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Measurements of the Firefighting Environment made during Tyne and Wear Metropolitan Fire Brigade's Positive Pressure Ventilation Trials at the Fire Service College

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Measurements of the Firefighting Environment made during Tyne and Wear Metropolitan Fire Brigade's Positive Pressure Ventilation Trials at the Fire Service College

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ABSTRACT

This report describes the temperature and thermal flux measurements made during a series of trials using Positive Pressure Ventilation (PPV) in the Breathing Apparatus Training Complex and the Ship at the Fire Service College. It addresses the impact of PPV on a casualty lying between the fire and the outlet vent. Results suggest that, at least for the scenario represented in these trials, such a casualty would be more severely injured by the initial fire than by the subsequent use of PPV during firefighting. Results also show that PPV cooled the compartment more rapidly than was possible using natural ventilation alone and that, although the use of either form of ventilation increased the risk of fire spread when compared with not using ventilation, there was no apparent difference between fire spread under natural ventilation and when using PPV.

MANAGEMENT SUMMARY

In the week 27-31 July 1998, Tyne & Wear Metropolitan Fire Brigade and the Fire Service College jointly undertook a set of trials to assess some of the consequences of using Positive Pressure Ventilation (PPV) as an offensive firefighting tactic. The Home Office Fire Experimental Unit assisted by measuring temperatures and thermal radiation in some of their trials.

The purposes of the initial set of trials in the Breathing Apparatus Training Complex were firstly to determine the relative effects of PPV on a casualty placed between the fire and an outlet vent, and secondly to assess the effect of PPV on fire spread.

In the scenario represented in these trials, PPV produced no measurable difference in fire spread from that observed under natural ventilation alone. However the use of ventilation, whether natural or forced, did appear to increase the risk of fire spread when compared with not using ventilation.

The results also suggest that, at least in the scenario represented in these trials, the use of PPV would cause much less harm to the casualty than the fire itself would already have done by the time firefighting commenced.

The FEU were asked to measure the gas temperatures experienced by the firefighters as they undertook an exercise on the Fire Service College ship simulator, the Sir Henry. The fires were in the engine compartment, and the firefighters approached from the stern, along the propeller shaft tunnel. The one measurable difference which was observed was that the firefighters reached the fire compartment more quickly when PPV was in use.

The cooling rate achieved with different sized fans appears related to the air flow through the inlet vent. In the particular scenario used in the Breathing Apparatus Training Complex, there was an intermediate ground floor room and a narrow stairway up to the fire compartment. In these circumstances, the effectiveness of the seal around the door does not appear critical to the effectiveness of smoke clearance.

The higher the airflow, the greater the temperature rise (or reduction in temperature drop) immediately after the BA Team enters, and ventilation commences. This is a feature of any ventilation action - fresh air causes fire growth in an oxygen-depleted compartment. However, provided firefighting commences immediately, this is not a serious problem.

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1. INTRODUCTION

In the week 27-31 July 1998, Tyne & Wear Metropolitan Fire Brigade and the Fire Service College jointly undertook a set of trials to assess some of the consequences of using Positive Pressure Ventilation (PPV) as an offensive firefighting tactic. The Home Office Fire Experimental Unit assisted by measuring temperatures and thermal radiation in some of their trials.

The FEU participated in three sets of trials:

DATE	FSC FACILITY	FEU CONTRIBUTION
Monday 27th July & Tuesday 28th July	Breathing Apparatus (BA) Training facility	1. Measurements of gas temperatures and thermal radiation levels which would have been experienced by a casualty placed between the fire and the outlet vent. 2. Estimates of the difference in fire spread between natural ventilation and PPV.
Wednesday 29 July	Sir Henry	Measurements of gas temperatures experienced by one of the firefighters, using a portable data logger.
Thursday 30 July	BA School	Measurements of gas temperatures at three different heights at one place in the compartment.

2 BREATHING APPARATUS TRAINING COMPLEX - MONDAY & TUESDAY

2.1 General

The purposes of these trials were firstly to determine the relative effects of PPV on a casualty placed between the fire and an outlet vent, and secondly to assess the effect of PPV on fire spread.

The fire was constructed from wooden pallets, with a bale of straw included to increase smoke production. There was considerable variation in the weight of wood in any one pallet, so the number of pallets in any fire was varied to try to counter this and keep a consistent fire size.

In each case, the fire was started and allowed to build up with the compartment fully ventilated. The ventilation to the fire was then closed down and firefighting operations commenced a set time afterwards.

In Test 1 of Day 1, it was decided to close down the compartment ventilation after 5 minutes, and to commence operations after a further 5 minutes. This seemed too long, so the next test, Test 2, timings were set at 3 minutes and 3 minutes. However, the fire burnt too quickly in this test, so that most of the fuel was consumed before the ventilation to the compartment was closed down. This produced very different conditions in the compartment.

Finally it was decided that the decision on when to shut down the compartment should be made on the basis of the judgement of the fire officer in the fire compartment as to when the fires were similar in size, and that there should be a shut down time of 3 minutes. This appeared successful on Test 3. In Test 4 there was no smoke build up despite delaying the start of firefighting.

On Day 2, the decision was made to follow the same procedure applied for Day 1 Test 3.

The fire compartment was on the first floor of the Breathing Apparatus (BA) Training Complex, with a single window on the down-wind side being used as an outlet vent (See Figure 1). This window was opened by the fire officer in the compartment at the same time as the BA Team entered the building on the ground floor. Entry was made via a double door on the up-wind side and this was also used as the inlet vent. The BA Team passed through the downstairs compartment, up the stairs, and opened the door to the fire compartment, allowing ventilation to take place.

In all seven trials were undertaken. These are listed below:

TRIAL	TITLE	DESCRIPTION	COMMENTS
D1 T1	No Ventilation	Fully Ventilated for 5 minutes, then closed down for 5 minutes before entry.	
D1 T2	Natural ventilation	Fully Ventilated for 3 minutes, then closed down for 3 minutes before entry.	Fire burnt most of the fuel before close down. Not as hot.
D1 T3	PPV Using a 24" fan	Fully Ventilated for 6 minutes, then closed down for 3 minutes before entry.	Fire built up slowly, so close down delayed. The fire officer observing in the compartment reported that the BA crew obstructed the doorway, reducing the effect of the PPV.
D1 T4	Natural Ventilation	Fully Ventilated for 8 minutes, then closed down for 5 minutes before entry.	Door accidentally left open when fire was supposed to be closed down. No smoke build up.
D2 T1	PPV Using a 24" fan	Safety Officer to decide how long to let fire burn fully ventilated. (5 minutes) Closed down for 3 minutes.	
D2 T2	Natural Ventilation	Safety Officer to decide how long to let fire burn fully ventilated. (4 minutes) Closed down for 3 minutes.	Fire burned through too quickly. Poor smoke build up. Not as hot.
D2 T3	Natural Ventilation	Safety Officer to decide how long to let fire burn fully ventilated. (6 minutes) Closed down for 3 minutes.	

2.2 Instrumentation

The purpose of the instrumentation was to determine the effect of different methods of firefighting on a casualty lying between the fire and the outlet vent. It has been argued that the use of PPV places such a casualty at greater risk.

These trials were also used to try to assess the effect of ventilation on fire spread. This is difficult to define as fire spread is dependent on the type and location of fuel in the compartment, as well as on hot gas movements.

Figure 1 shows the lay-out of the fire compartment, and the positions of the FEU instrumentation. This consisted of a steel frame (Figure 2) supporting four thermocouples [1*], at a height of 30mm above the floor. These were placed at this height to measure the gas temperatures likely to be experienced by a prone casualty. The steel frame also supported a wooden framework (Figure 3) made of vertical strips of chipboard. This was used to try to assess the effect of ventilation on fire spread. Beside the steel frame were two water-cooled thermal radiometers[2], one looking at the fire and one looking at the ceiling. These could be used to assess the size of the fire and the amount of heat flux falling on any casualty in that position. A sampling tube for a Oxygen/Carbon Monoxide gas analyser[3] was also terminated at this point but this tube got crushed during operation, and no results were obtained.

All data was recorded using a data logger[4], and transferred to EXCEL spreadsheets for subsequent analysis.

2. 3 Results

Figures 4-17 show the outputs from the thermocouples and the radiometers. The sharp spikes in the data are due to interference from the radios. Figures 18-23 show the heat damage to the chipboard frames. There was no discernible damage to the witness board in Day 1 Test 2, so it was re-used in Day 1 Test 3.

2. 4 Discussion

2.4.1 Heat Flux

The heat flux readings from the radiometers show that there are differences between the fires in all the tests. This is inevitable, given the nature of the fires, as only limited standardisation of the fuel was possible, and there might well have been significant variations in the amount of wood and its dampness, and in the construction of the fire.

It is clear that two of the fires (Day 1 Test 2 and Day 2 Test 2) are significantly smaller than the others. This was reported by the fire officers at the time.

The heat flux readings from the radiometers, after the compartment ventilation is shut down, all tell the same story: as soon as the compartment is closed down and smoke starts to build up, the heat flux reduces to very low values as the smoke absorbs any radiation from flame. In all the trials involving ventilation, there is a slight increase in the heat flux from the ceiling when the outlet vent is created, and this is most marked in one of the PPV trials (Day 2 Test 1).

Here it rises for a very short period to approximately half the heat flux levels recorded in the earlier stages of the fire (3 kW/m^2, compared with 7.5 kW/m^2). A heat flux of 3 kW/m^2 is likely to cause second degree burns in 100 seconds*. A heat flux of 7.5kW/m^2 will cause second degree burns in 15 seconds

This rise is probably due to a combination of improved smoke clearance and fire growth as fresh air gets into the compartment. As the smoke clears, the radiometers can see the fire more clearly, giving higher readings.

The heat flux record of the fire on Day 1 Test 4 shows the effect of the accidental extra ventilation due to a door being left open. The heat flux levels are still significant right up to the entry of the BA crew as there is insufficient smoke to obscure the flames. The maximum heat flux levels, achieved soon after the compartment ventilation was closed down, are broadly similar for the other four tests.

The heat flux readings show that two of the trials (Day 2 Test 1 and Day 2 Test 3) can be used for comparisons of ventilation with and without PPV. The results of Day 1 Test 3 can only be used with caution because the effectiveness of PPV was probably reduced due to the firefighters blocking the compartment doorway. Equally, the results of Day 1 Test 1 need to be used with caution because of the longer time before the fire compartment ventilation was closed down, and also the longer delay before BA Team entry.

2.4.2 Gas Temperature

All the traces show that, at the positions being measured, the gas temperatures in the compartment rise to approximately 160°C - 100°C soon after the fire compartment ventilation is closed down, and then reduce as the fire dies down due to oxygen starvation. Normally a temperature of 150°C is considered an upper limit for mouth breathing. Typically gas temperatures three minutes later, when the BA Team enters, have reduced to the range 90°C - 60°C depending on the distance from the fire.

In the case where no external vent is made (Day 1, Test 1), very little happens until the BA Team opens the door to the compartment approximately one minute after they first enter the building. There is then an initial reduction of about 20°C in the gas temperature at the measurement point nearest the fire, as cooler air can get into the compartment at low level, and hot gases flow out through the doorway at high level. The thermocouple nearest the fire is also close to the door and is cooled by this draught. Thereafter, the gas temperatures at the points measured in the compartment cool at the rate of approximately 4°C per minute.

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*THERMAL RADIATION: PHYSIOLOGICAL & PATHOLOGICAL EFFECTS by Ian Hynes, Warren Boydell & Belinde Prescott, IChemE Major Hazards Monograph ISBN 0 85295 328 3

The gas temperature traces for the natural ventilation case (Day 2 Test 3) again show that, after the outlet vent has been opened, very little happens until the BA Team opens the door to the compartment approximately one minute after they first enter the building. There is then an initial reduction in the gas temperature of about 35°C at the measurement point nearest the fire. This reduction is more marked than in the 'unventilated' case, and occurs because there is now an open window as well as the top of the open door to act as outlet vents, an inlet vent at the bottom of the open door, and a clear path between them. The thermocouple nearest the fire is also close to the door and is cooled by this draught. This effect is detectable, to a lesser extent, in the trace of the next two thermocouples as well. Cooling of all but the first thermocouple is of the order of 6°C per minute thereafter.

The temperature traces for the two PPV trials (Day 1 Test 3 and Day 2 Test 1) show very similar effects soon after the BA Team enters. Again, very little happens until the BA Team opens the door to the compartment. Then the gas temperatures nearest the fire reduce by about 40°C as fresh air flows into the compartment. Thereafter the gas temperatures at the points measured reduce by approximately 25°C per minute. This tails off to 10°C per minute after a few minutes.

Comparison of the trials with PPV and with natural ventilation alone (Day 2 Test 1 and Day 2 Test 3), both using an open window and the top of the doorway as outlet vents, show a similar initial reduction in the gas temperature at the measurement point nearest the fire as soon as the door to the compartment is opened. Thereafter, the gas temperatures at the other three points cool more rapidly with PPV (25°C per minute) than under natural ventilation alone (6°C per minute). If the top of the doorway has to serve as the outlet vent on its own, as well as being the inlet vent, the cooling rate reduces further (5°C per minute).

There is no evidence of any increase in gas temperature after the BA Team enter the compartment in any of these ventilation tests. This suggests that the increase in thermal radiation mentioned above is a consequence more of smoke clearance allowing the radiometer a sight of the fire, rather than of fire growth.

2.4.3 Fire Spread

The scorch marks on the three test specimens for the main tests (Day 1 Test 1, Day 2 Test 1 and Day 2 Test 3) suggest that there was less chance of fire spread in the 'unventilated' case, but that there was no real difference between the chances of fire spread in the two ventilated cases.

2.5 Conclusions from the Days 1 and 2 Trials

In the scenario represented in these trials, PPV produced no measurable difference in fire spread from that observed under natural ventilation alone. However the use of ventilation, whether natural or forced, did appear to increase the risk of fire spread when compared with not using ventilation.

PPV would have had some effect on a casualty. At a distance of 3.5 metres from the mid point of the fire:

- at the peak of the fire, a casualty would have experienced gas temperatures of 95°C to 140°C, and radiative heat fluxes of between $6kW/m^2$ and $7.5\ kW/m^2$. This would be considered extreme operating conditions for a firefighter in full protective equipment, when exposure times would have to be limited to less than a minute. Without protective clothing, a casualty would receive third degree burns in about 5 minutes, with a 50% chance of death.
- at the time that the BA Team entered the compartment, a casualty would be exposed to gas temperatures of 70°C, and radiative heat fluxes of typically $0.7kW/m^2$. This might be sufficient to cause some second degree blistering.
- in the case of PPV, as firefighting commenced, a casualty would have experienced a 30 second burst of heat flux at a level of $3kW/m^2$ as the smoke cleared but before firefighting commenced, but the gas temperature would have been rapidly reducing to 50°C. This might cause some second degree blistering. Thereafter, the casualty would be in rapidly cooling conditions.
- in the case of natural ventilation, as firefighting commenced, a casualty would be exposed to gas temperatures of 50°C, and radiative heat fluxes of typically $0.7kW/m^2$ for several minutes. This might also be sufficient to cause some second degree blistering.

2.6 Implications for Casualties

In the scenario considered in these trials, the casualty would probably have been dead before firefighters could perform a rescue. If the initial exposure conditions during fire growth are scaled down proportionately, so that the casualty can survive them, the effects of the heat pulse due to PPV would also need to be scaled down:

- if, at the peak of the fire, the casualty had experienced gas temperatures of 70°C and radiative heat fluxes of between $3kW/m^2$, second degree burns would be expected.
- if PPV were not used, as firefighting commenced the casualty would be experiencing radiative heat fluxes of approximately $0.3kW/m^2$, but the gas temperatures would only reduce slowly as firefighting continued. This would be insufficient to cause further blistering.
- in the case of PPV, as firefighting commenced, the casualty would then experience a 30 second burst of heat flux at a level of approximately $1kW/m^2$ as the smoke cleared and before firefighting commenced, and the gas temperature would have been rapidly reducing to 40°C. This also would be insufficient to cause further blistering.

Thus, at least in the scenario considered in these trials, none of the actions by the firefighters whether using PPV or not, would cause as much harm to the casualty as the fire itself would already have done by the time firefighting commenced.

3 SHIP FIRES - WEDNESDAY

The FEU were asked to measure the gas temperatures experienced by the firefighters as they undertook an exercise on the Fire Service College ship simulator, the Sir Henry. The fires were in the engine compartment, and the firefighters approached from the stern, along the propeller shaft tunnel.

In all two trials were undertaken. These are listed below:

TRIAL	TITLE	DESCRIPTION
D3 T1	PPV	Fire in the engine compartment. Entry from the stern via the propeller shaft tunnel.
D3 T2	Natural ventilation	As above.

The FEU contribution consisted of a platinum resistance thermometer connected to a small data logger[5] (Figure 24) The thermometer was fitted to the front of one of the firefighters' tunic with the data logger in an inside pocket. It was left running over the whole duration of the trial.

The temperatures which were recorded are shown in Figures 25 and 26. These show that there was little or no difference between the temperatures experienced by the firefighter in the two trials.

The one measurable difference is that the firefighters reached the fire compartment more quickly when PPV was in use.

4 BREATHING APPARATUS TRAINING COMPLEX - THURSDAY

4.1 General

In each case, the fire was started and allowed to build up with the compartment fully ventilated. The fire was closed down after a 3 minute pre-burn, and firefighting operations commented three minutes later.

In all six trials were undertaken. These are listed below:

TRIAL	TITLE	DESCRIPTION	COMMENTS
D4 T1	27" Fan		
D4 T2	18" Fan		
D4 T3	27" Fan - 2 Vents		
D4 T4	16" Ramfan	Not used as PPV	
D4 T5	21" Fan	Same fan as used on D1 and D2	
D4 T6	Multi-seated Fire	Fires on two floors. Two fans in series. Sequential ventilation applied.	No instrumentation used

4.2 Instrumentation & Results

Three thermocouples were mounted in the position shown in Figure 27. They were at heights of 1 foot, 4 foot and 6 foot above the floor. The results for the six trials are shown in Figures 28-32.

4.3 Discussion of Results

It was to be expected that the temperatures recorded on these trials would be very different from those recorded on Day 1 and Day 2, because the measurements have been taken in different places. Nevertheless, the temperature records for Day 4 Test 5 are similar in shape to those obtained for Day 2 Test 1. These were identical tests using the same fan. However, the 4 foot high thermocouple shows a maximum temperature of about 180°C, and this compares with a maximum of 100°C at the thermocouple nearest to the fire on Days 1 & 2. All subsequent discussion will therefore be based on the 4 foot high thermocouple results - roughly at head height for a kneeling firefighter.

Tests 1 - 5 can be placed in ascending order of air flow rate into the compartment, assuming a fan's capacity is related to its diameter, and that more vents will mean higher air flows. The first point of note is that, the higher the airflow, the greater the temperature rise (or reduction in temperature drop) immediately after the BA Team enters, and ventilation commences. This is a feature of any ventilation action - fresh air causes fire growth in an oxygen-depleted compartment. However, provided firefighting commences immediately, this is not a serious problem. This temperature rise occurs immediately on creating the outlet vent in the case of the Day 4 Test 3, so this raises the possibilities either that significant natural ventilation occurred due to there being two vents in the compartment, or that the door to the compartment was left open on this occasion and PPV commenced as the firefighters entered the building, rather than when they entered the compartment.

Trial	Scenario	Cooling Rate at 4 Foot Level
D4 T4	16" Ramfan	40°C per minute
D4 T2	18" Fan	20°C per minute
D4 T5	21" Fan	30°C per minute
D4 T1	27" Fan, 1 Vent	50°C per minute
D4 T3	27" Fan, 2 Vents	60°C per minute

After the initial rise (or reduction in fall) of temperature, the temperature drops rapidly. Perhaps surprisingly, the 16" Ramfan outperforms the 18" and 21" fans in the rate of temperature reduction which it achieves. In fact, the Ramfan produces an air flow rate similar to the 21" PPV fan, but with a much tighter cone. Thus more of the air would be getting into the building.

If the fan were blowing directly into the fire compartment, this might be highly undesirable as there would be a lot of swirling, stirring up the smoke rather than pushing it away. However, in this case, there was an intermediate ground floor room and a narrow stairway up to the fire compartment. In these circumstances, the dominant factor is likely to be the air flow rate through the inlet vent rather than the effectiveness of the seal around it.

4.4 Conclusions from the Day 4 Trials

The cooling rate achieved with the different fans appears related to the air flow through the inlet vent. In this particular scenario, there was an intermediate ground floor room and a narrow stairway up to the fire compartment. In these circumstances, the effectiveness of the seal around the door is not critical to the effectiveness of smoke clearance.

The higher the airflow, the greater the temperature rise (or reduction in temperature drop) immediately after the BA Team enters, and ventilation commences. This is a feature of any ventilation action - fresh air causes fire growth in an oxygen-depleted compartment. However, provided firefighting commences immediately, this is not a serious problem.

5 CONCLUSIONS

In the first set of trials in the Breathing Apparatus Training Complex, ventilation, whether natural or forced, did appear to increase fire spread when compared with not using ventilation of any sort. PPV produced no measurable difference in fire spread from that observed under natural ventilation alone. However, the results suggest that, although the effect of using PPV in this particular scenario was to momentarily make the conditions in the fire compartment more severe, overall the use of PPV would cause much less harm to the casualty than the fire itself would already have done by the time firefighting commenced.

In the ship fires, the one measurable difference which was observed was that the firefighters reached the fire compartment more quickly when PPV was in use.

In the second set of trials in the Breathing Apparatus Training Complex, the cooling rate achieved with the different fans appeared related to the air flow through the inlet vent. In this particular scenario, there was an intermediate ground floor room and a narrow stairway up to the fire compartment. In these circumstances, the effectiveness of the seal around the door is not critical to the effectiveness of smoke clearance. The higher the airflow, the greater the temperature rise (or reduction in temperature drop) immediately after the BA Team enters, and ventilation commences. This is a feature of any ventilation action - fresh air causes fire growth in an oxygen-depleted compartment. However, provided firefighting commences immediately, this is not a serious problem.

NOTES

1. Type K Thermocouple. Range 0°C - 1100°C, supplied by Minta Instrumentation Ltd.

2. Medtherm heat flux transducer type 64-10-20 supplied by Parr Scientific Ltd.

3. Triple Plus Gas Analyser supplied by Crowcom Ltd.

4. 1203 Squirrel Meter/Logger supplied by Grant Instruments (Cambridge) Ltd.

5. Tinytag PT100 Temperature Data Logger with Platinum Resistance Type sensor. Range -50°C - 300°C, supplied by Gemini Data Loggers (UK) Ltd.

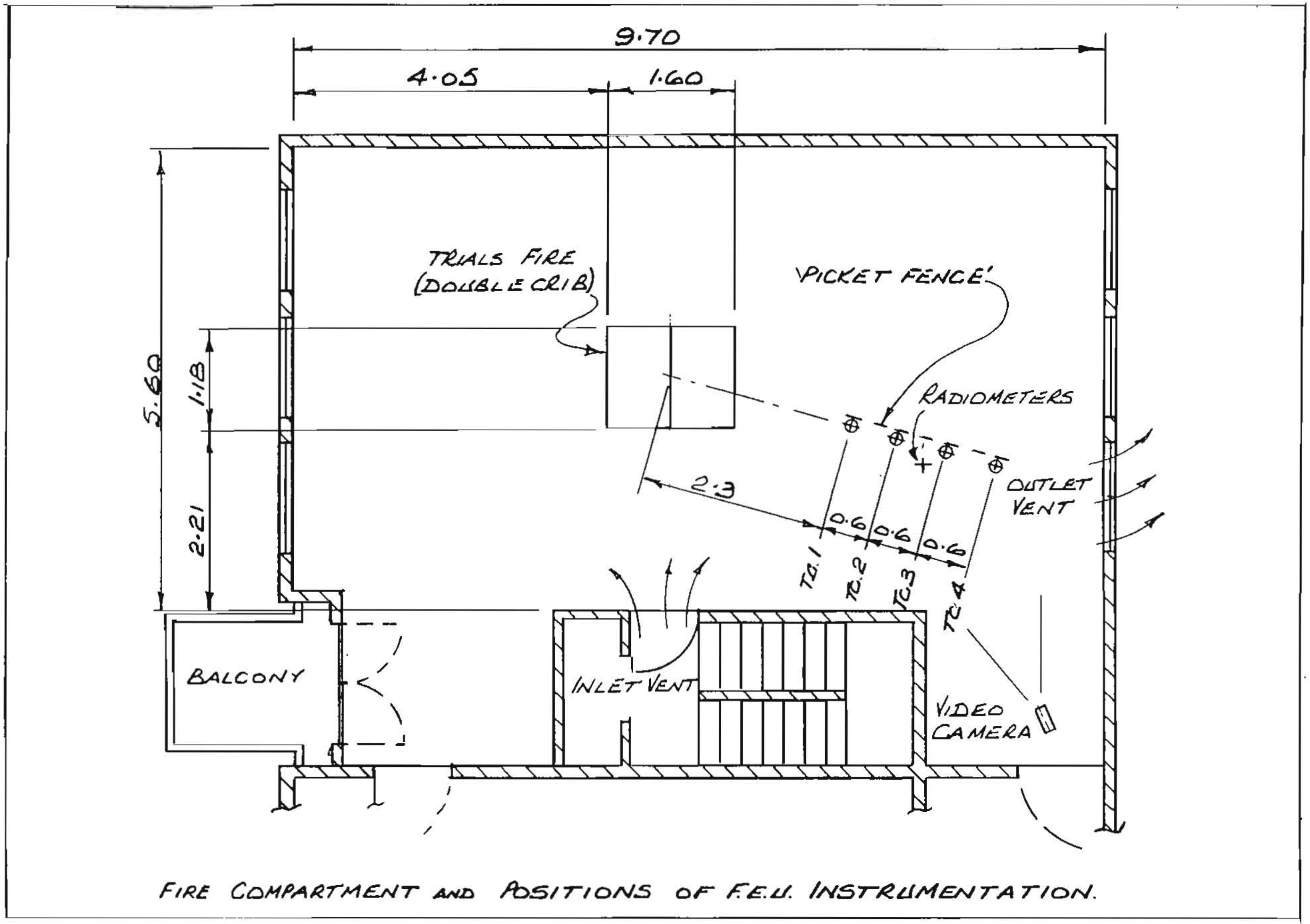

Figure 1 Layout of the Fire Compartment (Days 1 & 2)

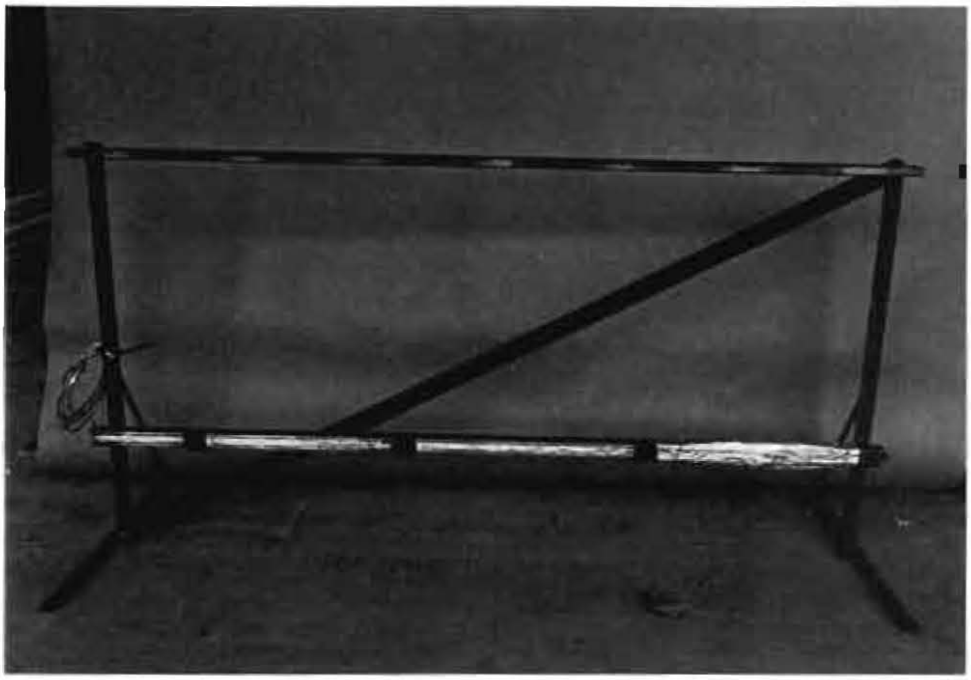

Figure 2 Thermocouple Support Frame (C253/1988)

Figure 3 Chipboard Slats Used to Detect Fire Spread (C225/1998)

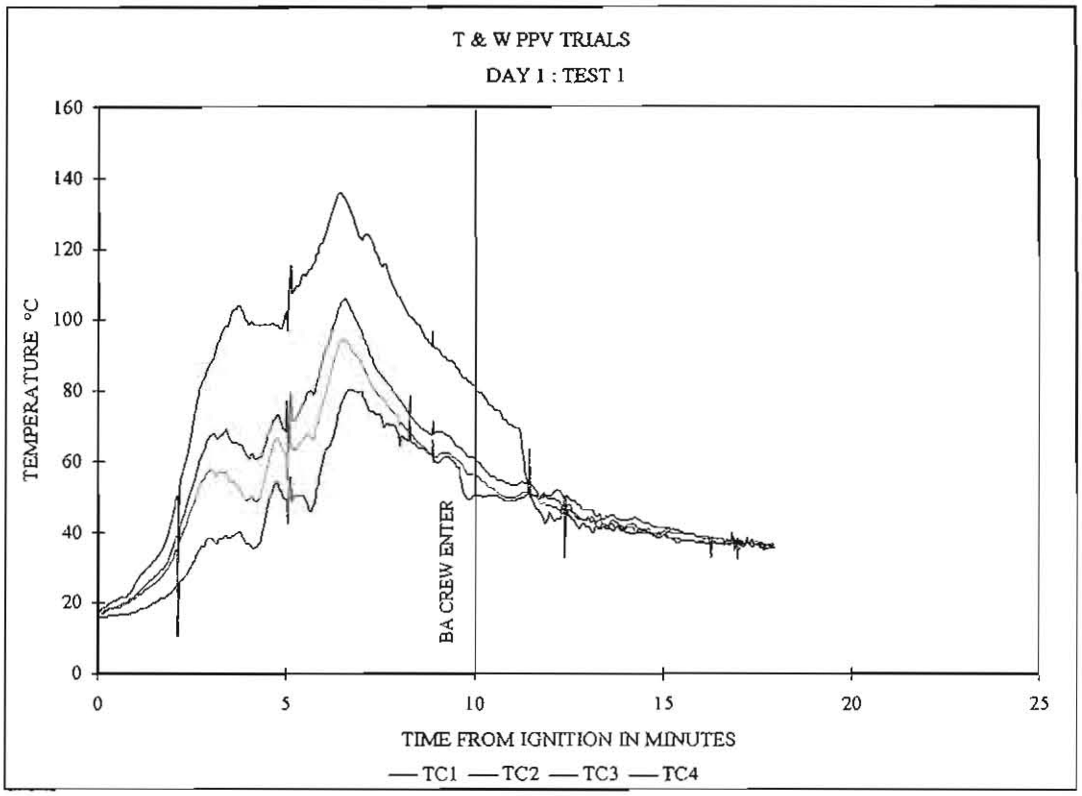

Figure 4 Thermocouple Records for Day 1 Test 1

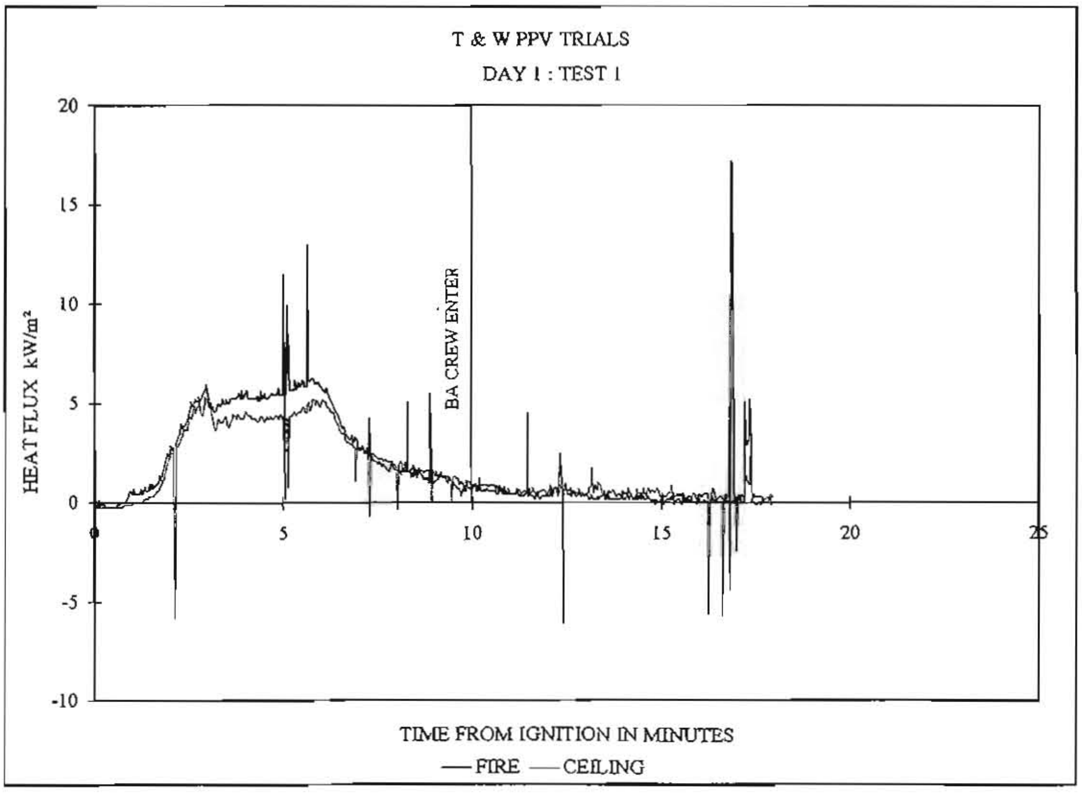

Figure 5 Heat Flux Records for Day 1 Test 1

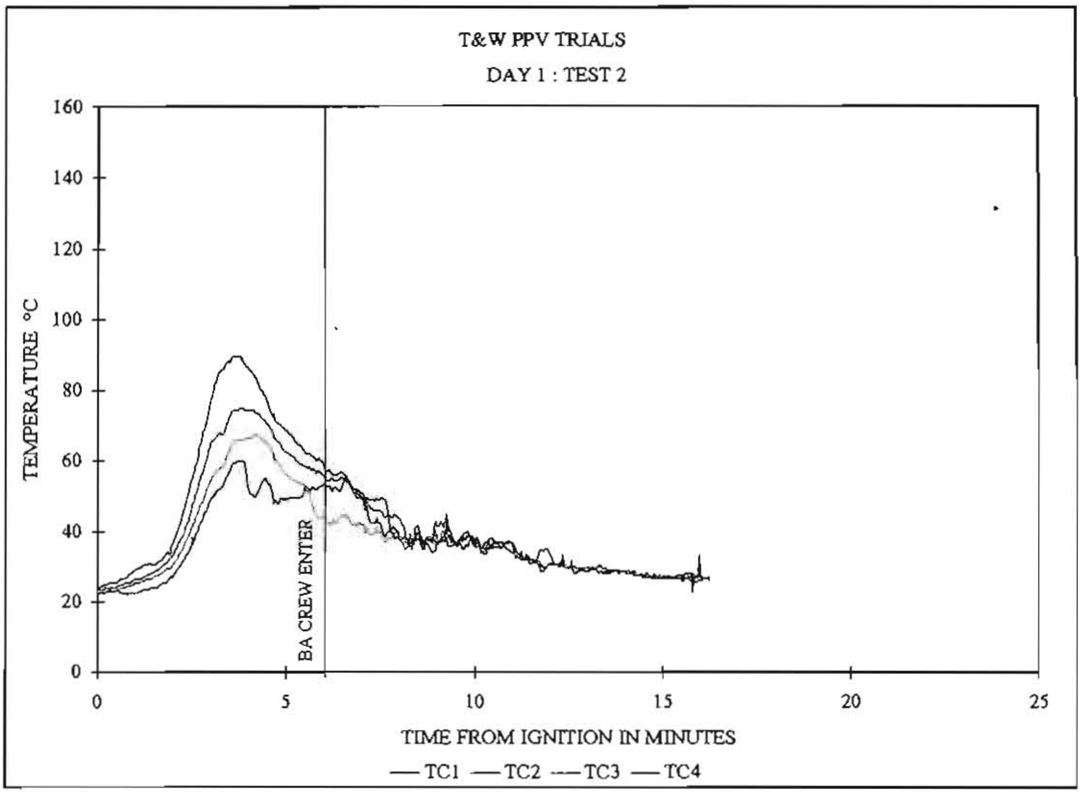

Figure 6 Thermocouple Records for Day 1 Test 2

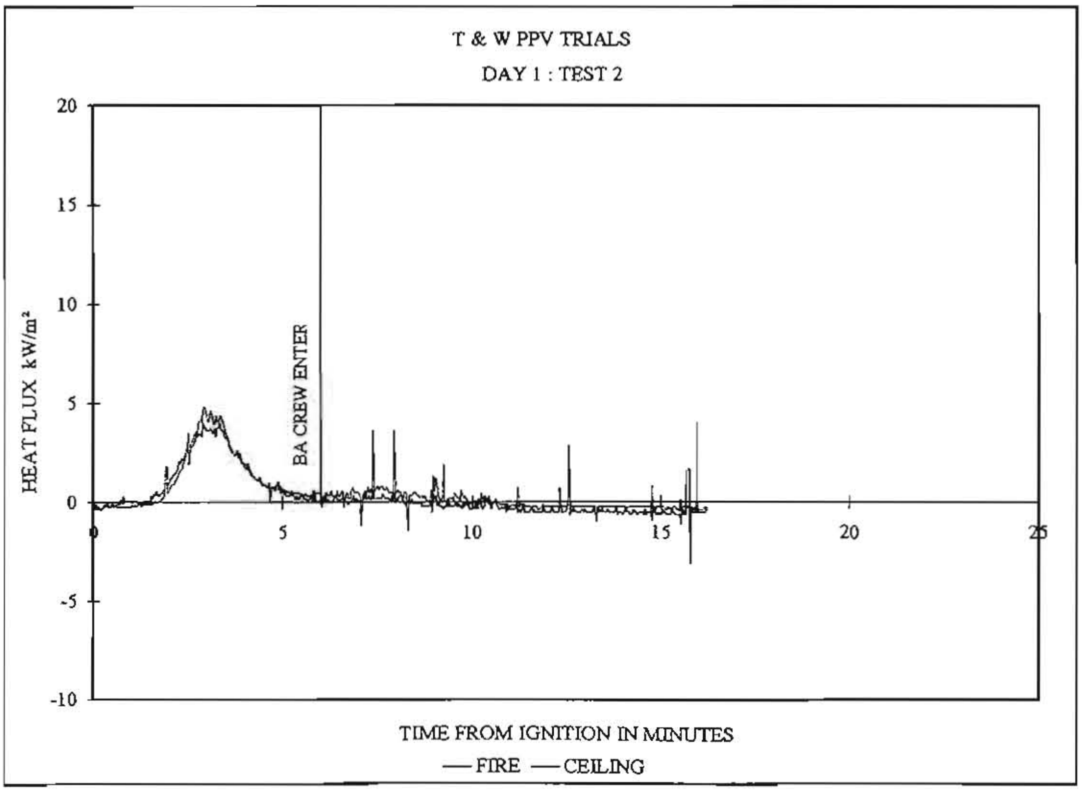

Figure 7 Heat Flux Records for Day 1 Test 2

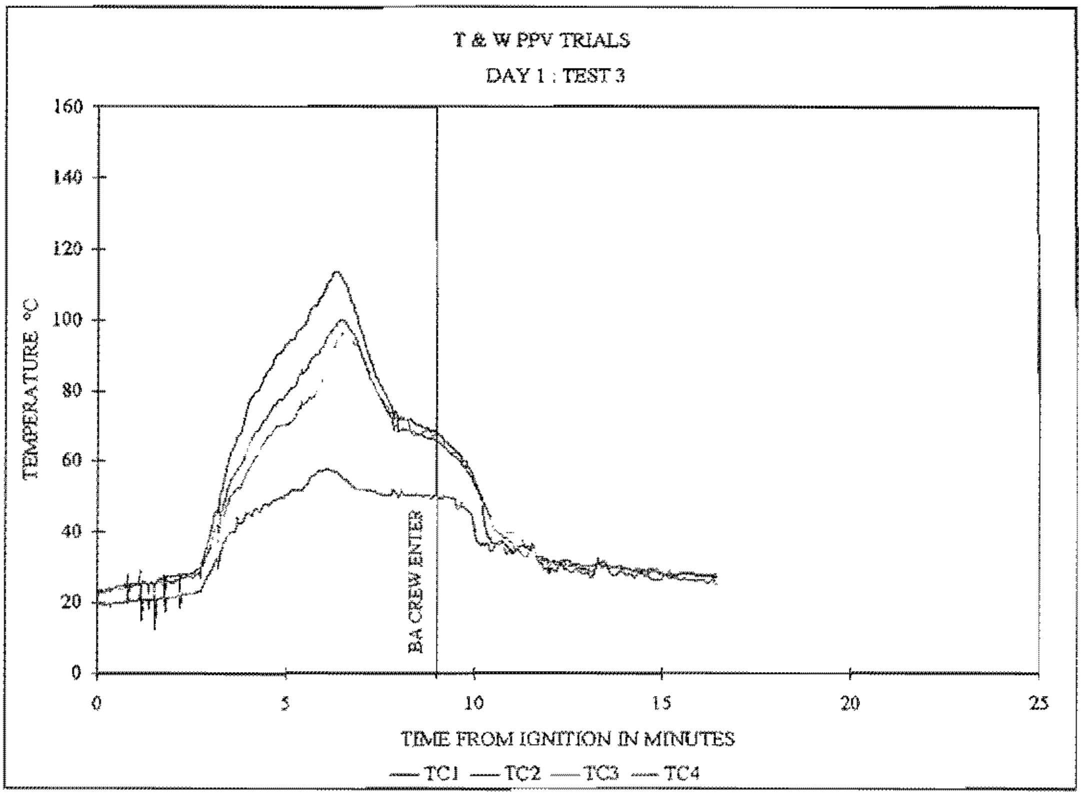

Figure 8 Thermocouple Records for Day 1 Test 3

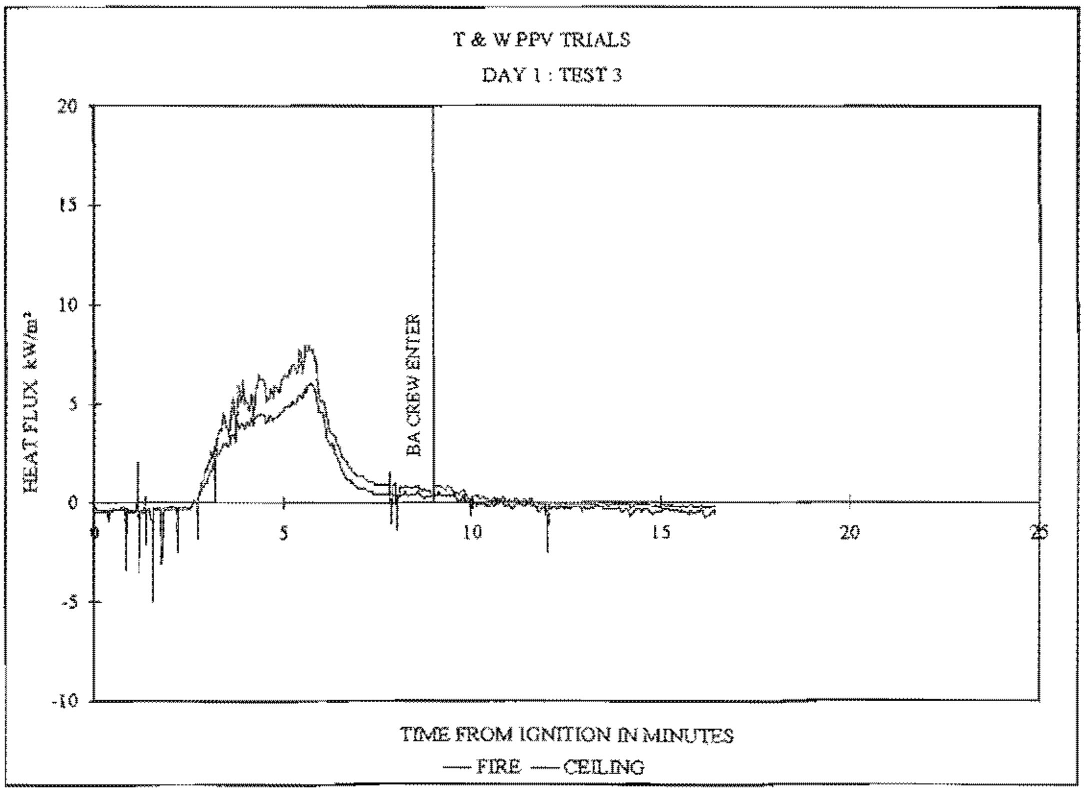

Figure 9 Heat Flux Records for Day 1 Test 3

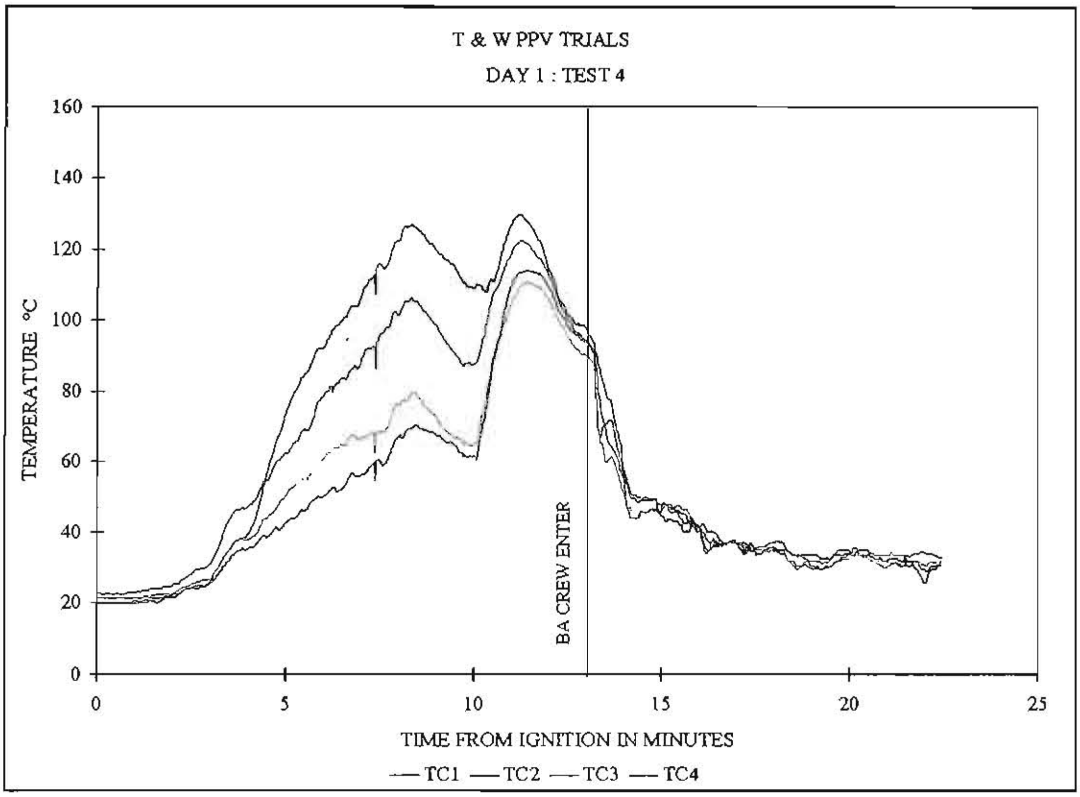

Figure 10 Thermocouple Records for Day 1 Test 4

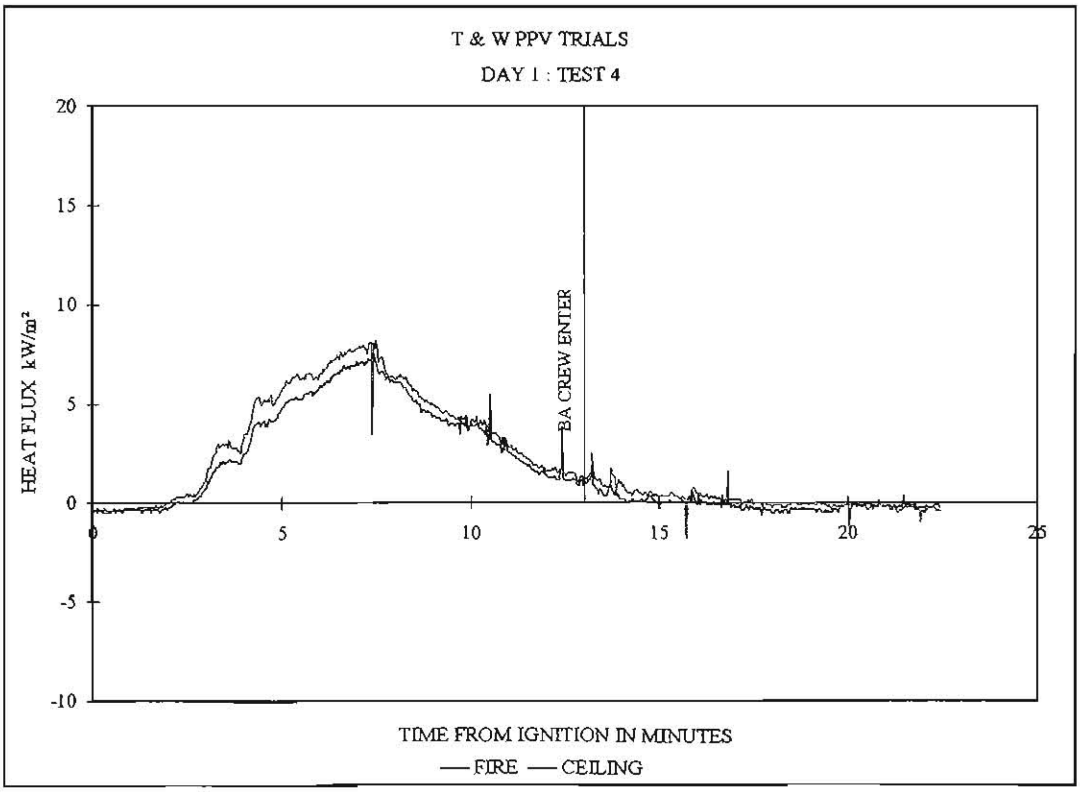

Figure 11 Heat Flux Records for Day 1 Test 4

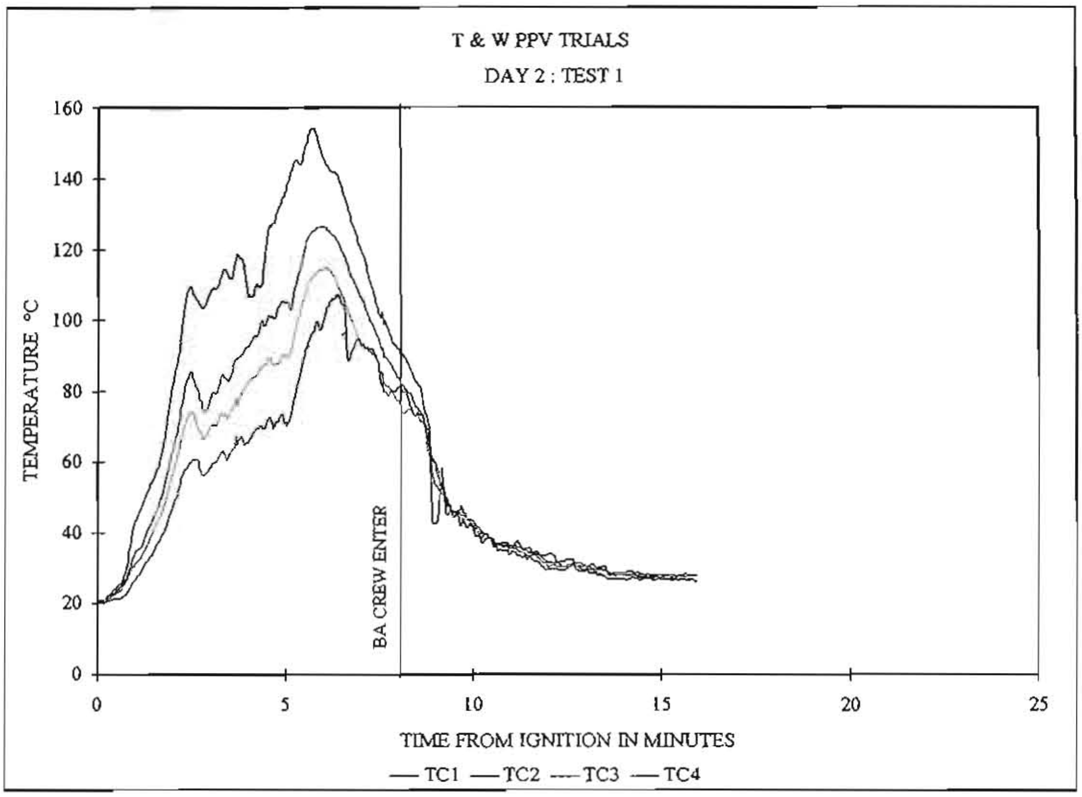

Figure 12 Thermocouple Records for Day 2 Test 1

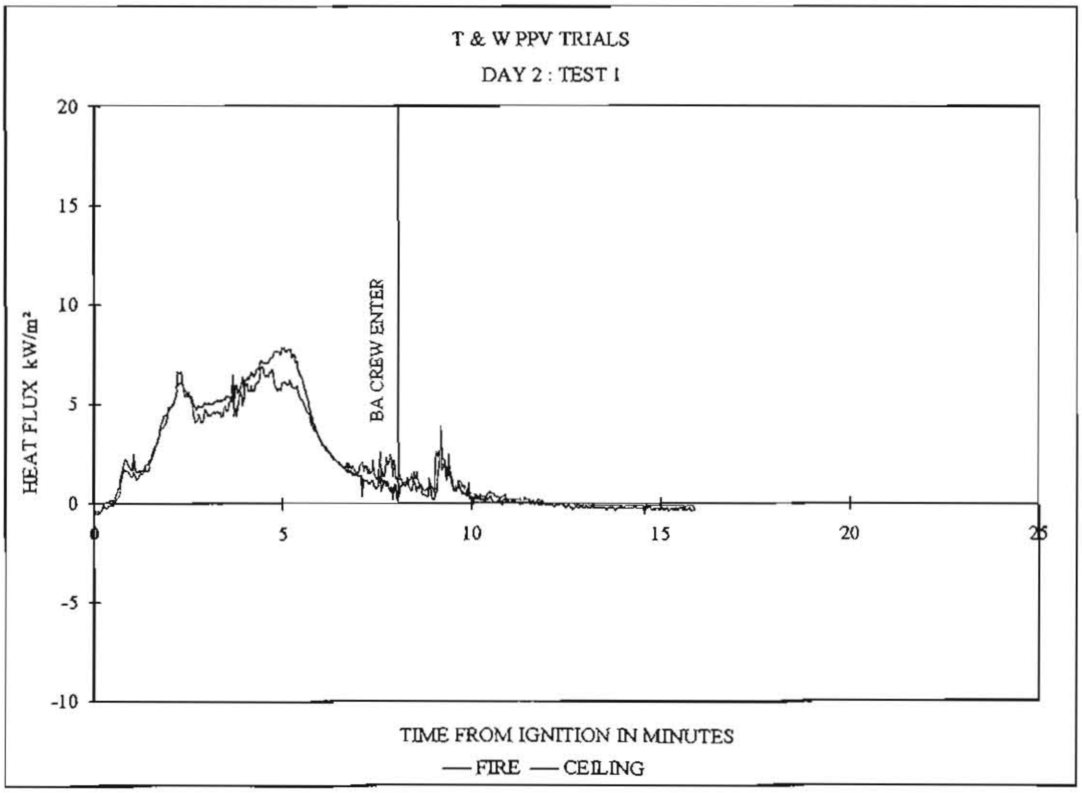

Figure 13 Heat Flux Records for Day 2 Test 1

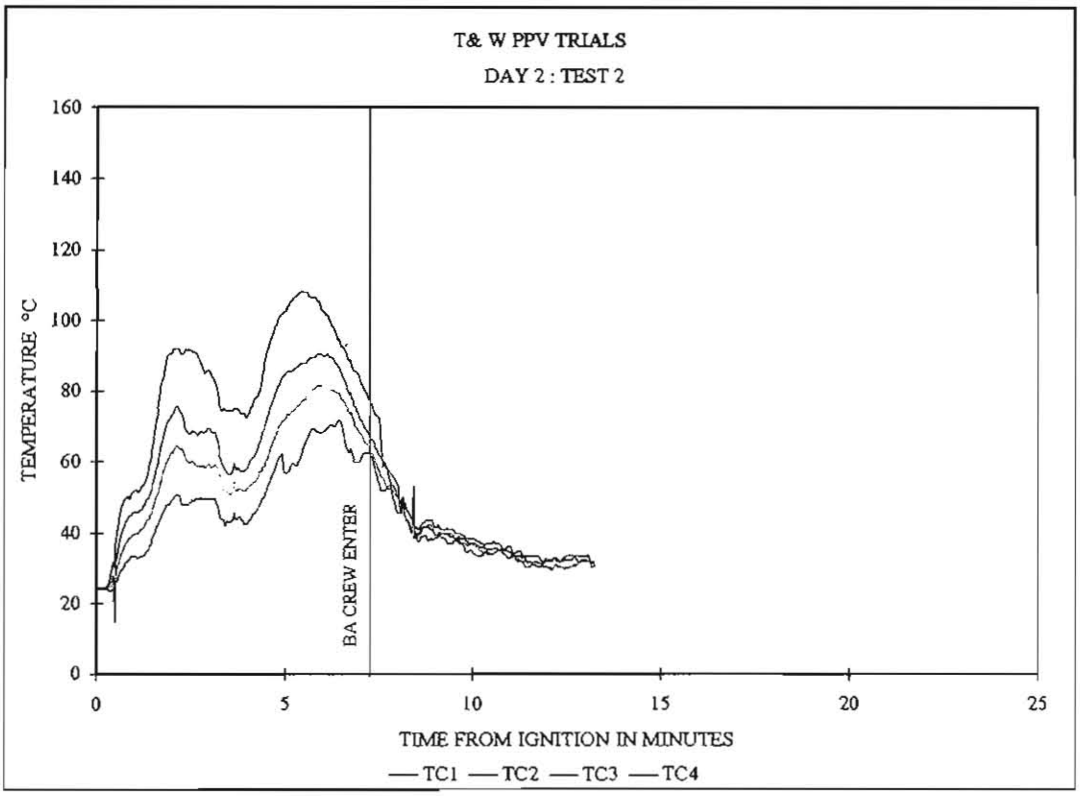

Figure 14 Thermocouple Records for Day 2 Test 2

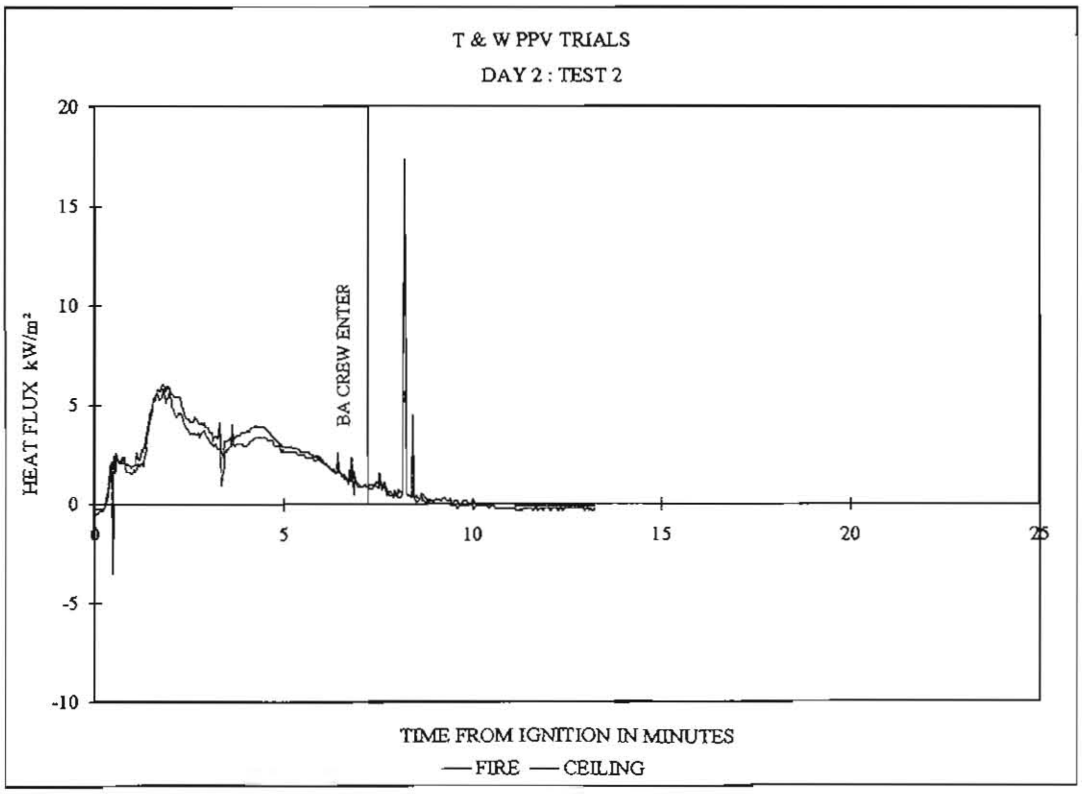

Figure 15 Heat Flux Records for Day 2 Test 2

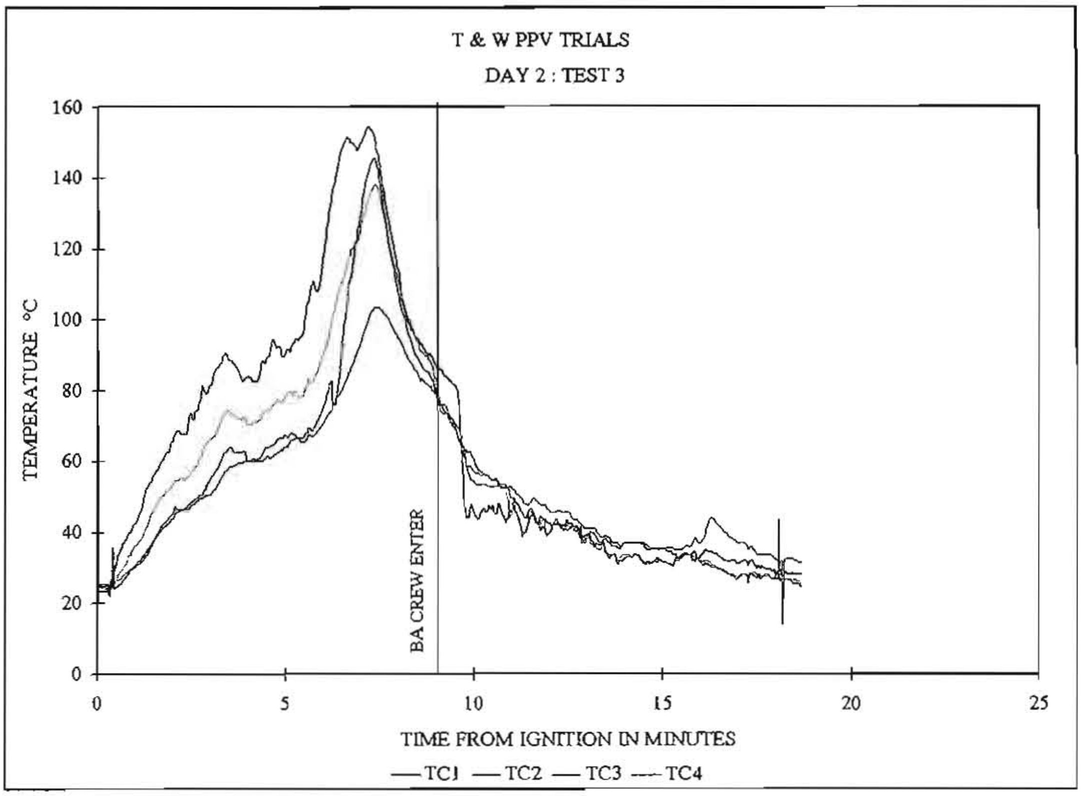

Figure 16 Thermocouple Records for Day 2 Test 3

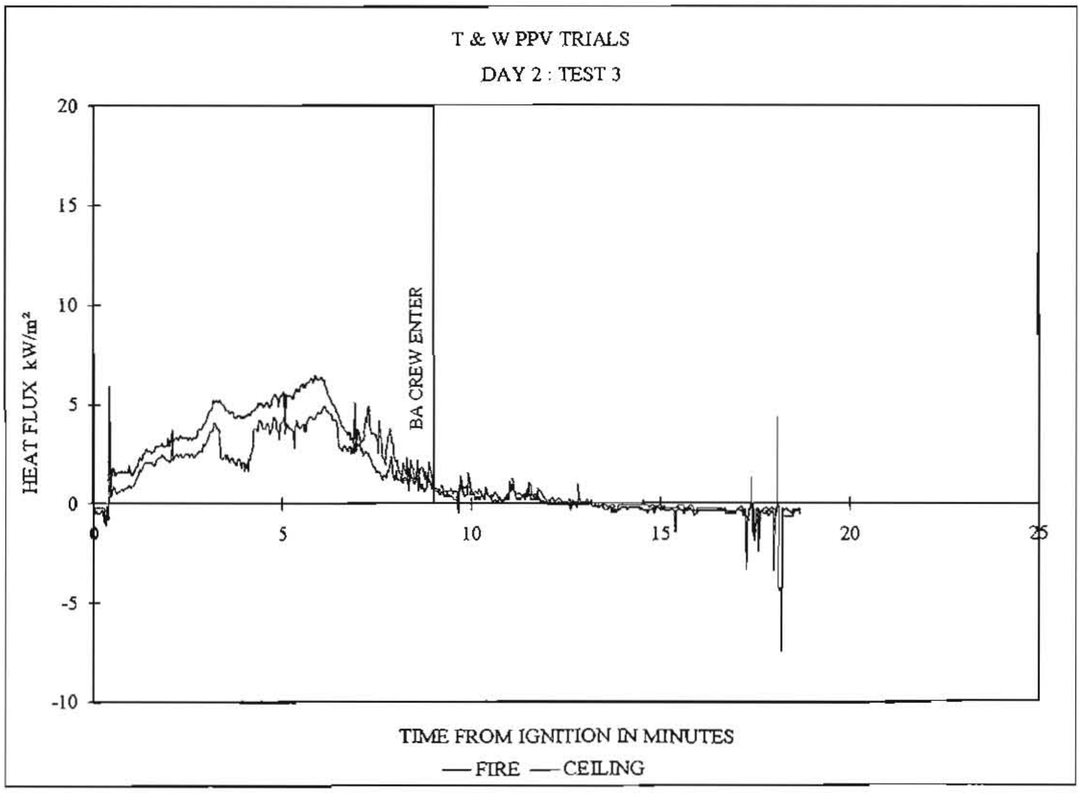

Figure 17 Heat Flux Records for Day 2 Test 3

Figure 18 Fire Spread Witness Marks for Day 1 Test (C250/1998)

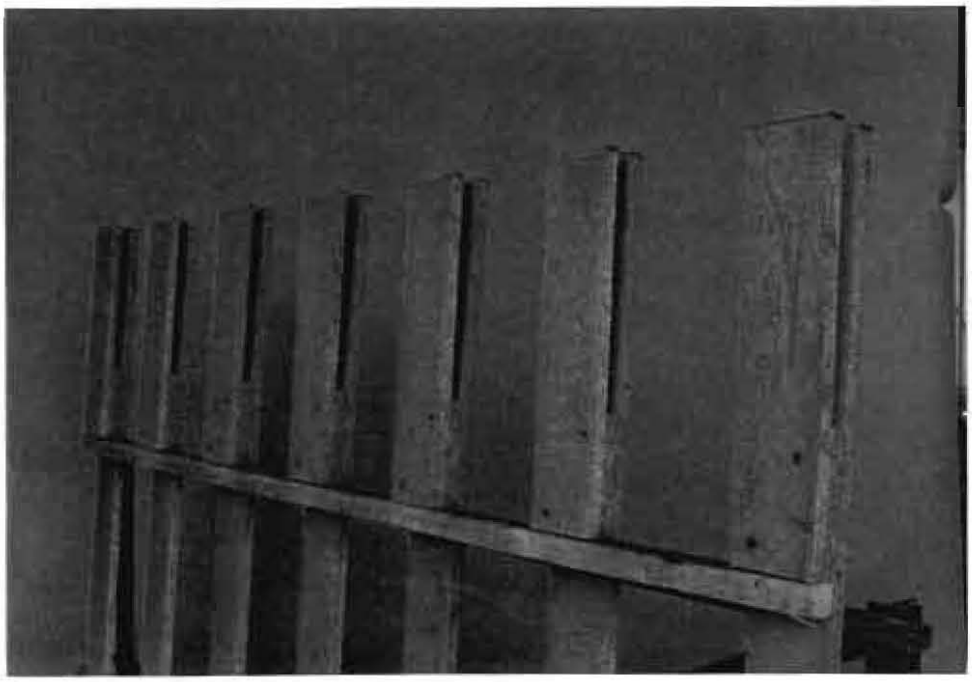

Figure 19 Fire Spread Witness Marks for Day 1 Tests 2 & 3
(C246/1998)

Figure 20 Fire Spread Witness Marks for Day 1 Test 4 (C238/1998)

Figure 21 Fire Spread Witness Marks for Day 2 Test 1 (C231/1998)

Figure 22 Fire Spread Witness Marks for Day 2 Test 2 (C226/1998)

Figure 23 Fire Spread Witness Marks for Day 2 Test 3 (C222/1998)

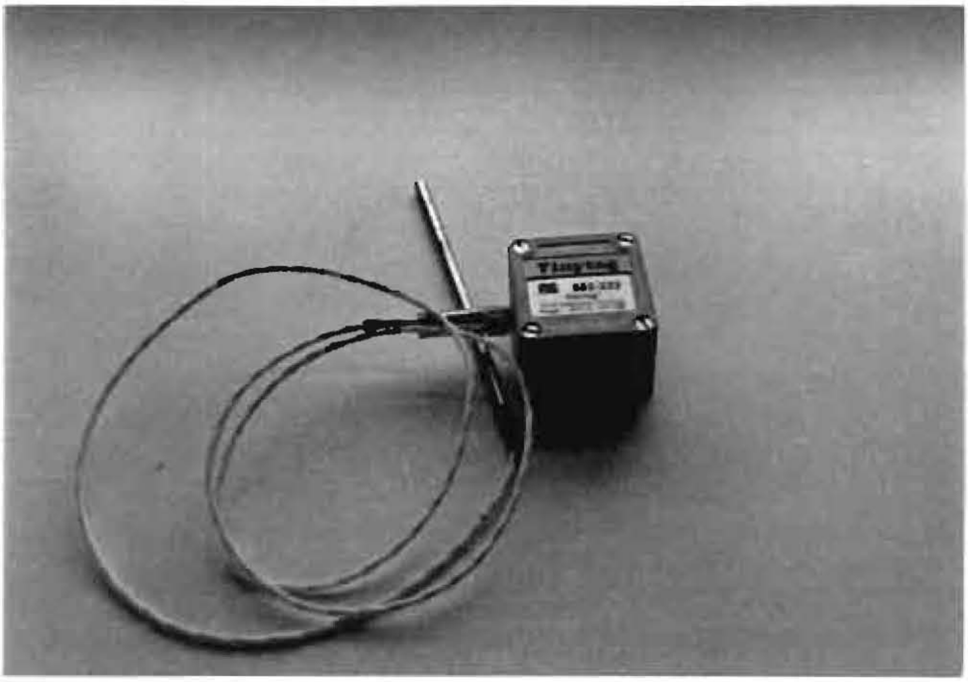

Figure 24 Minature Data Logger (C212/1998)

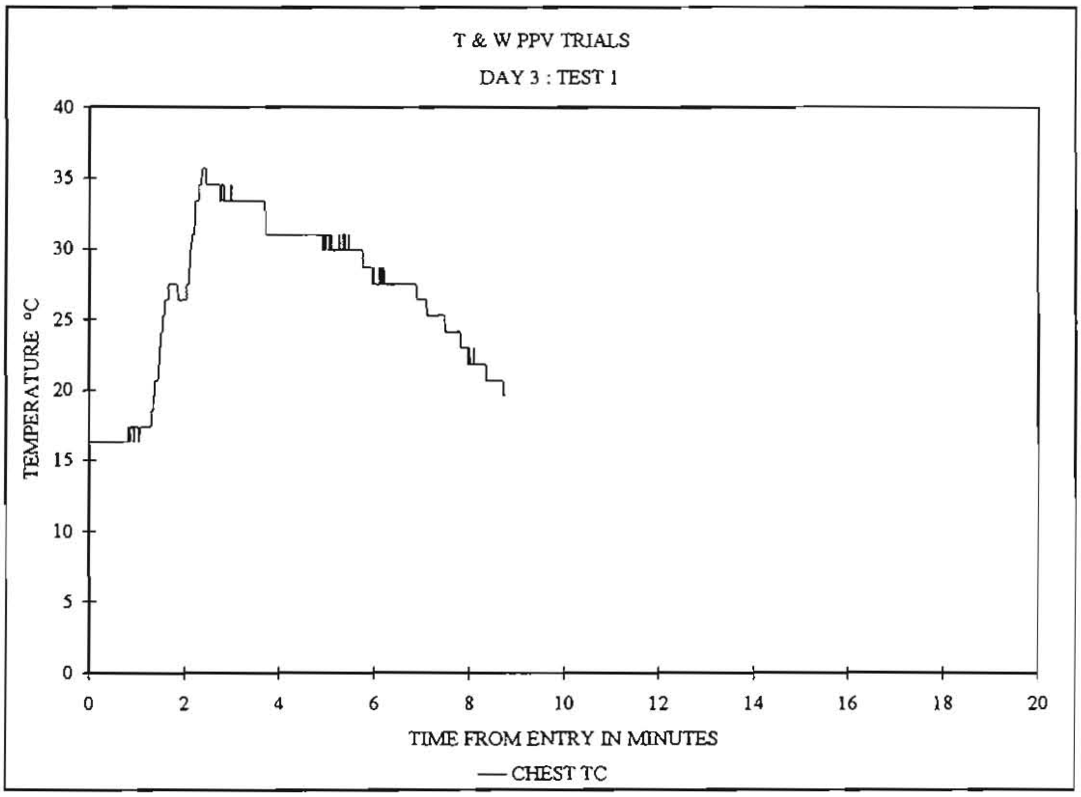

Figure 25 Temperature Records for Day 3 Test 1

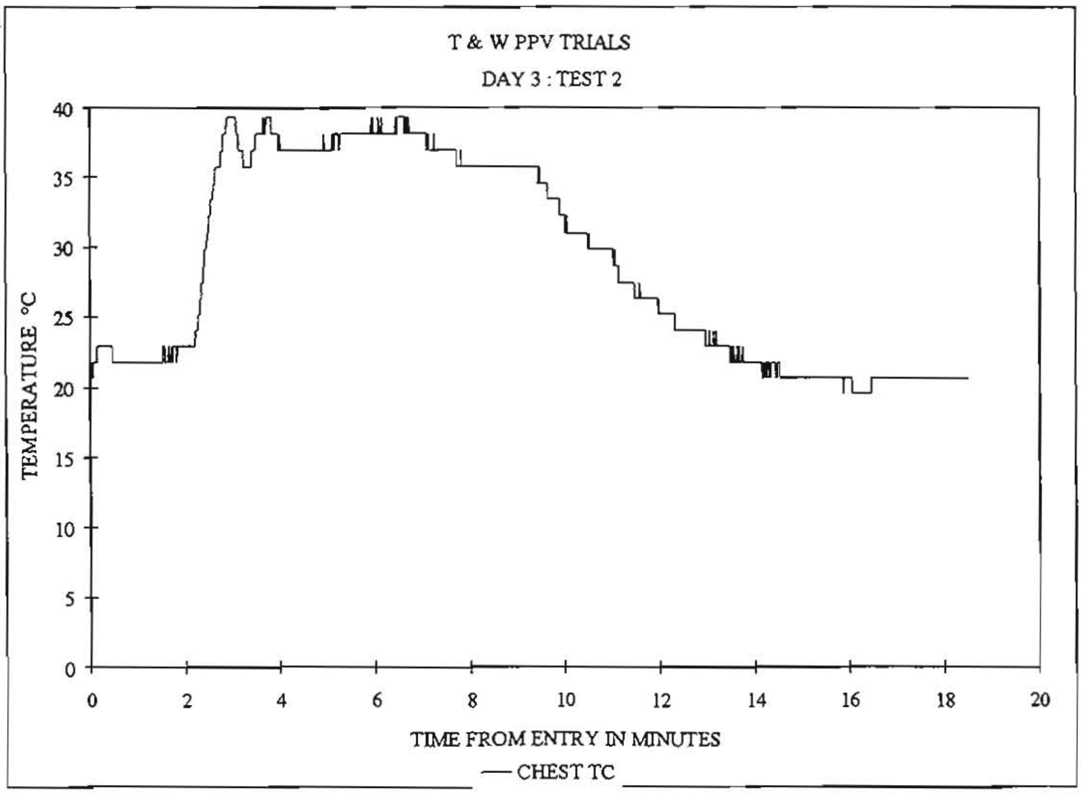

Figure 26 Temperature Records for Day 3 Test 2

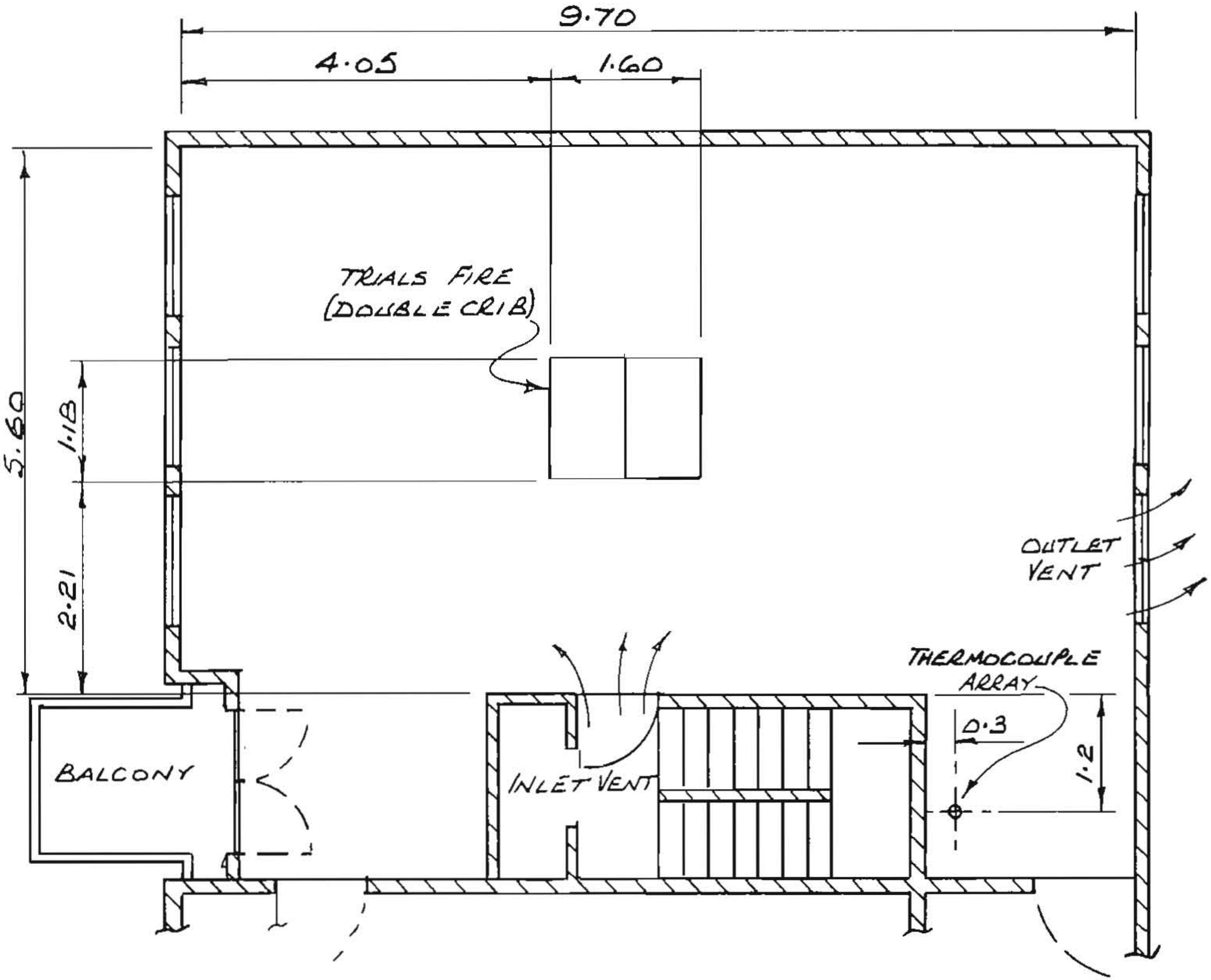

Figure 27 Layout of Fire Compartment (Day 4)

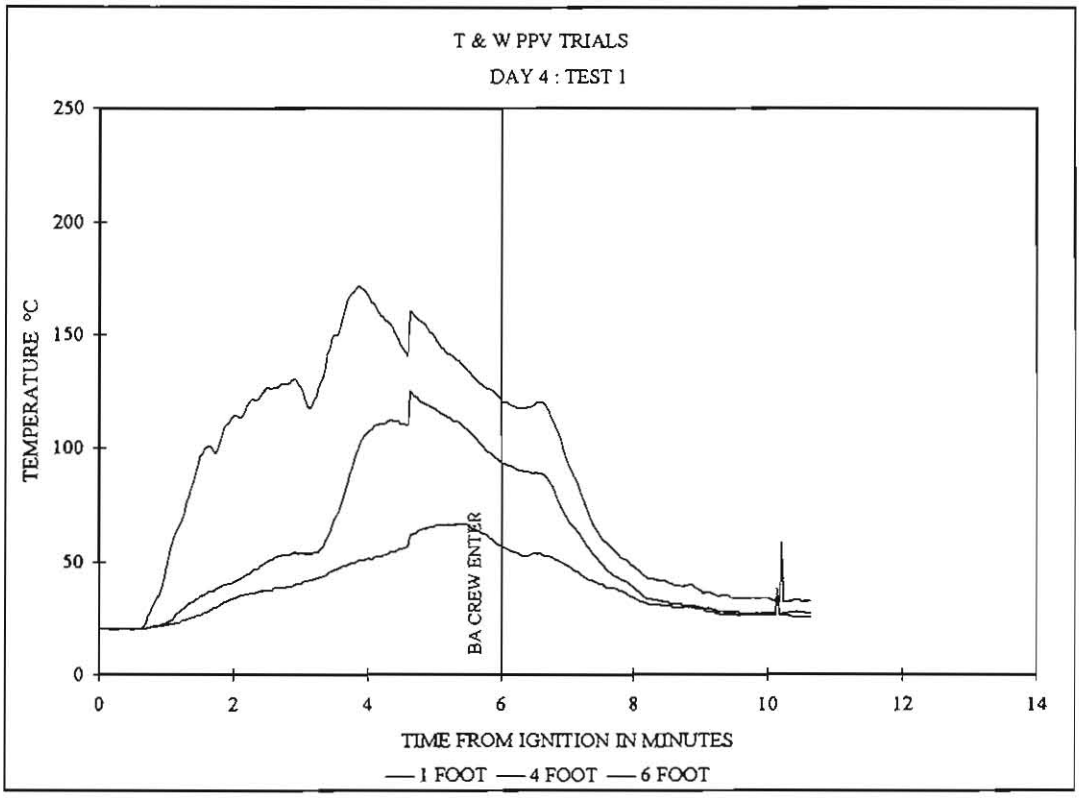

Figure 28 Thermocouple Records for Day 4 Test 1

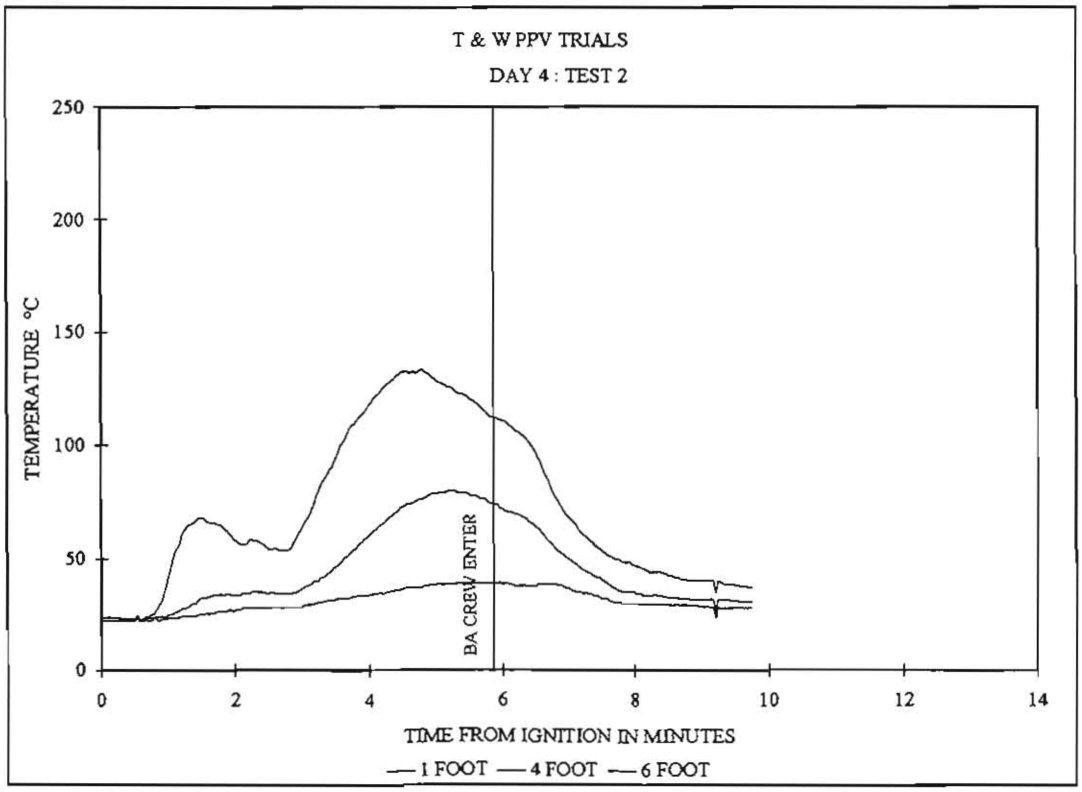

Figure 29 Thermocouple Records for Day 4 Test 2

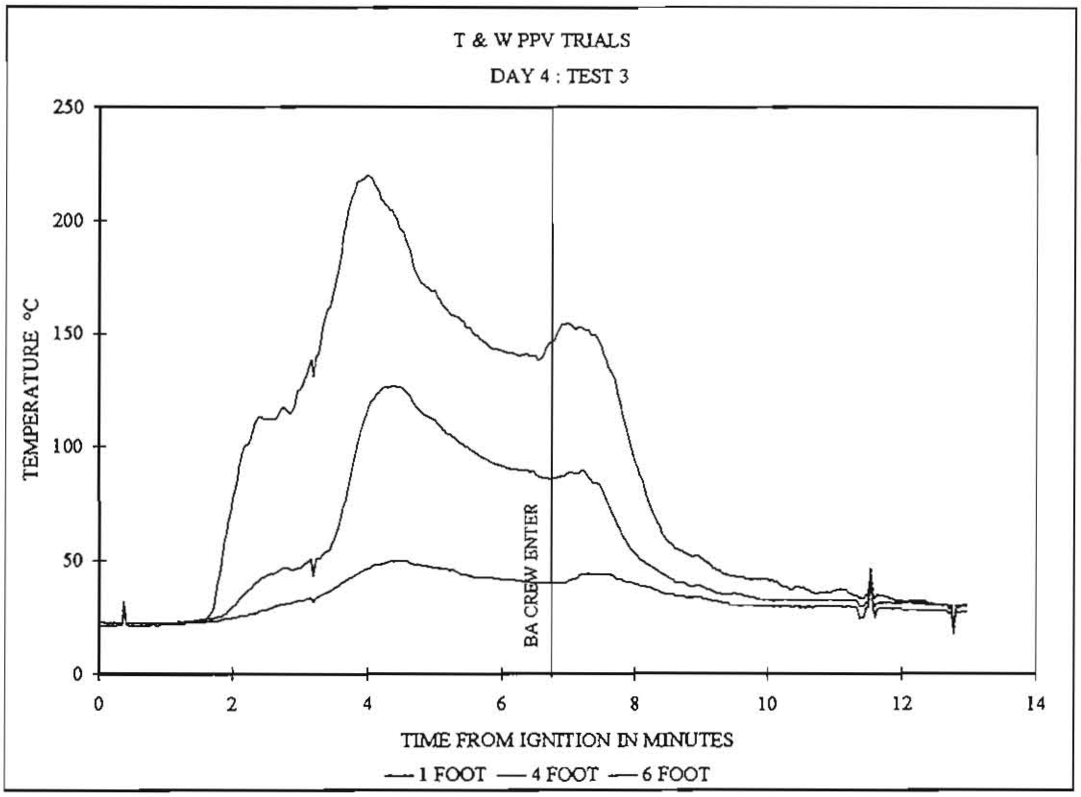

Figure 30 Thermocouple Records for Day 4 Test 3

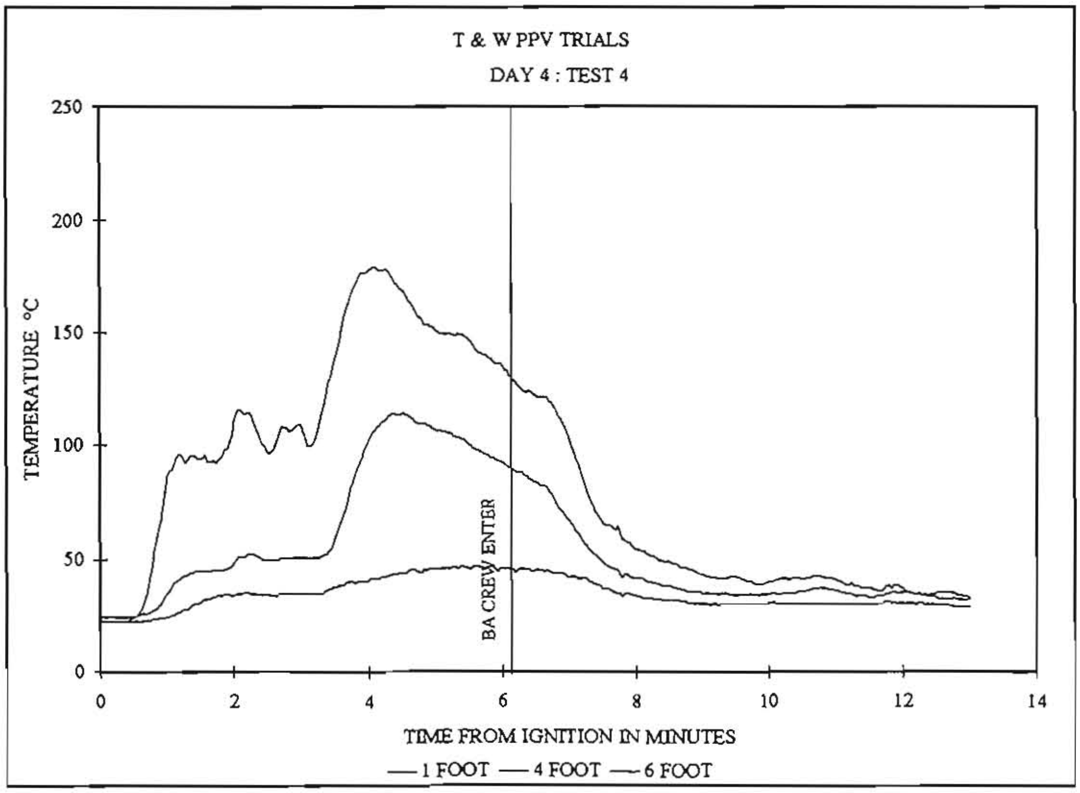

Figure 31 Thermocouple Records for Day 4 Test 4

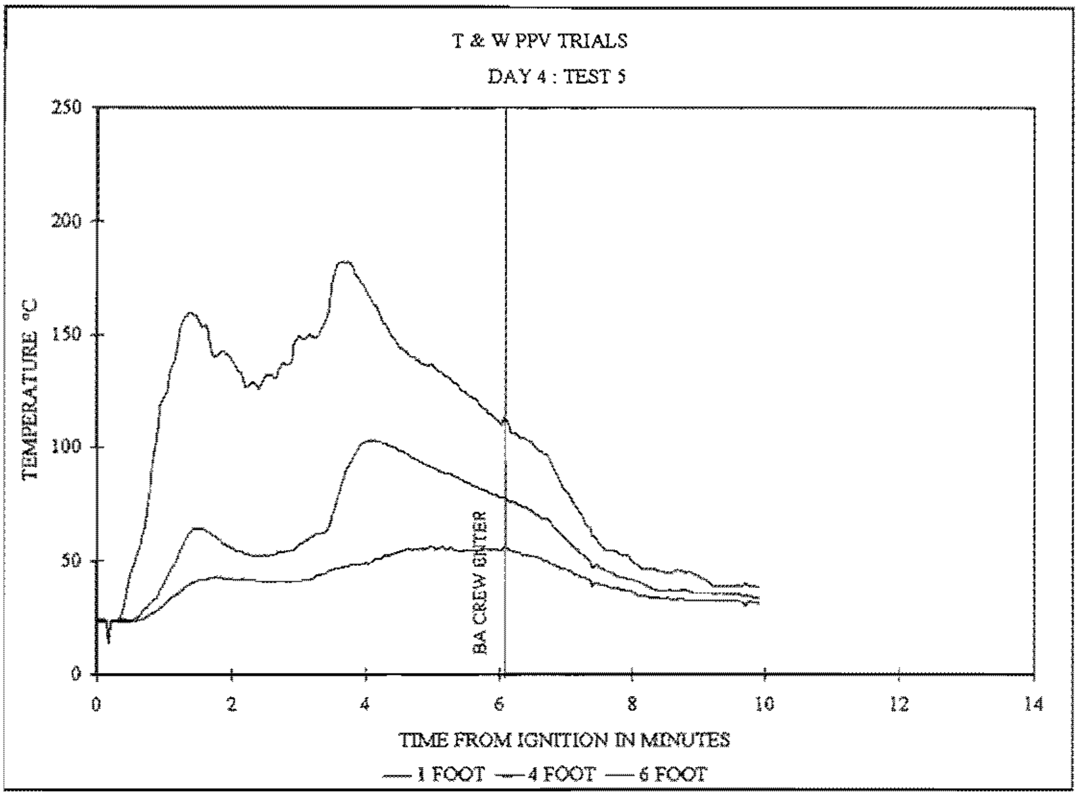

Figure 32 Thermocouple Records for Day 4 Test 5