (i) the imposition of stray potentials from different parts of the building (ii) the effect of water on the thermocouples (iii) lag in thermal response and (iv) physical damage. The effects of (i) and (ii) were minimised by waterproof insulation of the thermocouples and leads; the effect of (iii) was reduced by keeping the mass of junctions small, although the larger mass of the wet and dry bulb thermopile made their thermal lag greater. Few thermocouples suffered physical damage, although some masts fell to the ground during tests. The upper thermocouples closest to the fire in compartment C were damaged in the course of the tests, by heat and flames.

Calibration of the thermocouple junctions showed slight variations in response between the thermocouples, the variation for 95 per cent confidence limits was 4 per cent. There was no indication of faulty response from nearly all the installed thermocouples, and the majority of faults found were due to physical damage during the tests. The measured temperatures were in accord with the physical sensations of observers in the atmospheres.

The temperature of inert gas, measured at the jet engine, was consistently lower than that indicated in compartment L. Because of the small separation between the point of entry of the jet gases, and the position of the thermocouples in L, and the directness of the path of the gas between these points, the temperature of the gas at the point of entry would be only a few degrees hotter than the temperature in L. The temperature of inert gas measured at the jet engine was about 15 per cent lower than that recorded in L. Calibration of the thermocouples system at the jet engine showed the thermocouple response to be accurate. The cause of the discrepancy must therefore be associated with the properties of the gas stream, or the configuration of the thermocouples relation to the gas stream. Possible explanations are firstly, that water droplets carried by the gas stream impinged on the thermocouple junctions and lowered the temperature registered to a value between that of the gas stream and the temperature of the water drops, and secondly, that the gas stream was non-uniform in temperature, and the thermocouples were placed in position such that the temperature indicated was less than the mean temperature.

Measurements with the wet and dry bulb thermopiles suggest that sources of error were present other than those that could affect simple couples, particularly at high temperature, and these may have increased as the tests proceeded. For example, in Test 13, when gas containing 17 per cent water vapour was injected, the relative humidity measured in C at 100°C to 115°C varied between 90 and 100 per cent, 6 ft above the ground, which implied that the atmosphere consisted mainly of water vapour. It is however more likely that the supply of water to the wet bulb was insufficient, and a reduced temperature difference between wet and dry bulbs was therefore recorded.

Attempts were made to measure the total moisture in C by drawing gas through weighed drying tubes and reweighing. These were successful only in Test 1.

Gas flow - leakages and distribution.

During Test 1, gas flowed from B into C at about 10,000 - 12,000 ft^3/min. From the dimension of the openings in the basement system it was estimated that about two-thirds of total flow, i.e. 18,000 ft^3/min should enter compartment C. At least part of the difference between these two quantities could be accounted for by leakages. Although after the test obvious places where leaks occurred were sealed, there were many that could not be plugged. Officers of the London Fire Brigade commented that leakage was much less than would be expected in premises generally. However, as one of the purposes of the experiments was to estimate the flow requirements of inert gas for control of fires, the minimum amount of uncontrolled leakage was desirable.

Distribution and penetration of inert gas.

Lamps were positioned so as to show whether the inert gas penetrated the parts of the basements not in line with the general flow-path of the gas. All lamps were extinguished with the more inert gases, but an indication of the penetration of the gas was obtained from Tests 1 and 9 with gases of 15 to 16 per cent oxygen content. Although such gases could extinguish oil wick flames, only a small dilution with air would be needed for burning to be sustained. In Test 1 all lamps except two in compartment A were extinguished; these were at this lower positions on the masts, one between gas entry point T and the corridor to W, and one in the corridor to W. In Test 9, all lamps except four in compartment A were extinguished when the firemen entered the basement system. Although the positions of these four lamps were not ascertained, and they were all out at the end of the test, some of the lamps not on the general flow-path of the gas must have been extinguished in the earlier part of the test. The temperatures recorded in A also indicate that gas was distributed fairly uniformly throughout the compartment. Thus no parts of the basement system were found where the inert gas did not penetrate.

Entry of gas filled spaces.

The ease of approaching the seat of a fire and extinguishing it depend upon the temperature and clarity of the atmosphere. The present tests have shown that firemen in standard uniform and breathing apparatus can approach and tackle fires in atmospheres of Class 1 gases, visibility being good and the atmosphere feeling warm; but that visibility and comfort decreased as more inert gases were used. The general findings are given in Table 6.

TABLE 6

Working Conditions in Inert Gases

Test	Properties of injected gas		Temp °C	Conditions in basement	
	Class of gas	Moisture per cent		Visibility	Comfort*
9	1	15	35-50	Good	1
13	1	15-17	35-90	Good	1-2
1	2	18	30-80	Good	1-2
2	3	37	60-90	Poor	2-3
8	3	38	50-70	Poor	2-3
14	3	48	70	Fair	3

*Comfort Code.

1. Tenable work can be done.
2. Tenable work becoming difficult at higher temperatures.
3. Tenable for short time only, very hot.

In earlier tests(2), firemen wearing breathing apparatus could work for about 15 min in inert gas containing about 20 per cent water vapour, at 60° - 70°C. They found higher temperatures and water contents much more uncomfortable. These tests, conducted in the Models Laboratory, Fire Research Station, gave fairly clear atmospheres with Class 3 gases. The increase in clarity was due in part to the less massive construction, but primarily to the greater volume/surface area ratio of the building.

Two kinds of breathing apparatus were used in the present trials viz., oxygen demand apparatus, with mouthpiece, nose clip and rubber goggles, and compressed air, with a complete face piece. The latter type of breathing apparatus was used in the earlier tests at the Fire Research Station. It appeared that the compressed air breathing apparatus was more comfortable to wear in the hot atmosphere, probably because the area of exposed skin was less with this apparatus. In a similar way, gloves would be expected to increase comfort until they had become thoroughly warmed by the hot atmosphere.

The discomfort felt by firemen entering the atmosphere through small doors during Test 2 was probably due to two factors. Firstly, the high velocity of the gas stream emerging through the doors would increase heat transfer to the man. It is interesting to note that in tests conducted in the Models Laboratory(2), the buoyancy of the inert gas in the 40 ft high building caused air to enter when doors at ground level were opened, the hot gas escaping through gaps at high levels, and therefore entry was easier. (A similar effect was noted in compartment S after the flow of inert gas was stopped). Secondly, the inert gas entering the building would be lighter than air at temperatures up to 200°C(4). Thus the heated atmosphere at ceiling level in compartment C could be displaced downwards by the inert gas to lower levels, e.g. Test 10, Fig.10 and so increase the temperature at body height.

The tests indicate that some supersaturation of the atmosphere in the basement occurred before condensation of moisture reduced visibility. From the observation on visibility during the tests, a curve has been constructed showing the degree of apparent supersaturation, Fig.12. The degree of supersaturation may not be quite as high as indicated, as some of the excess moisture may have been condensed on, or, absorbed by, the surfaces in the basements.

The temperature of the injected gas fell as it passed through the basement system. The decrease in temperature with distance travelled by the inert gas will depend on the rate of flow of the gas and initial temperature of the gas and basements, inert gas entering the basement system at about 100°C and 40,000 ft^3/min fell by about 60°C after passing through about 200 ft of the basement system.

The control of Fires.

All three classes of gas appeared to diminish or extinguish flames, and to reduce smoke. Class 1 gas reduced tall columns of flames from wood fires to a height of about 3 ft; Class 2 gases further reduced flaming. The oxygen content at these gases was not very different, Class 1 containing about 16 per cent, and Class 2 about 15 per cent. Class 3 gas, 6 to 10 per cent oxygen, rapidly reduced flaming to at least insignificant proportions when it reached the wood fires. The time for control decreased as the oxygen content and water content increased. However, as control was rapidly achieved with all gases in this class, unless losses of inert gas and dilution with air were high, it would appear to be more economical to use gas at as high an oxygen concentration and as low a water concentration as possible for controlling the fire, which would have the additional advantage of containing less water that could condense and produce opaque atmospheres.

The test in compartment S showed that the inert gas could be conducted through flexible ducting and introduced through high openings into a building, or for example into a ship from a quay-side, and control fires a considerable distance below the point of injection. The ducting used in the present tests, a neoprene coated terylene duct supported by a wire helix, behaved satisfactorily. The ducting was damaged at the wire support by scuffing, but this kind of damage could be lessened by the provision of scuffing strips, which would wear sacrificially.

Foam Injection

High expansion foam generated with inert gas of Class 2 from the jet engine unit readily penetrated throughout the basement. The mean rate of production of foam, calculated from the volume produced and the time of production in Test 7 and test 11, was about 80 per cent of that measured in an open space. The reduction in flow rate was probably due to some breakdown on passing through narrow openings, and some breakdown on the dusty and soiled surfaces in the basement system.

The failure to completely extinguish the solid fuel fire may have been due to the high rate of drainage of the foam compounds used, and to the pyramidal construction of the fires, with flat timber sloping from base to apex forming a water shed, so preventing easy access of the foam and its water content to the seat of the fire. The transparency of foam some minutes after generation, Plate 9, gives evidence of the drainage. The lack of visibility in foam was said by the firemen concerned in the exercise to be a risk they were prepared to accept.

Concurrent laboratory tests at the Fire Research Station have shown that foam compounds with higher stability and a lower rate of drainage than those used in the present tests are commercially available[5]. The use of such compounds would increase the quantity of water carried to the fire, and should make extinction easier. It may also reduce the rate of breakdown of foam due to mechanical causes.

Tests on synthetic and cotton fabrics at the Fire Research Station suggest that the rapid failure of the cotton fabric experienced in the present trials was due to microbiological attack, and that synthetic fabrics of nylon, terylene or polypropylene would be far more resistant than cotton. Thus, provided foam can be made satisfactorily using socks of synthetic film mesh fabric, rupture of socks such as occurred in the present trials can be avoided.

General

The present tests have shown that inert gas or foam can control solid fuel fires in buildings, although complete extinction may not occur. The choice of the medium used for extinction depends on the location of the fire, and the degree of ventilation. For a fire at ground level either foam or inert gas may be used. Foam should be used when uncontrolled ventilation is high, such as could occur if a roof collapsed. When uncontrolled ventilation is low, there is much in favour of first introducing a cool Class 1 gas which would rapidly clear smoke, and provide a clear atmosphere in which firemen could advance through the building, and discover the location and extent of a fire before deciding on subsequent action. Subsequent action should consist of shutting off uninvolved parts of the building where possible, and, dependent on the location and nature of the fire, deciding which medium to use and arranging, where necessary, openings for the escape of gas. The present tests and earlier tests at the Fire Research Station suggest that, because inert gas is lighter than air, a fire at high level is best attacked with inert gas of Class 3, introduced as gently as possible e.g. by means of, say a foam making sock attached to the gas outlet. A fire generally involving the contents of a compartment is best attacked by a gas of Class 2 or 3 introduced through an open ended duct, so that it mixes freely with the atmosphere in the compartment. A fire at ground level only can be attacked with foam, or inert gas. Inert gas would be less effective than foam in lofty compartments, where air leaking into the compartment could feed a ground level fire. There would be less difference between gas and foam for fires in compartments of low ceiling height. Provided a foam with a substantially lower drainage rate than those used in the present trials is used, foam is more likely to extinguish the fire without assistance from hand lines.

With inert gas, it would be necessary in many circumstances for firemen to complete extinction. The approach of firemen to the fire would be assisted by changing the hot moist inert gas used for extinction for a cooler, less moist gas, after smoke emission and flaming had ceased. Firemen should then be able to approach the fire zone in reasonable comfort and visibility and the gas should permit only a limited increase in flaming to occur. It would also be helpful if such a gas were introduced after the control of a fire with high expansion foam, as it would assist in clearing foam while at the same time giving a degree of control of the rate of increase of any fires that had not been extinguished completely.

Such cooler gases may be made in several ways(6). In the present tests the cool, Class 1, gases were made by entraining air into inert gas made by the jet engine generator without reheat. Cool gases may also be made by entraining air into gas made with differing amounts of reheat, by vaporising liquid inert gases into the jet stream, by cooling the gas stream by extracting heat from the stream as sensible heats in water and by appropriate combinations of these processes. Water cooling could be obtained by copiously spraying, for example, a foam sock with water. The use of inert liquid gases would posses the additional advantage of permitting a cool gas with a low oxygen content to be obtained.

The introduction of gas into a compartment through a vertical run of flexible ducting is feasible. Thus the inert gas or foam can be used for controlling shipboard fires from a shore-based generator. The high salt content of sea water however would prevent its use for cooling the gas stream by evaporation, and the water supply for the inert gas generator should be drawn from mains.

The presence of a bluff wall close to the point of gas injection, or the use of a long length of ducting make it more difficult, because of back pressure, to introduce the gas or to entrain air in the gas stream. Gas should therefore be introduced if possible through an unobstructed opening, and air entrainment should be done as close to the point of entry of the gas as possible. The use of a short length of ducting within the building may allow the gas to be introduced beyond such obstructions.

Effect of Inert Gas and Foam on Building.

The introduction of inert gas or foam into a building will raise its temperature above ambient, the increase being greater at the point of introduction. The present trials have given an opportunity of observing damage to building resulting from the use of the inert gas generator.

At the end of the trials, the only damage observed at the entrance chamber for the inert gas was some paint blistering (Plate 8). This may have been caused by the vaporisation of some of the high water content of the walls, pillars and timber beneath the paint; the building had been unoccupied for many months, and the basement was damp. Damage elsewhere in the building was confined to the falling of some small areas of plaster from the ceiling of compartment B. Examination of the plastering before the tests had revealed areas of poor adhesion and the damage caused was probably due to the initial lack of adhesion, as the bulk of the plastering remained intact.

Conclusions

The tests reported herein have shown that it is possible to control fires in a series of compartments separated by narrow doors and passages, by the injection of gas of diminished oxygen content or by the injection of high expansion foam.

Gases containing about 5 to 17 per cent oxygen and 15 to 19 per cent water vapour cleared smoke rapidly and reduced the size of flames from timber fires. Gases containing 10.4 per cent or less of oxygen extinguished flames rapidly, although smouldering continued. High expansion foam could be conducted about 300 ft from the point of entry through the basement system, and seemed to be capable of filling a tall compartment. The conditions under which high expansion foam or inert gas may best be used for controlling and extinguishing fires in buildings can be defined. Some work remains to be done on the method and materials for foam generation to obtain the maximum possible rate of generation of foam of high stability and low draining rate, and the maximum life from the generating system.

Acknowledgements

Thanks are due to the London County Council for arranging the use of the premises for this programme, to the London Fire Brigade for their collaboration in these trials, to Dr. S. G. Burgess, Scientific Adviser, London County Council, and his staff for their assistance in performing the gas analyses, to Mr. Coiley and the Workshops staff, for their assistance in preparation and maintenance of equipment, and to all other members of staff who assisted in these tests.

Plates 1(a) (b) (c), 2, 4, 5, 6, 8 and 9 are reproduced by permission of the Chief Officer, London Fire Brigade.

References

(1) Control of Fires in Large Spaces with Inert Gas and Foam produced by a Turbo jet engine, Part 1, F.R. 507.

(2) Ditto. Part 2. Small Scale Tests.

(3) Ditto. Part 4. Tests in the Models Laboratory, Fire Research Station.

(4) Ditto. Part 5. The Production of High Expansion Foam. F.R. 512.

(5) Ditto. Part 7. Further tests on High Expansion Foams.

(6) D. J. RASBASH. "Inert Gas Generator for control of fires in large buildings". The Engineer, 215 No. 5601 p.978. May 31, 1963.

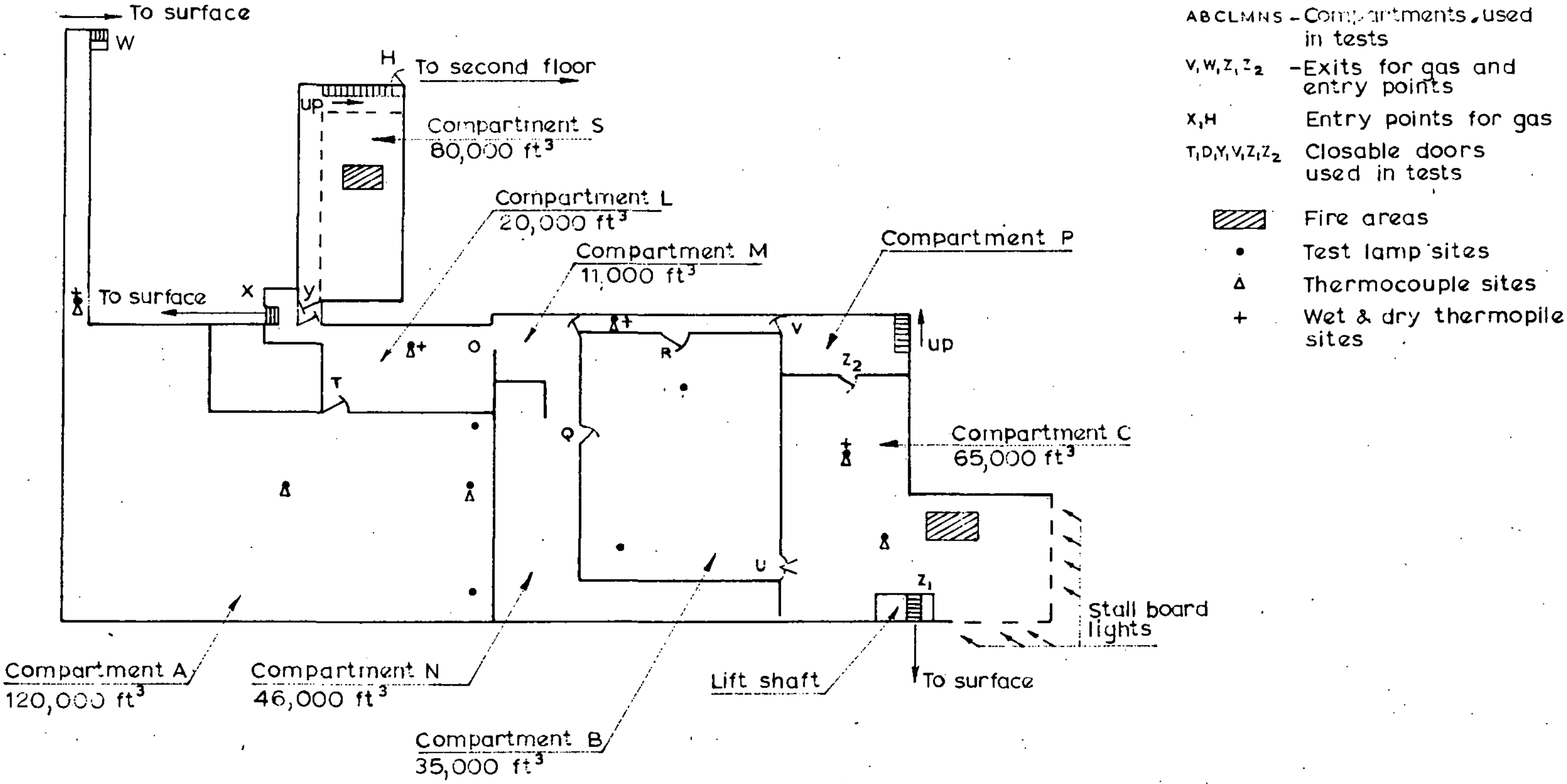


FIG.1. PLAN OF BASEMENT AND COMPARTMENTS

1/5133 F.R.527

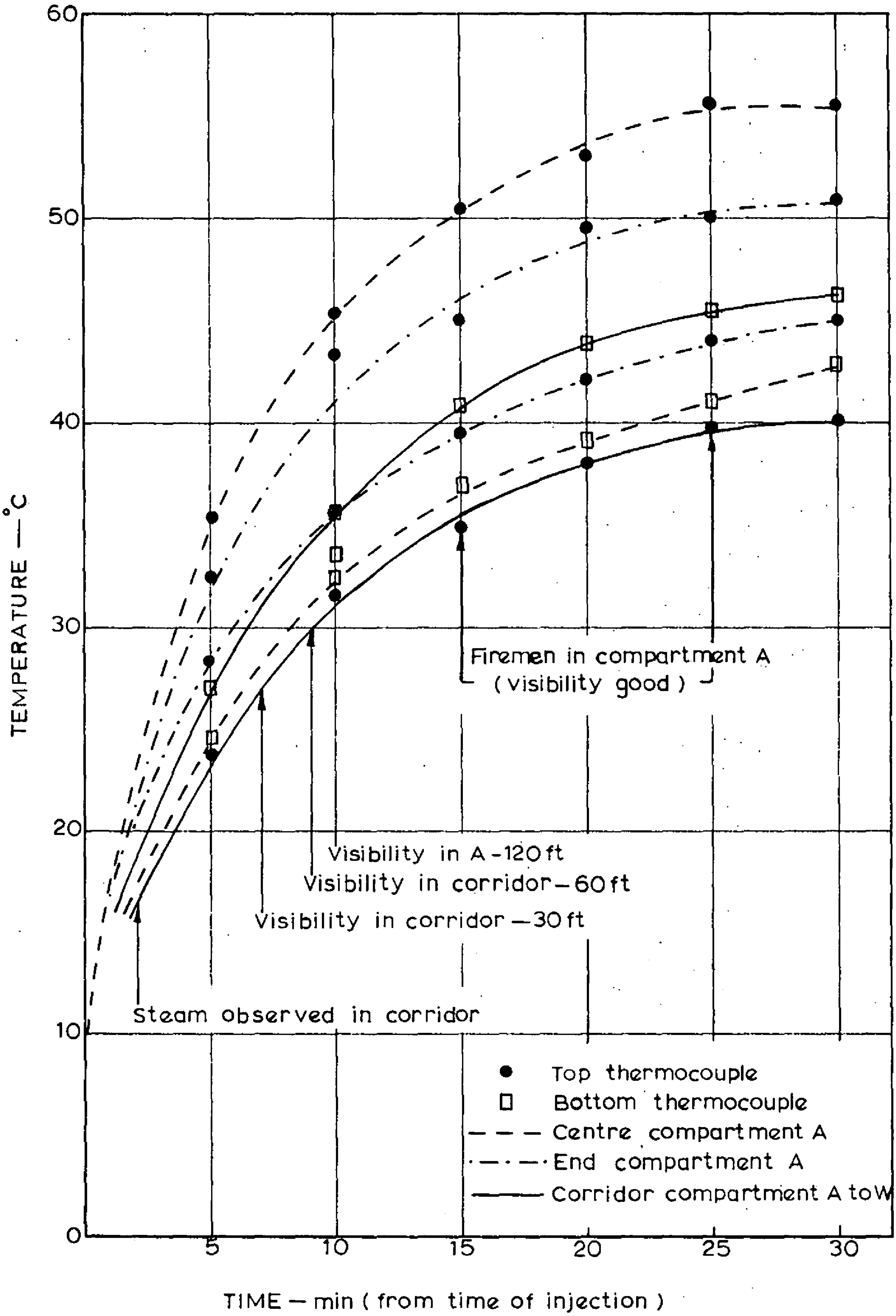


FIG.2. EFFECT OF TIME OF INJECTION ON TEMPERATURE IN A. TEST 9, CLASS 1 GAS

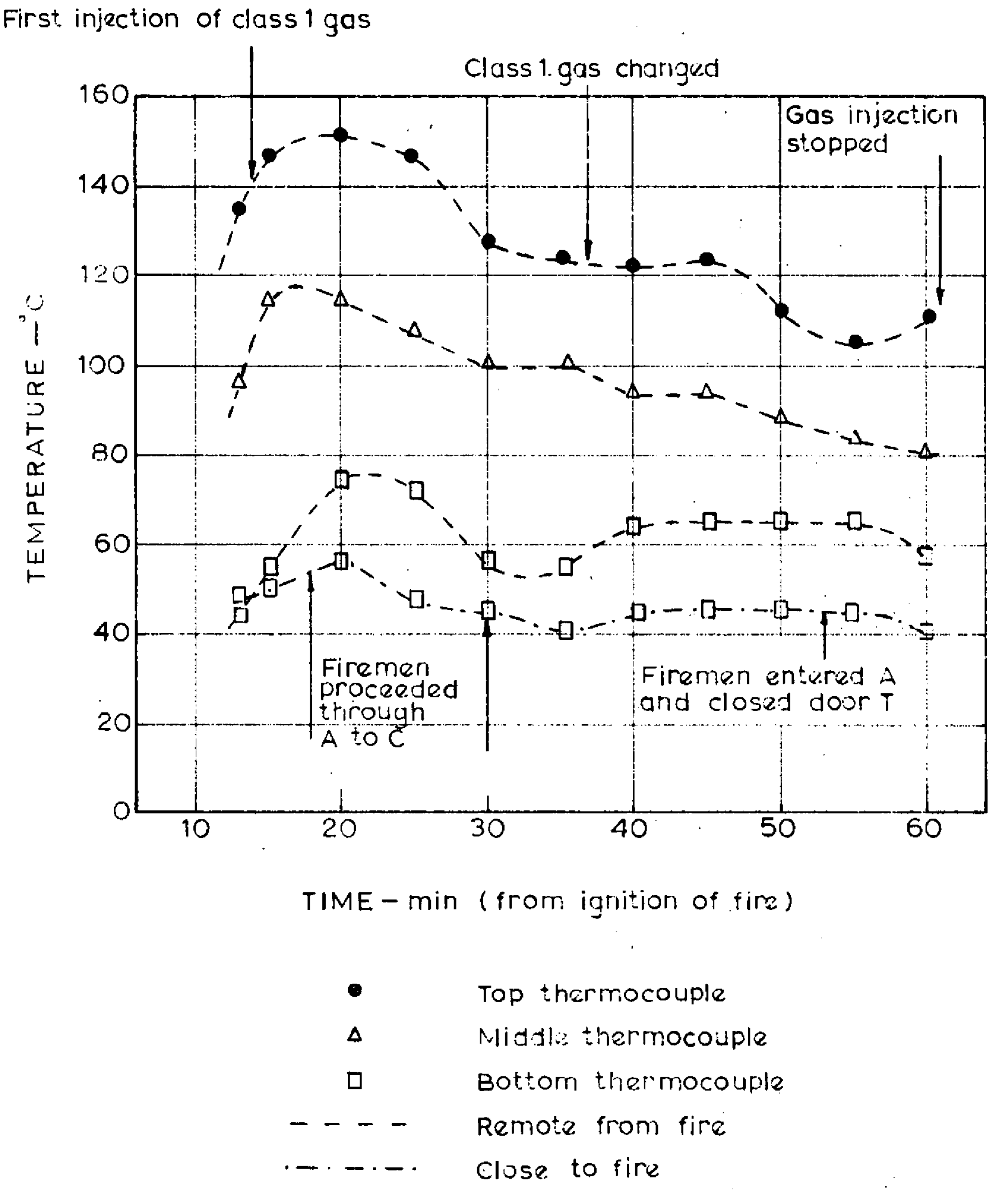


FIG.3. TEMPERATURE RECORD. COMPARTMENT C
TEST 13. INJECTION OF CLASS 1 GASES

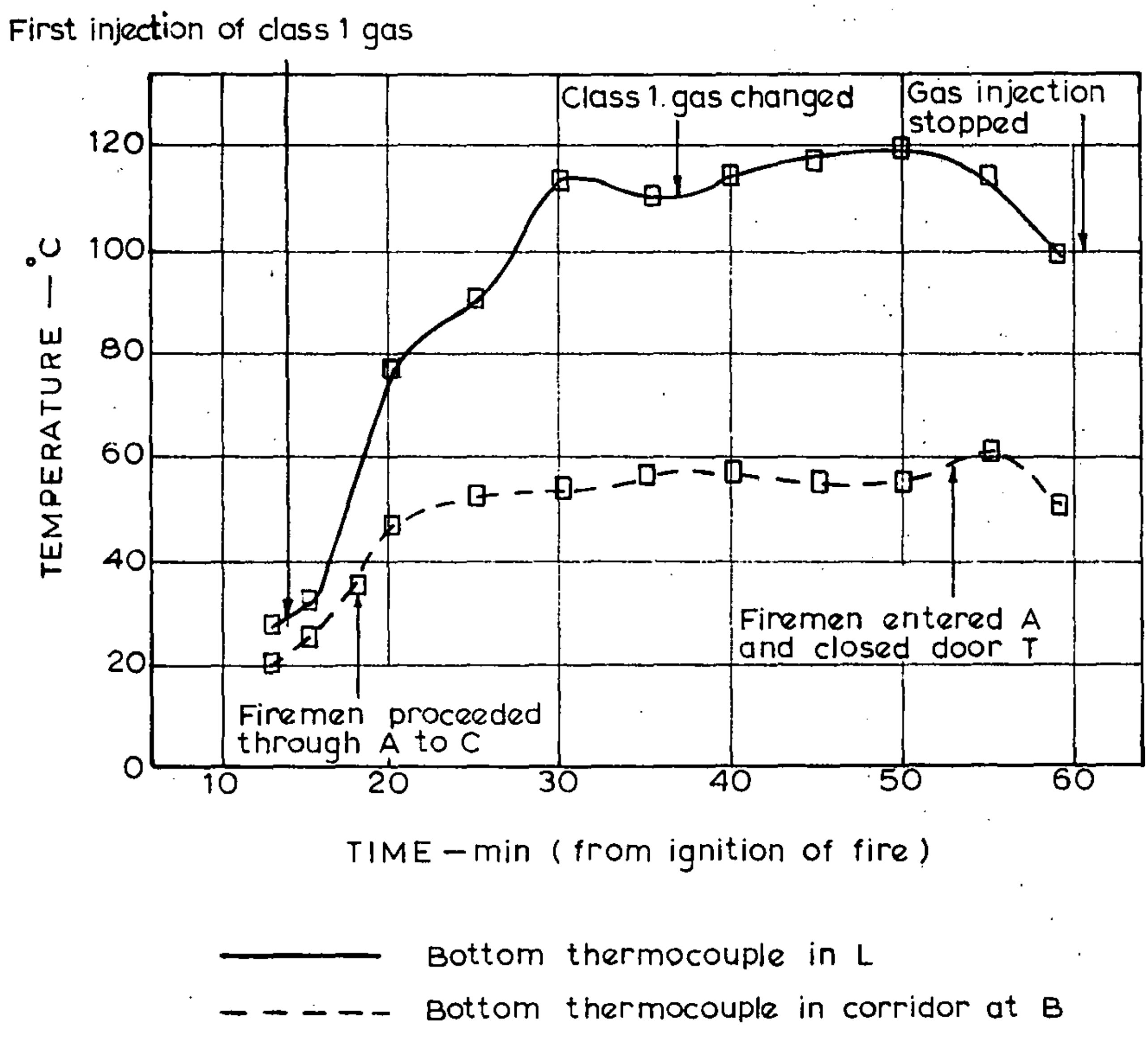


FIG.4. TEMPERATURE RECORD. COMPARTMENT L AND CORRIDOR BESIDE B

TEST 13. INJECTION OF CLASS 1 GASES

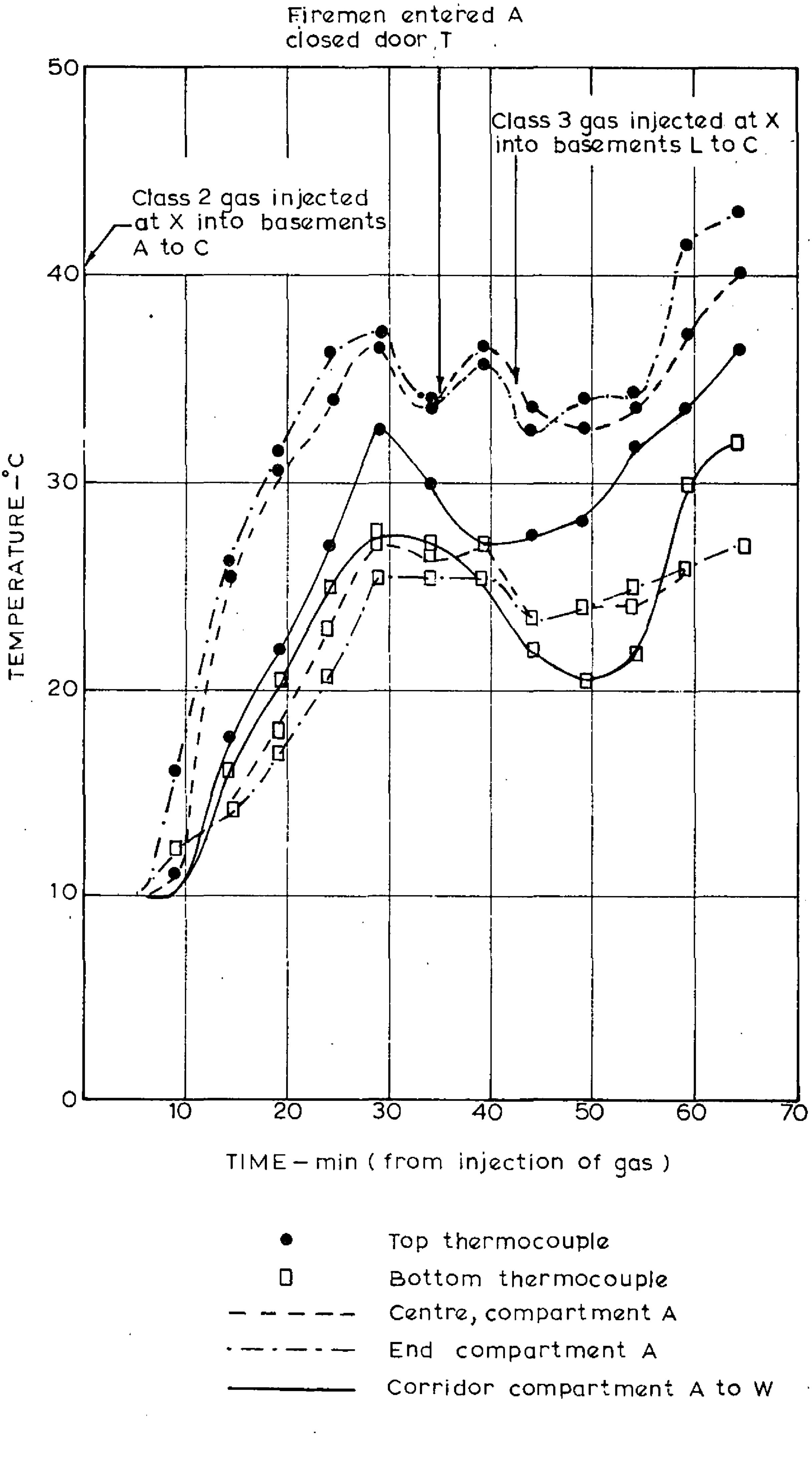


FIG.5. TEMPERATURE RECORDS, COMPARTMENT A
TEST 1. CLASS 2 AND CLASS 3 GASES

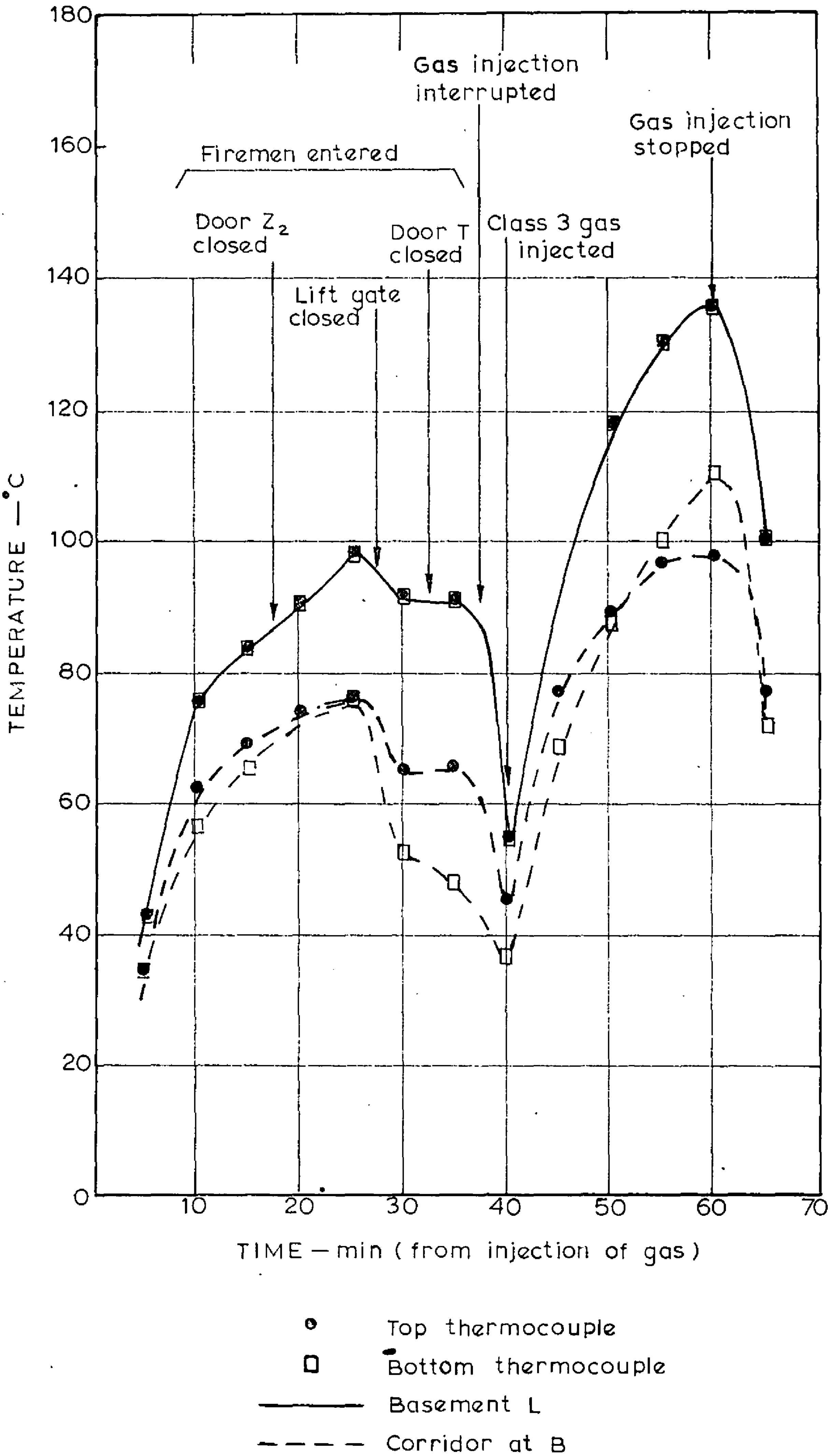


FIG.6. TEMPERATURE RECORD, BASEMENT L AND CORRIDOR BESIDE B

TEST 1. CLASS 2 AND CLASS 3 GASES

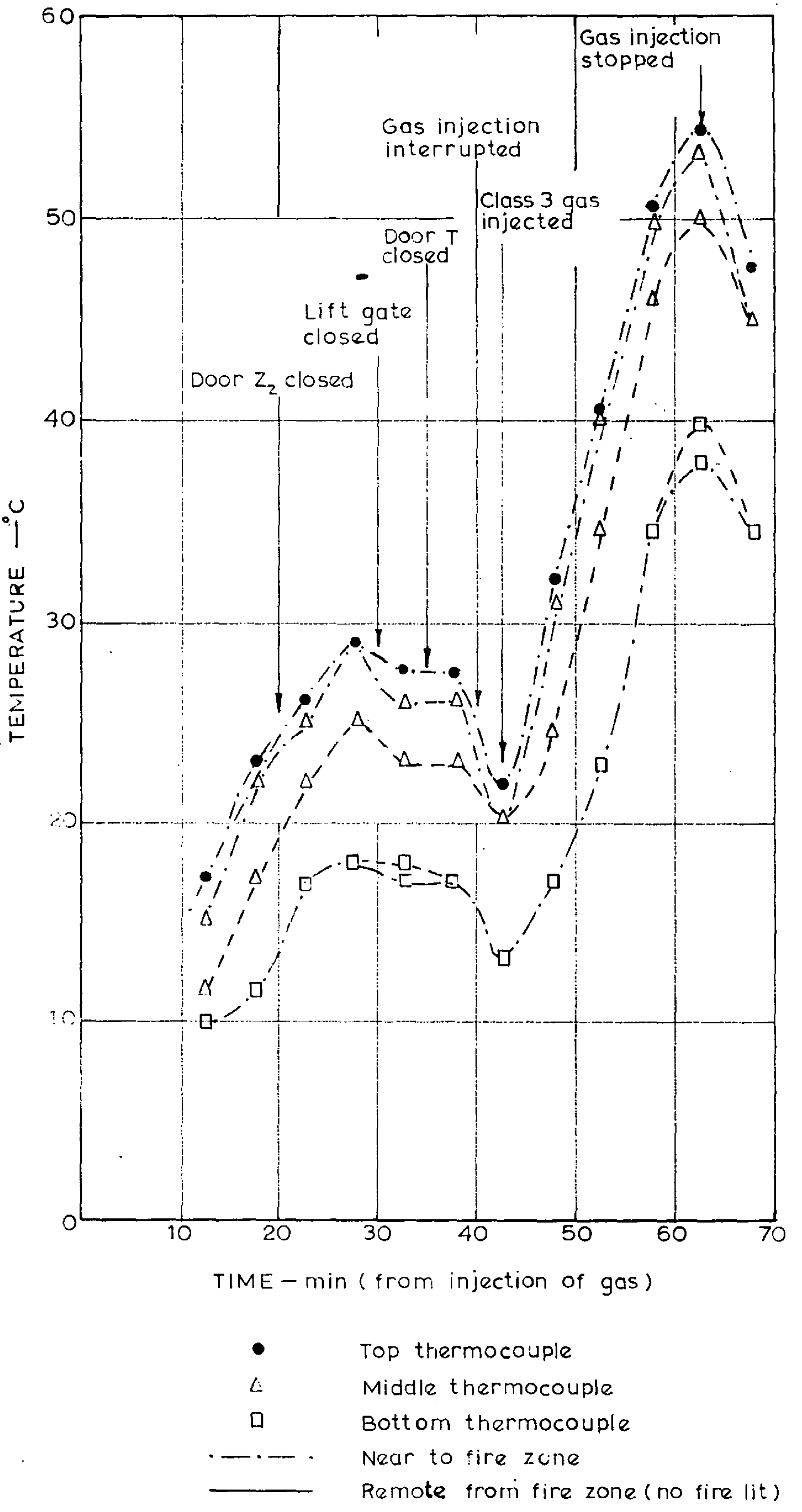


FIG. 7. TEMPERATURE RECORD, COMPARTMENT C
TEST 1. CLASS 2 AND CLASS 3 GASES

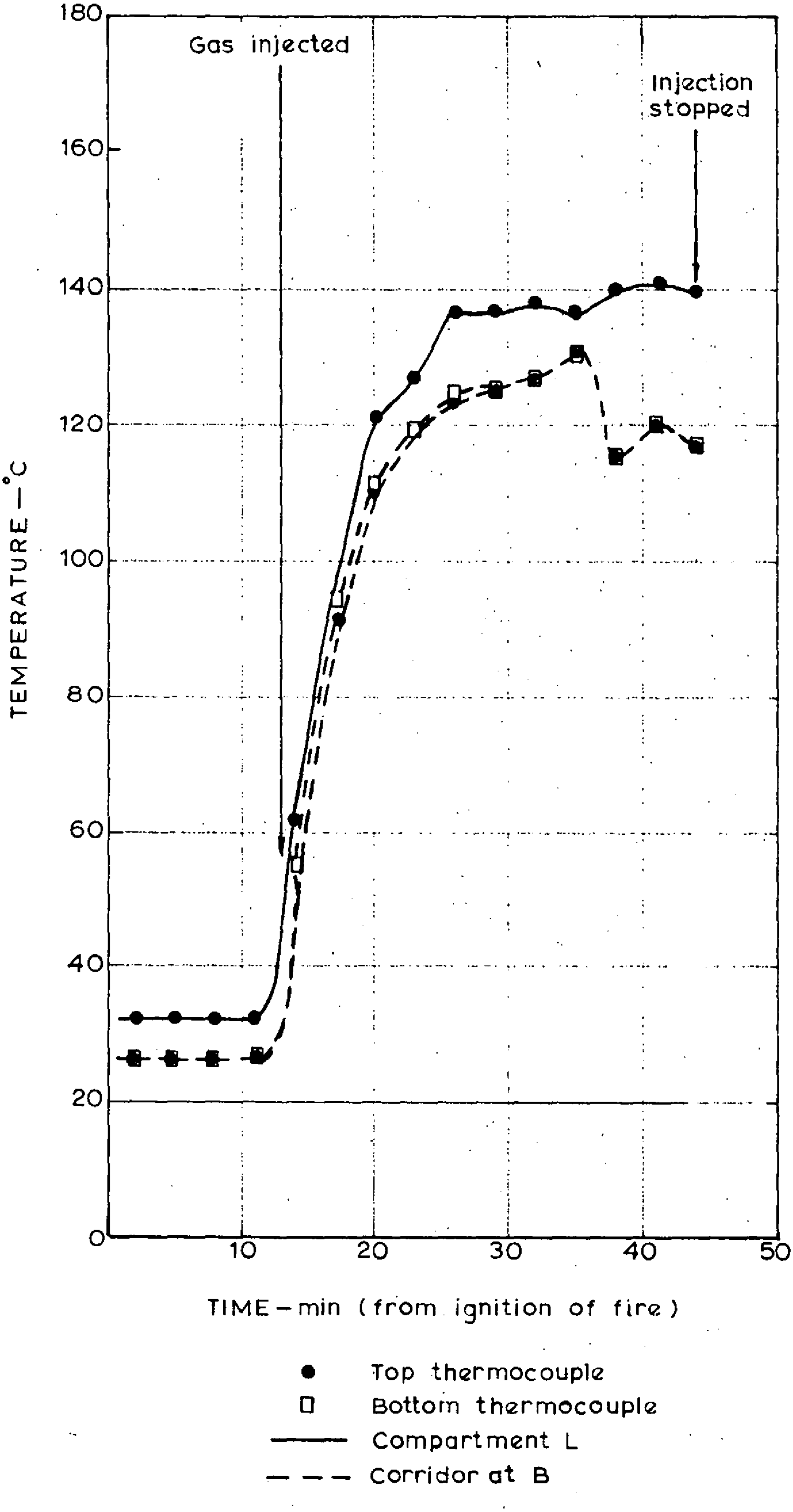


FIG. 8. TEMPERATURE RECORD, COMPARTMENT L AND CORRIDOR BESIDE B

TEST 2. CLASS 3 GAS

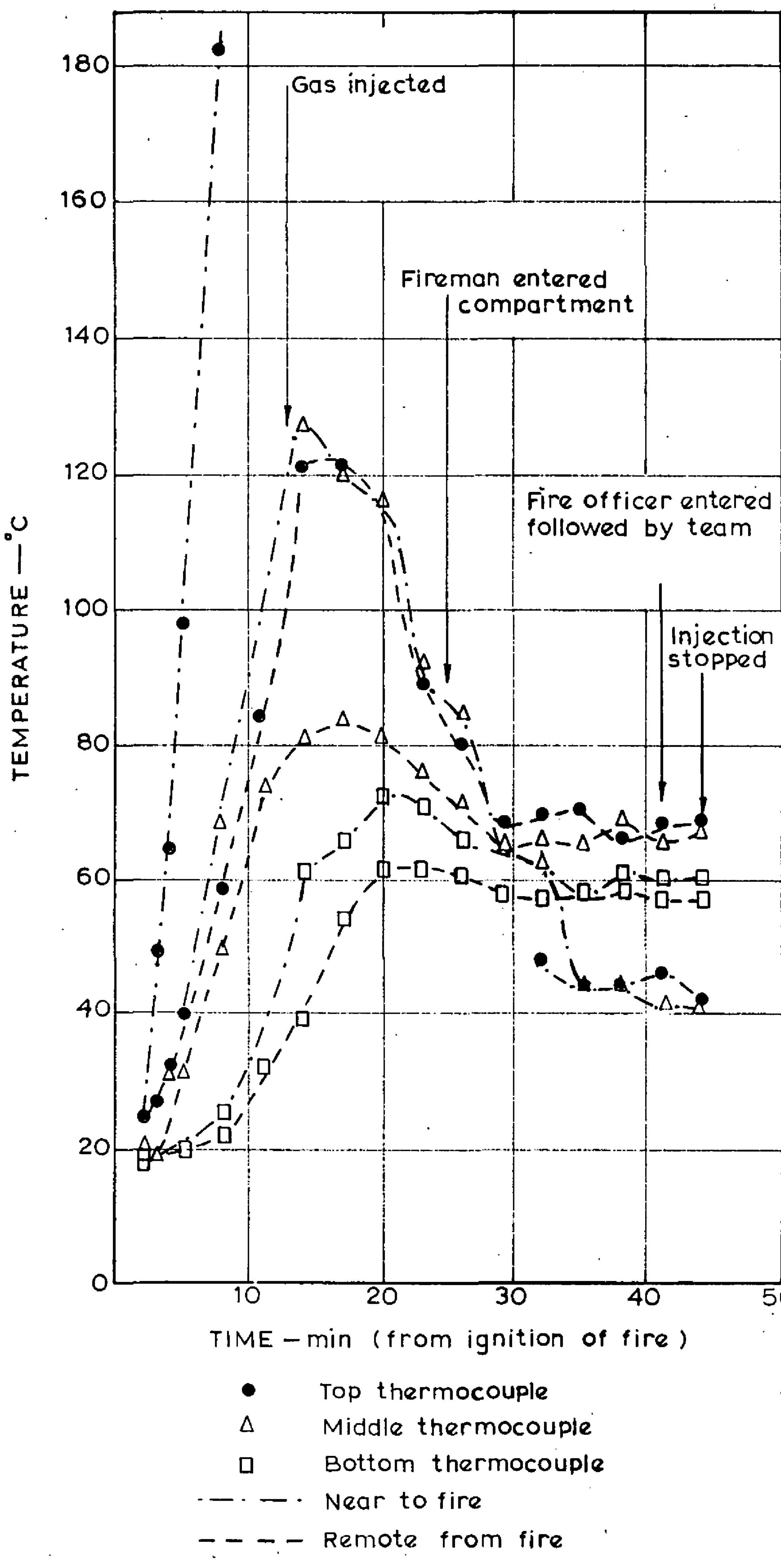


FIG. 9. TEMPERATURE RECORD COMPARTMENT C
TEST 2. CLASS 3 GAS

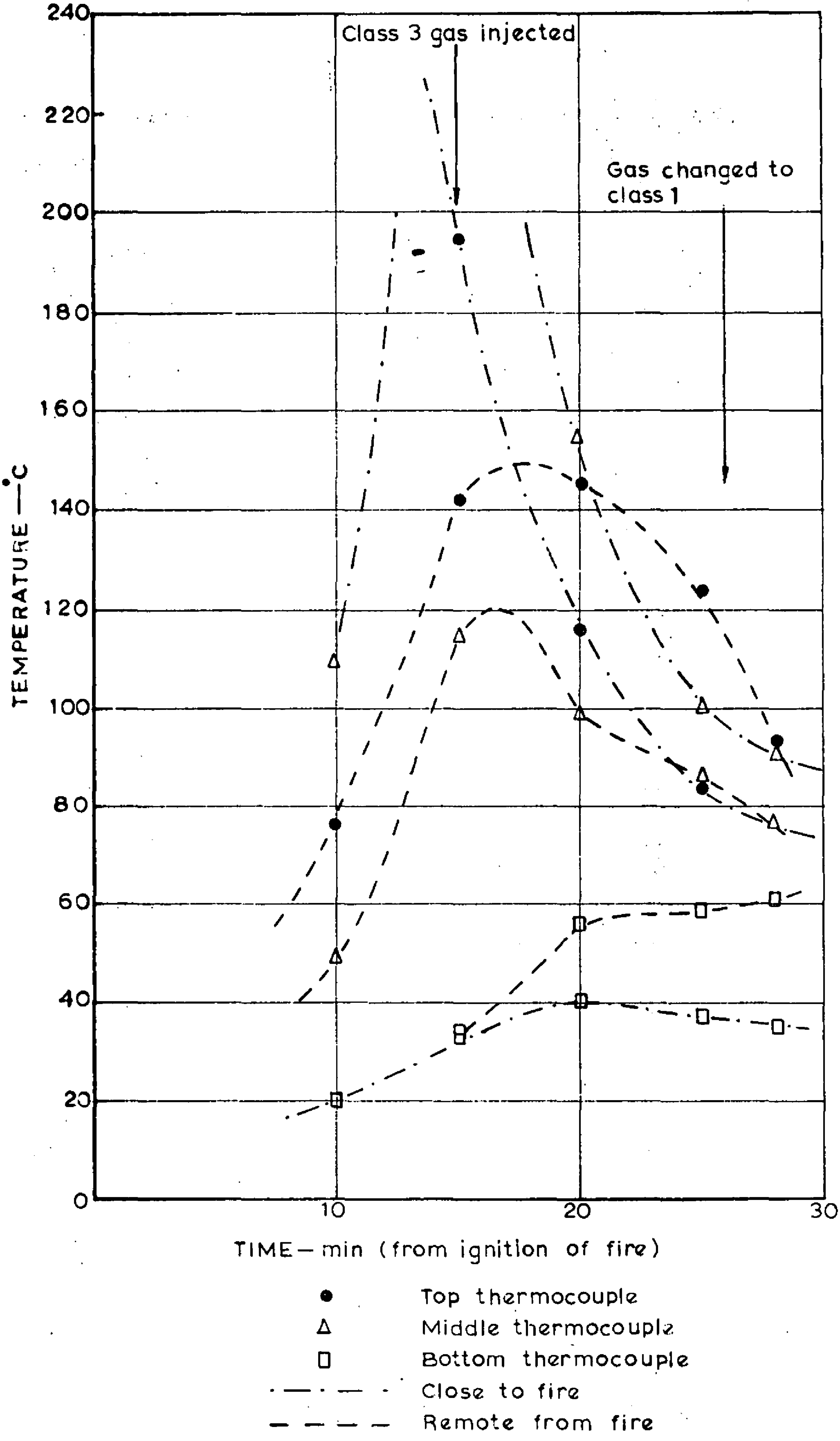


FIG.10. TEMPERATURE RECORD COMPARTMENT C
TEST 10. CLASS 3 GAS

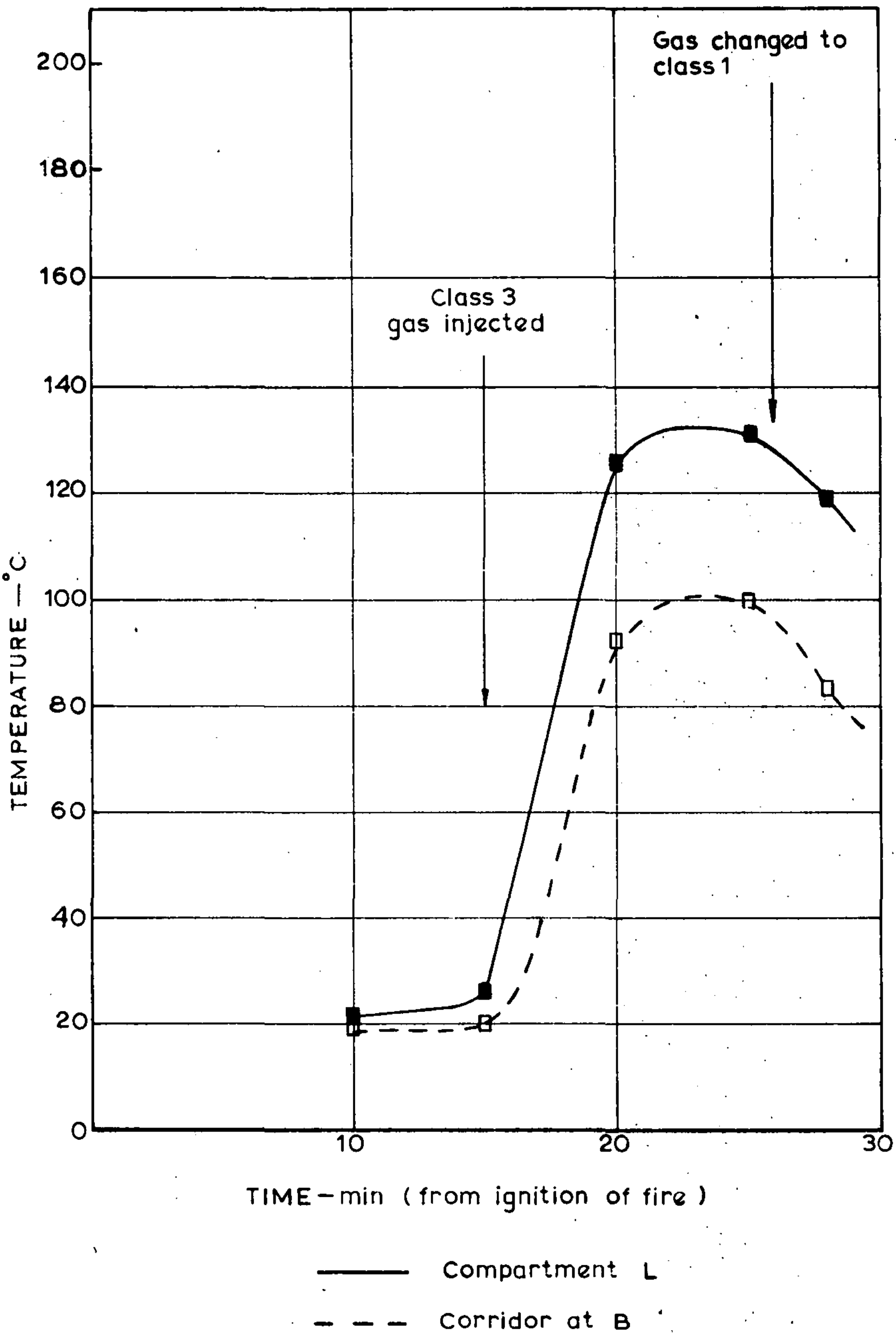


FIG. 11. TEMPERATURE RECORD, COMPARTMENT L, AND CORRIDOR BESIDE B

TEST 10. CLASS 3 AND 1 GASES

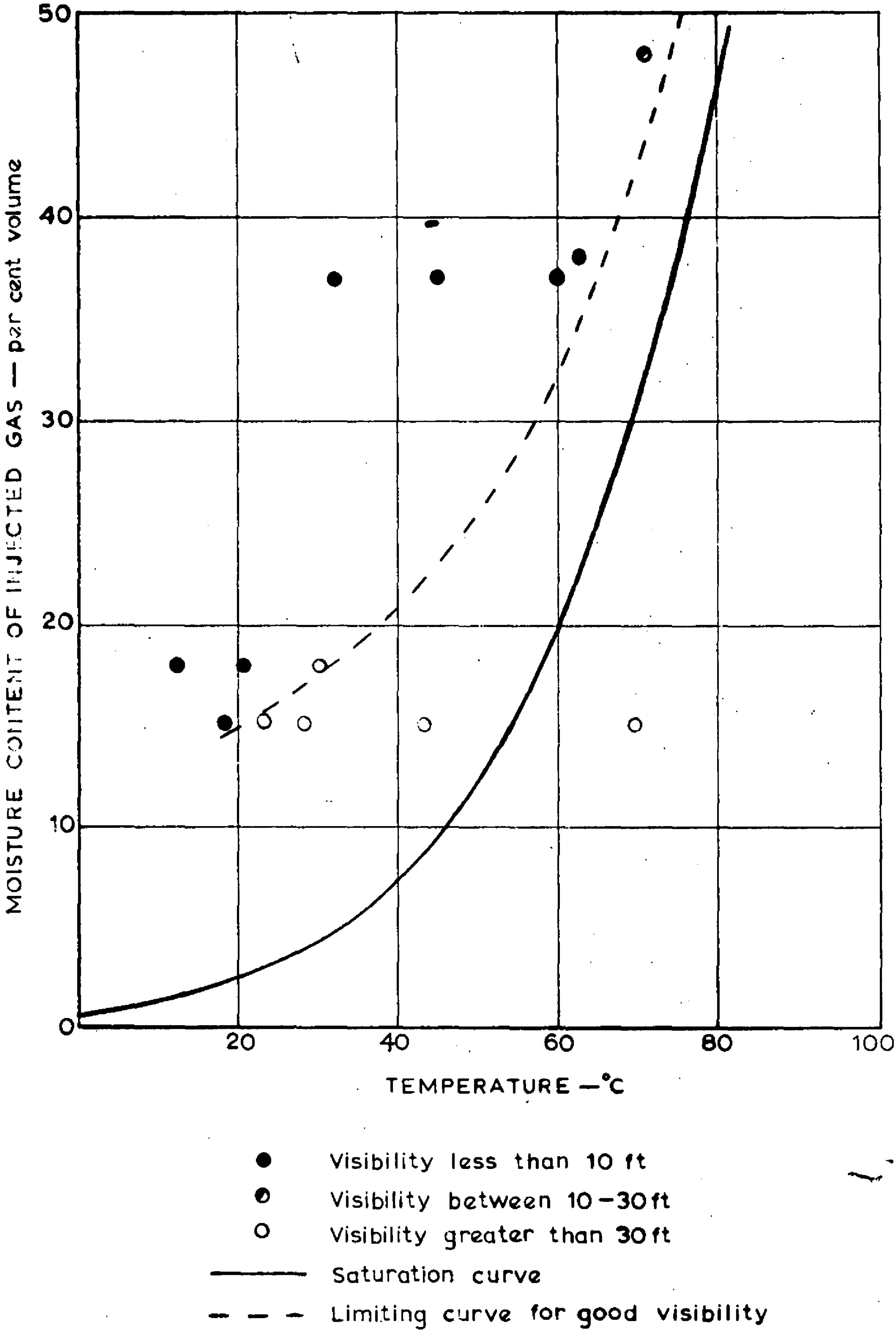
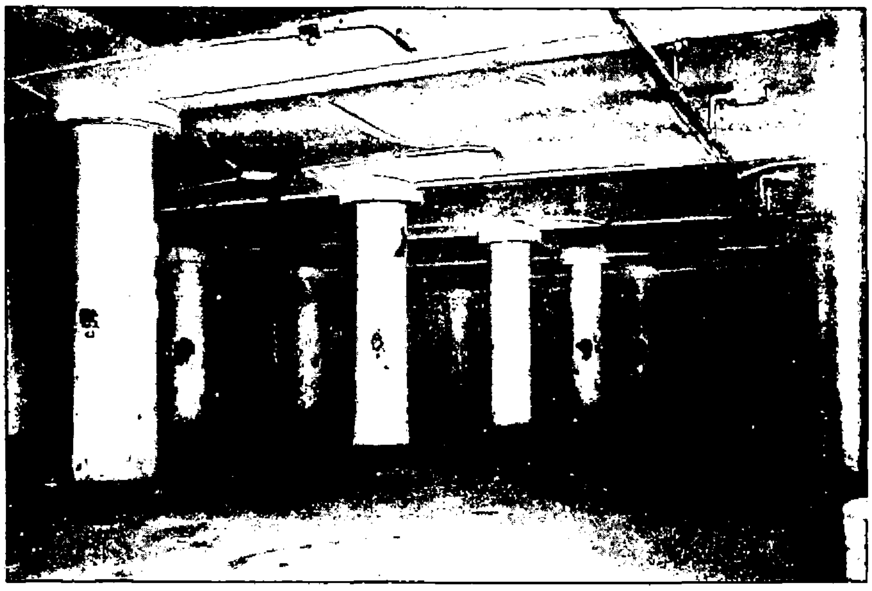
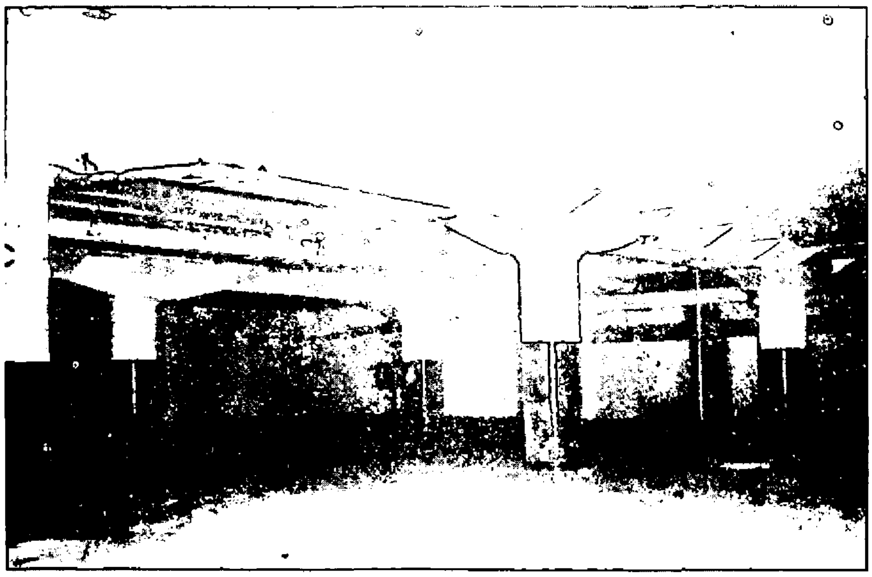


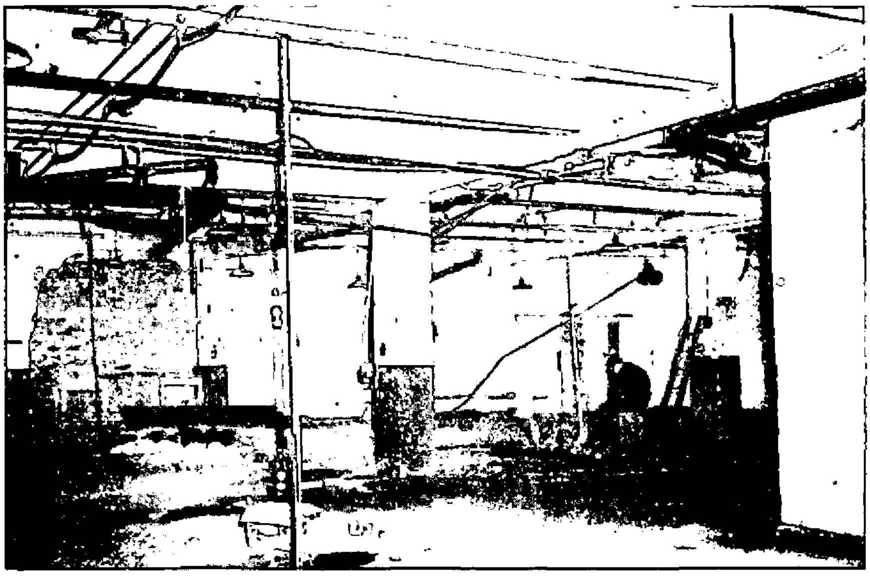
FIG.12. EFFECT OF TEMPERATURE ON VISIBILITY IN MOIST INERT GAS



(a) Compartment A (120 000 ft^3)

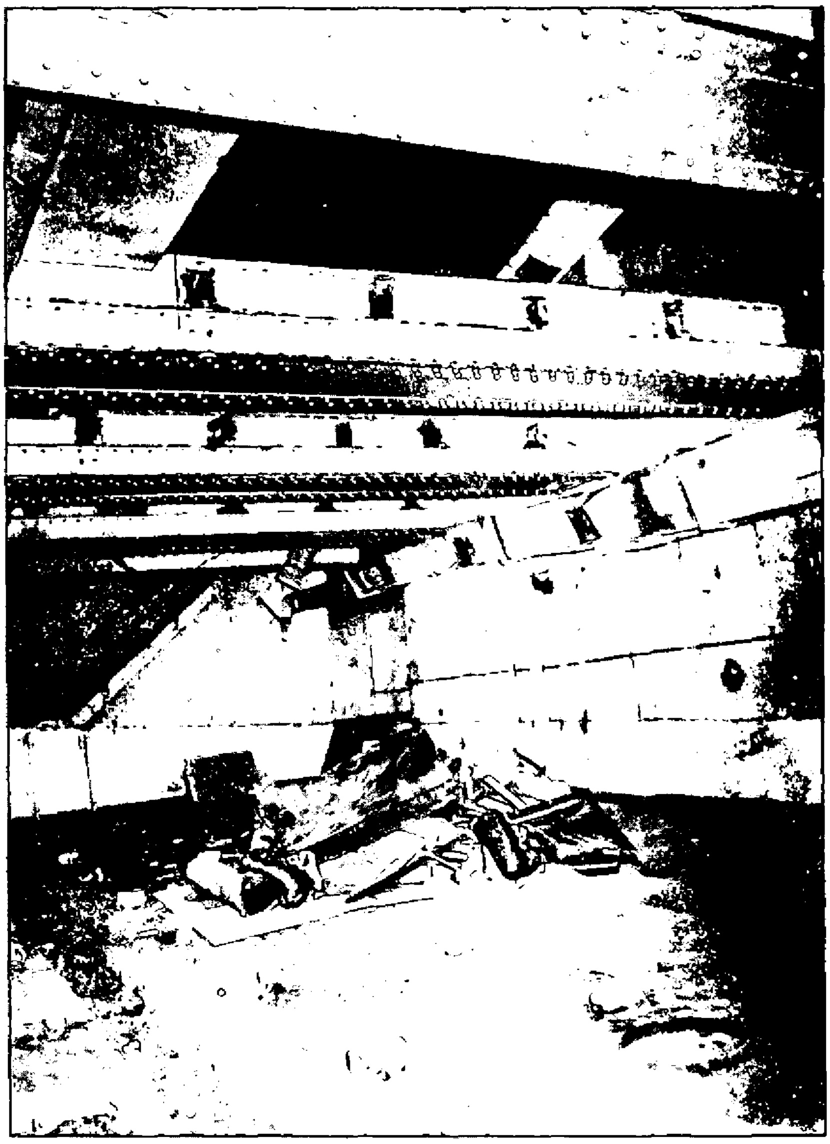


(b) Compartment B (35 000 ft^3)



(c) Compartment C (65 000 ft^3)

PLATE 1. THE BASEMENT COMPARTMENTS.



(d) Compartment S (89 000 ft^3)

(e) Compartment L (20 000 ft^3)

PLATE 1. THE BASEMENT COMPARTMENTS.

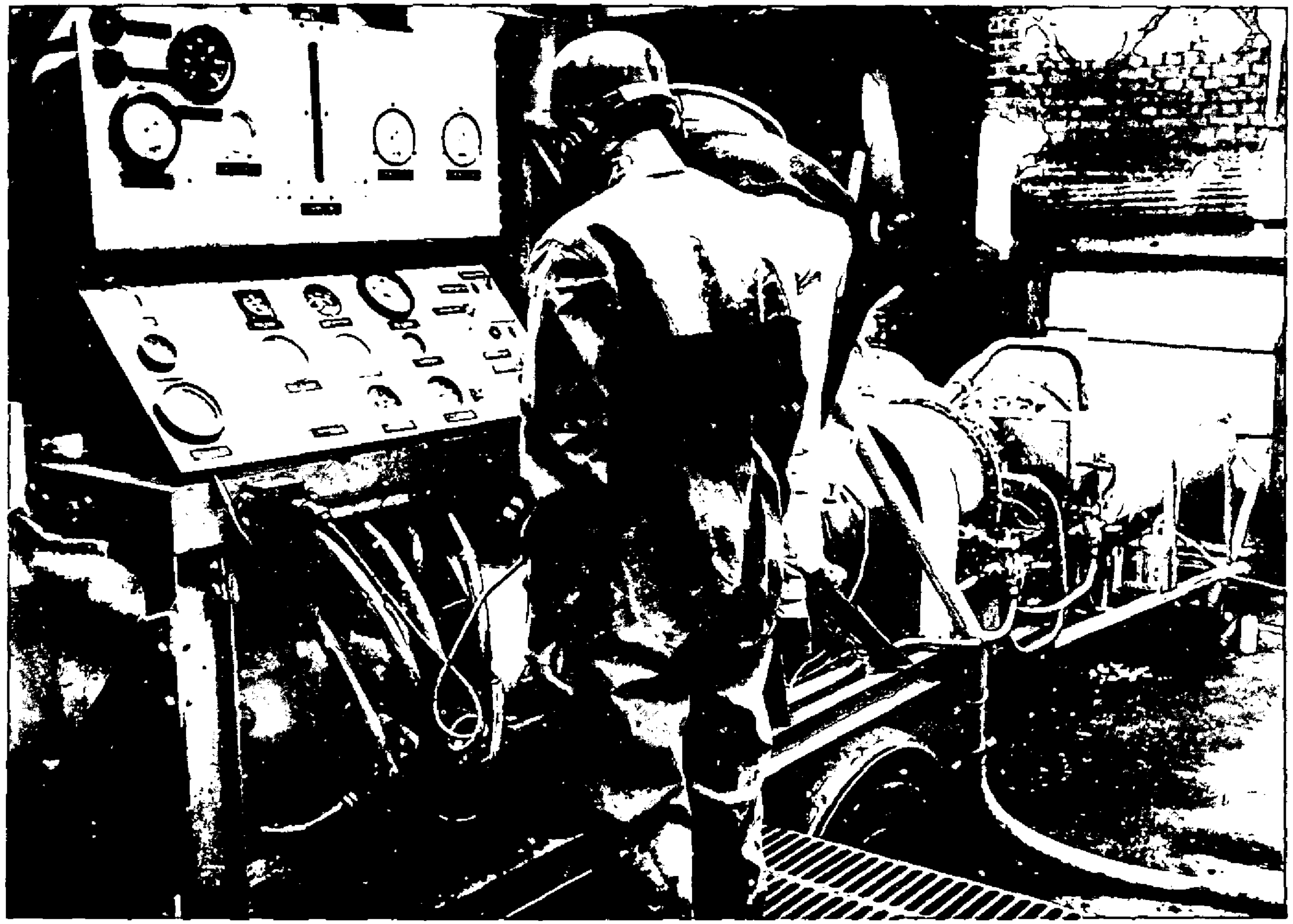
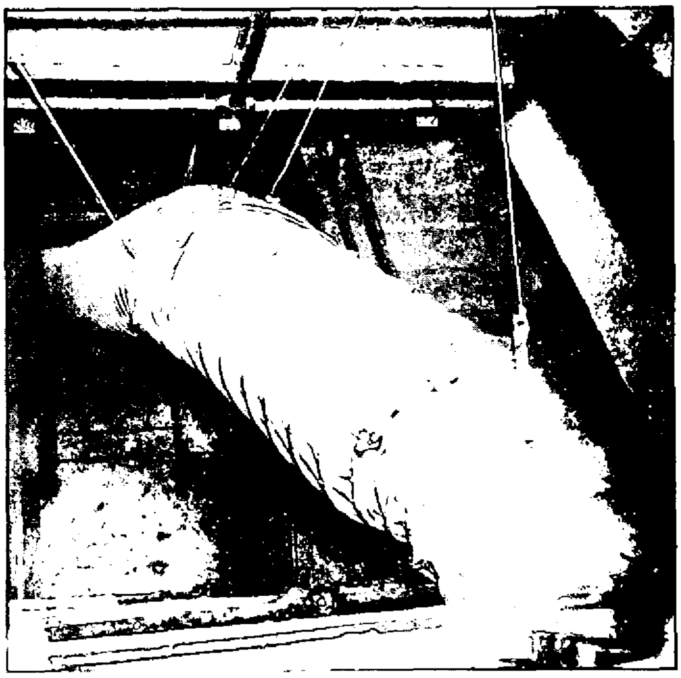
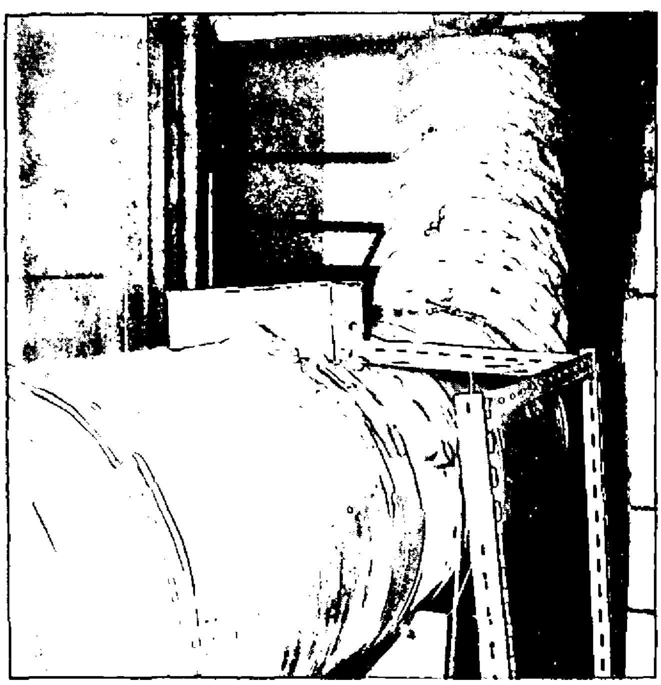


PLATE 2. ENTRY FOR INERT GAS INTO BASEMENT VIEW FROM CONTROL PLATFORM OF INERT GAS GENERATOR.

PLATE 3. FLEXIBLE DUCTING AND FOAM SOCK IN L.





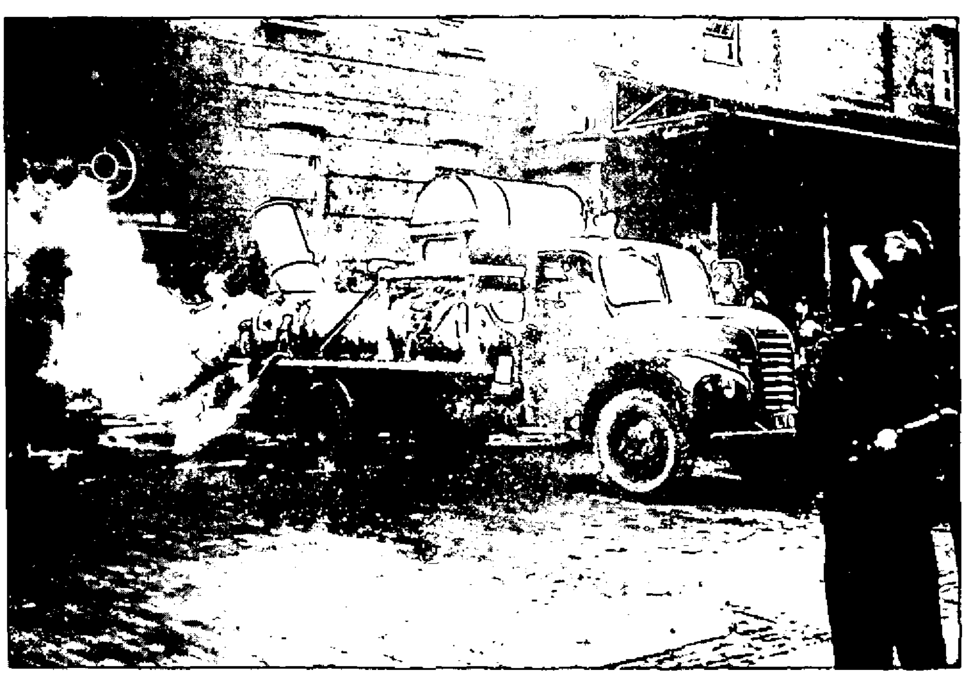
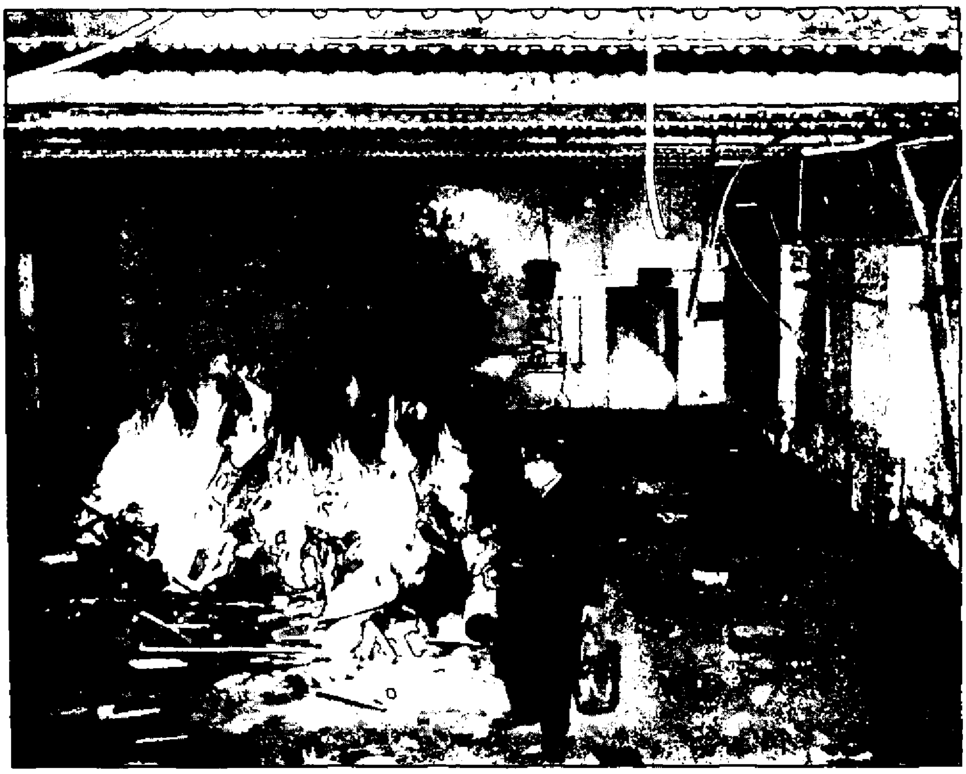


PLATE 4. SUPPLY OF GAS TO UPPER OPENING IN COMPARTMENT S
ARRANGEMENT OF GAS GENERATOR AND DUCTING.

PLATE 5. MEN WAITING AT ENTRY POINT 2.

Fire in Compartment C



Fire in Compartment S

PLATE 6. TYPICAL FIRES IN BASEMENTS.

PLATE 7. ARRANGEMENT OF MEASURING DEVICES IN COMPARTMENT C.

PLATE 8. RUPTURED FOAM SOCK AFTER TEST 12.

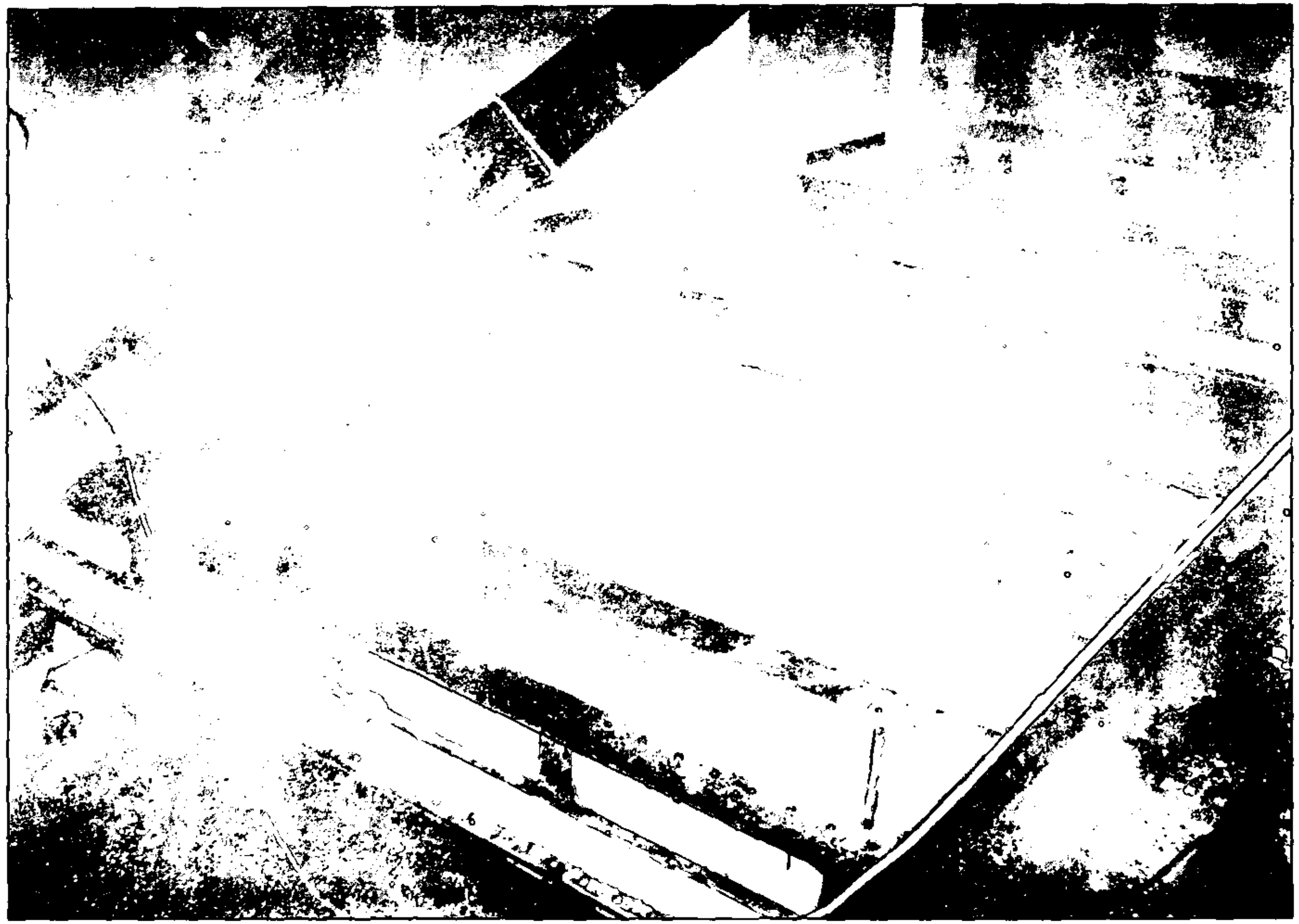


PLATE 9. APPEARANCE OF FOAM IN COMPARTMENT S AFTER TEST.