CIVIL AVIATION AUTHORITY

CAA PAPER 95013

THE DEVELOPMENT OF A HIDDEN FIRE TEST FOR AIRCRAFT HAND EXTINGUISHER APPLICATIONS

CIVIL AVIATION AUTHORITY, LONDON

Price: £13.00

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THE DEVELOPMENT OF A HIDDEN FIRE TEST FOR AIRCRAFT HAND EXTINGUISHER APPLICATIONS

A Chattaway

REPORT PREPARED BY KIDDE INTERNATIONAL RESEARCH, COLNBROOK
AND PUBLISHED BY
CIVIL AVIATION AUTHORITY, LONDON, DECEMBER 1995

ISBN 0 86039 645 2

First published December 1995
Reprinted May 1996

Acknowledgement

The research on which this report was based was commissioned by the Civil Aviation Authority Safety Regulation Group and carried out by Kidde International Research, Colnbrook, England. The author would like to thank everybody at KIR who was involved in the project, including Francis Clarence, Simon Davies, Robert Dunster, Julian Grigg, Lynda Hazelwood, Paul Rennie and David Spring. Also, the author would like to thank Nick Povey of the Civil Aviation Authority, Dick Hill of the Federal Aviation Authority Technical Centre and Claude Lewis of Transport Canada Aviation for helpful discussions during the course of this research.

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Printed and distributed by Civil Aviation Authority, Greville House, 37 Gratton Road, Cheltenham, England

Summary

In accordance with the Montreal Protocol, production of all Halon fire suppressants ceased on the first of January 1994. FAR/JAR regulations require Halon 1211 or equivalent hand extinguishers to be installed on transport category aircraft. Although there is a Halon 'bank', a replacement agent will have to be found. The Aviation Authorities require that 'no loss of safety' should occur if a replacement agent is used. One proven benefit provided by Halon 1211 is the ability to extinguish hidden fires by a total flooding effect. Therefore, it is necessary to quantify the hidden fire extinguishing ability exhibited by Halon 1211. Following an invitation for competitive tenders to develop a standard hidden fire test protocol, the Civil Aviation Authority (CAA) awarded a contract to Kidde International Research.

After some range-finding work, a suitable test fixture was devised. This test fixture comprised arrays of four fires in two of five locations to establish in which regions an extinguishing concentration had been attained. A matrix of 10 tests ensured that each fire location was adequately represented.

Tests have been carried out with hand extinguishers from Walter Kidde, Kidde Thorn, First Technology and Chubb. Results varied from 45% extinguishment to 60%, depending on the quantity of Halon contained in the extinguisher, and the discharge rate (a faster discharge rate creates more turbulence, aiding mixing and dispersion). In addition, tests were carried out using under- and over-filled extinguishers to examine the sensitivity of the test method. With the exception of the First Technology hand extinguisher, all results could be correlated to the mass and mass of agent flow rate used. This device extinguished a significantly higher percentage of fires than would be expected, based on its mass/mass flow rate characteristics.

Limited testing was carried out with six Halon replacements: FM–200, FE–25, CEA–410, CEA–614, FE–36 and Triodide, using apparatus designed to give a constant discharge time (10 ± 1 s). The results obtained appeared to be similar to Halon 1211 (50 ± 5% extinguishment), provided the quantity of agent is scaled according to its n-heptane cupburner concentration. The two exceptions are agents with markedly different volatilities to Halon 1211 (b.p. –4°C): FE-25, b.p. –49°C, (65% extinguishment) and CEA–614, b.p. +58°C (35% extinguishment).

Implications for the size and weight of a hand extinguisher, based on the results of these tests, are for the physically acting agents, a weight penalty of 1.4 to 2.6, and a volume penalty of 1.9 to 2.9. If Triodide is considered, there is a weight penalty of 1.06, and no volume penalty. However, it should be borne in mind that any hand extinguisher, before it is evaluated against hidden fires, will have had to have passed the traditional ratings (currently UL 5B:C, BS 3A:34B) to be approved for aviation use.

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1 INTRODUCTION

1.1 Background

In accordance with the Copenhagen amendments to the Montreal Protocol [1], production of Halon ceased in most countries on the first of January 1994. Although there is a substantial 'bank' of both unused and recycled Halon 1211, a replacement agent will eventually be required. A number of regulatory bodies, including the Civil Aviation Authority (CAA), the Federal Aviation Administration (FAA) and Transport Canada Aviation (TCA) formed the International Halon Replacement Working Group (IHRWG) which meets regularly to co-ordinate Halon-related issues. One recent task was the definition of an overall minimum performance standard for hand extinguishers. Thus once a Halon 1211 benchmark has been established, replacement agents can be evaluated against this, and the introduction of replacements controlled so that there is no loss of safety. This report describes one aspect of this minimum performance standard, the development of a hidden fire challenge.

1.2 Use of Halon 1211 Hand Extinguishers Aboard Aircraft

FAR/JAR 25.851 [2] requires that Halon 1211 or equivalent hand held extinguishers be installed on transport category aircraft. The regulation states that the type and quantity of extinguishing agent (if other than Halon 1211) must be appropriate for the kind of fires likely to occur where used.

These regulations had their origin with the requirement to mitigate the arsonist/hijacking threat which was prevalent in the 1970s. The FAA Technical Centre identified that Halon 1211 was vastly superior to the previously used CO_2 and dry chemical extinguishers for protecting against flammable fluid fires on typical seat materials.

Later it was noted that Halon 1211 hand extinguishers provided an additional benefit by having the capacity to fight fires in locations that are hidden from the cabin but nonetheless can be successfully extinguished from the cabin by flight attendants using the agent's total flood capability.

Fires have occurred behind cabin side walls, where the only access is by prising up the edge of a panel and discharging an extinguisher. In these examples it may be necessary for the extinguishant to travel up or down and/or across aircraft frames in order to reach the fire. There have been other examples where the fire has been below the floor in the relatively large and open cheek area between the cargo bay and the fuselage skin. Halon 1211 has been discharged through the floor level air grilles and averted what would have otherwise been a major catastrophe.

The US FAA Advisory Circular 20–42AC contains recommendations concerning the use of Hand Extinguishers aboard aircraft. The following points apply to Halon 1211:

- minimum weight: 2.5 lb
- minimum rating: UL 5B:C
- minimum discharge time: 8 s
- minimum range: 3 m (10 ft)
- may be equipped with discharge hose.

The Advisory Circular also gives details of requirements for Halon 1211 use in cargo compartments and in ventilated/non-ventilated occupied areas.

1.3 The CAA Initiative

When the details of the proposed minimum performance standard were being drawn up, it was decided that some means of quantifying the performance of Halon 1211 against hidden fires was required. No existing fire challenge was suitable, so a new one was proposed as shown in Figure 1.

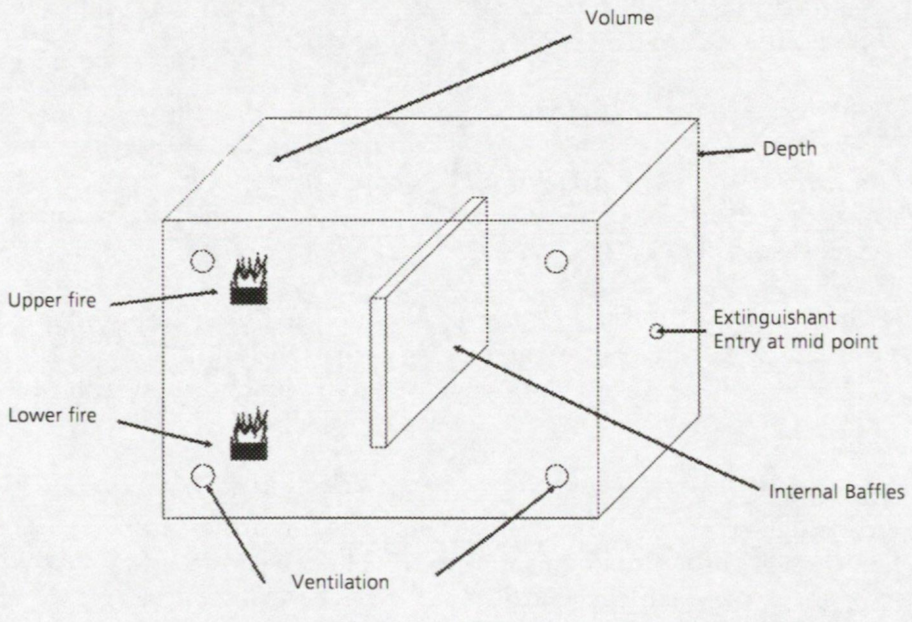


Figure 1 Hidden Fire Challenge Proposed by the CAA

The test fixture was to comprise two hidden fires, 'high' and 'low', a means of observing extinction and sufficient ventilation to render the suppression borderline. A criterion of 4 suppressions from 6 attempts was suggested.

As part of its contribution to the IHRWG, the CAA invited competitive tenders from a number of research organisations in the United Kingdom to develop this hidden fire test and evaluate replacement agents. Kidde International Research were awarded the contract, 8D/S/00003 on 3rd March, 1995. This report presents the results of the study.

2 EXPERIMENTAL

2.1 Test Fixture

2.1.1 *Initial Design*

The initial design for the test fixture is shown in Figure 2.1. It was based on the CAA initiative with some minor changes:

(1) The cross-section was changed from nominally square to a tall, thin rectangle, to represent the proportions of a cheek area better.

(2) The centre baffle was replaced with a 'stop-plate' close to the agent injection point, and two larger baffle plates halfway along the test article. This was to prevent liquid agent impacting on the centre baffle, falling to the floor, and spreading as a liquid film and subsequently vaporising in the vicinity of the fires.

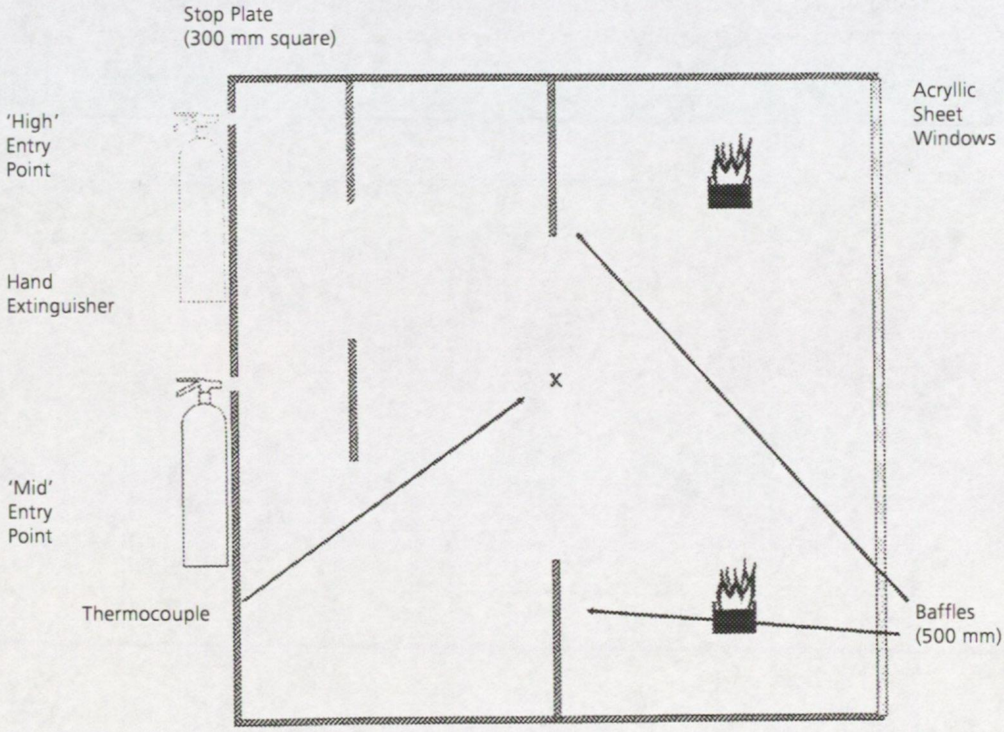


Figure 2.1 Test Fixture, Initial Configuration

The test article was fabricated from 25 x 25 x 3 mm steel angle, clad in 0.9 mm sheet steel. The dimensions of the test article are as follows: 2 m high, 2 m long, 0.5 m wide. One end panel was made from transparent plastic sheet to allow observation and video recording of the tests. The agent was introduced into the test article at one of two points, 'high' and 'mid', as shown in Figure 2.1. Several combinations of baffle size were used, including no baffles whatsoever, high and low both 0.5 m, and high 0.5 m, low 1.0 m.

A total of nine tests were carried out in the initial test article. Results were disappointing with extensive agent stratification occurring. Therefore the test article was modified as described in the following section.

2.1.2 *Variant 1*

The initial test article had no provision for heating, and since the testing, which was undertaken in an unheated building, commenced during the winter and early spring months, the ambient temperature varied between 9° and 11°C. Consequently, the test agent, Halon 1211, (bp –4°C) did not vaporise well. The effect of initial ambient temperature is shown in Appendix I. Following discussions with the CAA, it was decided to heat the test chamber. Therefore the test article was modified as shown in Figure 2.2. Four strip heaters (275 W each) were fixed to the outside of the test article, controlled by a CAL 9000 regulator, employing a type K thermocouple located in the geometric centre of the test chamber. Additionally, the test chamber was lagged with 18 mm polystyrene sheeting, which was in turn clad with 12.5 mm chipboard for protection. This allowed the air temperature of the test article to be controlled to 21 ± 1°C. Furthermore, the hand extinguisher was equilibrated in a water bath at 25 ± 1°C for a minimum of 15 minutes prior to discharge.

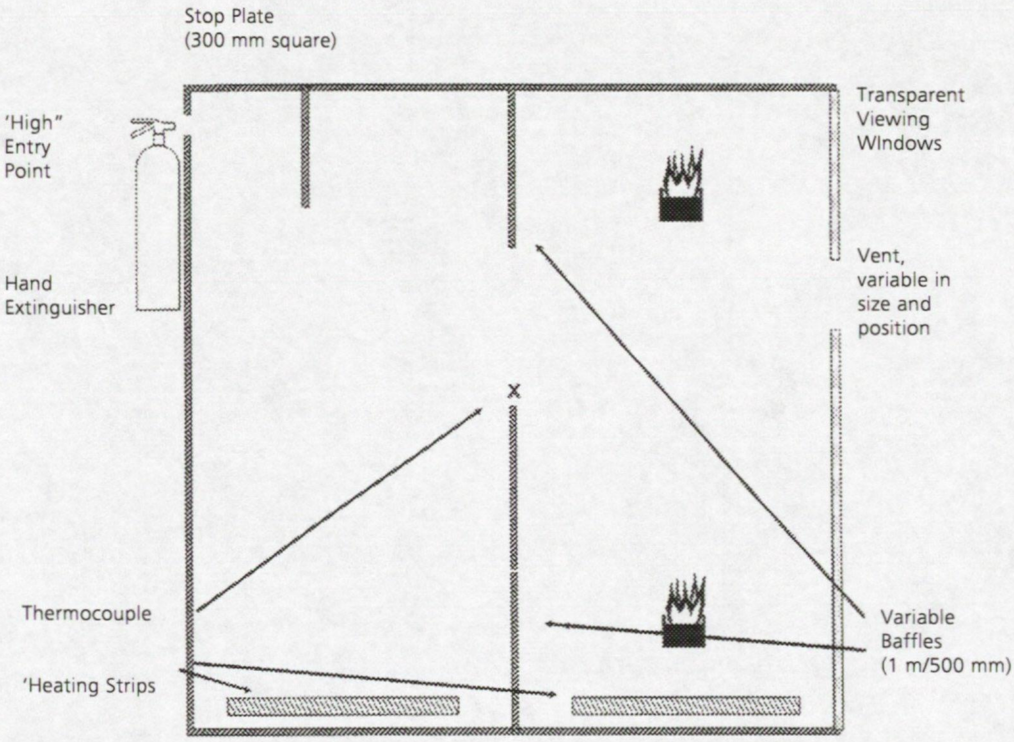


Figure 2.2 Test Fixture, Variant 1

A total of 28 tests were carried out with this first variant of the test fixture, using only the 'high' agent entry point, as shown in Figure 2.2. The number and position of the baffles plates along with the position and size of the ventilation was varied to achieve the borderline extinction criterion sought by the CAA. Following a progress meeting with the CAA, it was decided that two fires did not give enough information, and so test article Variant 2 was created.

2.1.3 *Variant 2*

Variant 2 of the test article is shown in Figures 2.3 and 2.4. The two fires ('high' and 'low') were replaced by two arrays of four fires, giving eight equally spaced vertically. The fires were reduced in size from 76 mm to 35 mm to keep the overall heat output approximately constant, see Appendix II for details of the calculations.

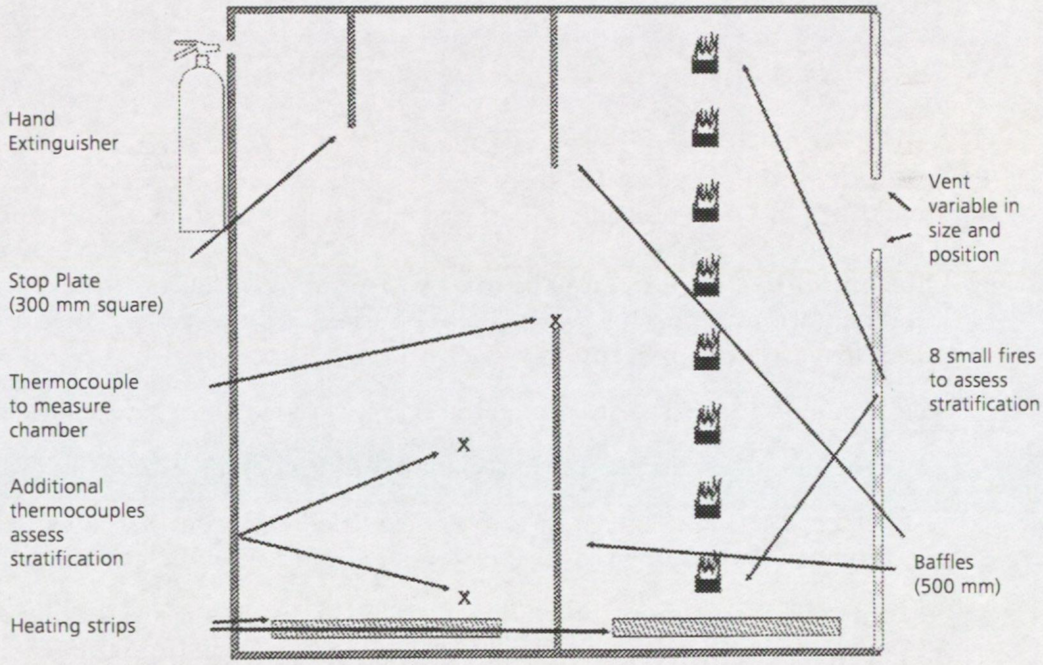


Figure 2.3 Test Fixture, Variant 2 (Side Elevation)

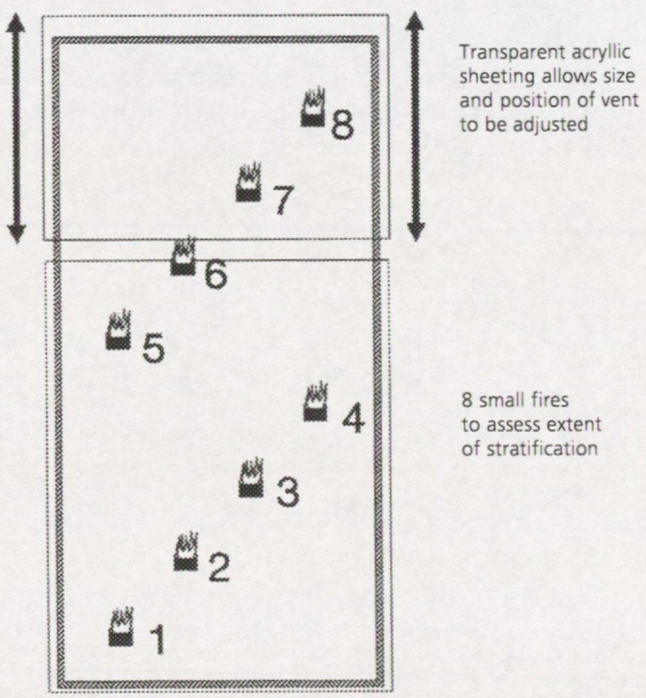


Figure 2.4 Test Fixture, Variant 2 (End Elevation)

As with Variant 1, only the 'high' agent entry point was used. Various combinations of baffle plates and position/size of vents were investigated, with a view to obtaining 6 suppressions out of 8 per test.

Following a second progress meeting with the CAA (with representatives from the FAA and Transport Canada Aviation in attendance) the configuration of the test article was changed again, giving rise to Variant 3. The reasons for these changes are given in the following section.

2.1.4 *Variant 3*

Variant 3 reflects the experience gained with the earlier variants, in terms of size and location of vents, and with respect to the size and location of the fires. It is therefore a better representation of real hidden fire situations, as explained below.

The initial test article and the two subsequent variants offer a reasonable representation of the below-deck cheek area of an aircraft. They do however suffer from some significant draw-backs:

(1) None of them simulate the 'infinite' aspect of an aircraft cheek area.

(2) The initial test article does not simulate a fire behind a cabin side wall.

(3) Once the 'high' agent entry point had been chosen (Variants 1 and 2) the ability to assess upwards dispersion and diffusion of the agent was lost.

(4) In real cheek and other hidden spaces, there is a considerable amount of clutter, (ribs, cable runs etc). This aspect was lacking from the test article.

(5) By placing the vent(s) at the far end of the test article, a natural flow path was set up (from left to right in Figures 2.2–2.3). The test did not demonstrate the agent's ability to extinguish fires off this natural flow path.

Figure 2.5 shows some of the possible locations for a hidden fire aboard an aircraft, and the agent flows that might be required to effect suppression. The fire locations, A through E, can be cross referenced to those in Variant 3, as shown in Figure 2.6. The numbering of the fires in zones A through E is shown in Figure 2.7.

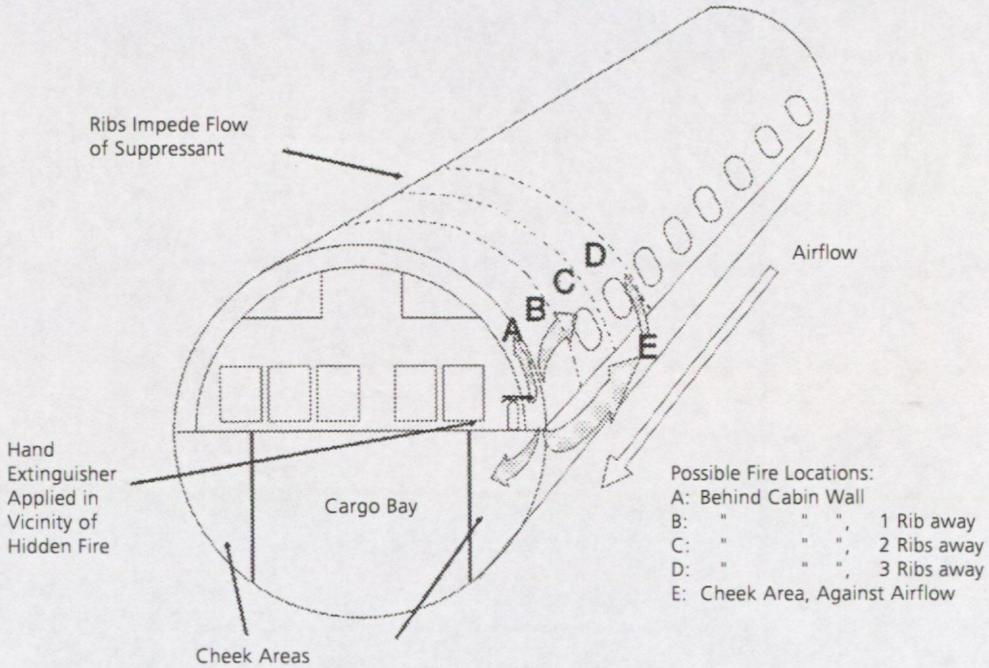


Figure 2.5 Hidden Fire Locations Aboard Aircraft

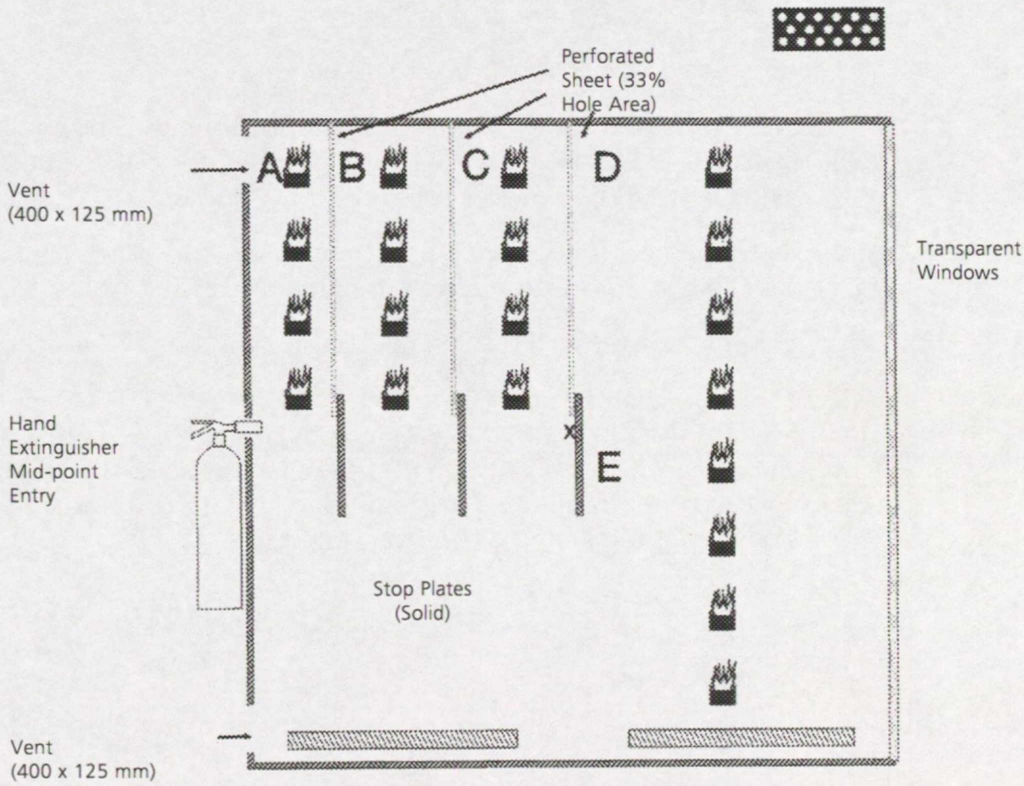


Figure 2.6 Test Fixture, Variant 3

Therefore, in an attempt to remedy the situation, Variant 3 of the test article was designed and built.

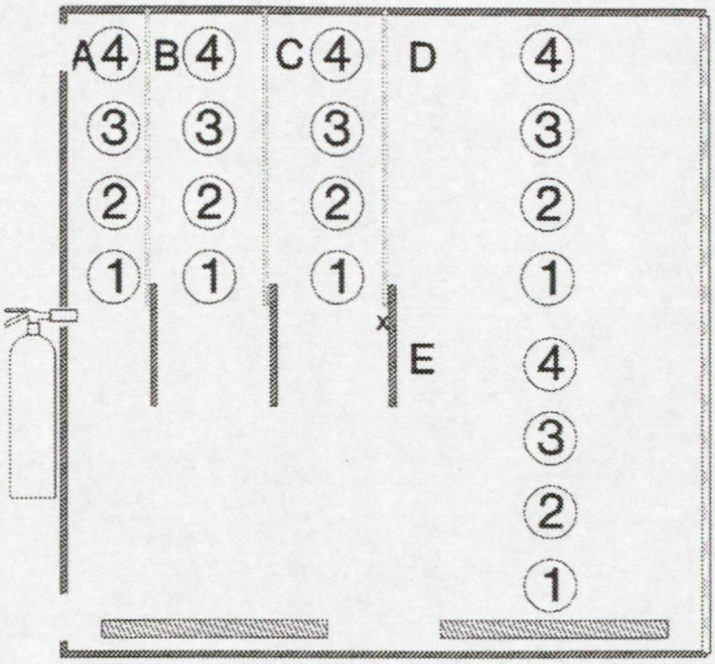


Figure 2.7 Test Fixture, Variant 3, Showing Fire Locations

The principal modifications embodied in Variant 3 are as follows:

(1) The agent entry point is now fixed at mid height.

(2) The baffle plates have been removed and replaced with 3 perforated baffles (67% obstruction, 33% hole area) which divide the test article into four zones A–D. The lower half of Zone D is referred to as Zone E.

(3) Attached to the perforated baffles are three solid 'stop plates' to prevent the agent travelling across the test article as a liquid stream.

(4) There are only two vents in the chamber as shown.

(5) Four fires are placed in two of the zones, A, B, C, D, E , making a total of eight fires per test. Typically, the zone combinations were A & B, B & C, C & E, A & D and D & E. For the Halon 1211 baseline tests, each combination was tested twice, for the replacement agents, each combination was tested once, giving grand totals of 80 and 40 fires respectively.

2.2 Hand Extinguishers Tested

Hand extinguishers from four manufacturers, Walter Kidde, Chubb, Kidde Thorn and First Technology, were tested. Details of the hand extinguishers are given in Table 2.1.

Table 2.1 Physical Characteristics of Hand Extinguishers Tested

Extinguisher	*Walter Kidde*	*Chubb*	*First Technology*	*Kidde Thorn*
Height (mm)	430	375	375	325
Max Diameter (mm)	83	76	80	88
Weight Full (kg)	2.135	1.645	1.515*	2.040
Water Capacity (L)	1.64	1.10	1.01	1.19
Headspace (L)	1.01	0.266	0.415	0.357
Charge (kg)**	1.14	1.50	1.14	1.50
Pressure (psi(g))	100-130	145	125	130
Pressure (bar)	6.9-9.0	10.0	8.6	9.0
Discharge Time(s)	9.2	17.4	9.4	9.8
Average Mass Flow Rate (kg s^{-1})	0.123	0.085	0.114	0.147
BS 5423 Rating	N/A	3A:34B	3A:34B	3A:21B
UL 711 Rating	5B:C	N/A	N/A	N/A

* Without Head

** Note: Agent charge is not the same as mass discharged.

2.2.1 *Walter Kidde (WK)*

This extinguisher was readily available at the start of the project and was used as a benchmark or 'standard' throughout the majority of the testing, apart from when the effect of hardware differences on performance were being sought. The extinguisher was a WK 2.5 lb (1.14 kg) Halon 1211 extinguisher, nominally pressurised to 130 psi(g). See Table 2.1.

2.2.2 *Chubb*

This extinguisher contained more Halon 1211 than the 'standard' WK extinguisher, but it exhibited a longer discharge time and hence a lower mass flow rate, see Table 2.1.

2.2.3 *First Technology*

The extinguishers supplied by First Technology were specially charged with 2.5 lb (1.14 kg) Halon 1211, to allow ready comparison with the WK device. In terms of mass flow rate, the First Technology is also closely matched with the WK extinguisher, see Table 2.1.

2.2.4 *Kidde Thorn*

In common with the Chubb extinguisher, the Kidde Thorn device had a nominal Halon 1211 charge of 1.5 kg rather than the 1.14 kg of the WK extinguisher. It had a similar discharge time to the WK device, implying a ~ 20% increase in mass flow rate, see Table 2.1.

2.2.5 *Apparatus Used for Halon Replacement Testing*

The final aim of this research project was to test Halon replacement agents in optimised hardware. During the course of the test work it became apparent that no manufacturers had suitable extinguishers containing replacement agents sufficiently well developed. The CAA did not wish to delay completion of study by waiting for suitable hand extinguishers to be developed. Therefore, to establish that the test protocol was equally suitable for testing Halon replacements, an alternative approach was adopted. Apparatus was designed to allow discharging of a number of agents at constant pressure, see Figure 2.8. By changing the limiting orifice (A) the appropriate quantity of either Halon 1211 or a replacement agent could be discharged in the time desired (10 ±1 s). In order to ascertain that this apparatus would give comparable results with the replacement agents, Halon 1211 was tested as a baseline agent. The 'appropriate quantity' of a replacement agent was obtained by ratioing its *n*-heptane cup burner concentration to that of Halon 1211. Table 2.2 lists the agents tested, along with the amount required, the limiting orifice used, and the discharge time obtained with that orifice. Further details of the physical, environmental, toxicological and fire suppression properties of the replacement agents are given in Appendix III.

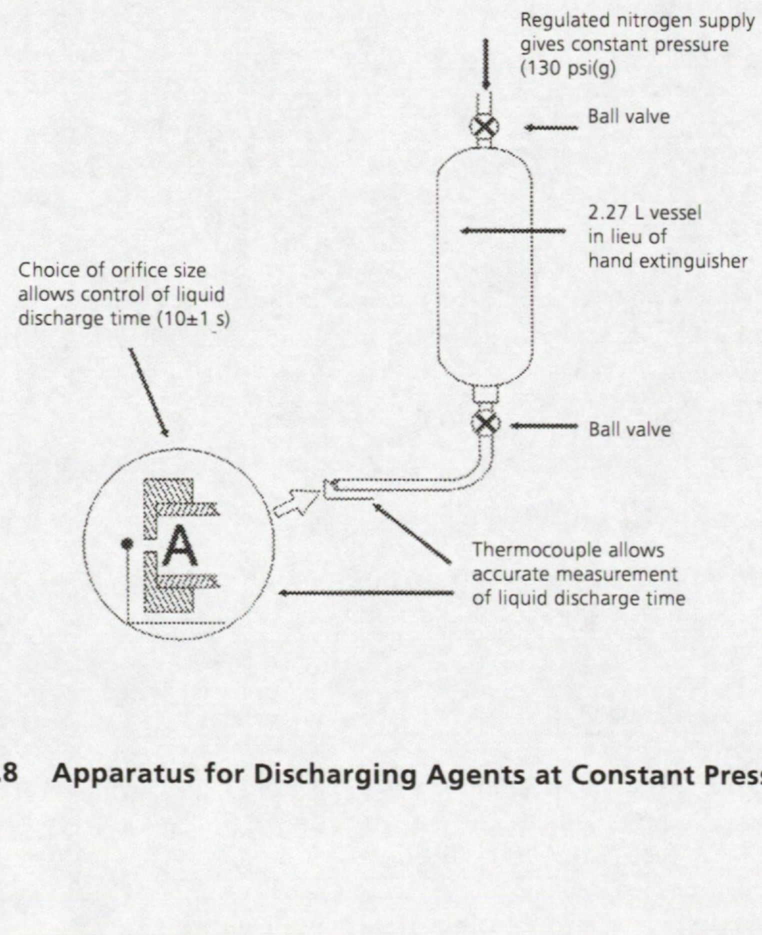


Figure 2.8 Apparatus for Discharging Agents at Constant Pressure

Table 2.2 Halon Replacement Agent Requirements

Agent	Heptane Cup burner Concentration, (C_{CUP}) (Volume %)	Required Concentration (C_{REQ}) (Volume%)	Mass Required (M_{REQ}) (kg)	Limiting Orifice Diameter (mm)	Mean Discharge Time (s)
Halon 1211	3.5	8.4	1.14*	2.0	9.5
FM–200	5.8	13.9	1.94	2.7	10.3
FE–25	9.1	17.9	2.14	3.7	10.8
FE–36	5.3	12.7	1.58	2.6	9.6
CEA–410	5.5	13.2	2.57	3.1	9.9
CEA–614	4.4	10.6	2.92	3.1	10.4
Triodide	3.1	7.5	1.20	1.9	10.0

* Defined Quantity

The mass requirement for the replacement agents was calculated using the following equations.

$$C_{REQ}(\text{Agent}) = \frac{C_{CUP}(\text{ Agent })}{C_{CUP}(\text{ Halon })} \times C_{REQ}(\text{Halon})$$

$$M_{RE}Q(\text{Agent}) = C_{REQ}(\text{Agent}) \times \left[\frac{V_{\text{Chamber}}}{V_M}\right] \times \text{Mol. Wt. (Agent)} \times 10^{-5}$$

$V_{\text{Chamber}} = 2\ m^3$ $\quad$ V_M = Volume occupied by 1 mole of gas ($0.02445\ m^3$ at 25°C)

Mol. Wt. = Molecular weight of Agent in g/mol.

2.3 Other Apparatus

2.3.1 *Video Recording*

All tests were recorded on VHS video, allowing fire extinguishment times to be checked. Two video cameras were used; a JVC GR–S77 and a Shibaden HV-16SU CCTV camera which exhibited enhanced sensitivity in the infrared, making it particularly suitable for the fires in zones A and B, which were furthest from the cameras and partially obscured by the perforated baffles.

2.3.2 *Temperature Measurement and Control*

In an attempt to understand the stratification of the agent, a number of K-type thermocouples were employed, the output being recorded by the data acquisition system (see Section 2.3.4). The results were used to provide relevant input data for the calculations detailed in Appendix I. Another thermocouple was also used verify that the temperature of the test chamber was within the range 20–22°C.

As mentioned previously, a CAL 9000 controller and 4 x 275 W heaters could be used to increase the temperature of the test article if required. On a number of occasions, the ambient temperature rose above 25°C, so an enclosure was erected around the test article and portable air conditioning unit used to bring the temperature back within range. The enclosure was fabricated from 50 x 2.5 mm wood laths clad in transparent polythene sheeting. It is recommended that any future tests are carried out in a temperature controlled environment.

2.3.3 *Gas Analysis*

A Kidde International Infrared 'Halonyser' was used for measuring Halon 1211 concentrations simultaneously in up to 3 locations. Although gas analysis was not included in the contract with the CAA, it proved invaluable in gaining an understanding of agent concentration inhomogeneities (stratification) and also allowed crude mass fluxes to be determined (see Section 4.1).

In addition to Halon concentration measurement, a Rosemount oxygen/carbon monoxide/carbon dioxide analyser was used to investigate oxygen depletion, and check that it was not influencing the fire suppression.

2.3.4 *Data Acquisition System*

Output from the gas analysers and the thermocouples was fed to a National Instruments AT–M1016–F–5 high speed analogue-to-digital (A/D) board installed in a 486 DX PC. The A/D board was controlled by National Instruments 'Labview' software running under Microsoft Windows. Raw data was converted to a 'spreadsheet text file' and imported into Microsoft Excel (v5.0) for subsequent analysis and presentation. Figure 2.9 summarises in schematic form the data acquisition system, including the temperature and gas analysis equipment.

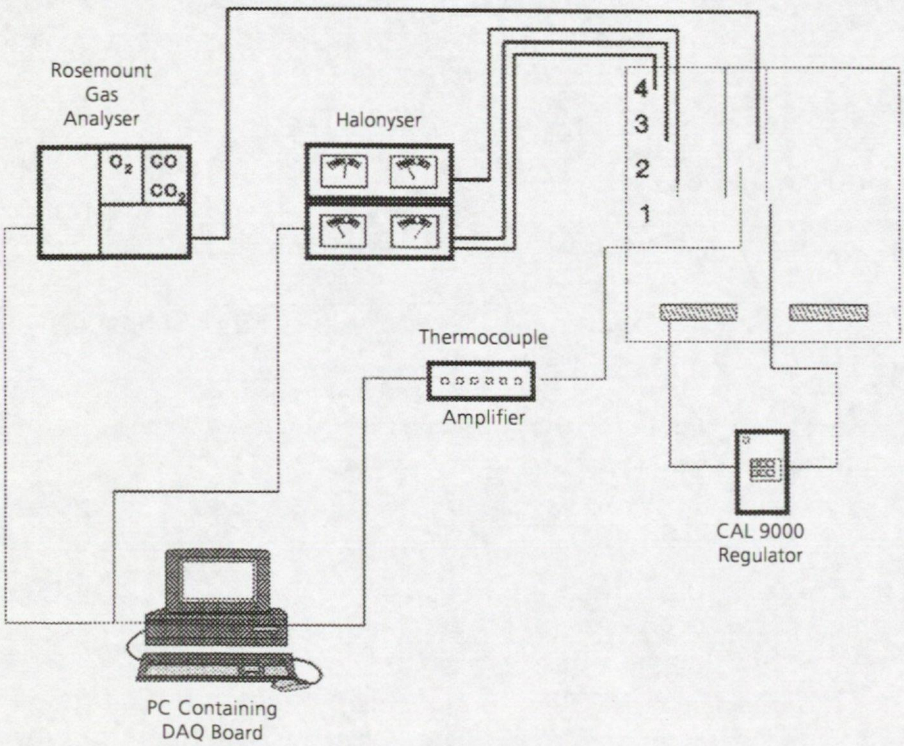


Figure 2.9 Schematic of Data Acquisition System

2.4 Fire Sizing Experiments

2.4.1 *n-Heptane Fires*

Initially two 76 mm diameter fires were used in the test chamber. This size was chosen as being large enough to resist being blown out, yet small enough to keep oxygen depletion to a minimum. When the fire threat was changed to an array of eight fires it was necessary to quantify the heat output of the 76 mm fires, so as to be able to define the size of the eight replacement fires.

One of the fires was placed on an analytical top pan balance with a mass resolution of ± 0.01 g and then ignited. The rate of mass loss was then used to calculate the heat output, knowing the calorific value of the *n*-heptane fuel. This exercise was repeated using pans with a range of diameters, in order to find one with a heat output of one quarter of the original fire. Appendix II includes the results of the three fire tests used.

2.4.2 *Paper Fires*

When the fires using the alternative fuel were chosen, it was considered to be important that they exhibited similar heat output characteristics. Shredded paper in perforated cups was chosen as being representative of Class A, but with a suitable heat output. As well as varying the diameter of the cups, it was found that the packing density of the shredded paper had an effect on the burn time and hence on the heat output. The results are given in Appendix II.

2.5 Test Procedure

The extinguisher was charged with the correct mass of agent on a balance with a mass resolution of ± 1g. The extinguisher was then equilibrated for a minimum of 15 minutes in a water bath temperature controlled to 25 ± 0.1°C. During the equilibration period the video equipment was set up and, if applicable, the gas analysis/data acquisition system checked. The fire cups were placed in position and 10 mL water and 5 mL *n*-heptane added. The fires were lit and any access panels closed. During the 60 s preburn period the video recorder was switched on. After 60 s preburn, the extinguisher was activated and the number of fires extinguished was noted. Any fire still burning 60 s after agent discharge was classed as a failed suppression, and was extinguished manually. The test chamber was thoroughly vented with a powerful extraction fan for at least 5 minutes to ensure no agent was left in the chamber before the next test was undertaken.

3 RESULTS

3.1 Halon Baseline Results

3.1.1 *Initial Test Configuration*

Appendix IV, Table 1 gives the results obtained using the initial test configuration. As neither the agent nor the test chamber were heated, extensive stratification occurred resulting in long extinguishment times for the upper fire. In extreme cases an interface was observed between the cold, Halon-rich air in the lower portion of the chamber and the hot smoke laden air in the upper portion of the chamber. The upper fire was seen to be extinguished as soon as the Halon-rich air reached it. When the chamber was heated (Tests 4 and 9) the upper fire was extinguished in under 10 seconds. In order to eliminate variation in extinguishing performance due to temperature, the test chamber was modified to Variant 1.

3.1.2 *Variant 1*

The results obtained using Variant 1 of the test fixture are given in Appendix IV, Table 2. With no ventilation and the agent and the chamber maintained at 25°C and 20°C respectively, both the upper and the lower fires were extinguished rapidly and reliably.

Tests 10 and 11 were carried out with the internal baffles removed, and just the stop plate between the hand extinguisher and the fires. Whilst the results are essentially the same, (both fires extinguished, the lower one first, there is a marked difference in the extinguishing times. There is no obvious reason for this difference; it does however serve as a reminder that the turbulent dispersion of a suppressant into an enclosure is a chaotic event, and occasional random results can occur.

Tests 12–37 represent an attempt to fine-tune the test to achieve borderline suppression and satisfy the CAA's initial requirement of approximately 4 suppressions from 6 attempts. Both plates were initially 0.5 m high, and the ventilation gap in the end panel was increased stepwise from 50 mm to 250 mm. As both fires were still extinguished reliably, the lower baffle plate was increased in height to 1.0 m with the result that the upper fire was no longer extinguished. At this point a progress meeting was held and Variant 2 was adopted.

3.1.3 *Variant 2*

The results obtained with the array of 8 fires are given in Appendix IV, Table 3. The results show that with mid-point ventilation, as shown in Figure 2.4, 6 out of the 8 fires are extinguished. With no ventilation 7 out of the 8 fires are extinguished, and the height of the baffle does not make any difference. What was surprising was that if the vent was placed at the bottom of the test chamber, all 8 fires were then extinguished.

In addition, two tests were carried out in the absence of agent. Burn times of 4–5 minutes were obtained, after which the fires would not relight, implying they had run out of fuel.

3.1.4 *Variant 3*

The results obtained with Variant 3 are given in Appendix IV, Table 4. It is extremely difficult to summarise extinguishing results for up to 8 fires in 14 tests, so the reader is referred instead to Figure 3.1, where the results are presented graphically. Note, this figure includes the results from all tests including those where variations in ventilation were examined, so tabulating the extinguishing results numerically would not be helpful. Instead, Figure 3.1 divides the test fixture into three zones:

(1) Fires never extinguished.

(2) Fires sometimes extinguished.

(3) Fires always extinguished.

The factors affecting the extents of these three zones are discussed in Section 4.

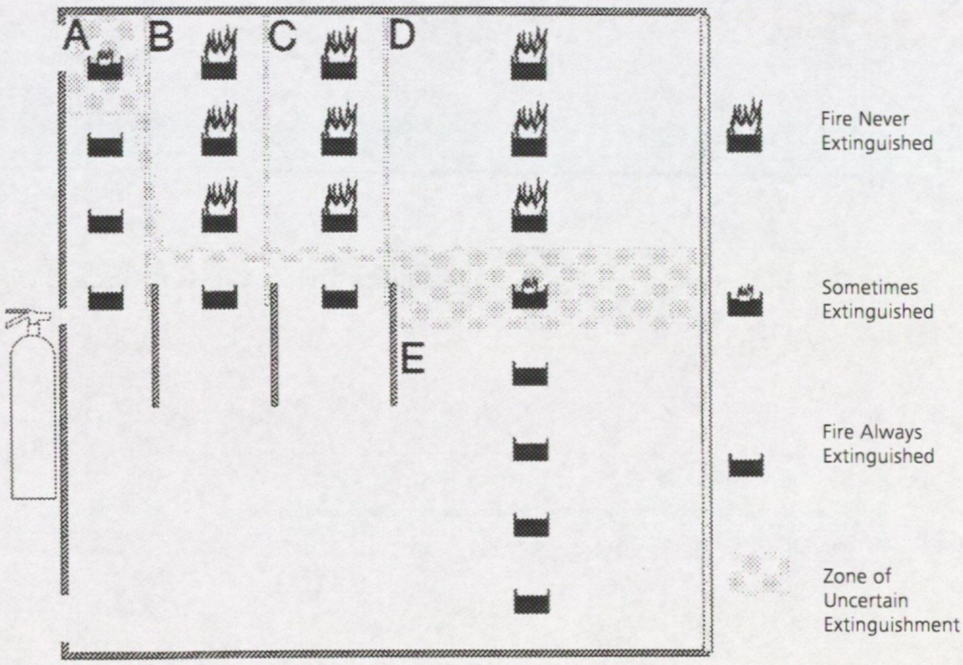


Figure 3.1 Summary of Initial Halon 1211 Results Using Variant 3

3.2 Sensitivity Tests

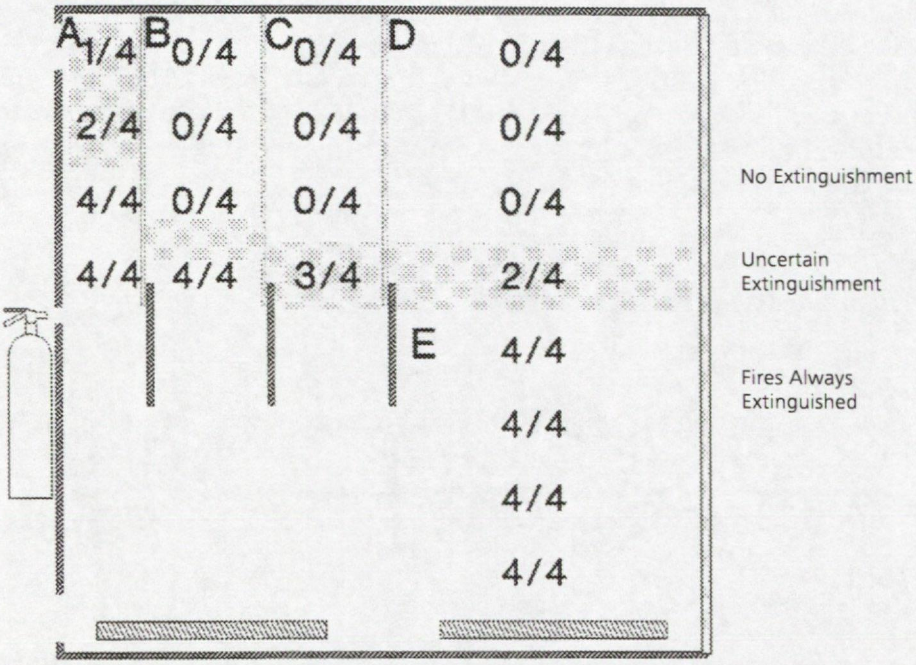
3.2.1 *Baseline Results*

In order to investigate the sensitivity of the test protocol to amount of agent, pressure and type of hardware, it was necessary to quantify the performance of the extinguisher under standard conditions. These were a charge of 2.5 lb (1.14 kg) Halon 1211, pressurised to 130 psi(g) (9.0 bar(g)) at 25°C.

Five tests were carried out in duplicate, using the following combinations of zones in Variant 3 of the test article:

Zones A & B, B & C, C & E, D & E, A & D.

The results are given in Appendix IV, Table 5 and are shown in Figure 3.2. In summary, the WK extinguisher under standard conditions extinguished 36 out of a possible 80 fires.

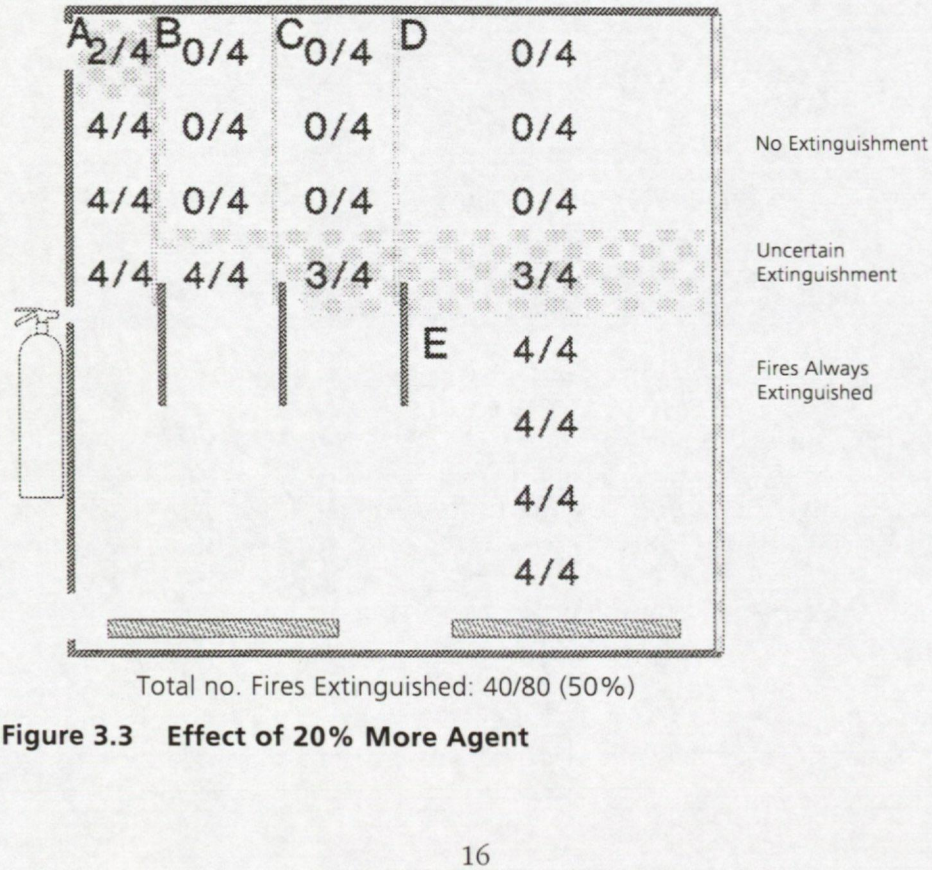


Total no. Fires Extinguished: 36/80 (45%)

Figure 3.2 'Standard' Halon 1211 Baseline Using Walter Kidde Extinguisher

3.2.2 *Effect of 20% More Agent*

The charge in the standard WK extinguisher was increased from 2.5 lb to 3 lb (1.14 – 1.36 kg). This resulted in an additional 4 fires being extinguished, as shown in Appendix IV, Table 6 and in Figure 3.3.

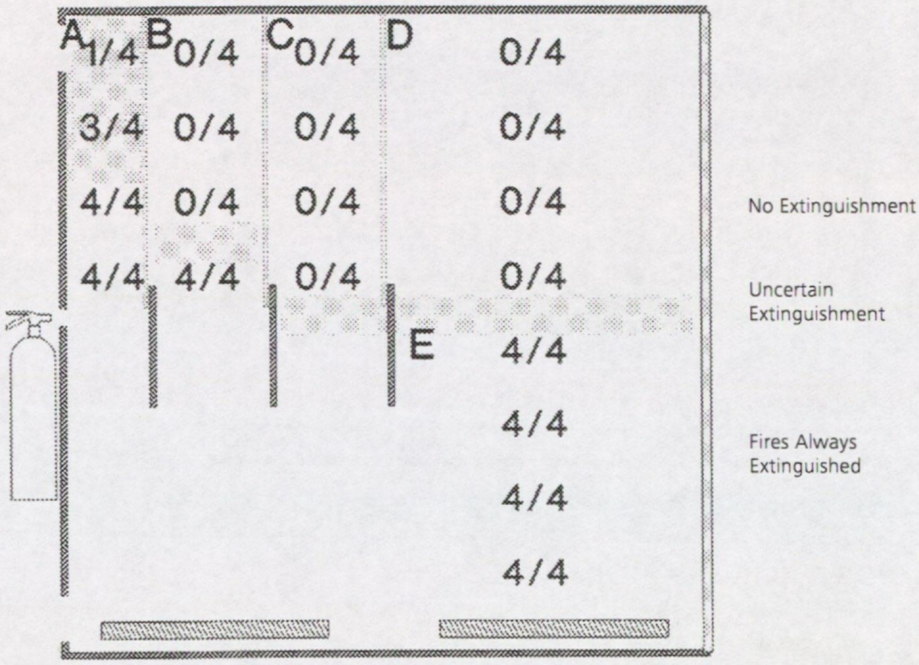


Total no. Fires Extinguished: 40/80 (50%)

Figure 3.3 Effect of 20% More Agent

3.2.3 *Effect of 20% Less Agent*

The charge in the standard WK was reduced to 2 lb (0.91 kg) and a further 10 tests were carried out. In this instance 32 out of a possible 80 fires were extinguished, 4 fewer than the 'standard'. The results are detailed in Appendix IV, Table 7 and Figure 3.4.



Total no. Fires Extinguished: 32/80 (40%)

Figure 3.4 Effect of 20% Less Agent

3.2.4 *Effect of Higher Pressure*

In order to probe the effect of a shorter discharge time, the pressure in the extinguisher was increased from 130 to 220 psi(g) (15 bar(g)). This gave a mean discharge time of 7.0 s, compared with 9.2 s for the extinguisher under standard conditions. This resulted in 41 out of the 80 fires being extinguished, 5 more than the 'standard'. Appendix IV, Table 8 and Figure 3.5 summarise the results.

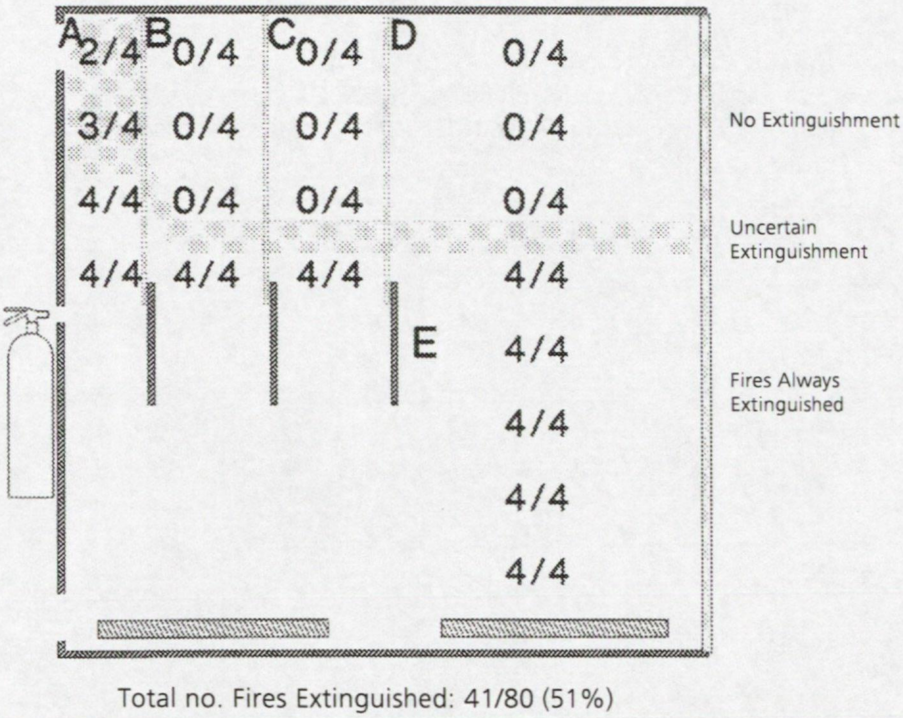


Figure 3.5 Effect of Higher Pressure

3.2.5 *Effect of Lower Pressure*

The pressure was reduced from 130 psi(g) to 100 psi(g) (6.9 bar(g)), giving an increased discharge time of 11.4 s, rather than 9.2 s, under the 'standard' conditions. This resulted in 32 out of a possible 80 extinctions, 4 fewer than those under the 'standard' conditions. The results are summarised in Appendix IV, Table 9 and Figure 3.6.

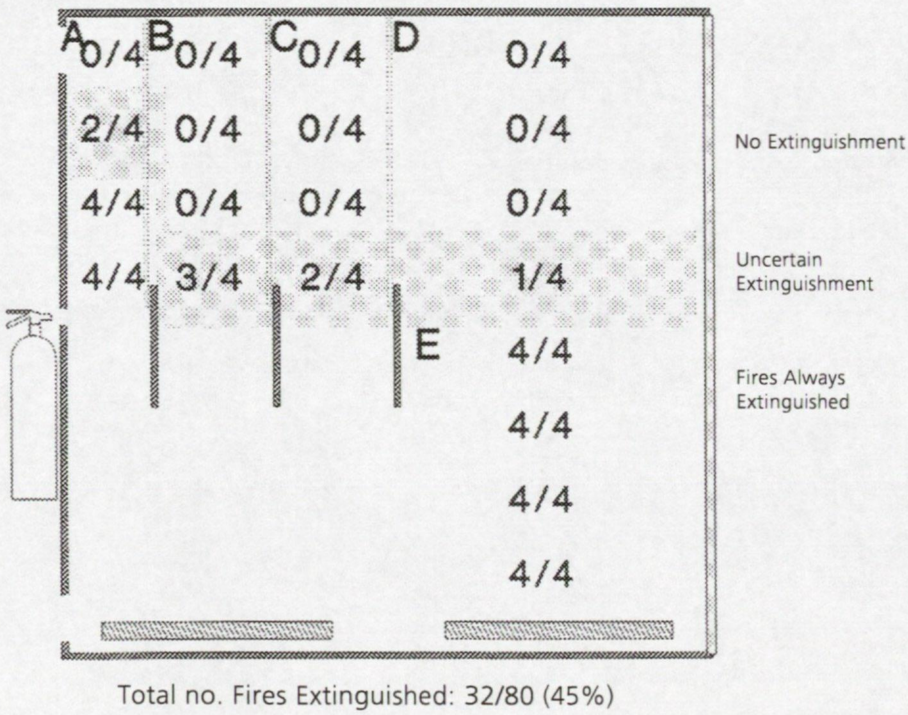


Figure 3.6 Effect of Lower Pressure

3.3 **Hardware Tests**

3.3.1 *Walter Kidde*

The baseline tests for the sensitivity investigation were also used for the hardware baseline tests. For reference, the extinguisher contained 2.5 lb (1.14 kg) Halon 1211, pressurised to 130 psi(g) (9.0 bar(g)) and had a mean discharge time of 9.2 s. A total of 36 out of the 80 fires were extinguished, see Appendix IV, Table 5 and Figure 3.2.

3.3.2 *Chubb Hand Extinguisher*

This extinguisher contained 1.5 kg (3.3 lb) Halon 1211 pressurised to 145 psi(g) (10 bar(g)) and had a mean discharge time of 17.4 s. A total of 40 out of 80 possible fires were extinguished as shown in Appendix IV, Table 10. Figure 3.7 presents the results pictorially, and it can be seen that basically the line dividing extinguishment and non(extinguishment resides higher in the test chamber, as would be expected if a greater quantity of Halon is used.

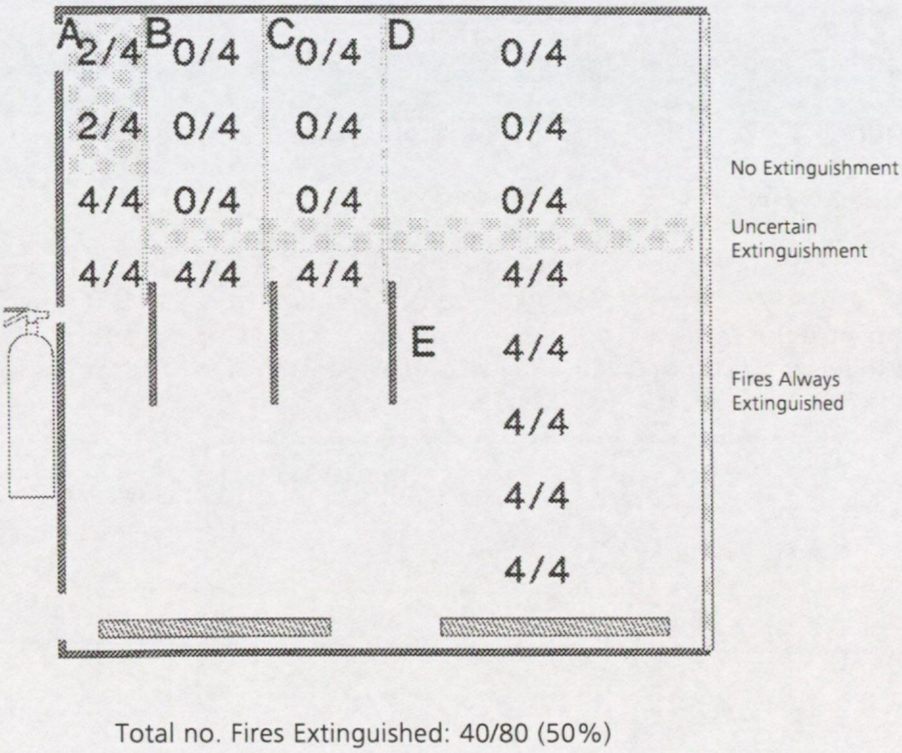
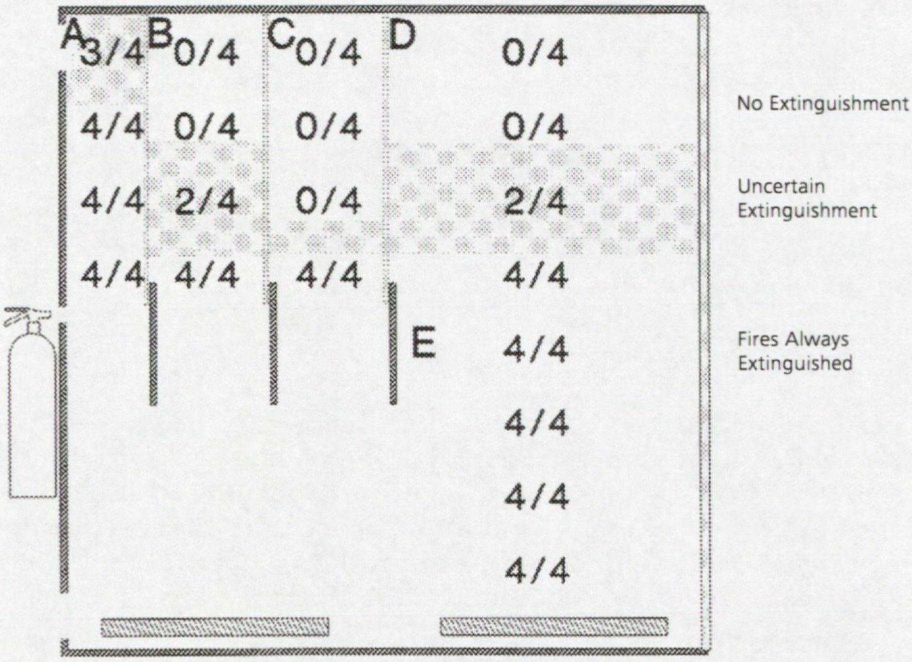


Figure 3.7 Results Using Chubb Extinguisher

3.3.3 *First Technology*

Although this extinguisher exhibited similar fill characteristics to the WK device (2.5 lb (1.14 kg) Halon 1211, a pressure of 125 psi(g) (8.6 bar(g)) and a discharge time of 9.4 s). A total of 47 out of 80 fires were extinguished, as detailed in Appendix IV, Table 11. If Figure 3.8 is examined it can be seen that, unlike the Chubb extinguisher, there is a more widespread zone of uncertain extinguishment, as might be expected from a more turbulent discharge.

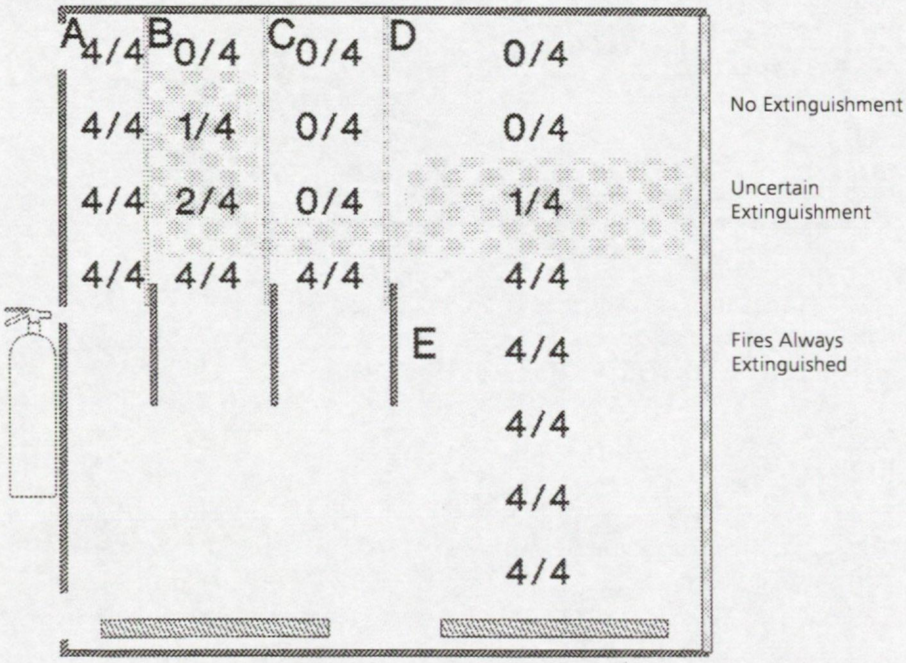


Total no. Fires Extinguished: 47/80 (59%)

Figure 3.8 Results Using First Technology Extinguisher

3.3.4 *Kidde Thorn*

This extinguisher was charged with 1.5 kg (3.3 lb) Halon 1211, pressurised to 130 psi(g) (9.0 bar(g)) and exhibited a comparatively rapid discharge of 9.8 s. Consequently, it was not surprising that a total of 48 out of 80 fires were extinguished. The detailed results can be found in Appendix IV, Table 12 and are shown in Figure 3.9.



Total no. Fires Extinguished: 48/80 (60%)

Figure 3.9 Results Using Kidde Thorn Extinguisher

3.4 Halon Replacement Agent Results

3.4.1 *Halon 1211 Baseline Calibration*

The apparatus, charged with 2.5 lb (1.14 kg) Halon 1211 and pressurised to 130 psi(g) (9.0 bar(g)), gave a mean discharge time of 9.5 s, with a 2.0 mm diameter orifice. This was close to the 'standard' WK extinguisher discharge time of 9.2 s. Using this apparatus a total of 19 out of 40 fires were extinguished, which correlated well with the 36 out of 80 obtained previously with the WK device. Therefore it is believed that the use of this apparatus is valid. For reference, the results are summarised in Appendix IV, Table 13 and Figure 3.10.

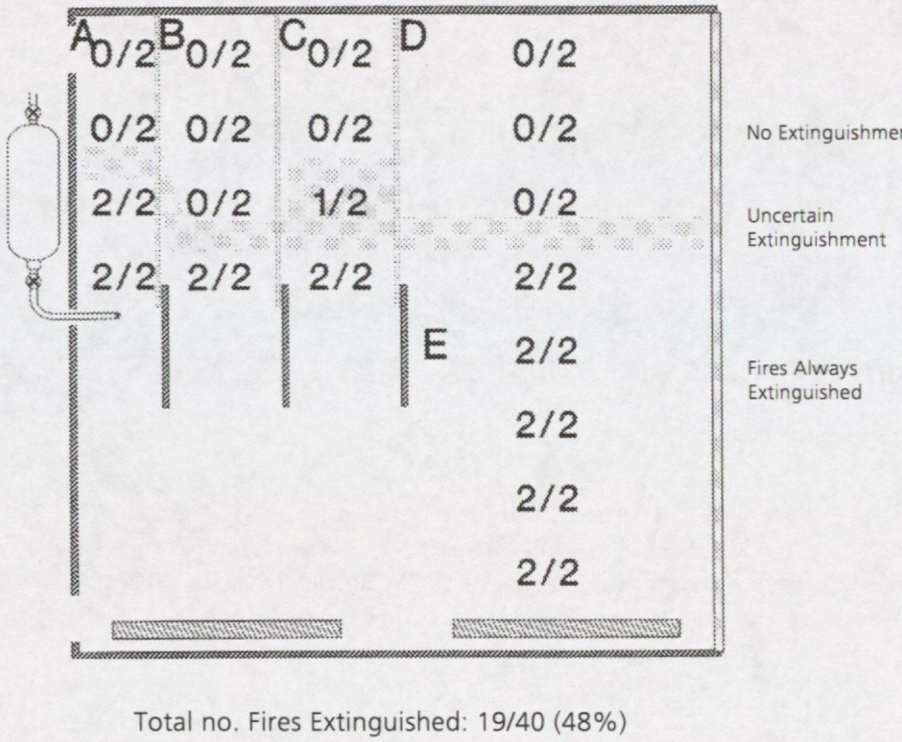


Figure 3.10 Halon 1211 Baseline Results Using Constant Pressure Apparatus

3.4.2 *FE–25*

Owing to the high vapour pressure of FE–25, no nitrogen pressurisation was required, and with a 3.7 mm diameter orifice, 2.14 kg (4.72 lb) was discharged in 10.8 s. This was within the specified discharge time of 10 ± 1 s. A total of 26 out of 40 fires were extinguished, which correlates well with the lower boiling point and greater volatility of FE–25. The results are detailed in Appendix IV, Table 14 and Figure 3.11.

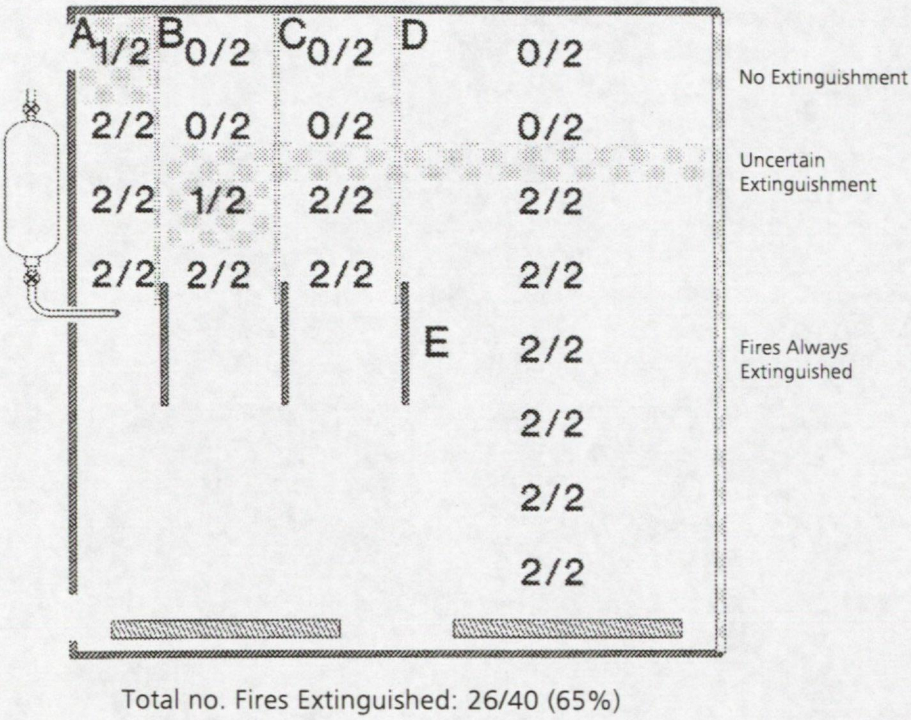


Figure 3.11 FE–25 Results Using Constant Pressure Apparatus

3.4.3 *FM–200*

With an orifice of 2.7 mm diameter and a charge of 1.94 kg (4.28 lb) a mean discharge time of 10.3 s was obtained. A total of 22 out of 40 fires were extinguished as detailed in Appendix IV, Table 15. As FM-200 is slightly more volatile than Halon 1211, these results seem sensible.

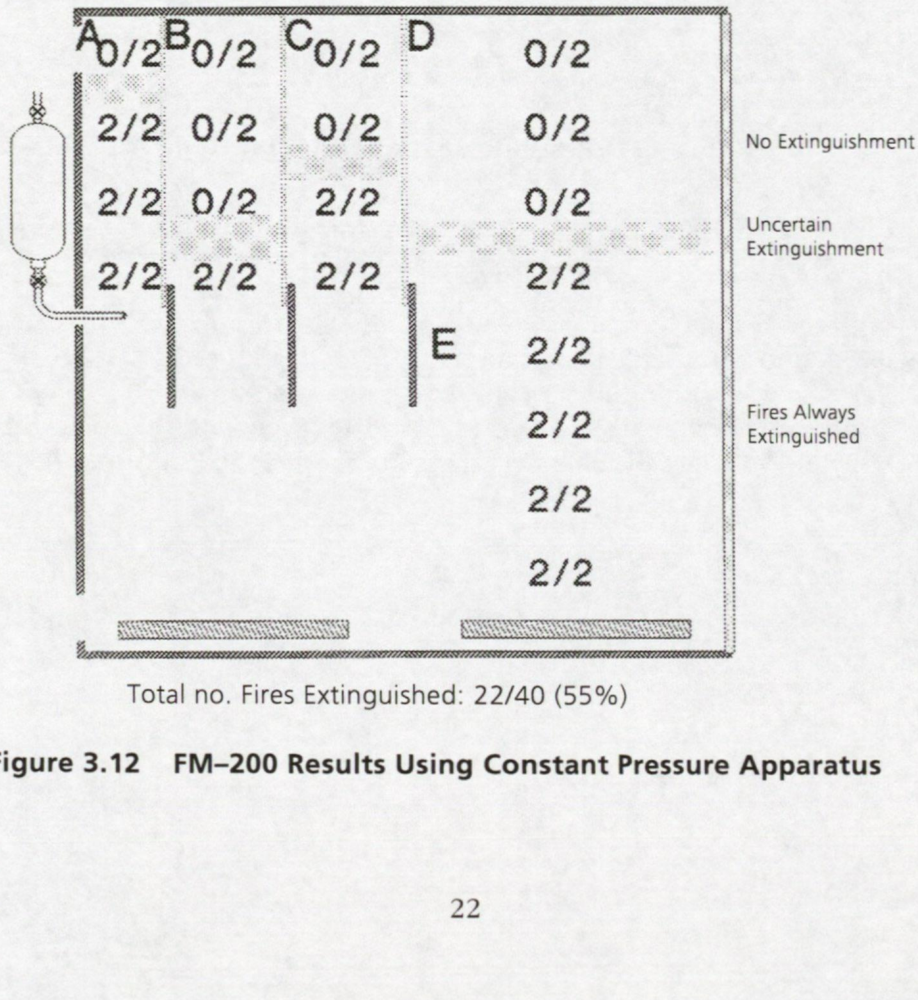


Figure 3.12 FM–200 Results Using Constant Pressure Apparatus

3.4.4 *CEA–410*

The apparatus, fitted with a 3.3 mm diameter orifice discharged 2.57 kg (5.66 lb) of agent in 9.0 s. Although within the specified range, the orifice was changed in subsequent tests to 3.1 mm diameter resulting in a discharge time of 10.2 s. Thus the average discharge time was approximately 9.9 s. A total of 20 out of 40 fires were extinguished. Full details of the results are given in Appendix IV, Table 16 and are shown in Figure 3.13. Given the similar volatility of CEA–410 to Halon 1211, these results appear reasonable.

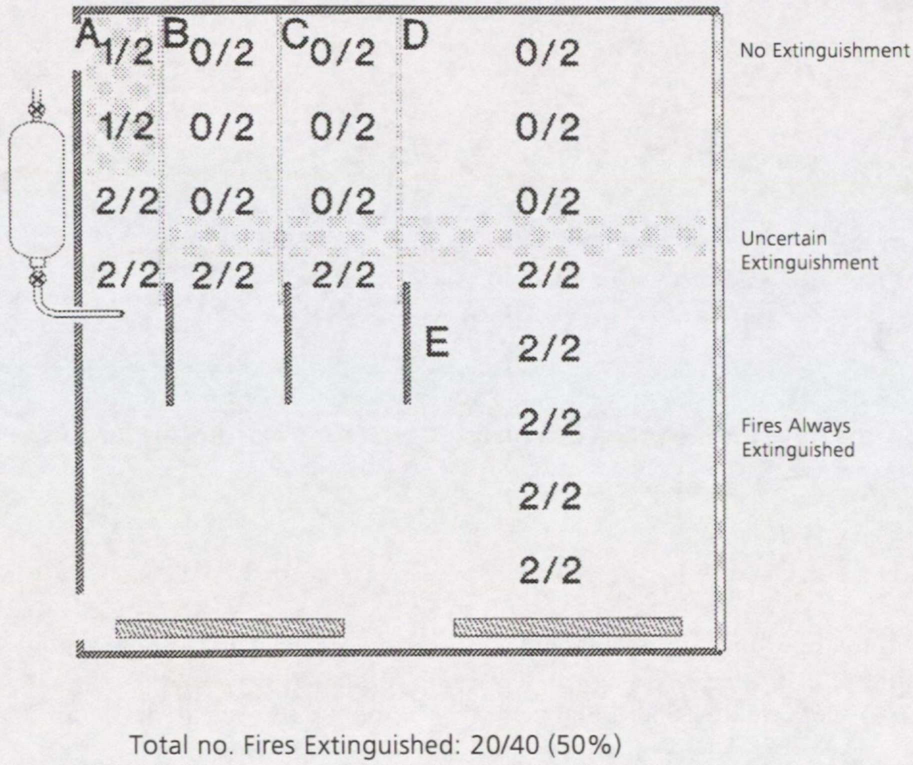


Figure 3.13 CEA–410 Results Using Constant Pressure Apparatus

3.4.5 *CEA–614*

With an orifice of 3.1 mm diameter and a charge of 2.92 kg (6.44 lb), a mean discharge time of 10.4 s was obtained. A total of 14 out of the 40 fires were extinguished, as would be expected, given the relatively high boiling point of this agent. The results are detailed in Appendix IV, Table 17 and are shown in Figure 3.14.

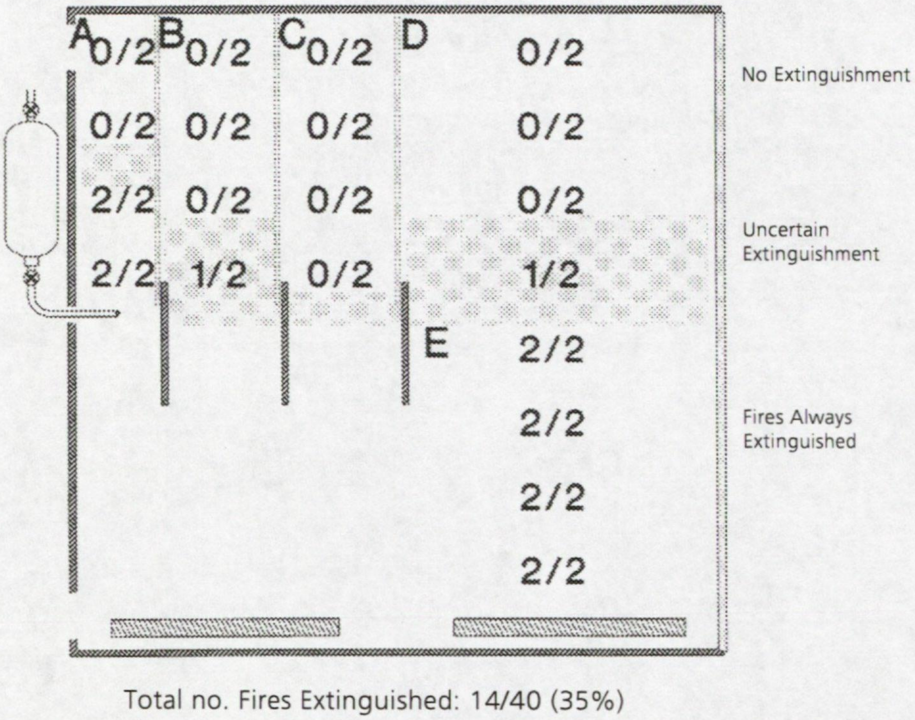


Figure 3.14 CEA–614 Results Using Constant Pressure Apparatus

3.4.6 *FE–36*

With an orifice of 2.6 mm diameter and a charge of 1.58 kg (3.48 lb), a mean discharge time of 9.6 s was obtained. A total of 20 out of 40 fires were extinguished, broadly similar to CEA–410 and Halon 1211. Again, considering the similarities in all three agent's boiling points, these results appear consistent. Appendix IV, Table 18 and Figure 3.15 summarise the results in detail.

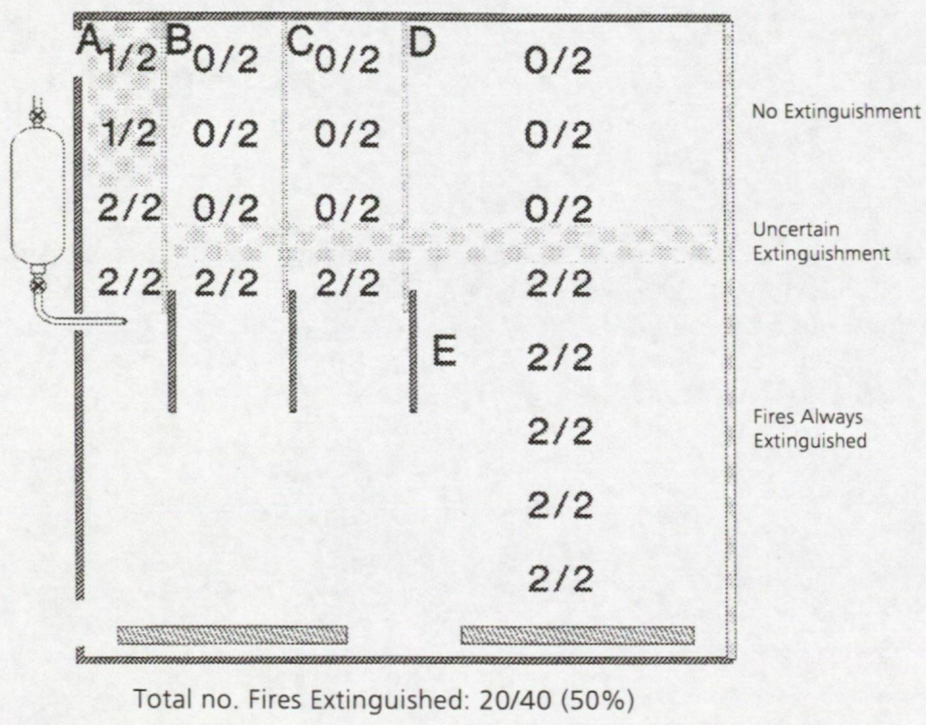


Figure 3.15 FE–36 Results Using Constant Pressure Apparatus

3.4.7 *Triodide*

A nozzle orifice of 1.8 mm diameter resulted in a discharge time of 10.9 s, whereas a 1.9 mm diameter orifice gave 9.8–9.9 s in the remaining tests. A charge of 1.20 kg (2.64 lb) Triodide extinguished 20 out of the 40 fires. This is possibly 1 or 2 fewer than might be expected, considering that Triodide has a similar boiling point to FM–200 (–22.5°C vs –17°C) and FM–200 extinguished 22 out of the 40 fires. Appendix IV, Table 19 and Figure 3.16 detail the results.

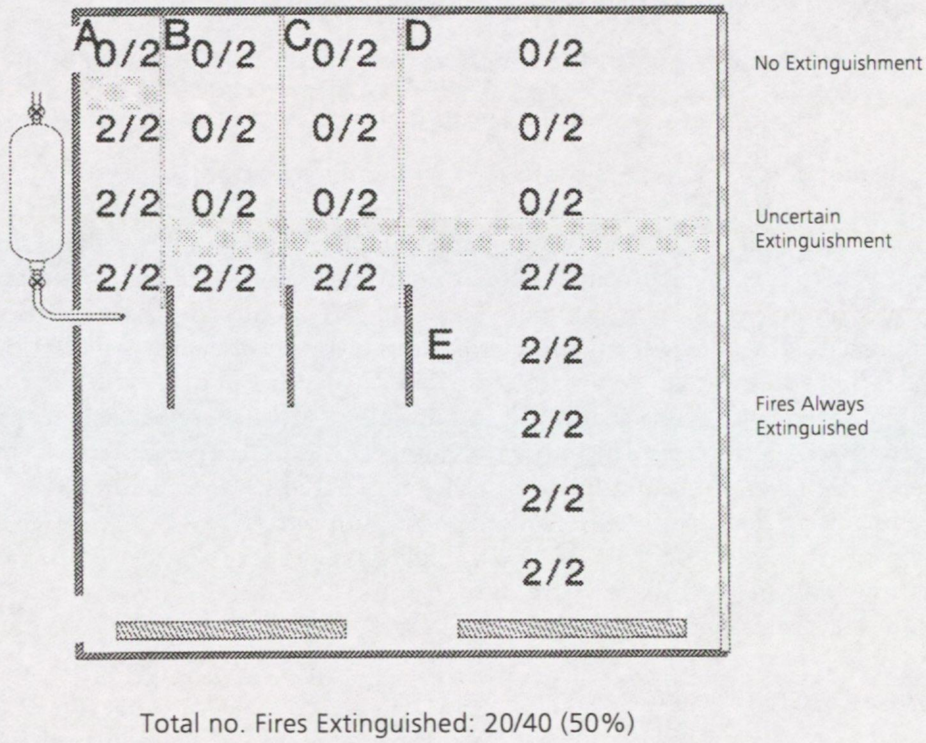


Figure 3.16 Triodide Results Using Constant Pressure Apparatus

4 DISCUSSION

4.1 Initial Test Fixture and Variant 1

4.1.1 *Effect of Temperature*

As mentioned previously, poor agent vaporisation and extensive stratification occurred in the initial test fixture. Basically there are three sources of heat available to vaporise the Halon;

(1) The internal energy of the agent, as it is initially above normal boiling point.

(2) The energy contained in the air in the test chamber.

(3) The energy contained in the steel of the test chamber.

Initially the Halon flash evaporates, cooling the liquid to its normal boiling point. Heat is also abstracted from the surrounding air, until that too is at, or near, the agent's boiling point. Liquid agent impacting the walls and base of the chamber will also abstract heat from the steel. Simple thermodynamic calculations can be used to predict the approximate contributions from each of these heat sources in aiding agent vaporisation. A Microsoft Excel spreadsheet was used to predict the quantity of agent vaporising under a range of initial temperature conditions. The results are given in Appendix I, in the form of Table I.1 and Figure I.1. In summary, if the initial test conditions (agent, air, chamber temperature) are 10°C then 0.44 kg of the Halon will evaporate, giving a concentration of 3.2 volume % assuming homogenous mixing, which is not the case. This explains the long extinction times observed for the upper fire.

4.1.2 *Effect of Airflow/Ventilation*

The initial test fixture exhibited almost no airflow, there being only one vent. The two relatively small fires set up a weak convection current which eventually was sufficient to entrain the cold Halon-rich air up to the level of the upper fire, thus extinguishing it. Moving the agent entry point from 'mid' to the 'high' position resulted in much more reliable extinguishment of the upper fire, especially when the centre baffle plates were removed. Although the stop-plate prevented direct impingement of the agent on the fire(s), they were obviously more accessible to the agent. When Variant 1 was adopted, and the temperature of both the agent and the test fixture were controlled, it was possible to probe the effect of airflow and ventilation. The findings may be summarised as follows:

(1) With no ventilation and no obstructions, both fires were rapidly extinguished.

(2) Adding 0.5 m baffles and a vent up to 200 mm high made very little difference.

(3) Increasing the size of the lower baffle plate from 0.5 m to 1.0 m and maintaining the vent size at 200 mm rendered the extinguishment of the upper fire extremely uncertain (1 extinction in 5 tests).

However, at this point it was decided that these large step-changes in either ventilation or size of baffle plate were not subtle enough to allow the test to be fine-tuned to the CAA requirement of 4 suppressions from 6 attempts, and a greater number of smaller fires was suggested.

4.2 Variant 2

The use of 8 fires to evaluate agent dispersion/stratification initially seemed to be the obvious solution. Varying the vent height and degree of obscuration allowed either 6 or 7 out of 8 fires to be extinguished repeatably. Furthermore, with no ventilation and a 1.0 m lower baffle, the extinction of the 7th fire was slow (30–50 s) whereas if the lower baffle was reduced to 0.5 m, this fire was extinguished more rapidly (approximately 11 s). There was, however, a flaw with Variant 2, in that with the vent two-thirds of the way up the test chamber, larger scale airflows were not present. When the vent was positioned at the bottom of the chamber, all 8 fires were extinguished. Presumably this was due to the fact that the convection plumes of the fires were better developed due to the entrainment of fresh air from the lower vent. This improved convection distributed the Halon 1211 more evenly, extiguishing all 8 fires. This improved extinguishment was contrary to expectation, as it was assumed that more of the Halon would leave the chamber via the lower vent.

4.3 Variant 3

4.3.1 *Results Obtained with n-Heptane Fires*

The reasoning behind the design of Variant 3 has been given in Section 2.1.4. The position of the vents in this variant follows directly from the unexpected results obtained using Variant 2; the importance of airflows has been clearly demonstrated.

The initial range-finding tests carried out with Halon 1211 in Variant 3 gave the following results:

(1) With the convective airflow set up by the fires, 1.14 kg (2.5 lb) Halon 1211 'climbs' up to 1 m above the injection point in sufficient quantity to extinguish fires A1 – A3 with certainty, but the extinction of fire A4 is uncertain. There is some evidence that if the other 4 fires are in Zone B, then the updraught is stronger, and fire A4 is more likely to be extinguished.

(2) On examining the extinction times for fires A1, A2 and A3 concern was expressed that these fires were blown out rather than extinguished by conventional means. Experiments were carried out where the extinguisher was filled with water to simulate the volume occupied by the Halon, and then pressurised with air. Air was chosen so as to be able to differentiate between extinguishment assisted by nitrogen and the flame being blown out by purely physical means. None of the fires was extinguished, (not even A1), so it appears that under the normal test conditions the fires are not blown out but extinguished, albeit perhaps with some aerodynamic assistance. This phenomenon has been noted previously [3].

To assess the extent of this aerodynamic assistance the Halonysers were set up in Zone A, sampling at the same heights as the fires A2, A3 and A4. Typical measured Halon 1211 concentrations are given in Table 4.1.

Table 4.1 Halonyser Results for n-Heptane Fires in Zone A

Test	*Fire Location*	*Maximum Halon 1211 Concentration (Volume %)*	*Extinction Time (s)*
154	A2	1.9	0.3
154	A3	1.3	1.1
154	A4	0.8	1.6
156	A2	1.7	0.8
156	A3	1.4	1.0
156	A4	1.0	1.5

The Halon concentration-time plots are included in Appendix V for reference. It can be seen that the fires are extinguished long before the Halon 1211 concentration reaches the peak value given in Table 4.1. This confirms the fact that the extinguishment is aerodynamically assisted to a large extent.

(3) Very few fires in Zones B and C were extinguished. It would appear that the percentage open area of the baffles (33%) is not sufficient to permit unimpeded dispersion of the agent through the baffle. Whether this figure is a realistic representation of the clutter between the structural ribs is open to question. Unfortunately, during this test program there was neither the time nor the resource to investigate alternative baffles with a different percentage open area.

(4) Looking at the extinguishment times it seems likely that sometimes fire B1 is extinguished quickly by agent passing through the first baffle, whereas on other occasions it is extinguished several sections later, by Halon rising up Zone B as the test chamber gradually fills up.

(5) Fire C1 in contrast is always extinguished slowly, presumably because diffusion through a second baffle occurs so slowly that the Halon can find an easier route. This is summarised in Figure 4.1, where the main flow directions have been identified, with considerable assistance from the gas analysis results.

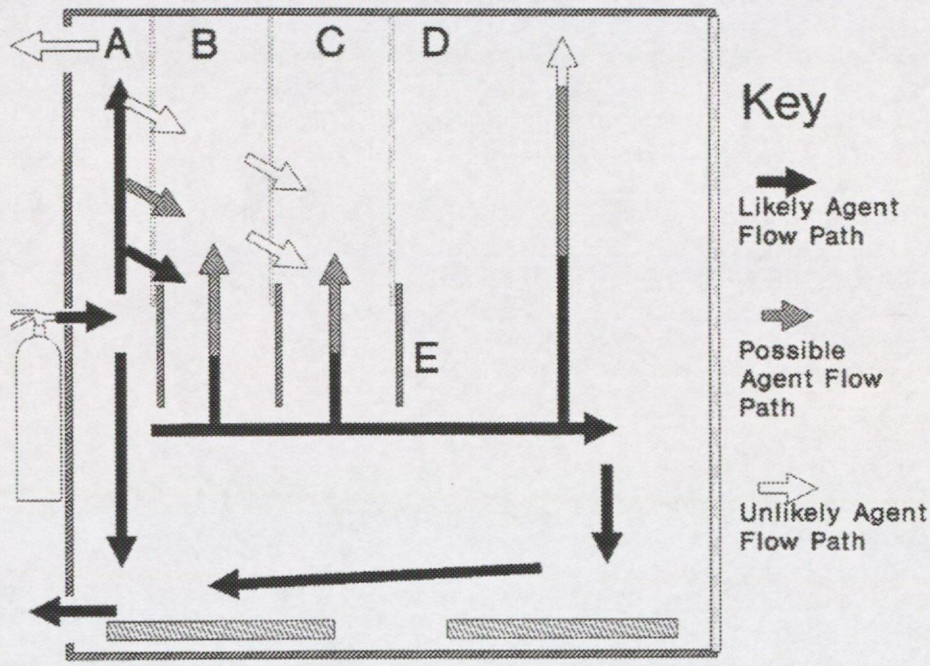


Figure 4.1 Flow of Suppressant

(6) The fires in Zone D are the most difficult to extinguish, being high up, the furthest away from the point of agent entry and also considerably off the natural flow path, see Figure 4.1.

(7) In contrast, the fires in Zone E are always extinguished – owing to the fact that despite conditioning the agent prior to discharge and maintaining the chamber at 20°C, stratification still occurs. This was confirmed by the Halonyser results, see Appendix V.

4.4 Sensitivity Analysis

4.4.1 *Amount of Agent/Effect of Pressure*

Tables 4.2 and 4.3 summarise the results obtained with the WK extinguisher under different fill conditions, along with the results obtained with the results from the other three manufacturers' extinguishers for *n*-heptane fires.

Table 4.2 Summary of Hand Extinguisher Discharge Characteristics

Extinguisher Details	*Mean Agent Mass (kg)*	*Mean Discharge Time (s)*	*Mass Flow Rate ($kg\ s^{-1}$)*	*Normalised Mass Rate*	*Normalised Mass Flow*
WK 2lb, 130 psi(g)	0.91	6.4	0.142	0.8	1.15
WK 'standard'	1.14	9.2	0.123	1	1
WK 3lb, 130 psi(g)	1.36	13.0	0.105	1.2	0.85
WK 2.5 lb, 100 psi(g)	1.14	11.4	0.100	1	0.81
WK 2.5lb, 220 psi(g)	1.14	7.0	0.162	1	1.32
First Technology	1.07	9.4	0.114	0.95	0.93
Chubb	1.47	17.4	0.085	1.29	0.69
Kidde Thorn	1.44	9.8	0.147	1.26	1.20

Table 4.3 Summary of Hand Extinguisher Results for *n*-Heptane Fires

Extinguisher Details	*Zone A*	*Zone B*	*Zone C*	*Zone D*	*Zone E*	*Total Number of Fires Extinguished*	*Percentage Extinguished*
WK 2lb, 130 psi(g)	12	4	0	0	16	32	40
WK 'standard'	11	4	3	2	16	36	45
WK 3lb, 130 psi(g)	14	4	3	3	16	40	50
WK 2.5 lb, 100 psi(g)	10	3	2	1	16	32	40
WK 2.5lb, 220 psi(g)	13	4	4	4	16	41	51
First Technology	15	6	4	6	16	47	59
Chubb	12	4	4	4	16	40	50
Kidde Thorn	16	7	4	5	16	48	60

In order to investigate the effect of mass of agent and the mass flow rate into the chamber both of these values are ratioed against those obtained with the WK extinguisher under 'standard' conditions (2.5 lb, 130 psi(g)). These 'normalised' values are used to produce Figure 4.2, where each set of the results from the tests are plotted according to the normalised mass and mass flow rate, along with the percentage of *n*-heptane fires extinguished. This plot shows that in general terms the test is equally sensitive to the effect of mass and mass flow rate.

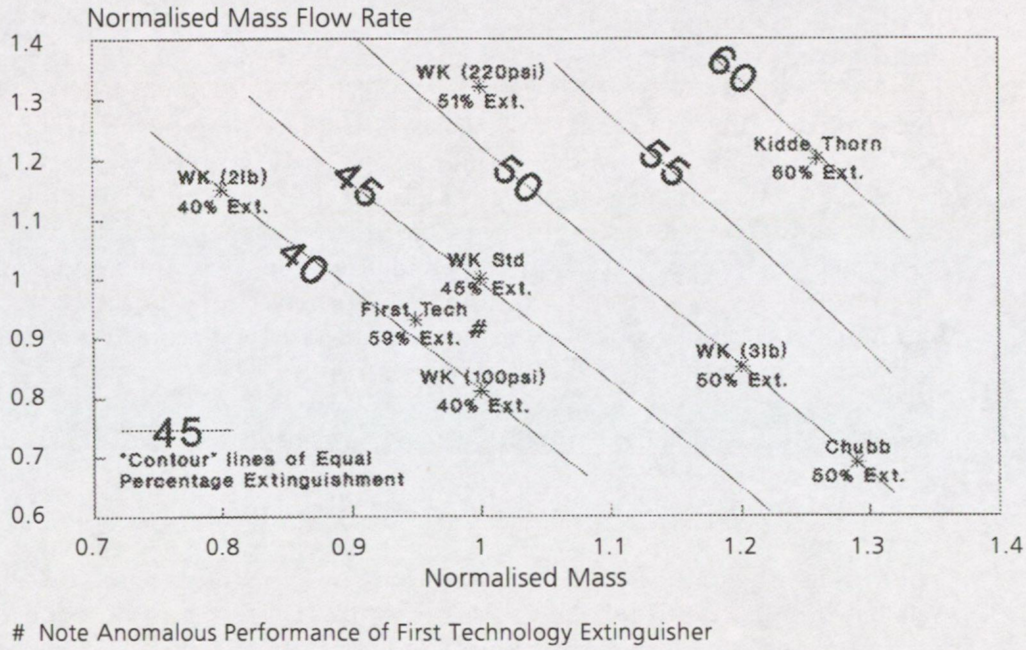


Figure 4.2 Effect of Mass and Mass Flow Rate

The contour lines in Figure 4.2 indicate equivalent extinguishing performance, where an increase in agent mass could be offset by a decrease in mass flow rate to keep extinguishing performance constant. Alternatively, 'contour lines' can be crossed, by increasing both mass and mass flow rate allowing a higher percentage of fires to be extinguished.

4.4.2 *Effect of Different Manufacturers' Hardware*

The results from the three additional manufacturers' extinguishers are also included in Figure 4.2. If Table 4.2 is examined it can be seen that the discharge time of the Chubb Extinguisher is almost double that of the other three. Not only was the discharge long, it exhibited considerable variation from test to test, probably due to slightly different amounts of nitrogen over-pressure. This variation in discharge time leads to a variation in mass flow rate and hence turbulence in the test chamber. As outlined in a previous section, the extinguishment of fires in Zone A depends on turbulence to distribute the agent satisfactorily. The Chubb tests where excessively long (≥ 20 s) discharge times were observed were repeated and, not surprisingly, more fires in Zone A were extinguished. Therefore the results presented for the Chubb extinguisher should be treated with caution, as they are 'optimised' to some extent. Nevertheless, the Chubb and Kidde Thorn extinguishers fit on the overall extinguishing profile very well in terms of extinguishing the percentage of fires that would be expected, based on their mass/mass flow characteristics.

However, the extinguisher supplied by First Technology extinguished 59% of the *n*-heptane fires whereas the WK extinguisher (which has similar mass/mass flow characteristics) extinguished 45% of the *n*-heptane fires. It was noted that the discharge of agent from the First Technology extinguisher, seemed inherently turbulent. This turbulent discharge gave better dispersion of Halon 1211 in the test chamber, extinguishing a greater proportion of fires.

4.4.3 *Defining a Minimum Performance Standard*

In this study a range of hand extinguishers (1 of US origin, 3 of UK origin) and fill conditions have been evaluated. The question of how to set minimum performance criteria arises. If the lowest performing extinguisher is judged to be the standard, then subsequent designs with replacement agents will be based on this minimum, and the average would fall. This would contravene the regulatory authorities requirement that "no loss of safety should occur". Therefore, the mean performance of the extinguishers tested should constitute the minimum performance criteria. Based on the results for the 4 hand extinguishers tested, this would be 54% extinguishment. Currently there is a bias towards UK extinguishers, which could be balanced by further test work using extinguishers from other geographical sources, (eg US, Europe).

4.5 Results Obtained with Constant Pressure Apparatus

4.5.1 *Halon 1211: Comparison with Standard WK Extinguisher Results*

The results obtained with the constant pressure apparatus agree closely with the WK baseline results (48% suppression vs 45%). This is to be expected as the pressure and discharge time (and hence the mass flow rate) were closely matched. One explanation for the slight improvement in performance (in reality, one extra suppression in 40 attempts), might be that the pressure was maintained at 130 psi(g) by regulator, rather than falling during the discharge.

4.5.2 *Effect of Agent Volatility*

As the quantity of each of the Halon replacement agents used was directly related to its *n*-heptane cup burner concentration, variations due to intrinsic agent efficiency were effectively cancelled out. Therefore, all other things being equal, all agents employed in the same manner should extinguish the same number of fires. To a first approximation this is the case, considering the small number of tests carried out. With exception of one extremely volatile agent (FE–25) and one agent of lower volatility (CEA–614) all agents extinguished 20 $\pm$ 2 fires. A 10% error margin is perfectly acceptable considering the range of permissible discharge times (10$\pm$1 s). Figure 4.3 plots percentage of fires extinguished against agent boiling point, and the correlation is reasonable. In fact, if the results for CEA–410 and FE–36 (bp for both agents –2°C) are examined in detail, it can be seen that the results are identical, not just in the numbers of fires extinguished, but also the patterns of extinguishment are the same. Triodide also extinguished 50% of the fires, but in a slightly different pattern.

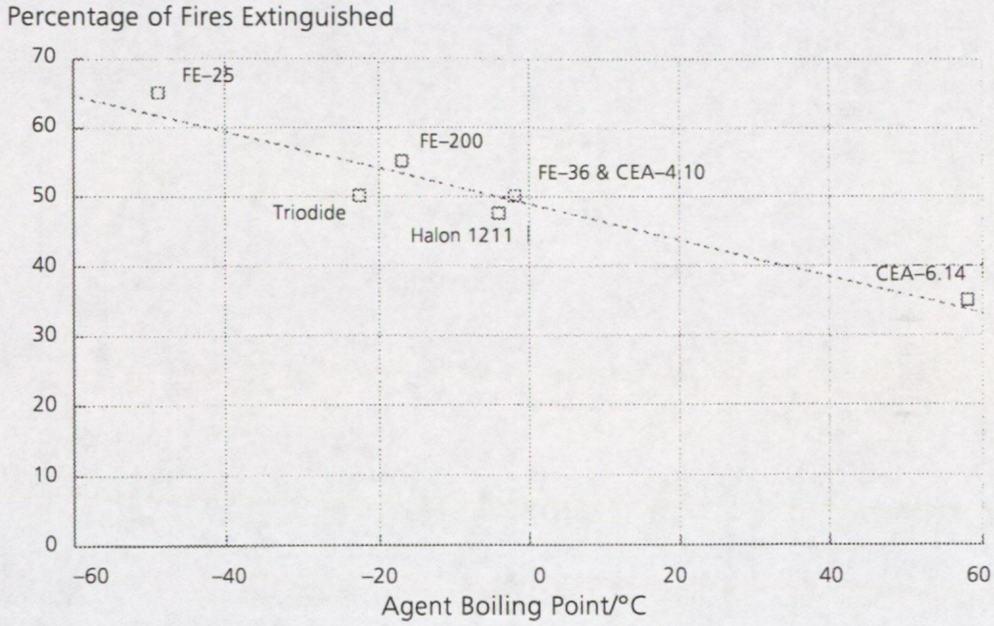


Figure 4.3 Effect of Agent Volatility

4.5.3 *Relative Performance of Replacement Agents*

The relative performance of the agents is summarised in Table 4.4 and Figures 4.4–4.5. Figure 4.4 is a histogram showing the mass of each of the six replacement agents, along with the percentage of the fires extinguished. This figure highlights the difference between the five physically acting agents and the two chemically acting agents (Halon 1211 and Triodide). On average the mass required is twice that of Halon 1211, whereas with Triodide, only 6% extra mass is required. Figure 4.5 plots a similar histogram on a liquid volume basis. Interestingly, much of the variation between the replacement agents has been removed. This is because the more volatile agents, of lower molecular weight, which tend to perform better, are typically less dense. The volume requirements range from 1.88 x Halon 1211 (FE-36) to 2.90 x Halon 1211 (FE-25). Only Triodide is comparable to Halon 1211, and due to its higher density, actually has a reduced volume requirement.

Table 4.4: Relative Performance of Replacement Agents for *n*-Heptane Fires

Agent	*Mass Used (kg)*	*Volume Required (L)*	*Relative Mass*	*Relative Volume*	*Percentage of n-Heptane Fires Extinguished*
Halon 1211	1.14	0.61	1	1	48
FM–200	1.94	1.36	1.71	2.22	55
FE–25	2.14	1.78	1.88	2.90	65
CEA–410	2.57	1.69	2.26	2.76	50
CEA–614	2.92	1.74	2.57	2.84	35
FE–36	1.58	1.15	1.39	1.88	50
Triodide	1.20	0.51	1.06	0.83	50

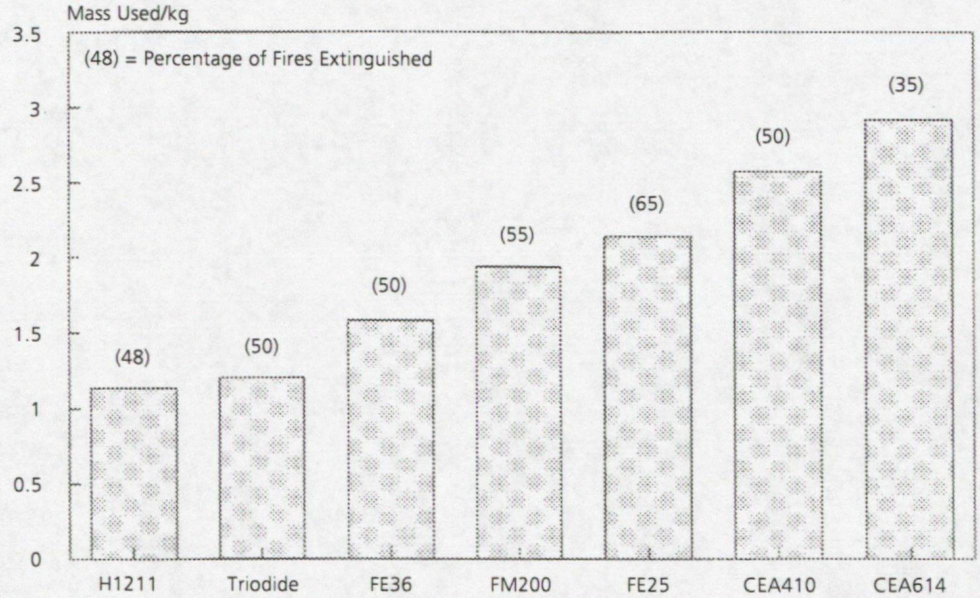


Figure 4.4: Agent Ranking by Weight

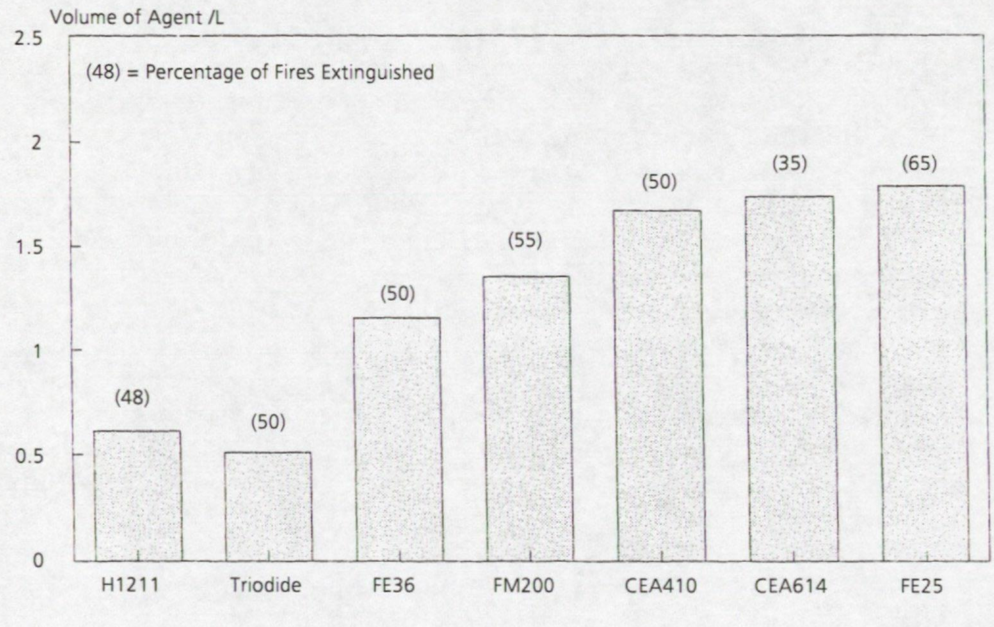


Figure 4.5: Agent Ranking by Liquid Volume

4.5.4 *Hand Extinguisher Size Implications*

If a physically acting agent is chosen, the size of the hand extinguisher is likely to be 2–3 times that of the current Halon 1211 hand extinguisher. This is based on the liquid volume of agent, and the fact that the headspace will also need to be increased to provide satisfactory discharge characteristics. If a chemically acting agent is chosen, then the size of the extinguisher need not necessarily be increased. However, it must be borne in mind that any hand extinguisher containing a replacement agent will still have to have obtained conventional ratings (currently UL 5B:C or BS 3A:34B for a 2.5 lb Halon 1211 hand extinguisher). It is likely that this rating will determine the size of the extinguisher, rather than the hidden fire challenge.

4.6 Results Obtained With Paper Fires

4.6.1 *General Observations*

The small paper fires exhibited much lower luminosity than the *n*-heptane fires and could only be observed (by eye and by the cameras) when in Zones D and E. In the two tests carried out, 6 out of 8 fires were extinguished in terms of gas phase combustion but one or two continued to smoulder, i.e. they exhibited true Class A behaviour. Halon suppressants in general require higher concentrations to either suppress, or more likely, control such fires [4,5].

4.6.2 *Results Obtained With Different Manufacturers' Hand Extinguishers*

The results obtained using the different manufacturer's extinguishers are summarised in Table 4.5, along with the corresponding results for *n*-heptane in Zones D and E. The results indicate that in broad terms, extinguishment of these small paper fires is easier than that of the *n*-heptane fires.

Table 4.5: Summary of Hand Extinguisher Results for Paper Fires

Extinguisher Details	*Percentage of Fires Extinguished*			
	Paper		*n-Heptane**	
Walter Kidde	75	(12/16)	56	(9/16)
Chubb	81	(13/16)	63	(10/16)
First Technology	88	(14/16)	63	(10/16)
Kidde Thorn	81	(13/16)	63	(10/16)

* Zones D and E only

4.6.3 *Results Obtained With Replacement Agents*

The paper fire extinguishment results are summarised in Table 4.6, along with the corresponding results for *n*-heptane in Zones D and E. As with the Halon 1211 results, the extinguishment of these small paper fires appears slightly easier than *n*-heptane fires in some cases, although the difference is less marked.

Table 4.6 Summary of Halon Replacement Agent Results for Paper Fires

Agent	*Percentage of Fires Extinguished*			
	Paper		*n-Heptane**	
Halon 1211	75	(6/8)	75	(6/8)
FE–25	75	(6/8)	75	(6/8)
FM–200	63	(5/8)	63	(5/8)
CEA–410	75	(6/8)	63	(5/8)
CEA–614	75	(6/8)	50	(4/8)
FE–36	63	(5/8)	63	(5/8)
Triodide	88	(7/8)	63	(5/8)

* Zones D and E only

5 CONCLUSIONS

A fire challenge has been developed which is suitable for evaluating the performance of hand-held extinguishers against hidden fires, such as those that can occur aboard aircraft. An outline of a possible draft test procedure is given in Appendix VI. It is envisaged that this hidden fire test will be used in conjunction with current Class A and Class B fire tests to define the minimum performance standard for hand held extinguishers containing Halon replacement agents. This is in order that the change to replacement agents be effected with no loss in safety over the levels provided by current hand extinguishers containing Halon 1211.

5.1 Validity of the Test Method

(1) The test procedure and test equipment has been shown to simulate hidden fires such as those that can occur below the floor in the cheek area and in the cabin behind side wall panels.

(2) The tests have been undertaken with both *n*-heptane fuel and shredded paper (of equivalent fire load). Since *n*-heptane fires are somewhat more difficult to suppress, it is concluded that, in future, evaluation tests could be limited to these.

(3) The test procedure and equipment appears to show equal sensitivity to the mass of agent used and to the rate of its deployment.

(4) Four different types of hand extinguisher (three of UK manufacture and one from the USA) containing Halon 1211 have been trialled against the procedure. Under standard conditions, the average proportion of *n*-heptane fires suppressed was 54%, actual values ranging from 45 to 60%. If there is to be no loss of safety, some form of average value should be used as the minimum performance standard. However, since three out of the four extinguisher types tested were of UK origin, it would be prudent to extend the testing to hand extinguishers manufactured in other countries, especially the USA, in order to achieve a better definition of the minimum performance standard.

5.2 Replacement Agent Performance

(1) Six different replacement agents were tested against the hidden fire challenge. Using an amount of each agent based on its intrinsic fire suppression capability, the relative performance of the six agents correlated well with agent volatility. Thus the procedure can be used along with other tests to evaluate the performance of hand extinguishers containing replacement agents against a Halon 1211 benchmark.

(2) There are likely to be significant weight and volume penalties in choosing physically acting Halon replacement agents. These penalties may be reduced or eliminated if a chemically acting agent is found acceptable.

References

[1] 'The Montreal Protocol on Substances that Deplete the Ozone Layer' Final Act, United Nations Environment Program, September 1987 and subsequent ammendments, (HMSO CM977).

[2] Federal Aviation Requirement 25.851, 'Fire Extinguishers', Section (a) 'Hand fire extinguishers', Part 6, Change 14 (1994).

[3] A Hamins, D Trees, K Seshadri & H K Chelliah; 'Evaluation of Nonpremixed Flames with Halogenated Fire Suppressants', *Combustion & Flame,* 99, (1994) 221(230.

[4] P C Cooke, P C Howell & D J Spring; 'Aircraft Cargo Bay Fire Suppression', *CAA Paper 91003*, March 1991.

[5] National Fire Codes 1984, Standard NFPA 12A, Section 2.4.3.

Appendix I Effect of Ambient Temperature

The table below shows the mass of Halon 1211 likely to evaporate under various ambient temperature conditions, and two different initial agent temperatures. Also given in the Table is a predicted Halon concentration assuming homogeneous distribution.

Table I.1 Effect of Initial Temperature on Anticipated Halon 1211 Concentration

	Initial Agent Temperature			
	10°C		*25°C*	
Initial Ambient Temperature (°C)	*Evaporating Mass (kg)*	*Halon Concentration (Vol %)*	*Evaporating ass (kg)*	*Halon Concentration Vol %)*
0	0.193	1.3	0.304	2.1
5	0.316	2.2	0.431	3.0
10	0.435	3.1	0.554	3.9
155	0.551	3.9	0.674	4.8
20	0.663	4.8	0.791	5.7
25	0.774	5.7	0.905	6.7

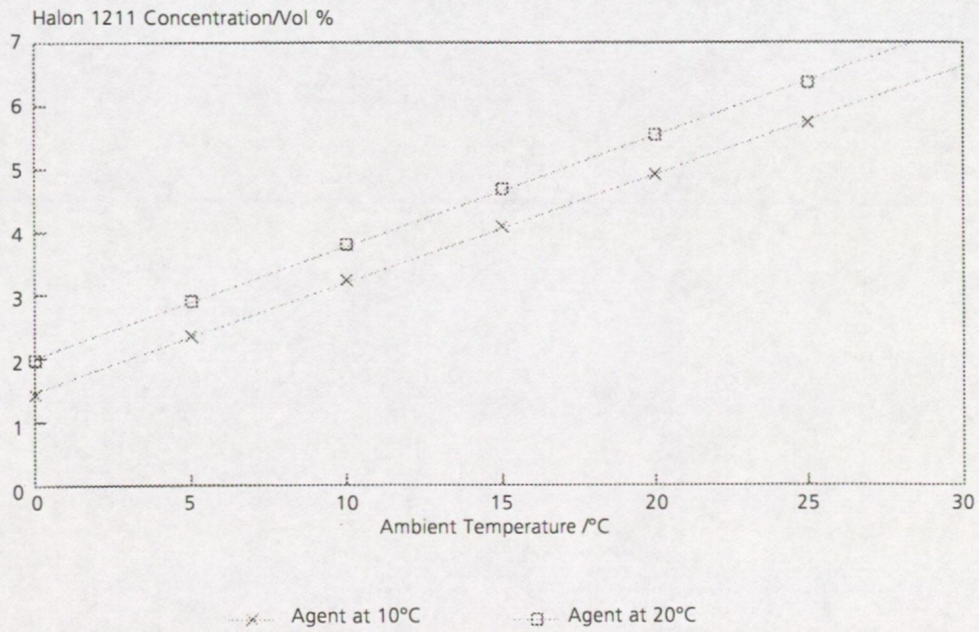


Figure I.1 Effect of Agent/Chamber Temperature

Appendix II Heat Output Calculations

A sample calculation for a 60 mm cup is shown below, and the relevant results for the three fire threats used are given in Table II.1.

Diameter of cup	=	60 mm
Fire Area	=	2830 mm^2
Mean Mass Loss	=	0.020 $g\ s^{-1}$
Heat of Combustion of *n*-heptane	=	44.4 $kJ\ g^{-1}$
Heat Output per Fire	=	44.44 x 0.020
	=	0.89 kW
Total Heat Output (8 fires)	=	7.1 kW

Table II.1 Heat Output Results

Case	*Two large n-Heptane Fires in Variant 1*	*Eight n-Heptane Fires Variants 2 & 3*	*Eight Paper Fires Variants 2 & 3*
Fire Diameter (mm)	76	35	80
Fire Area (mm^2)	4540	962	5030
Measured Mass Loss Rate over 60 s ($g\ s^{-1}$)	3.26×10^{-2}	7.73×10^{-3}	1.87×10^{-2}
Heat of Combustion of Fuel (kJ/g)	44.4	44.4	17.6
Heat Output of Single Fire (kW)	1.45	0.34	0.33
Total Heat Output (kW)	2.9	2.7	2.6

Note: The 'Total Heat Output' values given above do not allow for losses due to volatilisation and conduction to the fire container. However, as it is the relative values that are of interest, these losses can be neglected.

Appendix III

Table III.1 Properties of Halon Replacement Agents

Agent		*Halon 1211*	*FE–25*	*FE–36*	*FM–200*	*PFC–410*	*PFC–614*	*Triodide*
Chemical Formula		CF_2BrCl	C_2F_5H	$C_3F_6H_2$	C_3F_7H	C_4F_{10}	C_6F_{14}	CF_3I
Ozone Depletion Potential (ODP, CFC–11 = 1)		4	0.0	0.0	0.0	0.0	0.0	0.011
Halocarbon Global Warming Potential (HGWP, CFC–11 = 1)		–	0.58	–	0.3–0.6	18	6–12	–0?
100 Year GWP (CO_2 = 1)		–	3400	–	2050	5500	–	–0?
Atmospheric Lifetime (years)		25	41	–	31	2600	3000	1.15 days
Molecular Weight		165.4	120	152	170	238	338	196
Boiling Point (°C)		–4	–49	–2	–17	–2	+58	–22.5
Freezing Point (°C)		–161	–102?	–	–131	–128	(–90)*	–
Vapour Pressure (bar (abs) at 25°C)		2.8	12.9	1.75	4.5	2.9	0.31	4.38
Liquid Density (g cm^{-3} at 25°C)		1.8	1.25	1.37	1.43	1.52	1.68	2.36xx
Heat of Vaporisation (J g^{-1} at bp)		137	167#	162	132	96.3	88.4	112#
Specific	Liquid (J g^{-1} K^{-1} at 25 °C)	0.783	–	–	1.102	1.045	1.045	–
Heat	Vapour (J g^{-1} K^{-1} at 25 °C)	0.460	0.783	–	0.777	0.805	0.805	0.361
Lowest Conc Causing an Adverse Cardiotoxic Effect (LOAEL)		1.0	10.0	15.0	10.5	> 40	> 40	0.4
Highest Conc Causing No Adverse Cardiotoxic Effect (NOAEL)		0.5	7.5	10.0	9.0	40	40	0.2
Minimum Extinguishing Concentration (*n*–Heptane Cup burner)		3.5	9.1	5.3	5.8	5.5	4.4	3.1

\# estimated   * pour point   ** at –40°C   xx at –32°C   a Interpolated

Appendix IV Fire Extinguishment Results

Table IV.1 Halon 1211 Results Using Initial Test Configuration

Test Number	*Mass Halon 1211 (kg)*	*Extinction Time (s)*		*Temperature (°C)*		*Entry Point*	*Size of Baffles (m)*	
		Lower	*Upper*	*Ambient*	*Agent*		*Low*	*High*
1	1.14	5	188	11	11##	Mid	0.5	0.5
2	1.14	5	261	9	9##	Mid	0.5	0.5
3	Inadvertent Discharge . . . Null Test							
4	1.14	5	7	25#	9##	Mid	0.5	0.5
5	1.14	5	F	9	25	Mid	0.5	0.5
6	1.14	10	160	11	25	Mid	0.5	0.5
7	1.14	5	14	10	25	High	None	None
8	1.14	5	375	10	25	Mid	None	None
9	1.14	6.6	9.2	25	25	High	None	None

Notes:

\# Chamber very crudely heated; some 'hot-spots' probably aided agent vaporization.
\## During early tests agent temperature not controlled – probably ambient or slightly lower.
F Fire not extinguished within 300 s.

Table IV.2(A) Halon 1211 Results Using Variant 1

Test Number	*Mass Halon 1211 (kg)*	*Extinction Time (s)*		*Temperature (°C)*		*Size of Baffles (m)*		*Vent Height (mm)*
		Lower	*Upper*	*Chamber*	*Agent*	*Low*	*High*	
10	1.14	7.1	8.0	20	25	None	None	0
11	1.14	10.3	12.7	20	25	None	None	0
12	1.14	9.7	9.7	20	25	0.5	0.5	0
13	1.14	7.7	482*	23	25	0.5	0.5	100
14	1.14	10.4**	10.3**	23	25	0.5	0.5	50
15	1.14	8.0	8.8	24	25	0.5	0.5	50
16	1.14	12.5	12.5	24	25	0.5	0.5	75
17	1.14	10.9	10.9	24	25	0.5	0.5	100
18	1.14	6.7	F	24	25	0.5	0.5	100
19	1.14	6.8	10.3	21	25	0.5	0.5	100
20	1.14	11.7	11.7	20	25	0.5	0.5	100
21	1.14	10.3	9.7	21	25	0.5	0.5	100
22	1.14	9.3	10.9	20	25	0.5	0.5	75
23	1.14	8.7	15.7	20	25	0.5	0.5	75
24	1.14	13.5	12.8	20	25	0.5	0.5	75
25	1.14	10.2	10.2	20	25	0.5	0.5	125
26	1.14	9.9	10.9	20	25	0.5	0.5	125
27	1.14	7.6	10.0	20	25	0.5	0.5	125

* Fire ran out of fuel; thereafter any fire still alight after 60 s classed as a failure.

** Top fire extinguished first. Test repeated.

Table IV.2(B) Halon 1211 Results Using Variant 1 (continued)

Test Number	*Mass Halon 1211 (kg)*	*Extinction Time (s)*		*Temperature (°C)*		*Size of Baffles (m)*		*Vent Height (mm)*
		Lower	*Upper*	*Chamber*	*Agent*	*Low*	*High*	
28	1.14	7.2	11.0	20	25	0.5	0.5	175
29	1.14	11.2	11.2	20	25	0.5	0.5	200
30	1.14	9.9	9.9	20	25	0.5	0.5	200
31	1.14	14.5	11.3	20	25	0.5	0.5	250
32	1.14	10.9	10.0	20	25	0.5	0.5	250
33	1.14	8.7	12.1	20	25	0.5	0.5	200
34	1.14	10.9	F	21	25	0.5	0.5	200
35	1.14	8.7	F	20	25	0.5	0.5	200
36	1.14	12.1	F	20	25	0.5	0.5	200
37	1.14	10.0	F	20	25	0.5	0.5	200

Table IV.3 Halon 1211 Results Using Variant 2

Test Number	*Extinction Time at Location (s)*								*Temperature (°C)*		*Size of Baffles (m)*		*Vent Height (mm)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Agent*	*Chamber*	*Low*	*High*	
38	8.2	7.3	6.4	5.8	10.7	10.8	F	F	25	20	1.0	0.5	200
39	10.0	10.1	6.9	7.0	8.4	11.9	F	F	*	*	1.0	0.5	200
40	9.0	8.3	6.3	6.3	12.9	15.2	F	F	*	*	1.0	0.5	100
41	6.6	7.7	8.7	7.9	11.5	12.7	F	F	*	*	1.0	0.5	100
42	8.2	10.0	6.5	10.7	6.5	12.2	28.2	F	*	*	1.0	0.5	0
43	10.0	10.2	8.3	7.7	12.8	15.5	53.1	F	*	*	1.0	0.5	0
44	10.1	12.0	6.1	6.1	5.7	10.8	11.4	F	*	*	0.5	0.5	0
45	8.6	8.8	5.9	6.0	7.1	7.9	11.2	F	*	*	0.5	0.5	0
46	7.6	8.5	6.9	5.8	5.9	5.9	7.7	11.0	*	*	0.5	0.5	100 (low)
47	8.9	10.6	7.0	6.0	5.7	7.7	7.7	19.0	*	*	0.5	0.5	100 (low)
48	n.m	n.m	n.m	n.m	n.m	n.m	n.m	n.m	N/A	20	0.5	0.5	0
49	348	308	248	260	285	330	253	252	N/A	20	0.5	0.5	0

Note: In tests 48 and 49 no Halon was used in order to evaluate oxygen depletion caused by the fires, and to determine how long the fire would take to burn out due to fuel consumption.

n.m = not measured; data lost.

Table IV.4 Halon 1211 Results Using Variant 3

Test Number	*Fire Positions*	*Vent Height (mm)*	*Fire Extinction Time at Location (s)*							
			1	*2*	*3*	*4*	*1*	*2*	*3*	*4*
50	A & B	0	1.4	0.60	1.9	F	??	F	F	F
51	A & B	1200	1.5	1.5	F	F	F	F	F	F
52	A & B	400x125 (2 off)	1.1	1.1	0.9	F	2.4	F	F	F
53	A & B	"	1.4	0.7	1.5	2.4	3.7	F	F	F
54	A & B	"	1.1	0.6	1.0	1.0	2.6	F	F	F
55	B & C	"	0.8	F	F	F	8.1	F	F	F
56	B & C	"	0.8	F	F	F	11.7	F	F	F
57	C & D	"+ 100	8.8	F	F	F	F	F	F	F
58	C & D	400x125 (2 off)	7.6	F	F	F	5.7	F	F	F
59	D & E	"	4.0	4.4	10.7	10.7	F	F	F	F
60	D & E	"	2.6	2.9	4.1	5.6	9.1	F	F	F
61	D & E	"	3.0	3.3	5.7	4.7	11.1	F	F	F
62	D & E	+100mm at bottom	3.0	3.1	5.3	5.3	F	F	F	F
63	D & E	"	2.9	3.0	5.6	5.7	F	F	F	F
Class A Fire Tests: Only Positions A & E Used Due to Smoke Obscuration										
64	D & E	400 x 125	3.2	4.2	4.3	5.5	6.2	10.2	F	F
65	D & E	400 x 125	4.0	4.3	5.7	6.8	6.8	9.4	F	F

Agent Temperature 25°C   Chamber Temperature 20°C   'Mid' Entry Point

Table IV.5 'Standard' *Halon 1211 Baseline Results Obtained with WK Extinguisher

Test Details					*Fire Extinction Time(s) at Fire Location*							
Test Number	*Mass (kg)*	*Pressure (psi(g))*	*Discharge Time(s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
111	1.14	130	9.0	A & B	1.1	1.0	F	F	3.6	F	F	F
112	1.14	130	8.8	A & B	0.5	0.9	F	F	3.5	F	F	F
113	1.14	130	9.2	A & D	0.6	0.7	1.0	F	F	F	F	F
114	1.14	130	9.6	A & D	0.9	0.7	1.1	1.0	10.4	F	F	F
115	1.14	130	9.2	B & C	9.5	F	F	F	8.2	F	F	F
116	1.14	130	9.5	B & C	8.6	F	F	F	8.0	F	F	F
117	1.14	130	9.2	C & E	F	F	F	F	2.9	3.2	5.0	5.1
118	1.14	130	9.1	C & E	7.7	F	F	F	3.5	3.3	5.4	5.6
119	1.14	130	9.2	D & E	F	F	F	F	2.8	3.2	5.4	5.3
120	1.14	130	9.3	D & E	9.2	F	F	F	2.7	3.4	4.3	5.9
120A**	1.14	130	9.4	D & E	F	F	F	F	3.0	4.0	4.3	4.6

* Standard conditions: 2.5 lb Halon 1211, 130 psi(g).
** Test 120A was carried out for gas analysis purposes.

Total Number of Fires Extinguished: 36 out of 80 (45%).

Table IV.6 Effect of 20% More Agent

Test Details					*Fire Extinction Time(s) at Fire Location*							
Test Number	*Mass (kg)*	*Pressure (psi(g))*	*Discharge Time(s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
121	1.35	130	13.8	A & B	0.7	0.8	1.2	0.9	1.0	F	F	F
122	1.36	130	12.6	A & B	0.9	0.8	1.8	1.8	9.1	F	F	F
123	1.36	130	12.7	A & D	0.7	0.7	1.2	F	11.9	F	F	F
124	1.36	130	12.8	A & D	1.0	1.0	1.4	F	F	F	F	F
125	1.36	130	12.9	B & C	7.2	F	F	F	11.4	F	F	F
126	1.36	130	13.0	B & C	7.6	F	F	F	F	F	F	F
127	1.36	130	13.1	C & E	10.4	F	F	F	2.5	2.8	5.1	5.1
128	1.36	130	13.1	C & E	8.6	F	F	F	3.2	5.6	5.8	8.5
129	1.36	130	13.0	D & E	11.0	F	F	F	2.9	3.6	6.4	6.5
130	1.36	130	13.4	D & E	17.7	F	F	F	3.0	4.7	5.7	5.7

Total Number of Fires Extinguished: 40 out of 80 (50%).

Table IV.7 Effect of 20% Less Agent

Test Details					*Fire Extinction Time(s) at Fire Location*							
Test Number	*Mass (kg)*	*Pressure (psi(g))*	*Discharge Time(s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
101	0.91	130	6.2	A & B	1.1	0.9	1.0	F	1.1	F	F	F
102	0.91	130	6.6	A & B	1.4	1.0	4.9	F	5.3	F	F	F
103	0.91	130	6.3	A & D	1.0	0.9	F	1.2	F	F	F	F
104	0.91	130	6.6	A & D	0.7	0.9	1.5	F	F	F	F	F
105	0.91	130	6.6	B & C	1.0	F	F	F	F	F	F	F
106	0.91	130	6.5	B & C	1.2	F	F	F	F	F	F	F
107	0.91	130	6.4	C & E	F	F	F	F	2.7	3.1	5.5	5.5
108	0.91	130	6.2	C & E	F	F	F	F	2.9	3.6	5.1	5.2
109	0.91	130	6.3	D & E	F	F	F	F	2.8	4.6	5.4	5.4
110	0.91	130	6.3	D & E	F	F	F	F	2.8	3.3	5.2	4.5
110A*	0.91	130	6.7	D & E	12.3	F	F	F	3.0	4.3	4.8	5.2

* Test 110A was carried out for gas analysis purposes. Total Number of Fires Extinguished: 32 out of 80 (40%).

Table IV.8 Effect of Higher Pressure

Test Details					*Fire Extinction Time(s) at Fire Location*							
Test Number	*Mass (kg)*	*Pressure (psi(g))*	*Discharge Time(s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
131	1.14	220	7.2	A & B	0.4	0.6	F	F	9.8	F	F	F
132	1.14	220	6.8	A & B	0.4	0.5	1.4	1.7	2.0	F	F	F
133	1.14	220	7.0	A & D	0.5	0.4	1.4	F	4.8	F	F	F
134	1.14	220	7.0	A & D	0.5	0.5	0.9	0.8	5.2	F	F	F
135	1.14	220	6.5	B & C	2.7	F	F	F	7.2	F	F	F
136	1.14	220	6.6	B & C	7.0	F	F	F	7.0	F	F	F
137	1.14	220	7.2	C & E	8.9	F	F	F	2.4	3.2	3.7	5.8
138	1.14	220	7.2	C & E	7.7	F	F	F	2.7	3.3	4.4	4.9
139	1.14	220	7.2	D & E	5.6	F	F	F	2.9	2.9	3.7	4.5
140	1.14	220	7.2	D & E	8.8	F	F	F	3.1	3.0	3.5	6.2

Total Number of Fires Extinguished: 41 out of 80 (53%).

Table IV.9 Effect of Lower Pressure

Test Details					*Fire Extinction Time(s) at Fire Location*							
Test Number	*Mass (kg)*	*Pressure (psi(g))*	*Discharge Time(s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
141	1.14	100	12.0	A & B	1.4	1.1	1.7	F	F	F	F	F
142	1.14	100	11.1	A & B	1.1	1.2	F	F	12.9	F	F	F
143	1.14	100	11.5	A & D	0.7	0.7	1.1	F	F	F	F	F
144	1.14	100	11.1	A & D	1.1	0.7	F	F	F	F	F	F
145	1.14	100	12.8	B & C	13.0	F	F	F	F	F	F	F
146	1.14	100	10.9	B & C	9.4	F	F	F	F	F	F	F
147	1.14	100	10.5	C & E	9.8	F	F	F	2.8	3.3	6.3	6.4
148	1.14	100	11.3	C & E	14.4	F	F	F	2.7	2.8	5.7	5.4
149	1.14	100	11.3	D & E	F	F	F	F	3.0	3.1	6.9	9.6
150	1.14	100	11.6	D & E	12.4	F	F	F	3.2	6.2	5.5	10.4

Total Number of Fires Extinguished: 32 out of 80 (40%).

Table IV.10 Results Obtained with Chubb Extinguisher

Hardware Details						*Extinction Time(s)*							
Test Number	*Fuel*	*Mass (kg)*	*Nominal Pressure (psi(g))*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
313*	*n*-heptane	1.44	145	18.6	A & B	0.3	0.3	0.4	0.9	2.3	F	F	F
302	*n*-heptane	1.46	145	16.8	A & B	0.5	0.3	0.6	1.0	2.3	F	F	F
314*	*n*-heptane	1.46	145	20.0	A & D	0.7	0.3	F	F	10.3	F	F	F
304	*n*-heptane	1.46	145	15.2	A & D	0.3	0.3	F	F	5.3	F	F	F
305	*n*-heptane	1.46	145	19.3	B & C	6.8	F	F	F	10.9	F	F	F
306	*n*-heptane	1.49	145	15.6	B & C	7.3	F	F	F	6.5	F	F	F
307	*n*-heptane	1.51	145	13.8	C & E	8.0	F	F	F	1.7	2.3	3.3	3.6
308	*n*-heptane	1.46	145	18.0	C & E	11.0	F	F	F	3.1	3.1	5.2	8.9
309	*n*-heptane	1.47	145	18.6	D & E	5.0	F	F	F	2.4	2.5	5.5	5.0
316*	*n*-heptane	1.48	145	18.0	D & E	11.7	F	F	F	3.0	3.3	4.5	4.8
Mean Values		**1.47**	**145**	**17.4**	**Total Number of Fires Extinguished: 40 out of 80 (50%)**								
311	Paper	1.46	145	18.2	D & E	5.5	8.4	20.5	F	2.3	2.3	3.8	4.7
312	Paper	1.47	145	17.1	D & E	4.6	8.6	F	F	2.7	2.8	3.1	3.7

* Tests 301, 303 and 310 all had long discharge times (in excess of 20 s) and were therefore repeated.

Summary: *n*-heptane 50% Extinguishment
Paper 88% Extinguishment

Table IV.11 Results Obtained with First Technology Extinguisher

		Hardware Details				*Extinction Time(s)*							
Test Number	*Fuel*	*Mass (kg)*	*Nominal Pressure (psi(g))*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
201	*n*-heptane	1.06	125	–	A & B	0.5	0.5	0.5	1.6	6.4	F	F	F
203	*n*-heptane	1.06	125	10.2	A & B	0.4	0.4	0.9	F	1.3	F	F	F
204	*n*-heptane	1.06	125	9.1	A & D	0.4	0.4	0.4	1.4	6.4	6.4	F	F
205	*n*-heptane	1.06	125	–	A & D	0.4	0.4	1.0	1.3	5.7	5.7	F	F
207	*n*-heptane	1.07	125	8.8	D & D	5.4	F	F	F	5.8	3.8	4.2	6.3
208	*n*-heptane	1.06	125	8.9	D & D	6.9	F	F	F	4.4	4.1	3.9	4.3
209	*n*-heptane	1.18	125	9.4	B & C	1.8	2.0	F	F	8.4	F	F	F
210	*n*-heptane	1.05	125	10.04	B & C	0.3	8.0	F	F	7.1	F	F	F
211	*n*-heptane	1.05	125	–	C & E	8.9	F	F	F	2.4	2.7	3.6	5.7
212	*n*-heptane	1.04	125	–	C & E	5.8	F	F	F	3.4	3.7	4.8	5.6
Mean Values		**1.07**	**125**	**9.4***	**Total Number of Fires Extinguished: 41 out of 80 (59%)**								
206	Paper	–	125	–	D & E	5.7	4.4	> 5	> 5	2.4	2.4	2.4	4.6
215	Paper	1.07	125	10.6	D & E	6.3	11.4	F	F	3.8	3.6	3.9	8.0

Summary: *n*-heptane 50% Extinguishment
Paper 88% Extinguishment

* Mean of only 6 values, due to difficulties in measuring discharge times.

Table IV.12 Results Obtained with Kidde Thorn Extinguisher

Hardware Details					*Extinction Time(s)*								
Test Number	*Fuel*	*Mass (kg)*	*Nominal Pressure (psi(g))*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
401	*n*-heptane	1.45	130	9.6	A & B	0.7	0.7	0.7	0.9	0.7	1.2	1.0	F
402	*n*-heptane	1.43	130	10.0	A & B	0.3	0.3	0.7	1.0	0.9	F	F	F
403	*n*-heptane	1.44	130	9.6	A & D	0.8	0.6	0.7	0.9	4.7	8.9	F	F
404	*n*-heptane	1.43	130	9.9	A & D	0.5	0.5	0.6	0.6	9.2	F	F	F
405	*n*-heptane	1.41	130	9.4	B & C	1.5	F	F	F	6.7	F	F	F
406	*n*-heptane	1.44	130	9.6	B & C	1.4	0.7	F	F	6.6	F	F	F
407	*n*-heptane	1.44	130	10.3	C & E	6.7	F	F	F	2.9	2.9	4.9	5.2
408	*n*-heptane	1.45	130	10.3	C & E	6.7	F	F	F	2.6	2.6	3.0	5.4
409	*n*-heptane	1.44	130	9.7	D & E	8.7	F	F	F	2.8	2.9	3.0	5.0
410	*n*-heptane	1.45	130	9.6	D & E	8.3	F	F	F	2.0	2.8	2.9	3.9
Mean Values		**1.44**	**130**	**9.8**	**Total Number of Fires Extinguished: 48 out of 80 (60%)**								
411	Paper	1.45	130	8.3	D & E	6.5	27.4	45.0	F	2.8	3.2	4.4	5.0
412	Paper	1.44	130	8.6	D & E	4.3	18.2	F	F	2.9	3.3	3.5	4.2

Summary: *n*-heptane 60% Extinguishment
Paper 81% Extinguishment

Table IV.13 Halon 1211 Baseline Results Obtained with Constant Pressure Apparatus

Test Details						*Extinction Time(s) at Fire Locations*							
Test Number	*Fuel*	*Mass (kg)*	*Nozzle Orifice (mm)*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
1001	*n*-heptane	1.14	2.0	9.6	A & B	0.4	0.4	F	F	7.5	F	F	F
1002	*n*-heptane	1.14	2.0	9.5	A & B	0.6	0.4	F	F	10.1	F	F	F
1003	*n*-heptane	1.14	2.0	9.6	B & C	0.8	F	F	F	8.0	F	F	F
1004	*n*-heptane	1.14	2.0	9.5	C & E	8.7	8.8	F	F	3.9	5.8	6.1	6.4
1005	*n*-heptane	1.14	2.0	9.4	D & E	6.6	11.4	F	F	3.8	3.0	3.6	6.1
Mean Values		**1.14**	**2.0**	**9.5**	**Total Number of Fires Extinguished: 19 out of 40 (48%)**								
1006	Paper	1.14	2.0	9.5	D & E	6.6	11.4	F	F	3.5	3.5	3.6	4.1

Table IV.14 FE-25 Results obtained with Constant Pressure Apparatus

Test Details						*Extinction Time(s) at Fire Locations*							
Test Number	*Fuel*	*Mass (kg)*	*Nozzle Orifice (mm)*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
1020	*n*-heptane	2.14	3.7	10.7	A & B	0.4	0.4	2.9	3.0	5.7	6.3	F	F
1021	*n*-heptane	2.14	3.7	11.0	A & D	0.3	0.8	4.1	F	10.3	10.7	F	F
1022	*n*-heptane	2.14	3.7	10.7	B & C	4.6	F	F	F	4.7	4.9	F	F
1023	*n*-heptane	2.14	3.7	10.7	C & E	5.5	6.6	F	F	3.7	4.9	5.9	6.3
1024	*n*-heptane	2.14	3.7	10.7	D & E	6.5	9.5	F	F	3.6	3.8	6.0	7.5
Mean Values		**2.14**	**3.7**	**10.8**	**Total Number of Fires Extinguished: 26 out of 40 (55%)**								
1025	Paper	2.14	3.7	9.5	D & E	6.6	11.4	F	F	3.5	3.5	3.6	4.1

Table IV.15 FM-200 Results obtained with Constant Pressure Apparatus

Test Details						*Extinction Time(s) at Fire Locations*							
Test Number	*Fuel*	*Mass (kg)*	*Nozzle Orifice (mm)*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
1011	*n*-heptane	1.94	2.7	10.4	A & B	0.7	0.6	1.7	F	6.8	F	F	F
1011	*n*-heptane	1.94	2.7	10.5	A & D	0.6	0.4	2.6	F	8.2	F	F	F
1012	*n*-heptane	1.94	2.7	9.9	B & C	1.7	F	F	F	10.5	12.2	F	F
1013	*n*-heptane	1.94	2.7	10.2	C & E	8.3	10.6	F	F	4.7	4.4	5.9	7.9
1014	*n*-heptane	1.94	2.7	10.4	D & E	9.3	F	F	F	4.5	5.9	6.8	7.8
Mean Values		**1.94**	**2.7**	**10.3**	**Total Number of Fires Extinguished: 22 out of 40 (55%)**								
1015	Paper	1.94	2.7	10.6	D & E	9.7	F	F	F	3.8	4.5	5.2	8.9

Table IV.16 CEA-410 Results obtained with Constant Pressure Apparatus

Test Details					Extinction Time(s) at Fire Locations								
Test Number	Fuel	Mass (kg)	Nozzle Orifice (mm)	Discharge Time (s)	Fire Zones	1	2	3	4	1	2	3	4
1040	*n*-heptane	2.57	3.3	9.0	A & B	0.5	0.4	1.9	4.9	5.5	F	F	F
1041	*n*-heptane	2.57	3.1	10.2	A & B	0.6	0.4	F	F	6.9	F	F	F
1042	*n*-heptane	2.57	3.1	10.2	B & C	8.1	F	F	F	8.7	F	F	F
1043	*n*-heptane	2.57	3.1	10.2	C & E	8.8	F	F	F	2.9	4.2	6.0	6.5
1044	*n*-heptane	2.57	3.1	10.0	D & E	8.5	F	F	F	2.9	3.7	5.6	6.6
Mean Values		**2.57**	**3.1**	**9.9**	**Total Number of Fires Extinguished: 20 out of 40 (50%)**								
1045	Paper	2.57	3.1	10.1	D & E	8.2	9.0	F	F	3.6	4.6	6.1	7.9

Table IV.17 CEA-614 Results obtained with Constant Pressure Apparatus

Test Details					Extinction Time(s) at Fire Locations								
Test Number	Fuel	Mass (kg)	Nozzle Orifice (mm)	Discharge Time (s)	Fire Zones	1	2	3	4	1	2	3	4
1050	*n*-heptane	2.92	3.1	10.2	A & B	0.9	2.3	F	F	F	F	F	F
1051	*n*-heptane	2.92	3.1	10.3	A & D	12.8	F	F	F	11.8	F	F	F
1052	*n*-heptane	2.92	3.1	10.5	A & C	1.5	0.6	F	F	F	F	F	F
1053	*n*-heptane	2.92	3.1	10.7	C & E	F	F	F	F	7.5	10.0	12.7	10.2
1054	*n*-heptane	2.92	3.1	10.3	D & E	6.3	8.0	10.8	12.4	F	F	F	F
Mean Values		**2.92**	**3.1**	**10.4**	**Total Number of Fires Extinguished: 14 out of 40 (35%)**								
1055	Paper	2.92	3.1	10.5	D & E	9.5	14.3	F	F	F	F	F	F

Table IV.18 FE-36 Results Obtained with Constant Pressure Apparatus

Test Details						Extinction Time(s) at Fire Locations							
Test Number	*Fuel*	*Mass (kg)*	*Nozzle Orifice (mm)*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
1030	*n*-heptane	1.58	2.6	9.5	A & B	0.3	0.5	4.4	4.8	10.0	F	F	F
1031	*n*-heptane	1.58	2.6	9.9	A & D	1.1	0.4	F	F	8.7	F	F	F
1032	*n*-heptane	1.58	2.6	9.7	B & C	3.1	F	F	F	10.9	F	F	F
1033	*n*-heptane	1.58	2.6	9.7	C & E	11.7	F	F	F	3.8	5.3	5.7	6.9
1034	*n*-heptane	1.58	2.6	9.4	D & E	9.9	F	F	F	4.7	5.4	5.8	7.0
Mean Values		**1.58**	**2.6**	**9.6**	**Total Number of Fires Extinguished: 20 out of 40 (50%)**								
1035	Paper	1.58	2.6	9.4	D & E	9.5	F	F	F	4.3	4.9	5.1	6.5

Table IV.19 Triodide Results Obtained with Constant Pressure Apparatus

Test Details						Extinction Time(s) at Fire Locations							
Test Number	*Fuel*	*Mass (kg)*	*Nozzle Orifice (mm)*	*Discharge Time (s)*	*Fire Zones*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
1060	*n*-heptane	1.20	1.8	10.9	A & B	1.3	0.4	9.3	F	4.2	F	F	F
1061	*n*-heptane	1.20	1.9	9.8	A & D	0.2	0.2	1.3	F	8.4	F	F	F
1062	*n*-heptane	1.20	1.9	9.8	B & C	1.3	F	F	F	10.0	F	F	F
1063	*n*-heptane	1.20	1.9	9.8	C & E	8.6	F	F	F	2.5	3.3	5.0	6.0
1064	*n*-heptane	1.20	1.9	9.8	D & E	6.0	F	F	F	2.5	3.2	5.8	5.1
Mean Values		**1.20**	**1.9**	**10.0**	**Total Number of Fires Extinguished: 20 out of 40 (50%)**								
1065	Paper	1.20	1.9	9.9	D & E	6.0	12.0	35.0	F	2.5	3.7	4.6	6.0

Appendix V Gas Analysis Results

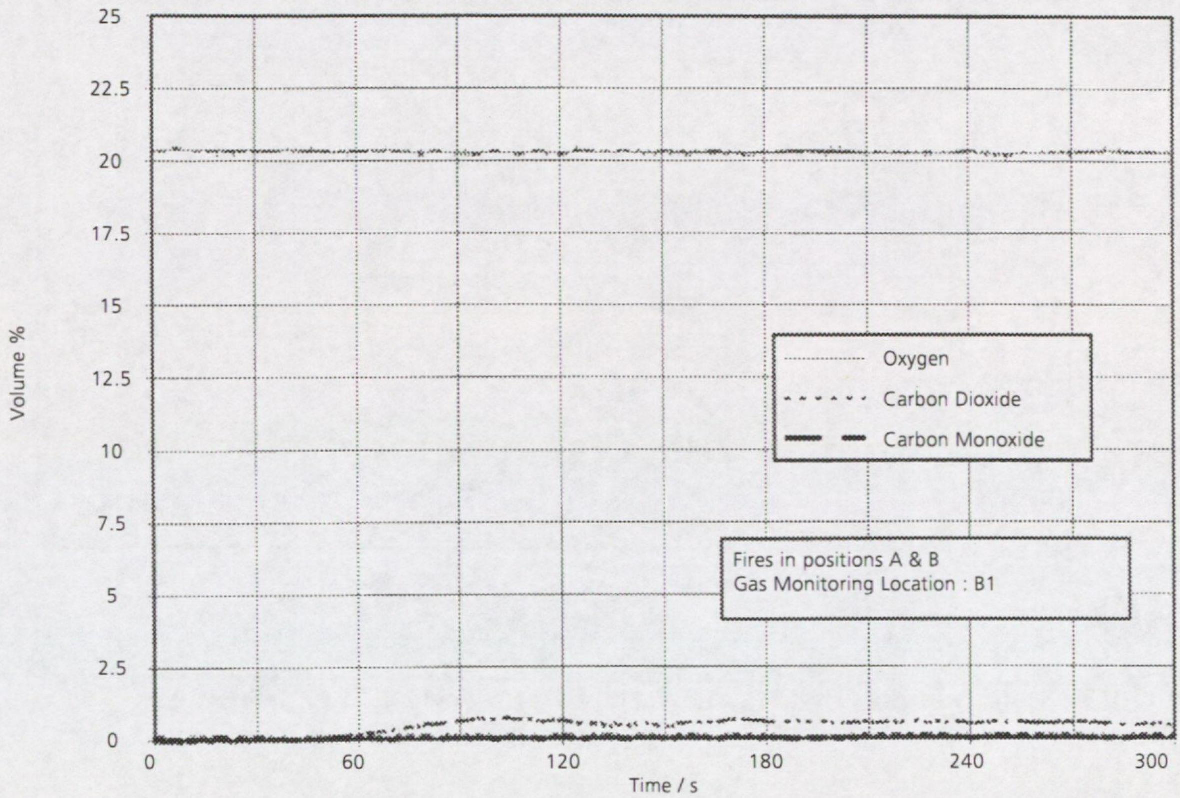


Figure V.1 Assessment of Oxygen Depletion in Variant 3

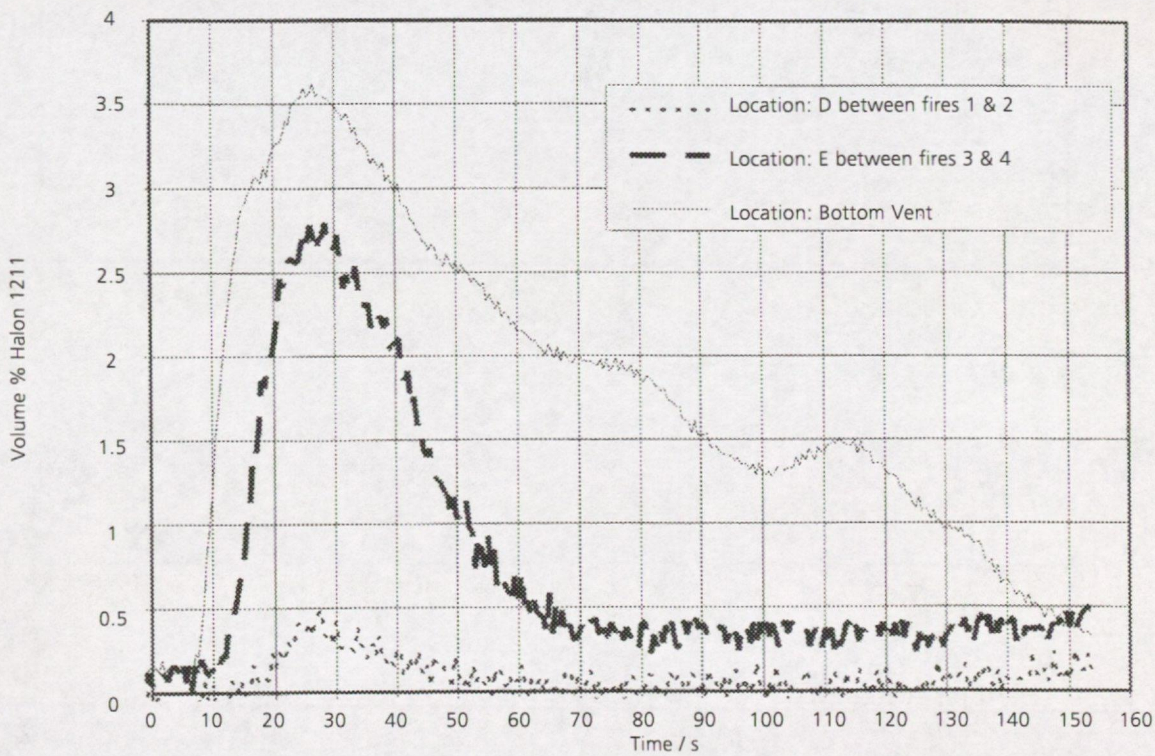


Figure V.2 Halonyser Results: Test 110A (0.91 kg Halon 1211, 130 psi(g))

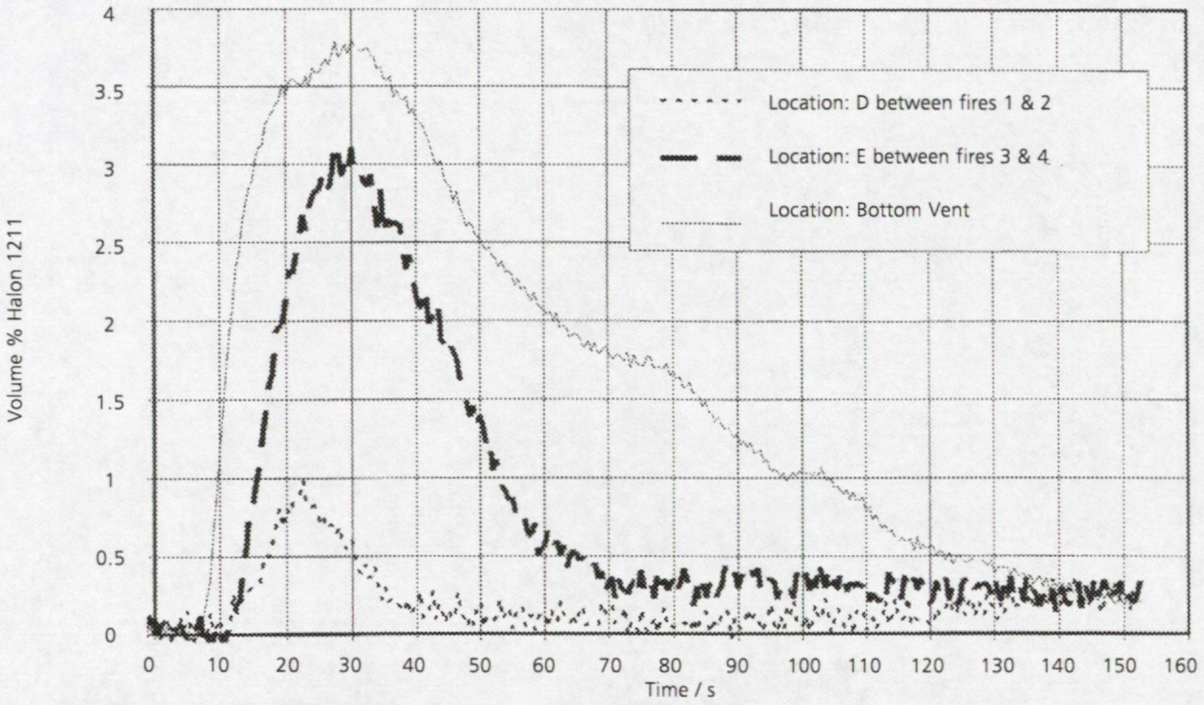


Figure V.3 Halonyser Results: Test 120A (1.14 kg Halon 1211, 130 psi(g))

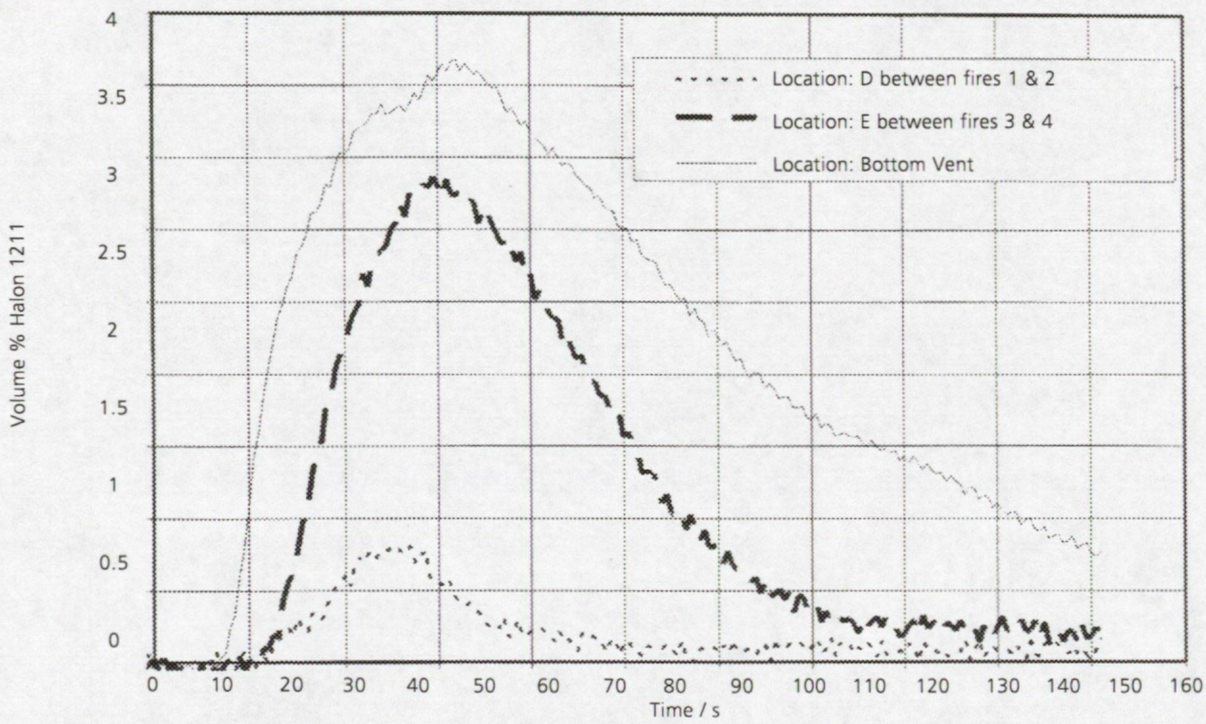


Figure V.4 Halonyser Results: Test 130 (1.36 kg Halon 1211, 130 psi(g))

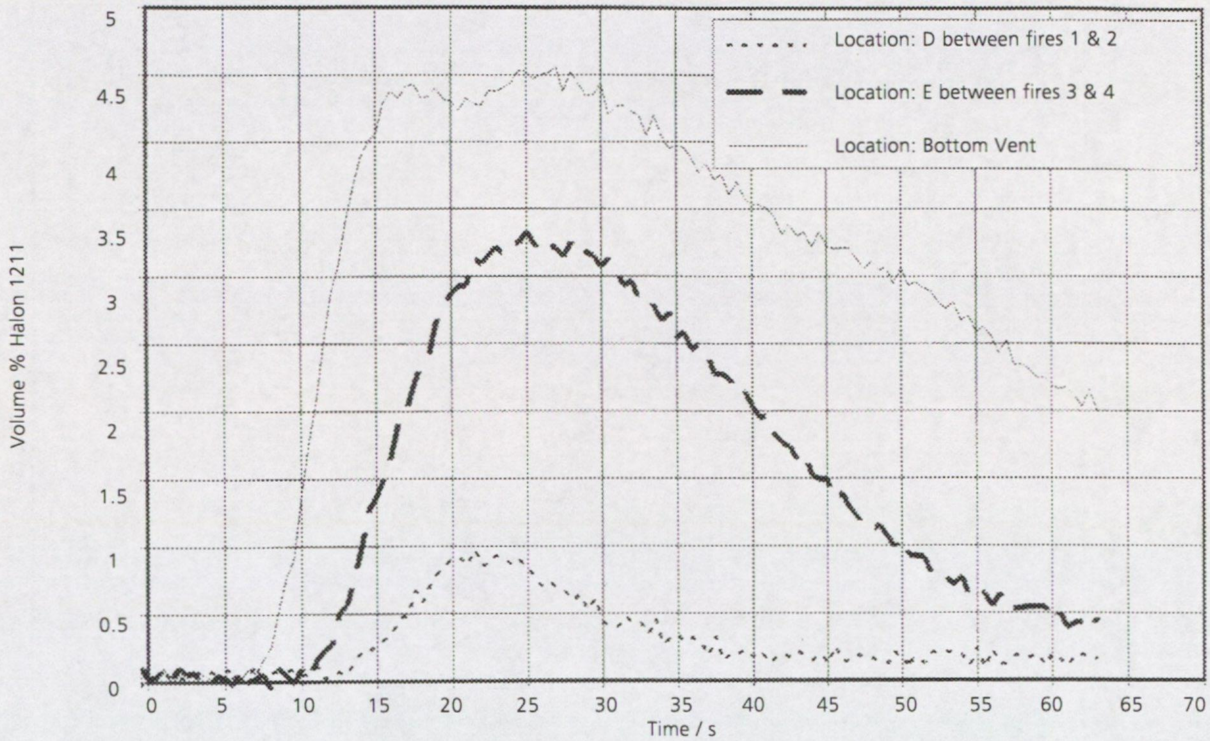


Figure V.5 Halonyser Results: Test 140 (1.14 kg Halon 1211, 220 psi(g))

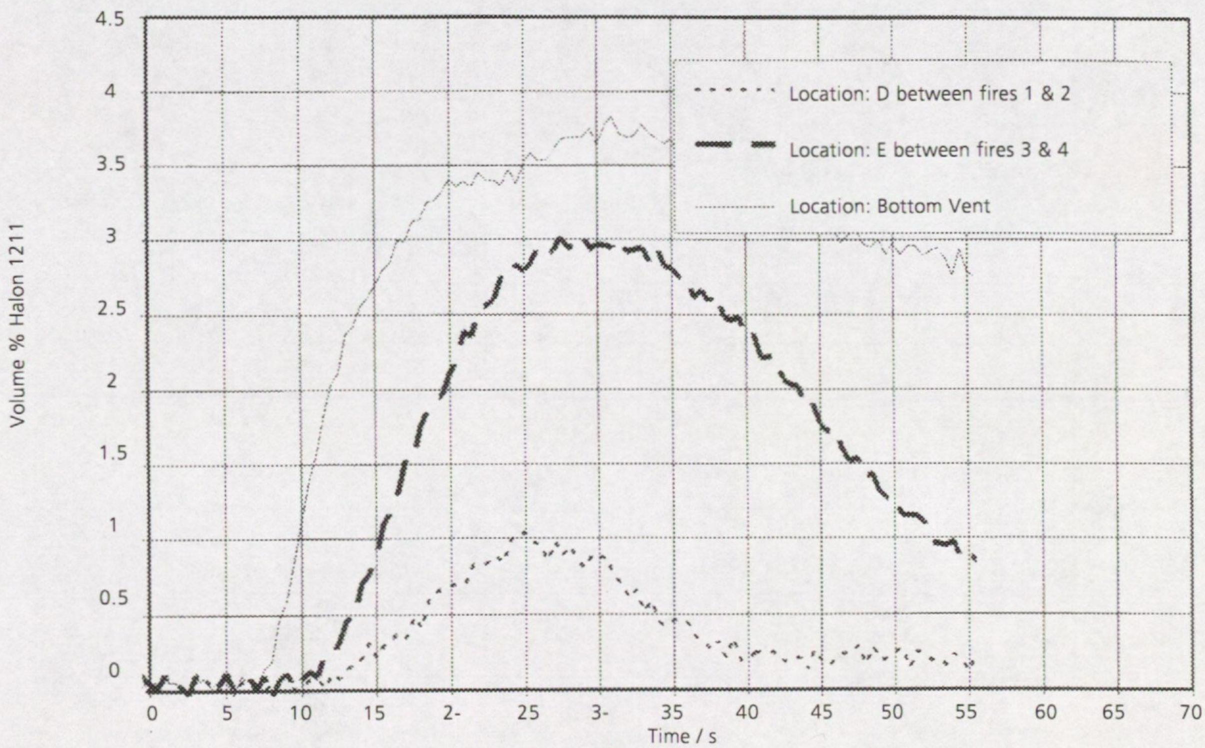


Figure V.6 Halonyser Results: Test 149 (1.14 kg Halon 1211, 100 psi(g))

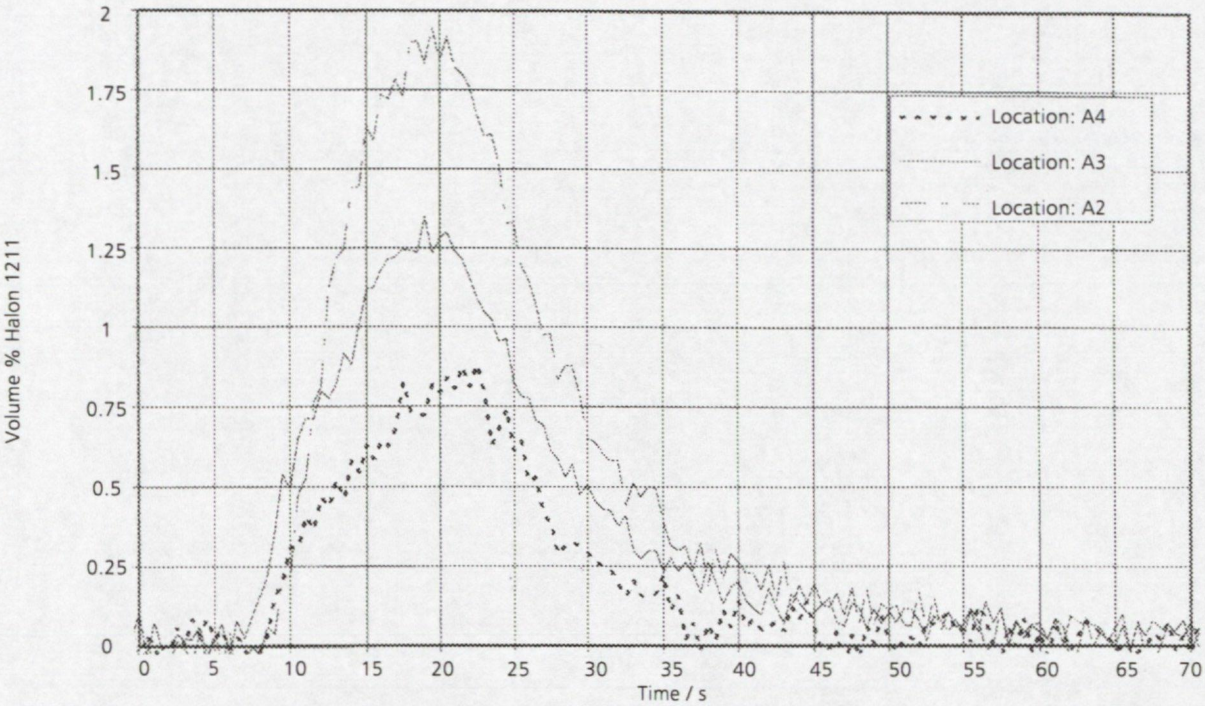


Figure V.7 Halonyser Results: Test 154 (1.14 kg Halon 1211, 220 psi(g))

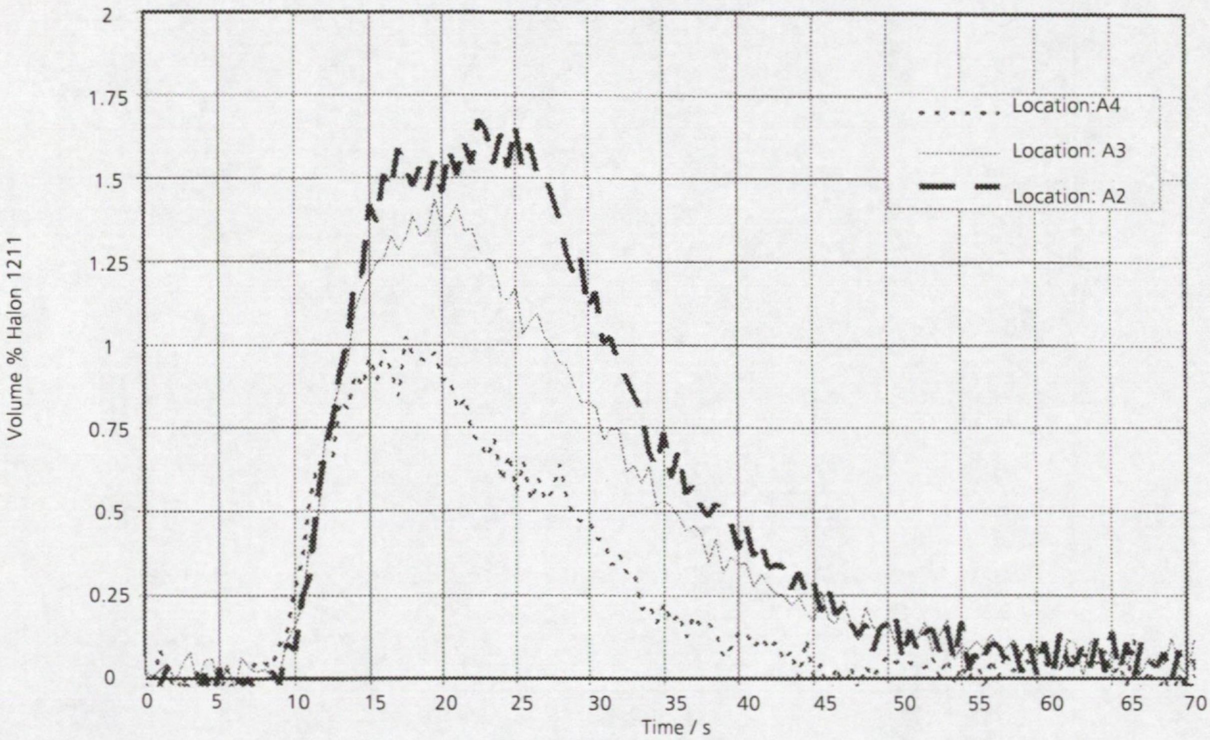


Figure V.8 Halonyser Results: Test 156 (1.36 kg Halon 1211, 130 psi(g))

Appendix VI Proposed Draft Test Standard

VI.1 TEST FIXTURE

The test fixture shall be 2 ± 0.050 m high, 2 ± 0.050 m long and 0.5 ± 0.025 m wide, fabricated from 0.9 ± 0.1 mm sheet steel, as shown in Figure VI.1 (see also Figures 2.5 & 2.7 for reference). The temperature within the test fixture shall be maintained at 21 ± 1°C (70 ± 2°F). The agent shall be introduced through a hole positioned centrally in one of the end walls of the test chamber. The internal baffles shall comprise 33% hole area, and shall occupy the upper half of the test fixture, adjacent to the end wall through which the agent is injected. The baffle plates shall extend to the side walls and the roof. The spacing between the baffle plates shall be not less than 0.300 mm and not more than 0.350 m (refer to Figure VI.1). The solid 'stop' plates shall be 0.300 ± 0.025 m, centrally aligned with the agent injection point. Transparent plastic windows will be placed either at one end, or along one side of the test fixture to allow observation (or preferably video recording) of fire extinction times.

VI.2 FIRE THREATS

The *n*-heptane fire cups shall be 35 ± 2 mm in diameter, and are positioned in two arrays of four as shown in Figure VI.1. The fire cups shall be charged with 5 ± 1 mL *n*-heptane, floated on 10 ± 2 mL water. The trays for the paper fires shall be made from the same perforated material as the baffle plates, and shall be 80 ± 5 mm in diameter, 60 ± 5 mm deep. The fire load shall be 8 ± 0.1 g shredded white 80 g.s.m. copier paper, dosed with 1 ± 0.1 mL *n*-heptane to aid ignition.

VI.3 TEST PROCEDURE

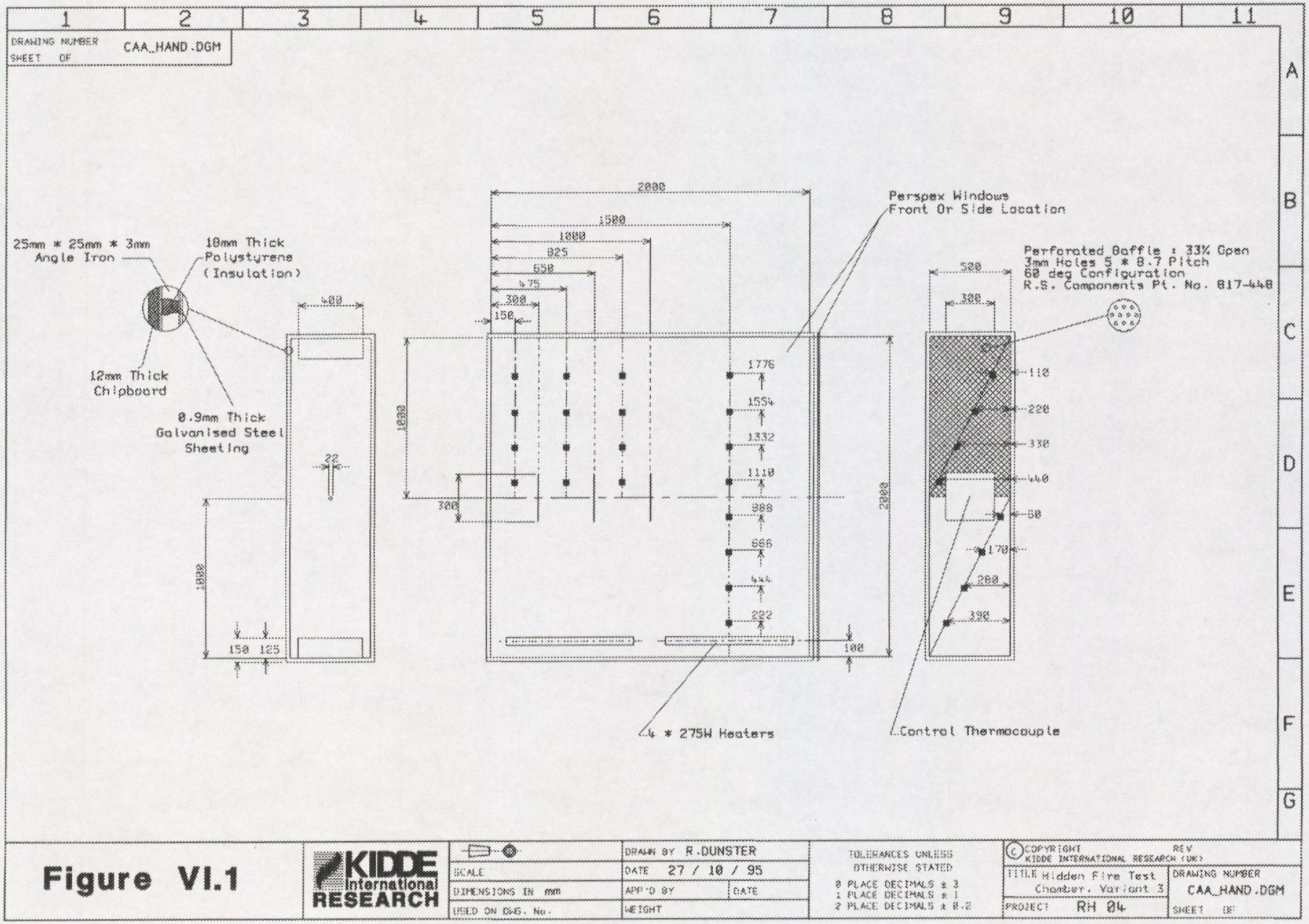
The extinguisher is charged with the agent then equilibrated at 25°C for a minimum of 15 minutes in a temperature controlled water bath. The fires are positioned in the correct zones, charged with water and *n*-heptane and ignited. Any access doors or windows are closed at this time. A pre-burn of 60 seconds is allowed, after which the agent is discharged. The discharge time and the fire extinction times shall be noted. Any fires remaining alight 60 seconds after discharge are classed as failed suppressions, and are to be extinguished manually. The chamber should then be thoroughly vented to remove both the acrid decomposition products and traces of agent which might otherwise affect the outcome of the following test. A suggested test matrix is outlined below:

Test No	Fires in Locations
1	A & B
2	A & B
3	B & C
4	B & C
5	A & D
6	A & D
7	C & E
8	C & E
9	D & E
10	D & E

Thus each location is tested four times, in two different configurations.

VI.4 PRESENTATION OF RESULTS

For each fire location the aggregate number of successful and failed suppressions shall be plotted in a figure similar to 3.2. The overall percentage extinguishment for *n*-heptane fires shall be calculated and compared to the minimum performance standard, which is yet to be defined.



DRAWING NUMBER CAA_HAND.DGM
SHEET OF
25mm * 25mm * 3mm Angle Iron
18mm Thick Polystyrene (Insulation)
12mm Thick Chipboard
0.9mm Thick Galvanised Steel Sheeting
400
22
1000
150
125
2000
1500
1000
825
650
475
300
150
300
1776
1554
1332
1110
888
666
444
222
100
Perspex Windows Front Or Side Location
Perforated Baffle : 33% Open
3mm Holes 5 * 8.7 Pitch
60 deg Configuration
R.S. Components Pt. No. 817-440
500
300
110
220
330
440
50
170
280
390
4 * 275W Heaters
Control Thermocouple
KIDDE International RESEARCH
SCALE
DIMENSIONS IN mm
USED ON DWG. No.
DRAWN BY R.DUNSTER
DATE 27 / 10 / 95
APP'D BY
DATE
WEIGHT
TOLERANCES UNLESS OTHERWISE STATED
0 PLACE DECIMALS ± 3
1 PLACE DECIMALS ± 1
2 PLACE DECIMALS ± 0.2
COPYRIGHT KIDDE INTERNATIONAL RESEARCH (UK)
REV
TITLE Hidden Fire Test Chamber, Variant 3
PROJECT RH 04
DRAWING NUMBER CAA_HAND.DGM
SHEET OF

Figure VI.1

Appendix VII Photographs

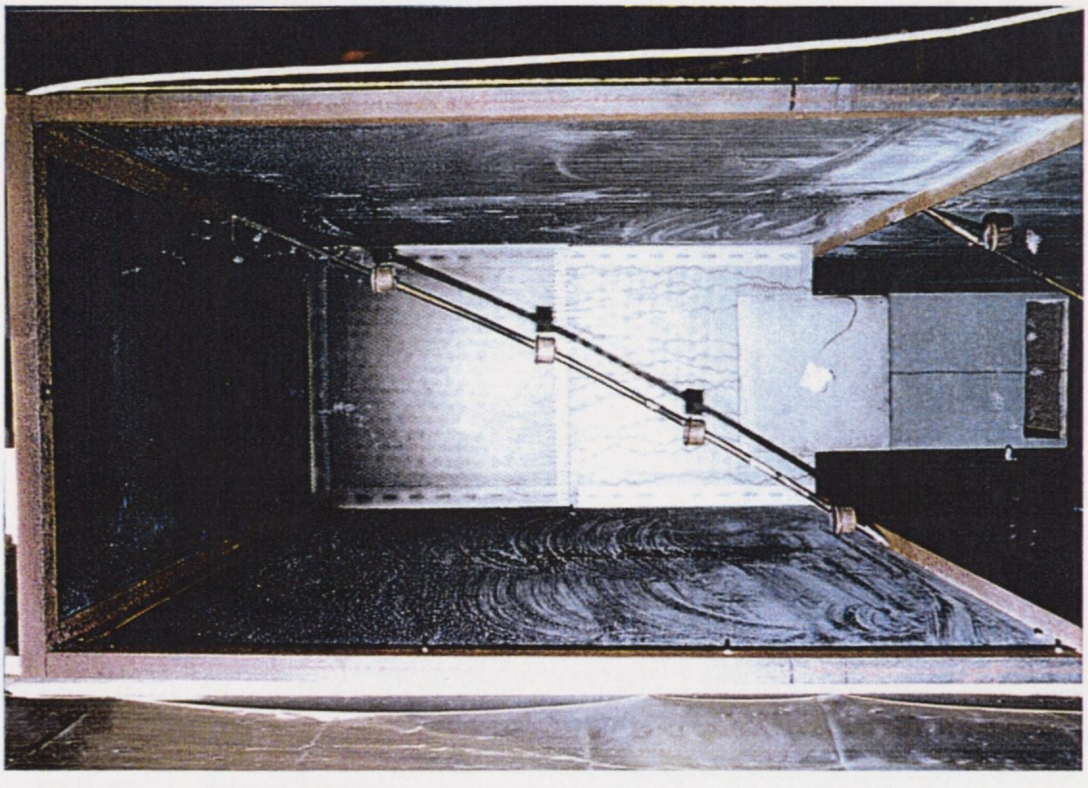


Plate VII.1 Variant 3, Upper Section

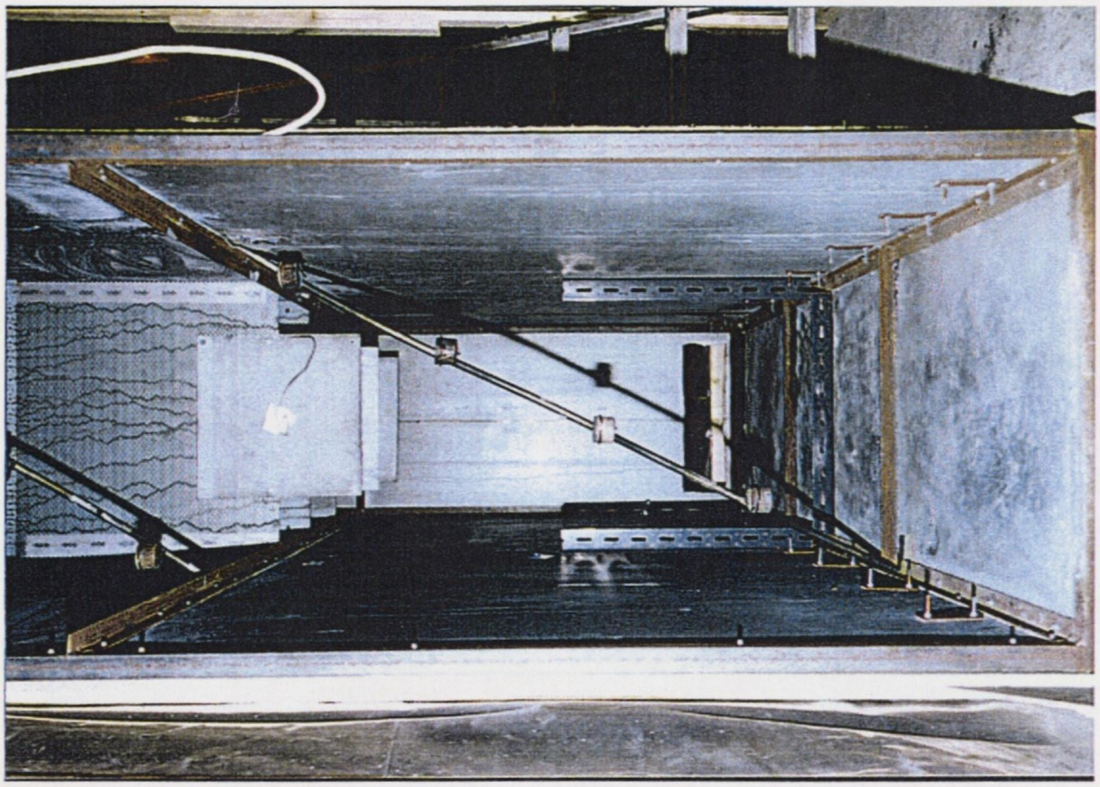


Plate VII.2 Variant 3, Lower Section

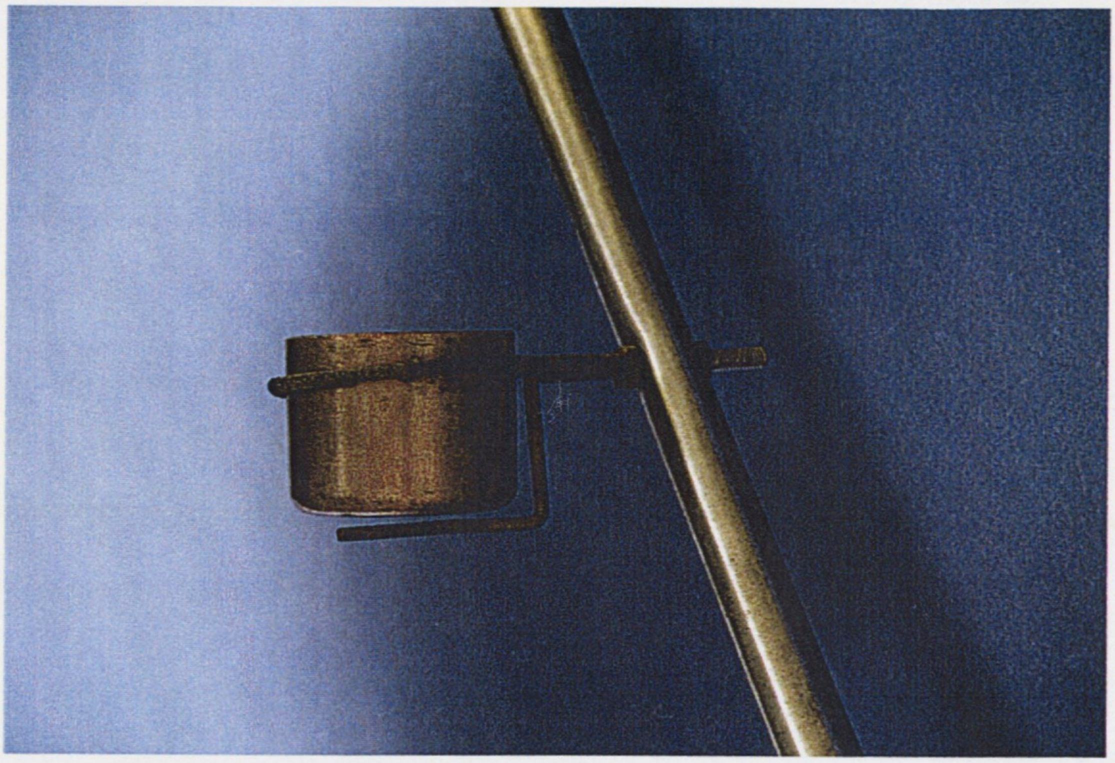


Plate VII.3 35 mm *n*-Heptane Fire and Support

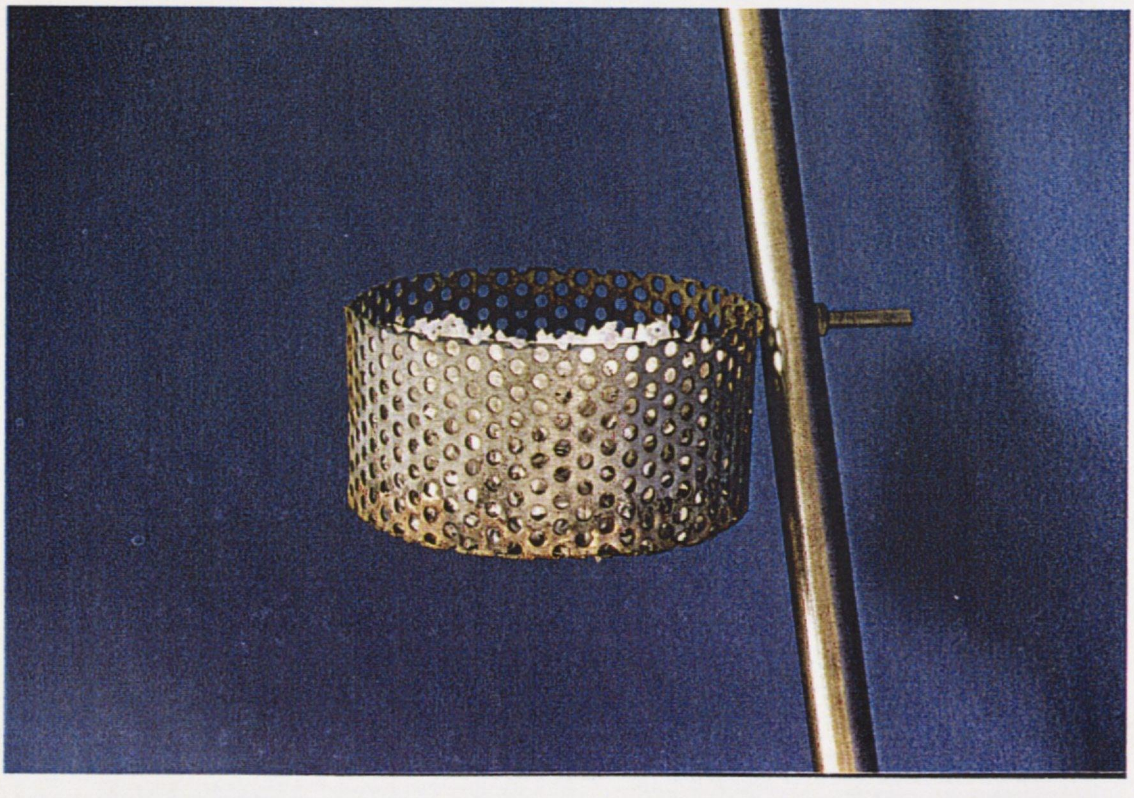


Plate VII.4 80 mm Paper Fire and Support

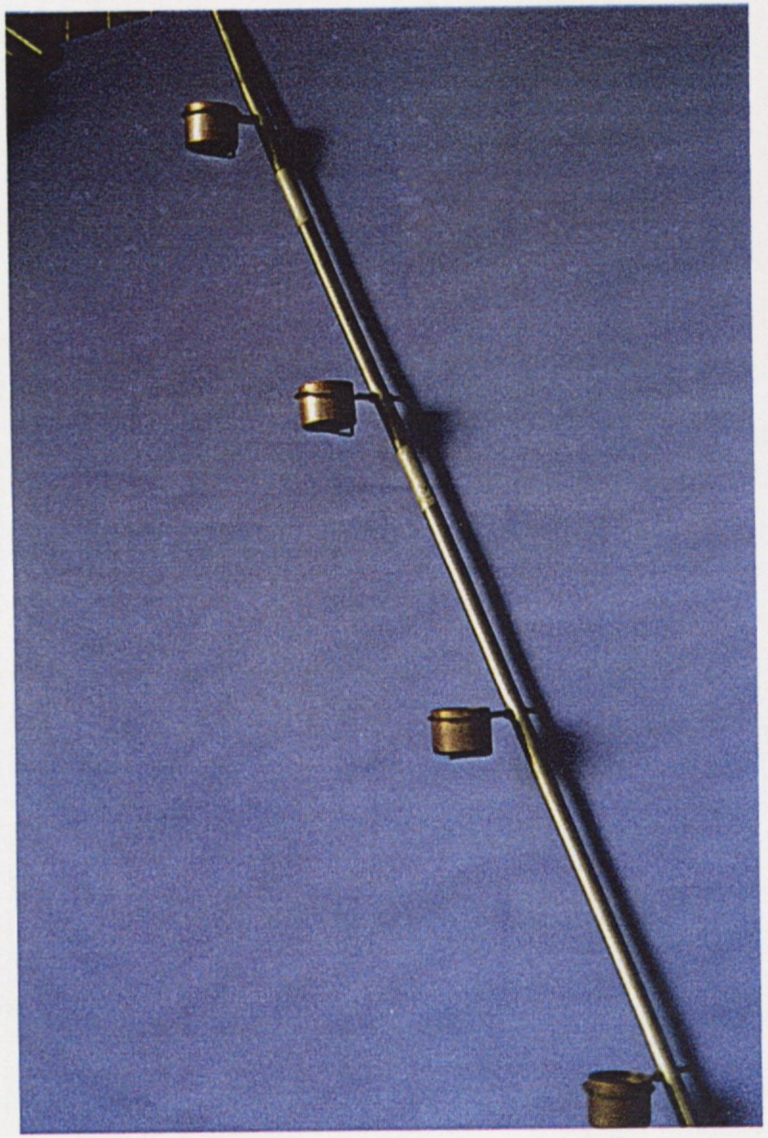


Plate VII.5   Array of 4 *n*-Heptain Fires

Plate VII.6   Constant Discharge Time Apparatus