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ON THE CONDUCT OF FAST COOKOFF TESTS IN AUSTRALIA

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L.M. BARRINGTON AND K.J. SCHEBELLA

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On the Conduct of Fast Cookoff Tests in Australia

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Abstract

The conduct of full scale fast cookoff or liquid fuel fire tests in Australia is becoming increasingly important as Australia moves to adopt and implement an official policy on Insensitive Munitions. EOD-Salisbury has considerable experience in the development and conduct of these tests, and some relevant findings are summarised here. This report is presented in five Sections:

Section 1 introduces the official Australian Insensitive Munitions policy,

Section 2 discusses the various fast cookoff test specifications which exist both internationally and in Australia,

Section 3 describes the results of a number of trials conducted to measure the spatial distribution of temperature within a liquid fuel fire, in order to firstly establish an upper wind limit for such tests, and secondly to locate the 'hottest' region of the fire,

Section 4 examines meteorological (wind) conditions at three potential fast cookoff test sites in Australia, and

Section 5 briefly summarises the report's findings.

DEPARTMENT OF DEFENCE
DSTO MATERIALS RESEARCH LABORATORY

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DSTO Materials Research Laboratory
Cordite Avenue, Maribyrnong
Victoria, 3032 Australia

Telephone: (03) 246 8111
Fax: (03) 246 8999

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On the Conduct of Fast Cookoff Tests in Australia

1. Introduction

Australia is in the process of adopting and implementing an official Australian Defence Organisation policy on Insensitive Munitions (IM). The Defence Instruction (General) (DI(G)) to set implementation in train (ref 1) was issued in November 1993.

The DI(G), which follows from a recommended policy outlined in an earlier Australian Ordnance Council Proceeding (ref 2), states that:

> "IM are to be introduced into Service with the Australian Defence Organisation, where it is sensible, practicable and cost-effective to do so ... All further procurement of Defence explosive ordnance should meet the applicable Insensitive Munitions criteria at Annex A, subject to consideration of the cost benefits ..."[1]

Annex A to the DI(G)[1] lists nine hazardous stimuli to which munitions may be exposed during the logistic cycle covering both peacetime and war. When a munition is proposed to be tested against these IM criteria, a threat analysis would first be carried out to define which of the nine hazards represent credible threats. The fast cookoff stimulus, which simulates a munition engulfed in a fast burning fire, is almost certain to be a requirement in all cases and the acceptance criteria for IM is that the response is no more severe than burning[1].

As part of Project Nulka, a considerable number of fast cookoff tests have been carried out to develop the test procedure as well as to assess the response of the Nulka round and earlier prototypes. This report details the specifications available for fast cookoff tests, the development of the test including recommendations for a preferred site, and discusses the results of tests to date.

2. Fast Cookoff Test Specifications

2.1 Introduction

Full scale fast cookoff tests, also referred to as liquid fuel fire tests, have been conducted routinely in the US and the UK for a number of years. These tests have been conducted in accordance with specifications which have changed little in technical content but repeatedly in title and specification number. Further, NATO has recently issued a Standardisation Agreement to cover liquid fuel fire tests, and with the adoption of an Insensitive Munitions policy, Australia has also adopted a fast cookoff test specification.

Given the increasing number of specifications in existence, this Section describes the current Australian and international situation with regard to full scale fast cookoff test specifications.

2.2 *US Specifications*

In September 1982, the US Department of the Navy issued a military standard, MIL-STD-1648A(AS) (ref 3), for the conduct of aircraft fuel fire tests. This MIL-STD superseded MIL-STD-1648(AS), issued in 1974. Clearly the emphasis of this MIL-STD was directed towards air launched ordnance involved in aircraft carrier fires, after the spate of catastrophic accidents aboard US carriers during the late 1960s. MIL-STD-1648A(AS) specified definitions of reaction severity and pass/fail criteria, as well as the test procedure. Key features of the test procedure included:

i. the ordnance shall be engulfed in a fuel fire for at least 15 minutes.

ii. the ordnance is suspended 3 feet (900 mm) above the fuel, in an attitude and position similar to those which would be encountered on an aircraft on a flight deck.

iii. two ordnance items shall be individually tested.

iv. the flame temperature shall reach 1000°F (537°C) within 30 seconds after ignition of the fuel.

v. an average flame temperature of at least 1600°F (870°C) ... will be considered a valid test.

In that same month (September 1982), the Department of the Navy issued military standard DOD-STD-2105(NAVY), superseding BUWEPS WR-50 of February 1964, for the conduct of Hazard Assessment Tests for Navy Non-nuclear Ordnance. In the section 'Fast Cookoff Test', DOD-STD-2105(NAVY) stated that the test should be conducted in accordance with MIL-STD-1648.

In 1985 and 1986, when the Department of the Navy issued NAVSEA INSTRUCTIONs 8010.5 and 8010.5A, 'Technical Requirements for Insensitive Munitions', these Instructions stated that fast cookoff tests should be conducted in accordance with DOD-STD-2105(NAVY), which in turn referred to MIL-STD-1648 as stated above.

NAVSEA INSTRUCTION 8010.5B (ref 4), 'Insensitive Munitions Program Planning and Execution', was issued in 1989. This Instruction stated that fast cookoff tests should be conducted in accordance with MIL-STD-2105A, which caused some consternation in Australia since at that time MIL-STD-2105A was still in draft form.

Finally, in March 1991, MIL-STD-2105A(NAVY) (ref 5) was issued, superseding DOD-STD-2105(NAVY). The fast cookoff section of this military standard no longer references MIL-STD-1648; instead it contains approximately one page of specifications for the test procedure. The key features of the MIL-STD-1648A(AS) procedure listed above are still retained, with one exception: the test item shall be engulfed in the fuel until it reacts, not for at least 15 minutes. This represents a considerable saving in fuel expense if a short reaction time can be confidently predicted.

The major problem encountered in conducting a fast cookoff test to this specification is in achieving the high required average flame temperature. This is discussed further in Section 3.

2.3 *UK Specifications*

As with the US documents which govern the conduct of fast cookoff or liquid fuel fire tests, a similar trend of revising specifications while keeping the technical details virtually intact has occurred in the UK. The following background is taken directly from UK Ordnance Board Proceeding (OB Proc) 42242 (ref 6):

> "By the late 1960's, Proc 39211, which had been used by the Board for some 10 years as a guide when preparing environmental test schedules, had become outdated and required replacement. The Board were aware that a new Defence Standard on environmental testing (... DEF STAN 07-55 entitled 'Environmental testing of Service Materiel') was being prepared ...
> The Standard evolved during the period 1968 to 1975 and DEF STAN 07-55/ Issue 1 was published in parts between February 1975 and February 1976. In the interim, the Board decided it was necessary to update Proc 39211 ... and Proc 41254 was published in October 1972.
> With the publication of DEF STAN 07-55 there came into existence a similar document that specified possible environmental tests. Although similar, some differences did exist between the documents ...
> The Defence Standard has more authority than the Proceeding and, moreover, it is more comprehensive in that it covers a wider range of environmental conditions. There remain, however, certain aspects contained in the Proceeding that were not reflected in the Standard."[6]

Consequently, in 1983 the Board issued OB Proc 42242, which:

i. formally acknowledged the existence of DEF STAN 07-55 by the cancellation of Proc 41254, to remove any ambiguity,

ii. provided guidance on the philosophy, principles and practice of environmental testing of armament stores, and

iii. published a summary of the trials not as yet fully defined in DEF STAN 07-55.

Specifically, DEF STAN 07-55 did not contain test information in sufficient detail on the Standard Liquid Fuel Fire test, amongst others. Consequently, these test details, reproduced from OB Proc 41254, were published as Annex C to OB Proc 42242. Key features of this specification for the standard liquid fuel fire test included:

i. the hearth area is to occupy an area at least 6 m x 6 m.

ii. the height of the store is to be arranged so that either the horizontal axis is 0.5 - 0.6 m above the initial fuel surface or so that the lowest part of the store is not less than 0.3 m above the initial fuel surface.

iii. the quantity of fuel should be sufficient to cause a reaction of the store

iv. to reduce the effects on the fire of wind, the hearth is to be enclosed on all sides by a fire-resistant ventilated wall or screen .... (details given)

v. trials should not be attempted with wind speeds exceeding 11 knots (20 km/h).

vi. a satisfactory development of the fire will be generally indicated if a temperature of 550°C is reached within 35 s.

Note that the most significant difference between this and the US test specification is the lack of a requirement for an average flame temperature. The UK specification simply sets an upper wind limit on test conditions, which is easier to achieve. This specification also allows flexibility in the height above fuel at which the test item is to be placed, so that the 'hottest' region of the fire can be selected if known.

In 1988, the UK Ministry of Defence issued a revised version of BR 8541 (ref 7) 'Safety Requirements for Armament Stores for Naval Use'. Chapter 18 of this BR, 'Safety Requirements for the Response of Armament Stores to Fire', states that new weapons and explosives stores must be so designed that if subjected to the Standard Liquid Fuel fire Test as specified in Annex C to OB Proc 42242, it shall not explode or detonate. Further, this Chapter states that the liquid fuel fire test procedure as defined above has been agreed by both UK and US authorities and is therefore mutually acceptable to both (ref 8).

In 1990, the Board published OB Proc 42657 (ref 9) 'Insensitive Munitions Pillar Proceeding'. In this Proc, the Board endorsed the use of NATO Standardisation Agreement (STANAG) 4240 (ref 10), for the conduct of a Standard Liquid Fuel Fire test. This STANAG is discussed in the following sub-section.

2.4 *NATO STANAG 4240*

NATO AC/310 is the NATO committee charged with munition safety. Its task is to standardise safety tests and it provides the most effective forum in which internationally agreed test criteria acceptable to Insensitive Munitions may be defined. AC/310 drafted a STANAG for the conduct of a liquid fuel fire test for munitions. This STANAG was ratified by Canada, Denmark, France, Germany, Norway, the Netherlands, Spain, the UK and the US at various times from 1989 to 1991, and published by the NATO Military Agency for Standardisation (MAS) as STANAG 4240, in August 1991.

Essentially, the technical details of the STANAG are a combination of the above discussed UK and US test procedures:

i. a hearth of at least 6 m square is required.

ii. the height of the lower surface of the test item above the initial fuel surface shall be sufficient to allow full combustion of the fuel below the test item.

iii. an average flame temperature of at least 870°C ... will be considered a valid test.

iv. the flame temperature shall reach 550°C within 30 seconds after ignition.

v. fire tests should not be conducted in the rain or when wind velocities in the test area exceed 20 km/h.

The STANAG then suggests that if a windbreak is required, it could be designed along similar lines to the UK windbreak in Annex C to OB Proc 42242.

Note that the STANAG contains the requirement for an average flame temperature of 870°C (taken from the US specification), however the height above the fuel for suspension of the test item can be selected to match the hottest region of the fire, as discussed in Section 3. One requirement of the STANAG which will increase the difficulty in obtaining the average flame temperature is its placement of thermocouples: four thermocouples must be mounted 40 - 60 mm from the surface of the test item at positions fore, aft, starboard and port, along a horizontal plane through the centreline of the test item. It is known that the readings obtained by the flame temperature thermocouples are lower than the true flame temperature. The main source of error in the readings is believed to be due to radiative heat loss from the thermocouples. This error is greatest for thermocouples as they get nearer the test item, and according to the STANAG the thermocouples are only 40 - 60 mm from a potentially large, relatively cool surface. This error is a maximum during the early part of the test and decreases as the test item heats up. Thermocouples in the MIL-STD-2105A(NAVY) test are 100 - 200 mm from the surface of the test item, which should give a slightly better measure of flame temperature.

2.5 Australian Specification

Included in Annex A to the Australian DI(G) for IM implementation[1] are the accepted Australian test and response criteria for Insensitive Munitions, and for the potential threat of a magazine, store or vehicle fuel fire, the stated test specification is STANAG 4240.

EOD-Salisbury has conducted a small number of full scale fast cookoff qualification tests in accordance with MIL-STD-2105A(NAVY), and problems were encountered in trying the achieve the required average flame temperature. Testing to the STANAG still requires the same average flame temperature, and although the flexibility in height above fuel for suspension of the test item is an advantage with this specification, the closeness of the thermocouples to the test item is a disadvantage.

EOD-Salisbury has also conducted a number of developmental fast cookoff tests during recent years, and results and recommendations from these tests are described in the following Section.

3. Temperature Distributions Within Fast Cookoff Tests

3.1 Introduction

It is known that the presence of wind during a fast cookoff test will significantly affect the temperature distribution within the fire. In order to achieve the required average flame temperature of 870°C according to STANAG 4240 or MIL-STD-2105A(NAVY), it is necessary to quantify this wind effect in some way, to set an upper wind speed limit for the conduct of fast cookoff tests. A number of studies (eg refs 11 to 16) have examined the influence of wind on temperature distributions within fuel fires, and their results are discussed briefly below.

Further, two series of short burn time fast cookoff tests were conducted by EOD-Salisbury in 1989 to investigate the spatial distribution of temperature in a fuel fire, in order to determine the 'hottest' region of the fire. Results from these tests, including a recommended upper wind speed limit and a height for suspension of the test item, are also presented.

3.2 *Literature Review*

Bader (ref 11) describes a series of eight basic fire tests conducted prior to 1965, to obtain the temperature distribution as a function of time within a fire. These tests were conducted in an 18 foot square (5.5 m square) pit, fed by JP-4 aviation turbine fuel, and were conducted with wind velocities less than 5 miles per hour (4.4 knots). JP-4 is a wide boiling range distillate with the joint service designation AVTAG/FSII. The burn time was approximately 10 minutes per test, and temperatures within a 5 foot square (1.5 m square) at the centre of the pit were measured at heights above the fuel surface from 8 inches to 50 inches (200 mm to 1250 mm). Tests are not discussed individually, nor is any further information given on wind conditions, so that only an overall summary of results is meaningful here. Bader found that temperature increased as a function of height above fuel (HAF) up to a point, and then remained constant. This 'point' varied from test to test, and ranged from 15 inches to 40 inches (375 mm to 1000 mm). From measurements made at 30 inches (750 mm) HAF, he calculated an approximate average flame temperature of 1850°F (1010°C), ignoring the initial temperature rise. It is believed that the use of thermally massive thermocouples (chrome-alumel thermocouples peened into a 1 inch square, 1/16 inch thick mild steel plate) may have helped in reducing wind effects.

Wind speeds are not recorded by Gordon and McMillan (ref 12), who conducted five tests comparing fires with JP-4 and 100/130 octane aviation gasoline. Using a 12 foot by 24 foot (3.6 m by 7.2 m) fuel pan, with thermocouples at HAF varying from 6 inches to 66 inches (150 mm to 1650 mm), they concluded that:

i. JP-4 burns with a higher temperature than aviation gasoline, and

ii. with JP-4 fuel, the average fire temperature increases with HAF up to approximately 30 to 40 inches (750 to 1000 mm), then decreases slightly.

Alger et al (ref 13) studied structural differences in JP-5 aviation turbine fuel and methanol fires, with wind speeds less than 2 m/s (4 knots). JP-5 is a kerosene type fuel, with joint service designation AVCAT/FSII. With methanol, the combustion zone consists of fuel eddies and air eddies that extend very close to the surface of the fuel (ie within 1 cm): for JP-5, the combustible species extended further above the surface, consistent with considerations of stoichiometry. The main observation to be drawn from their temperature profiles with HAF up to 1.2 m was that the heat release occurs relatively high (no quantitative height given) above the fire for JP-5 and extremely close to the surface for methanol.

References 14, 15 and 16 describe a total of five large, pool fire tests conducted by Sandia National Laboratories from 1983 to 1987. These tests were conducted with JP-4 aviation fuel in a 9 m by 18 m pool. For the first three tests (ref 14), an average wind speed of 2 m/s (4 knots) was set as the upper limit. Temperatures were measured at HAF from 1.4 m up to 11.2 m, with the trend being for the mean temperature to be highest at the lowest elevation and the decrease with HAF. Further, standard deviations from the means were calculated: the trend was for the standard deviations to be smaller at the lowest elevation and to increase with HAF, which is to be expected as wind effects are greater at the higher elevations. In the fourth test (ref 15), the mean wind speed over the time of burn was 1.7 m/s (3.4 knots) and temperatures were measured at HAF from 0.57 m up to 5.3 m. On each tower in the pool, the average temperature was highest at a HAF of 1.5 m, and decreased above and below this elevation. A similar trend was observed in the final test in this series (ref 16).

3.3 EOD-Salisbury Short Burn Time Fast Cookoff Tests

Two series of short burn time fast cookoff tests were conducted by EOD-Salisbury in 1989 to investigate the spatial distribution of temperature in a fuel fire.

3.3.1 First Test Series - Test Setup

In the first series, four tests were conducted in April and May 1989, at P&EE, Port Wakefield. Figure 1 shows the site layout for these four tests. Significant features of the test setup are described in the following paragraphs.

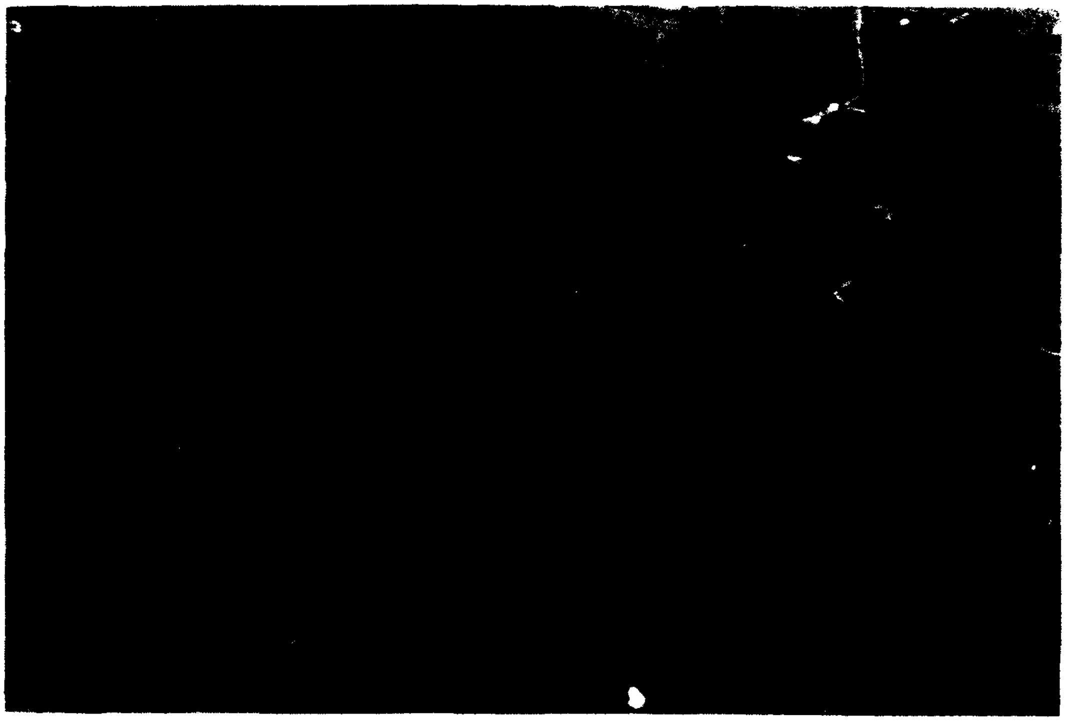

Figure 1: *Test setup - first EOD series.*

A 6 m x 6 m x 0.3 m pit was lined with plastic to contain the fuel for the tests. Five test stands were placed in the pit: one was placed in the centre and the remaining four were each located 1 m from the pit centre, towards the northeast, northwest, southeast and southwest corners. A 13 m x 13 m x 3.05 m high windbreak was erected around the pit area. This windbreak was manufactured from steel sheet, nominally 406 mm wide x 6500 mm long. Each wall of the windbreak was five sheets high, with a nominal 150 mm gap between sheets.

Sixteen stainless steel sheathed, mineral insulated type-K thermocouples (TCs) of 3 mm diameter were clamped to the five test stands at predetermined heights above the nominal initial fuel surface, to measure flame temperature. The thermocouple locations were constant for the four tests, and are given in Table 1.

Table 1: Thermocouple Locations - First Series of EOD Tests

TC No.	Height above fuel (mm)	Test Stand
1	150	Centre
2	300	Centre
3	450	Centre
4	600	Centre
5	900	Centre
6	1200	Centre
7	450	SE
8	600	SE
9	900	SE
10	600	SW
11	900	SW
12	1200	SW
13	450	NE
14	900	NE
15	300	NW
16	900	NW

Type K thermocouples were chosen as they best meet the potential temperature range of a fuel fire from ambient to in excess of 1200°C. All thermocouples were calibrated to 1000°C by Australian Defence Industries, Maribyrnong.

The thermocouples were connected via a junction box, housed in an underground cable pit, to a sixteen pair K-type extension cable which ran underground to the thermocouple signal conditioners. Analog Device's 5B37-K-02 Signal Conditioners were used to amplify the thermocouple outputs from millivolts to a zero-to-five volt signal representing -100°C to +1350°C. The signal conditioners also linearised the thermocouple outputs and compensated for the temperature of the thermocouple termination. The signal conditioners were battery powered to avoid ground loops and reduce any power supply-induced noise. The output signals from the thermocouple signal conditioners were applied to the data acquisition system via a multiple twisted pair, shielded cable. For the data acquisition system, an Analog Device's RTI-800 Multifunction Input/Output Board which has a 12-bit analog to digital converter and 16 pseudo-differential input channels was plugged into a Microbyte PC230 (an IBM compatible personal computer, with an XT bus and 8 MHz clock), running Quinn-Curtis' 'Control-EG' software, version 2.53. Each thermocouple input was sampled and logged every 0.5 seconds.

Five 200 litre drums of a kerosene type aviation turbine fuel, NATO designation F-35, Joint Service Designation AVTUR, were used in each test to give a burning time of approximately 5 minutes.

Prior to each test, a hand-held ball-in-tube flow meter was used to measure the wind speed.

In addition to investigating the 'hottest' region of the fire, these four tests were conducted to determine the effects of wind and the windbreak configuration on temperatures in the fire. To vary the windbreak configuration, for tests 2 and 3 the upwind wall was completely closed in. That is, the 150 mm gaps between the steel sheets were covered with an insulating material. Dates and windbreak configurations for the four tests are given in Table 2 below.

Table 2: *Test Configurations - First Series of EOD Tests*

Test	Time/Date	Wind Speed and Direction	Windbreak Configuration
1	07:25:37 11 April 89	3 kts, SW	4 walls standard
2	06:38:47 12 April 89	0 kts	3 walls standard, Southern wall covered
3	18:50:33 13 April 89	3 kts, S	3 walls standard, Southern wall covered
4	06:16:41 9 May 89	0-1 kts, NW	4 walls standard

Notes on Table 2:

a. Wind speeds were measured inside the windbreak
b. Wind speed accuracy is estimated to be ± 1 kt.

3.3.2 First Test Series - Results

Average flame temperatures (°C) and standard deviations (°C) for the four tests are given in Table 3.

These averages (and corresponding standard deviations) are calculated from the time any two thermocouples at 900 mm HAF record 1000°F (537°C), for five minutes. For short burn time tests, this is consistent with the definition of 'average' in MIL-STD-1648A(AS), which was the specification in use in Australia in 1989 when the tests were conducted, and in MIL-STD-2105A(NAVY). In STANAG 4240, the 'average' flame temperature is calculated from the time any two thermocouples record 550°C, which is not expected to change the averages significantly.

These results all follow the trend of upwind thermocouples having the lowest averages, and downwind the highest as these are closest to the nominal centre of the 'fire' as opposed to the centre of the pit.

Table 3: *Average Temperatures and Standard Deviations (°C) - First Series of EOD Tests*

TC No.	Test 1		Test 2		Test 3		Test 4	
	Avg	StDev	Avg	StDev	Avg	StDev	Avg	StDev
1	731	139	618	76	828	130	681	92
2	810	112	756	97	850	80	842	79
3	831	102	863	106	900	76	949	77
4	828	91	950	112	832	50	1010	85
5	794	91	1007	109	768	66	1060	107
6	726	110	1046	111	731	72	1061	131
7	849	53	870	86	878	55	900	118
8	830	61	942	89	766	47	977	148
9	769	78	1008	89	635	74	1026	175
10	759	73	966	73	924	62	1014	87
11	665	93	1023	90	833	42	1052	111
12	586	112	1055	108	675	59	1072	137
13	884	69	928	93	897	69	987	109
14	906	102	996	89	753	82	925	141
15	799	87	804	70	910	63	946	72
16	823	96	1050	90	897	71	963	97

As described in Section 2, according to the US specifications, and the STANAG if the test item is suspended at 900 mm HAF, a valid test is achieved if all thermocouples at 900 mm HAF record an average flame temperature of at least 870°C. In this test series, that corresponds to thermocouples 5, 9, 11, 14 and 16. From Table 3 it is concluded that Tests 2 and 4 (wind speeds less than 3 knots) were valid and Tests 1 and 3 (wind speeds equal to or greater than 3 knots) were not.

The average temperature versus height above fuel for Tests 2 and 4 are plotted in Figures 2 and 3 respectively. These figures show very similar results: in both cases, average temperature increases with HAF from 150 mm to 1200 mm, exceeding 870°C at approximately 450 mm HAF. The spread in averages at each HAF is particularly small for Test 2 which was conducted in very still conditions, and slightly larger for Test 4 where the influence of the slight breeze is evident. Standard deviations in temperature for Tests 2 and 4 are shown in Figures 4 and 5. These figures both show standard deviation increasing only slightly as HAF increases. Even though conditions during Test 2 were extremely calm, temperature standard deviations were still of the order of 100°C, illustrating the natural fluctuations in temperature which occur in large pool fires. Figure 6 shows a temperature versus time record for three thermocouples at constant HAF in Test 2, which is 'typical' of results obtained in Tests 2 and 4.

Figures 7 and 8 show average temperature versus height above fuel for the wind affected tests, Tests 1 and 3. The trend in both tests is similar: average temperature increases with HAF up to approximately 450 - 600 mm, and then decreases with HAF above 600 mm as the higher thermocouples are more influenced by the wind. The wind effect is also evidenced by the larger spread of results at the higher elevations where the temperature difference between upwind and downwind thermocouples is large. Overall, the averages were predominantly below 870°C. Comparing temperatures at the lowest HAF in Tests 1 to 4 shows higher averages for Tests 1 and 3 (the invalid tests) than 2 and 4, which suggests that the wind which is causing the temperatures at the higher HAFs to decline, is leading to increasing temperatures near the fuel surface. This is consistent with observations made by Schneider and Kent (ref 15). Standard deviations versus HAF for Tests 1 and 3 are shown in Figures 9 and 10. The trend in both tests is virtually the reverse of the average temperatures: standard deviations decrease with HAF up to approximately 450 - 600 mm, then increase slightly with HAF above 600 mm. The relatively low average temperatures and standard deviations at higher HAFs suggest that the flame tilt in these tests is such that the thermocouples are not engulfed by the flames for most of the test. Relatively high temperatures and high standard deviations for the lowest thermocouples confirm the turbulent mixing which is occurring close to the fuel surface during windy tests. Figure 11 shows a 'typical' temperature versus time record for three thermocouples at constant HAF in Tests 1 or 3. In contrast to Figure 6, the wind in Tests 1 and 3 is causing a significant difference between thermocouple temperatures at constant HAF.

The use of a different windbreak in Test 3, where the upwind (Southern) wall of the windbreak was completely sealed, appears to have had no effect on the wind conditions for that test. The wind speed measured in the centre of the pit just prior to addition of the fuel was the same as that measured outside of the windbreak.

3.3.3 Second Test Series - Test Setup

In the second series, another four tests were conducted in November and December 1989, at P&EE, Port Wakefield. In these tests, the pit size was increased to 9 m square in an attempt to reduce the wind effect and hence increase the average flame temperatures in the central region of the pit. Also, a dummy test item was suspended in the pit, and thermocouples mounted around it to more accurately simulate conditions in a fast cookoff test. Figure 12 shows the site layout for these four tests. Significant features of the test setup are described in the following paragraphs.

A 9 m x 9 m x 0.35 m pit was lined with plastic to contain the fuel for the tests. A gantry-beam assembly was assembled diagonally across the pit, from which a dummy test item was suspended. The dummy test item was an open steel tube, 2.4 m long x 200 mm diameter, suspended so that the horizontal centreline of the tube was 900 mm above the initial surface of the fuel. Seven test stands were placed in the pit: four were 200 mm from the surface of the dummy test item at positions fore, aft, starboard and port, and the remaining three were each located north from the centre of the pit, at 1.5 m, 2.5 m and 3.0 m. No windbreak was constructed.

Eleven stainless steel sheathed, mineral insulated type-K thermocouples (TCs) of 3 mm diameter were clamped to the seven test stands and on the gantry-beam assembly, to measure flame and gantry-beam temperatures. The thermocouple locations were constant for the four tests, and are given in Table 4.

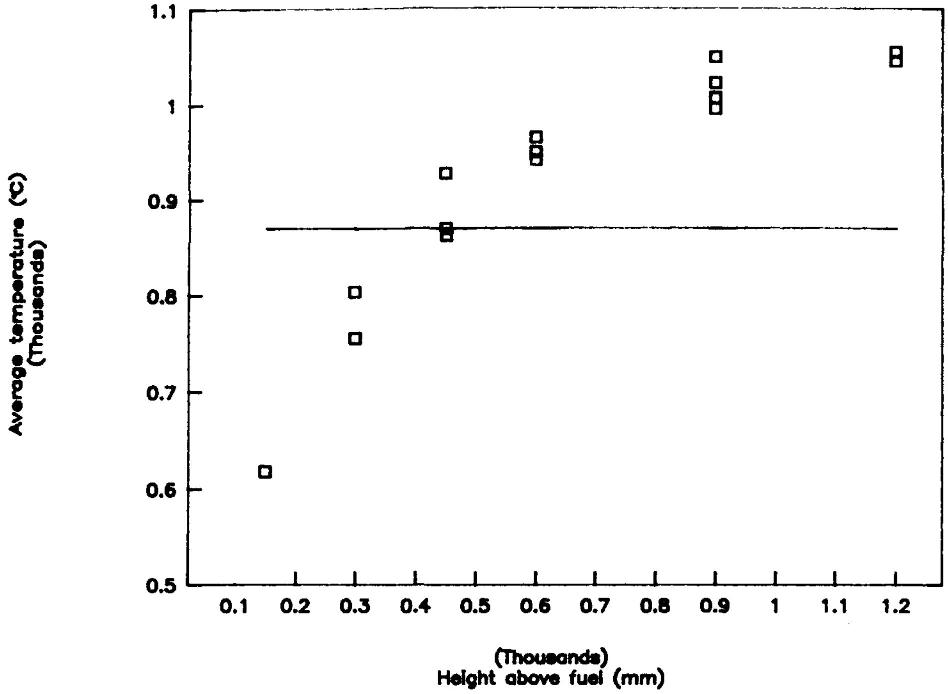

Figure 2: Average temperature as a function of height above fuel - test 2.

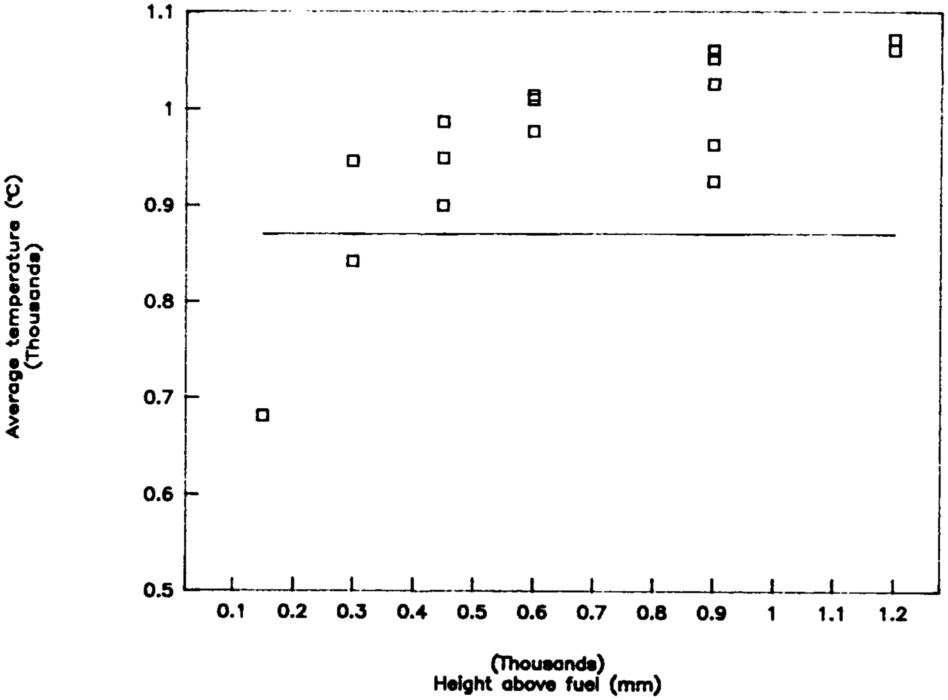

Figure 3: Average temperature as a function of height above fuel - test 4.

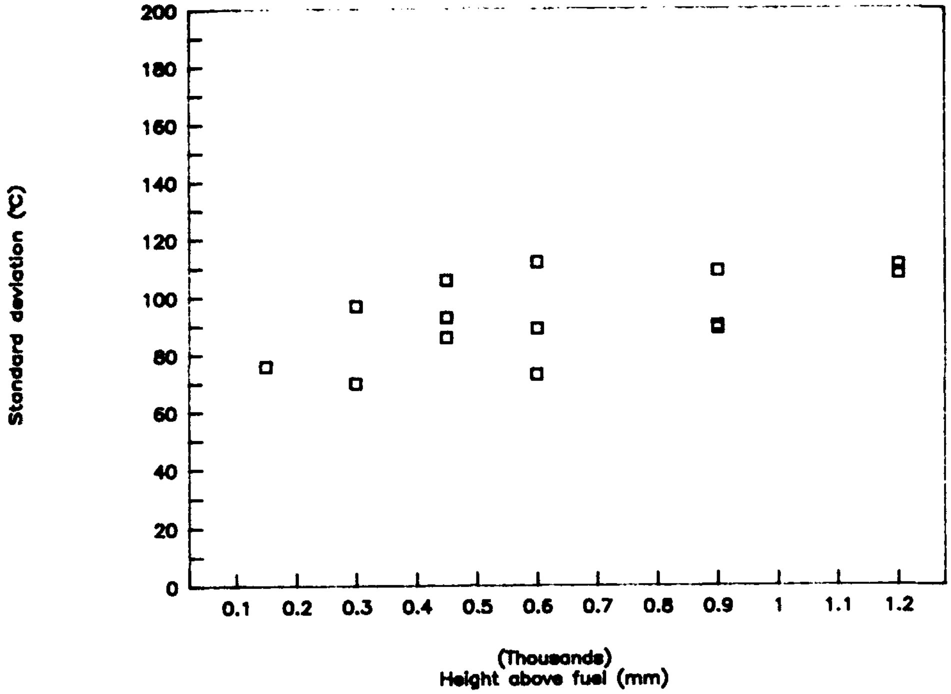

Figure 4: Standard deviation - test 2.

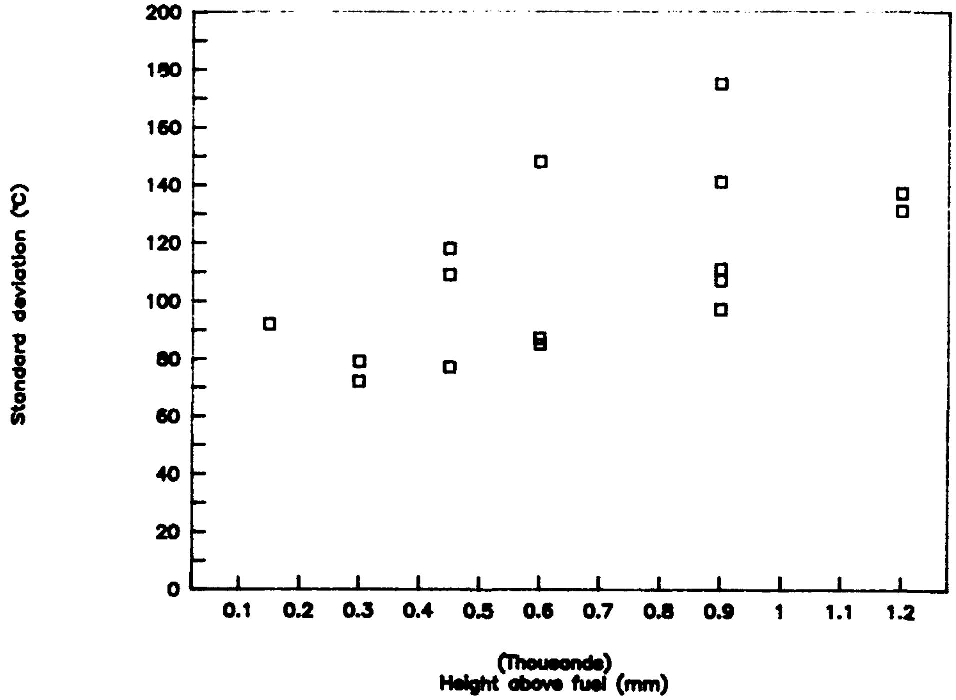

Figure 5: Standard deviation - test 4.

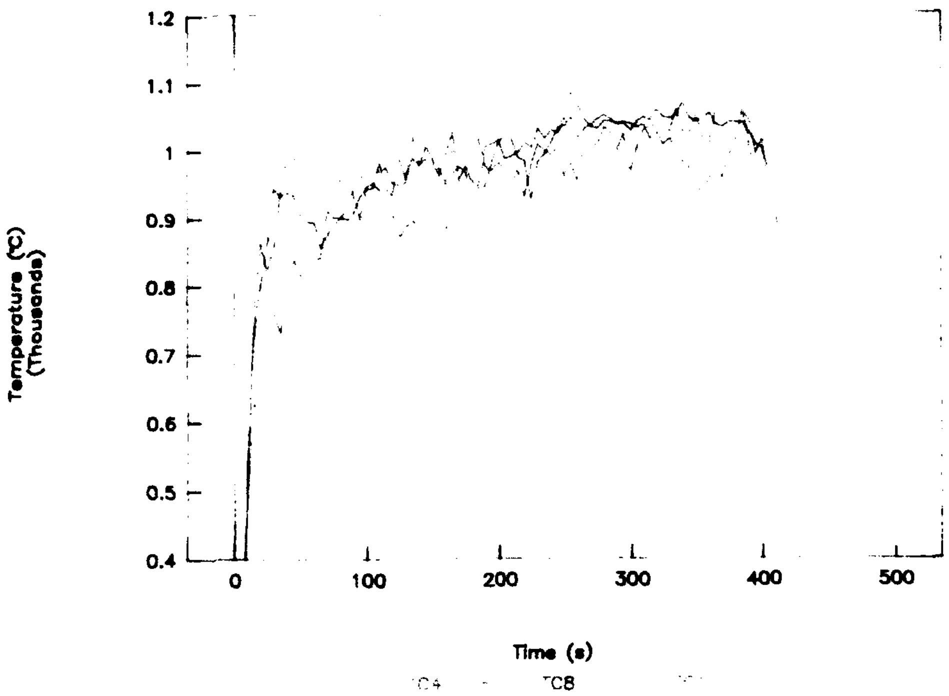

Figure 6: Temperature versus time record for three thermocouples at 600 mm - test 2.

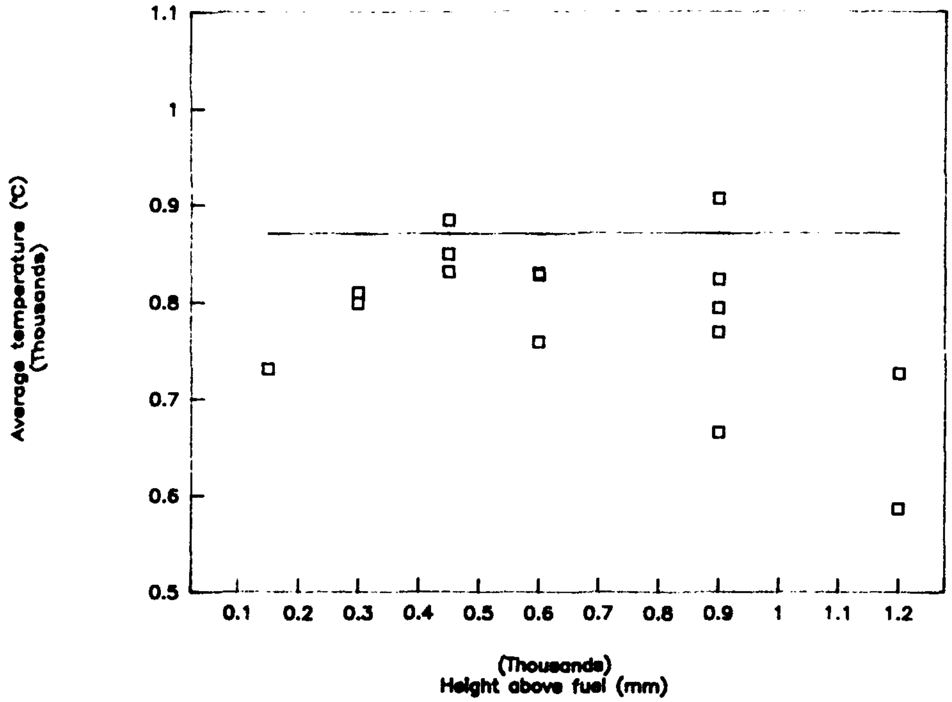

Figure 7: Average temperature as a function of height above fuel - test 1.

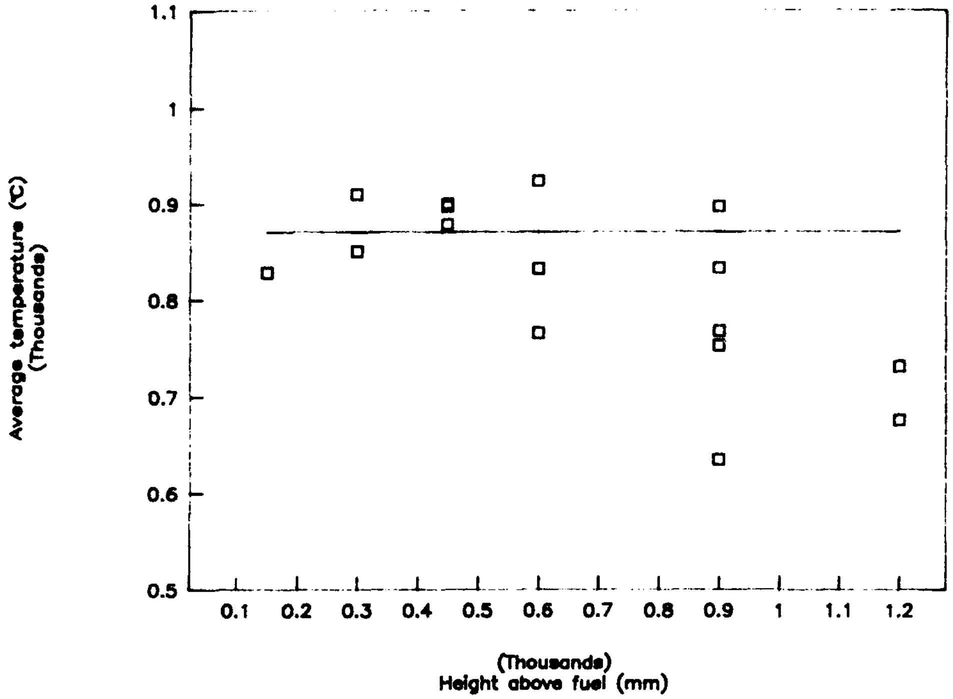

Figure 8: Average temperature as a function of height above fuel - test 3.

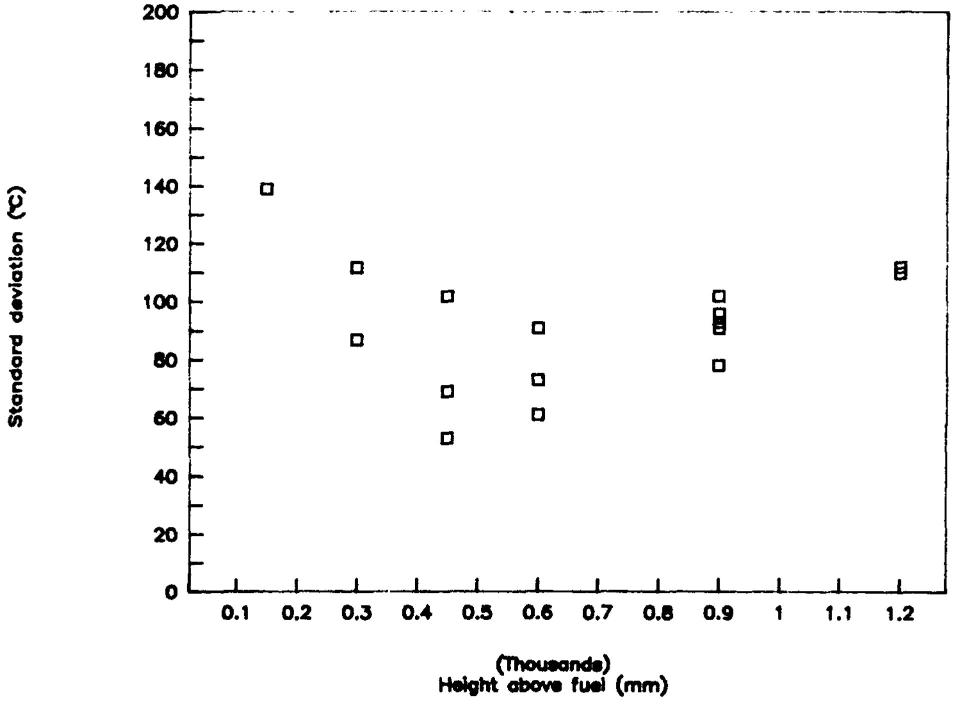

***Figure 9:** Standard deviation - test 1.*

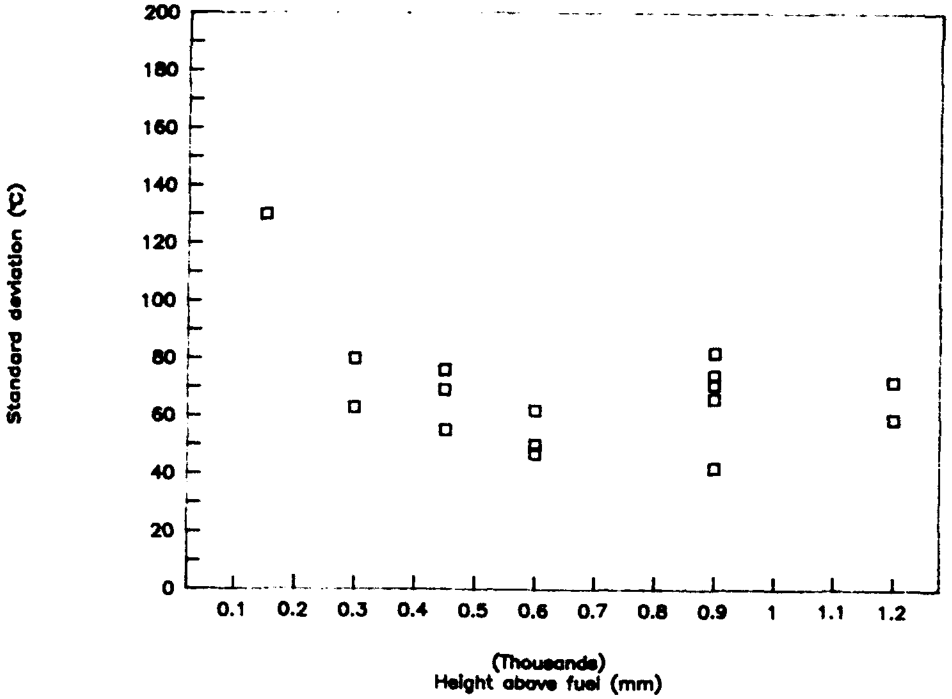

Figure 10: Standard deviation - test 3.

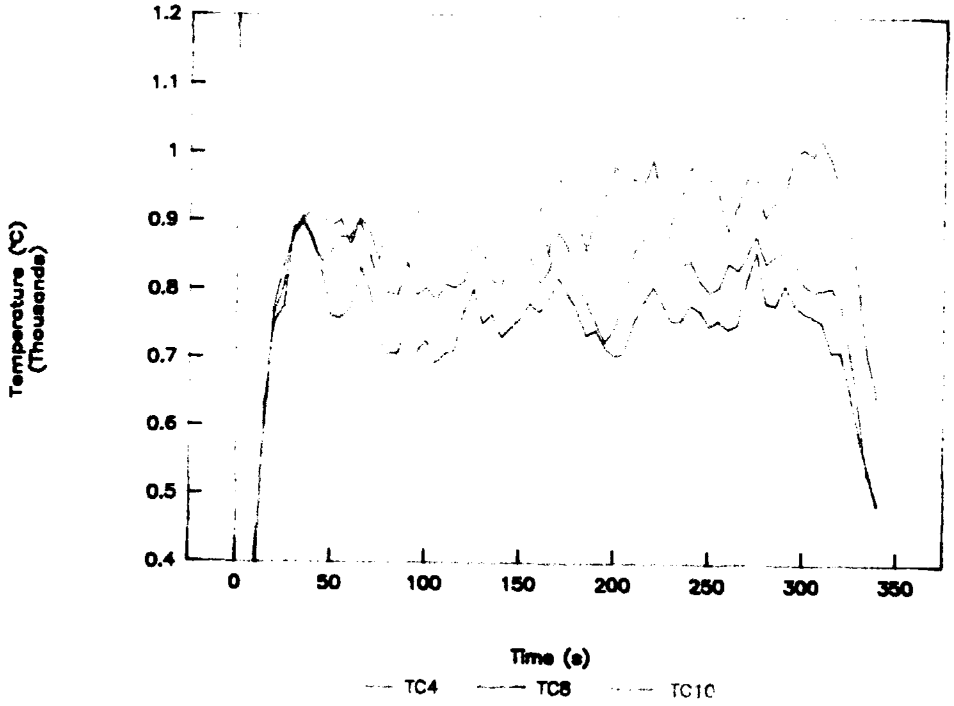

Figure 11: Temperature versus time record for three thermocouples at 600 mm - test 3.

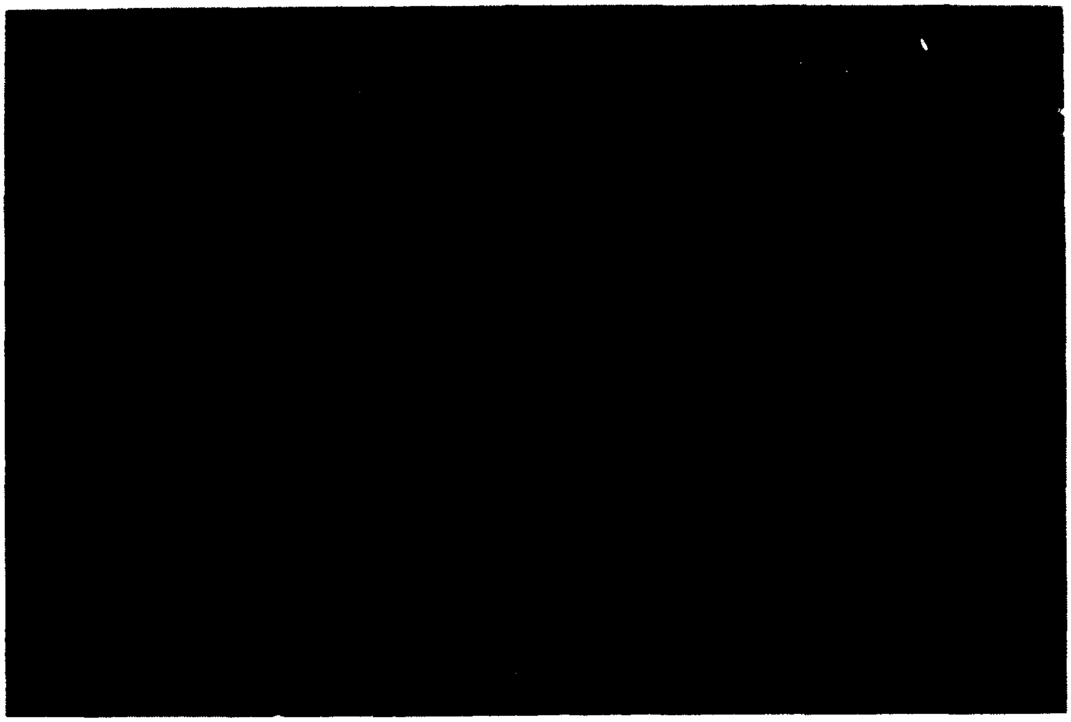

Figure 12: Test setup - second EOD test series.

Table 4: Thermocouple Locations - Second Series of EOD tests

TC No.	Height above fuel (mm)	Dist from centre of Pit (m)	Direction from centre of Pit
1	900	1.4	NE
2	900	0.3	SE
3	900	1.4	SW
4	900	0.3	NW
5	Top of Gantry-Beam Assembly	-	-
6	900	1.5	N
7	900	2.5	N
8	900	3.0	N
9	600	1.5	N
10	600	2.5	N
11	1200	0	-

The same temperature data acquisition system as the first series of tests was used in this series.

Nine 200 litre drums of fuel, NATO designation F-35, Joint Service Designation AVTUR, were used in each test to give a burning time of approximately 5 minutes.

Prior to and during each test, an Airflow LCA 6000 rotating vane anemometer was used to measure the wind speed. Test dates and wind speeds are given in Table 5 below.

Table 5: *Test Configurations - Second Series of EOD Tests*

Test	Time/Date	Wind Speed and Direction
5	06:52, 24 Nov 89	2.6 - 5.6 kts, SSE
6	06:10, 28 Nov 89	2.2 - 3.0 kts, NE
7	05:58, 29 Nov 89	3.4 - 4.0 kts, ENE
8	08:30, 1 Dec 89	5.0 - 6.0 kts, NNE

Notes on Table 5:

a. Wind speeds were measured approximately 40 m from the pit.
b. Wind speed accuracy is estimated to be ± 0.5 kt.

3.3.4 *Second Test Series - Results*

Average flame temperatures (°C) and standard deviations (°C) for the four tests are given in Table 6 below.

Table 6: *Average Temperatures and Standard Deviations (°C) - Second Series of EOD Tests*

TC No.	Test 5		Test 6		Test 7		Test 8	
	Avg	StDev	Avg	StDev	Avg	StDev	Avg	StDev
1	949	128	872	127	819	54	622	99
2	902	84	1000	59	767	86	727	104
3	682	48	1123	108	870	81	716	64
4	824	62	1067	163	945	83	708	111
5	172	65	415	161	216	89	122	50
6	1036	76	991	188	n/a	n/a	614	87
7	1066	40	714	151	870	139	404	57
8	1084	59	475	103	588	99	280	40
9	1037	38	976	163	n/a	n/a	719	110
10	1005	38	641	90	901	105	576	82
11	646	56	933	126	710	89	590	90

These averages (and corresponding standard deviations) are calculated from the time any two of thermocouples 1 to 4 record 1000°F (537°C), for five minutes.

From Table 6 it is concluded that Test 6 (wind speed less than 3 knots) was valid and Tests 5, 7 and 8 (wind speeds greater than 3 knots) were not.

Figure 13 shows the position of the dummy test item and the average temperatures for Test 6 as a function of their location in the pit. During this test, the prevailing wind was from the northeast (bottom left of Figure 13). The results are as expected: of thermocouples 1 to 4, the upwind thermocouple recorded the lowest average and the downwind thermocouple the highest. For a given HAF, temperatures decrease moving upwind and away from the nominal centre of the fire, and averages at 600 mm HAF are lower than at 900 mm HAF: these observations are both consistent with the results of the first test series discussed above for 'valid' tests.

Figure 14 shows average temperatures as a function of pit location for Test 5. In Test 5, the prevailing SSE breeze (top left of Figure 14) means that thermocouples 6 to 10 are closer to the centre of the 'fire' and hence record significantly higher averages than thermocouples 1 to 4. In Tests 7 and 8, average temperatures at 600 mm HAF were higher than at 900 mm HAF on the same stands, confirming the observation from the first series that during tests with wind speeds in excess of 3 knots, average temperatures increase with HAF up to approximately 600 mm, then decrease with HAF above 600 mm.

3.4 Discussion

Numerous studies have demonstrated the effect of wind on temperature distribution in kerosene-based fuel fires. Only a small number of these studies has been discussed in this Section; however the trends are clear and are confirmed by the two series of tests conducted by EOD-Salisbury.

In 'ideal' conditions (that is, wind speed of ≈0 knots), temperatures at a given height above fuel are hottest in the centre of the fire and decrease moving towards the fire's edges. As a function of HAF, temperatures increase with increasing HAF, up to at least approximately 1.5 m. In the EOD-Salisbury tests, average temperatures at any HAF above approximately 500 mm were in excess of 870°C and would have constituted a valid test.

In conditions where the wind speed lies in the range from 3.0 to 4.5 knots, temperature increases with increasing HAF up to a point, and then decreases with HAF. The HAF at which this reversal occurs can vary significantly and is influenced by the size of the fire, as well as the wind speed. In the studies discussed, this temperature inversion point varied from 375 mm (ref 11) to approximately 1.4 m HAF (refs 14, 15). During the EOD-Salisbury first test series this reversal typically occurred at 450 mm to 600 mm, and the averages at these HAFs varied from 750°C to 920°C.

Recognising that EOD-Salisbury fast cookoff tests are now conducted in 9 m square pits, and considering the results discussed throughout this Section, it is recommended that in order to maximise the frequency of valid tests:

i. Fast cookoff tests should not be conducted in conditions where the wind speed exceeds 3 knots, and

ii. In general, the test item should be suspended such that its horizontal centreline is 600 mm above the initial fuel surface. For bulky test items, this height must be increased to ensure that the fire is fully developed beneath the test item.

In order to decrease the local windspeed in the pit, a number of options discussed below can be considered.

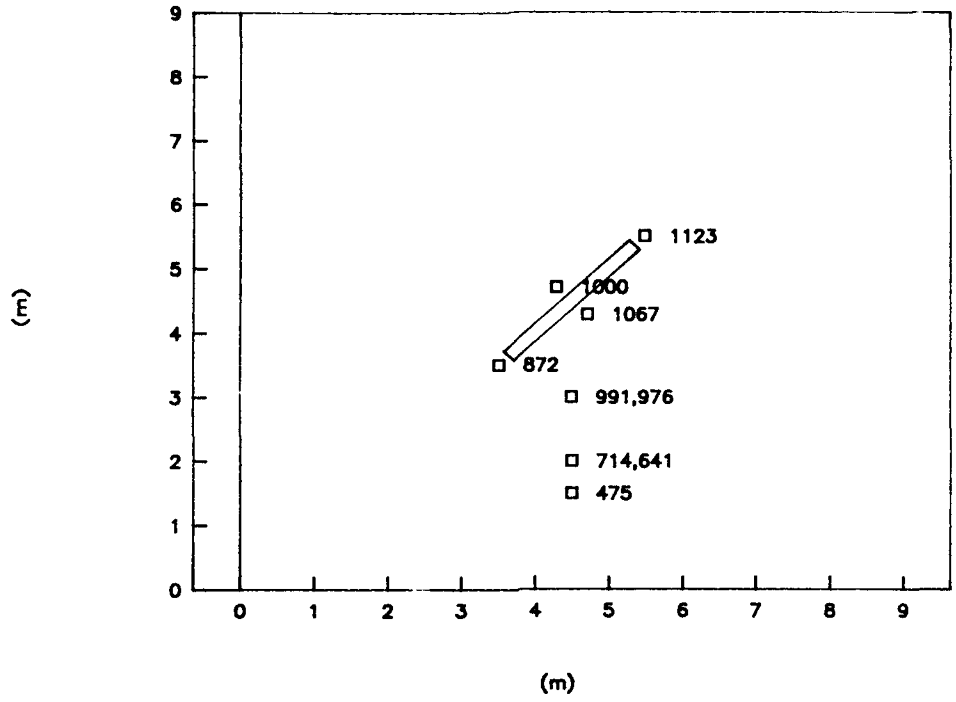

Figure 13: *Average temperature as a function of location in the pit - test 6.*

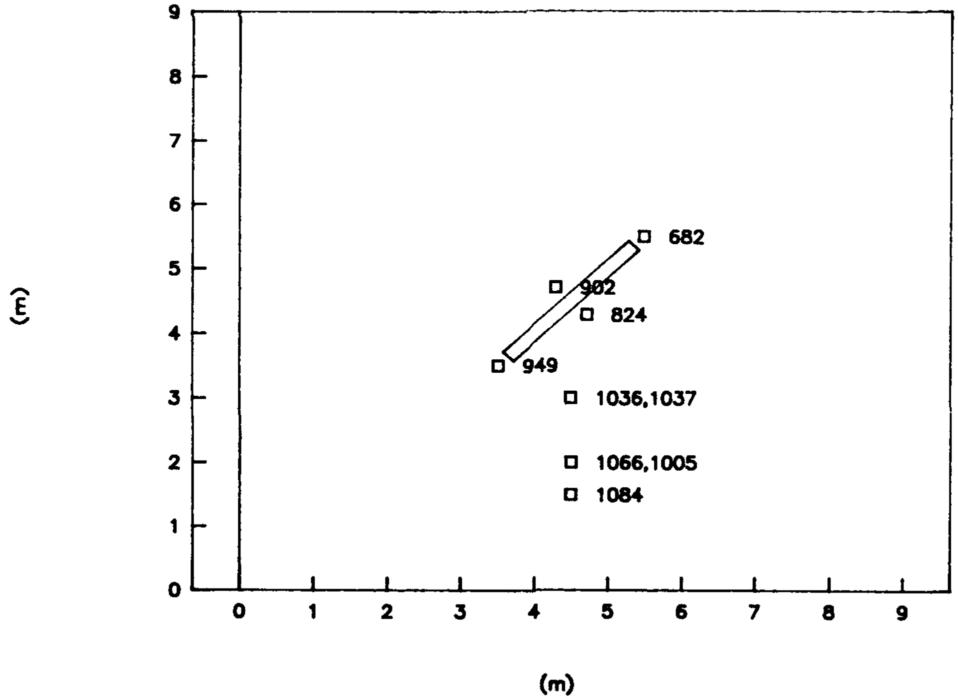

Figure 14: *Average temperature as a function of location in the pit - test 5.*

STANAG 4240 states that if it is necessary to reduce the effect of wind on the fire, the hearth may be enclosed by a fireproof screen or wall. Alternatively, a windbreak could be employed: the configuration described in Section 3-3 was clearly unsatisfactory as it had no effect on the wind speed in the pit area. However, the use of a properly designed, proven windbreak could virtually guarantee that every test would be valid, and the UK and NATO specifications do include an optional windbreak.

One consideration which must be addressed concerning the use of a fireproof screen or wall, or a windbreak, is 'fragment mapping'. The presence of a wall or windbreak may mean that it is not possible to determine how far any debris would have been thrown by the test item when it reacts. This information has historically been used as one indicator of the reaction violence. This is not considered to be a major problem however, as other criteria such as video records, and the nature and size of the post-test debris can be used. Further, it may be possible for the design of the wall or windbreak to incorporate pressure transducers to measure any blast overpressure from the test item reaction. This would also provide valuable information for determining the level of reaction violence. The cost of a wall or windbreak must also be considered, relative to the number of tests likely to be conducted in Australia in, say, the next decade. If sufficient tests are envisaged then a permanent or semi-permanent site could be established in Australia and a wall or windbreak could be costed as part of this total facility. At present, there is no permanent site and all fast cookoff tests are conducted by EOD-Salisbury at P&EE, Port Wakefield, on a 'one-off' basis. This makes the design, manufacture and erection of a wall or windbreak prohibitively expensive.

An alternative to a wall or windbreak could be to use an excavated pit. This concept was briefly described in UK OB Proc 41254 which suggested that where the situation permits, the hearth could be made 11 m square and 2.5 m deep with sloping sides and a windbreak would not be required. As stated earlier, this OB Proc did not require a minimum average flame temperature to be achieved, so that the dimensions of 11 m square and 2.5 m deep may not be suitable to satisfy the requirements of the current specifications. However, by modelling the wind conditions in a given size pit as a function of surface winds, it should be possible to determine appropriate pit dimensions so that less than three knots can be achieved in the pit with surface winds in excess of, for example, 5 or 6 knots. This would significantly increase the number or likelihood of tests being conducted. An advantage of a pit with sloping sides over a wall or windbreak is that fragment mapping would still be possible for the majority of fragments. The cost of this option must again be considered, relative to the number of tests planned and to the wall/windbreak option.

4. Potential Fast Cookoff Test Sites in Australia

4.1 Introduction

The previous section discussed two series of fast cookoff tests conducted by EOD-Salisbury at Proof and Experimental Establishment (P&EE), Port Wakefield during 1989. From these tests, it has been concluded that to achieve a valid test (according to STANAG 4240 or MIL-STD-2105A(NAVY)), wind speeds of less than 3 knots in the fuel pit are required for the duration of the test. In the worst case scenario where the effects of the wind are not mitigated, such meteorological conditions do not occur often at P&EE, Port Wakefield, in part because of its proximity to the coast.

To investigate alternate test sites, wind speeds from a meteorological station close to Port Wakefield have been compared with those at two other potential fast cookoff test locations, one in South Australia and one in Victoria. Information for this comparison was obtained from the Australian Bureau of Meteorology, and the results are discussed in this section.

4.2 *Potential Test Sites*

The conduct of a full scale fast cookoff test requires a test site with a number of features including the appropriate safety distances around the site, a hardened structure for instrumentation and personnel, 240V power, water, explosives storage and transport facilities, range clearance, control of access, fire fighting facilities and appropriate meteorological conditions.

Historically, fast cookoff tests managed by EOD-Salisbury have been conducted at P&EE, Port Wakefield, because it offers almost all of these features and it is convenient to Salisbury. The site is approximately 100 km north of Adelaide, on the northeastern tip of the Gulf of St Vincent. Excellent support is provided by P&EE, and the only feature which Port Wakefield does not offer is optimum meteorological conditions. The closest meteorological station to Port Wakefield is located at Price, on the northwestern side of the Gulf of St Vincent. Price is approximately 20 km southwest of Port Wakefield, and for the purpose of comparison with other potential sites, its wind conditions are taken to be representative of those at Port Wakefield.

An alternative South Australian test site is the Defence Support Centre, Woomera (DSCW). Woomera is located approximately 450km north northwest of Adelaide. Although full scale fast cookoff tests have not been conducted at Woomera, it offers similar facilities to Port Wakefield, and for wind speed data there is a meteorological station at the Woomera airport.

Army's P&EE located at Graytown in Victoria is the third potential test site to be considered, as it also satisfies all of the above requirements. P&EE, Graytown, is situated approximately 110 km north of Melbourne, and 25 km east northeast of the closest meteorological station at Mangalore.

It can be reasonably assumed that the wind speeds and directions recorded at Woomera airport and Mangalore are closely representative of conditions at the Woomera range and P&EE, Graytown respectively, given their proximities and their similar topographies. Further, the recorded data is obtained from an anemometer at these stations, measuring at the standard height of 10 m above the ground, and hence is quite accurate. In the case of Price and P&EE, Port Wakefield, while the sites are only approximately 20 km apart, the fact that they lie on opposite sides of the Gulf of St Vincent means that wind directions may vary significantly between the two sites. More importantly, the recorded data from Price is not obtained from an anemometer: an observer *estimates* the wind speed twice daily by looking at the effects of the wind on exposed objects, based on a set of guidelines from the Bureau of Meteorology. Consequently, wind speeds and directions recorded at Price may not be accurate indications of the conditions at Port Wakefield. This is discussed further in later paragraphs.

4.3 Wind Speeds

Wind speed data for Price, Woomera and Mangalore were obtained from the Australian Bureau of Meteorology - Surface Wind Analysis records (ref 17). For each location, these data consist of twenty four tables of 'percentage occurrence of wind speed versus direction', based on at least 22 years of records. Data in these tables, two per calendar month, are compiled from twice-daily measurements, at 0900 h and 1500 h. The percentage occurrence of wind speed conditions less than 3 knots at each location is given in Table 7 below.

Table 7: *Percentage Occurrence of Wind Speeds < 3 Knots - Woomera, Price and Mangalore*

Month	Woomera		Mangalore		Price	
	0900 h	1500 h	0900 h	1500 h	0900 h	1500 h
JAN	7	15	15	12	31	5
FEB	8	17	22	16	29	7
MAR	13	19	29	19	30	13
APR	18	20	40	22	33	18
MAY	28	20	47	25	38	21
JUN	35	19	54	29	42	39
JUL	34	14	49	25	33	31
AUG	22	13	38	19	31	27
SEP	11	13	29	18	25	18
OCT	5	12	23	17	19	11
NOV	6	14	21	16	21	8
DEC	7	13	20	13	25	4

Results for each of the three locations are also presented in Figures 15 to 17.

At Price (Figure 15) the trends observed are to be expected: the proximity to the coast means that, in winter, there is a relatively small difference between land and sea surface temperatures, so that there is very little difference between the 0900 h and the 1500 h wind speed results, with the latter being only slightly worse because of the small amount of increased mixing occurring later in the day when the land has warmed up a few degrees. During summer months, the sea breeze dominates in the afternoons when the land has warmed sufficiently, so that 0900 h results are typically much calmer than at 1500 h.

The Mangalore results (Figure 16) are also reasonable: being inland by some 110 km, winter surface temperatures can vary significantly during the day. At 0900 h, the cold ground air decouples from any wind above it and results in very calm conditions, however by 1500 h the ground air has warmed, considerable mixing and convection occurs and wind speeds increase. During summer, the warmer air is mixing throughout the day, so that 0900 h results are only slightly better than the 1500 h data.

Figure 17 shows the 0900 h and 1500 h results from Woomera. As with Mangalore, the 0900 h results are best in winter because of the cold ground air layer. At 1500 h, percentages only vary from 12% to 20% throughout the year. Surprisingly, results in summer are significantly improved at 1500 h than at 0900 h. The Bureau of Meteorology could give no explanation for this trend, and suggested that it may be due to some aspect of the local topography in the vicinity of the Woomera airport (ref 18).

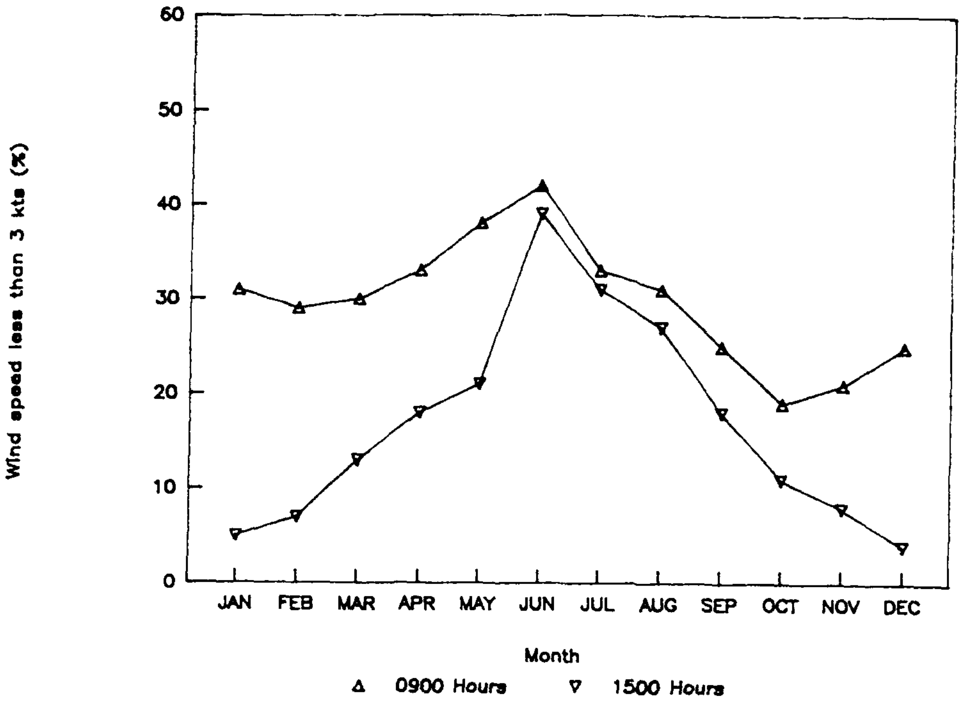

Figure 15: Percentage of occurrences of wind speeds less than three knots, by month - Price.

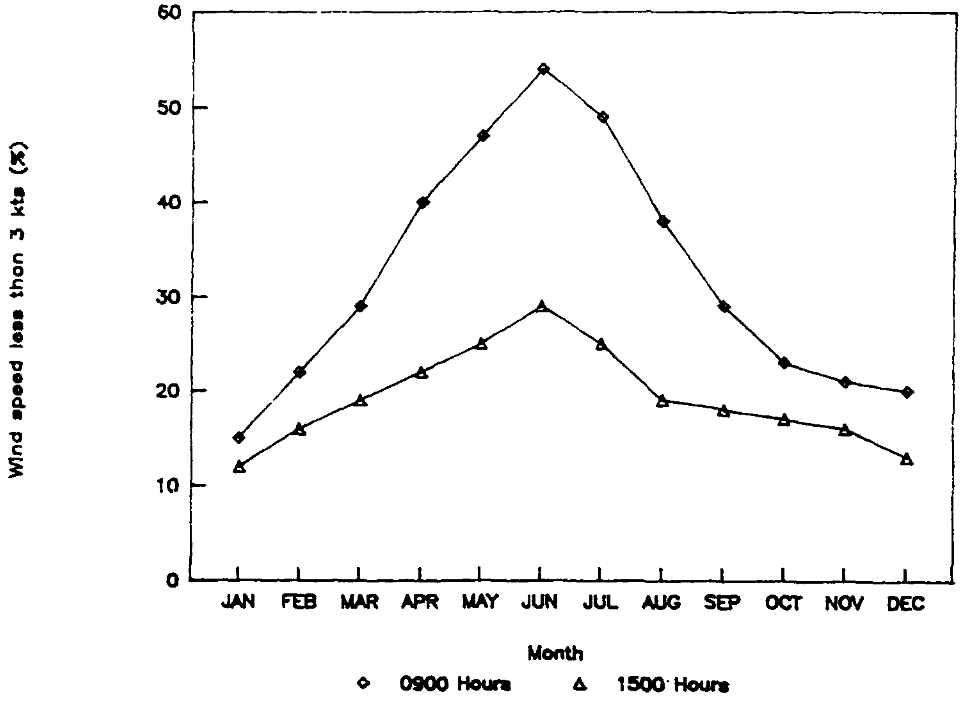

Figure 16: Percentage of occurrences of wind speeds less than three knots, by month - Mangalore.

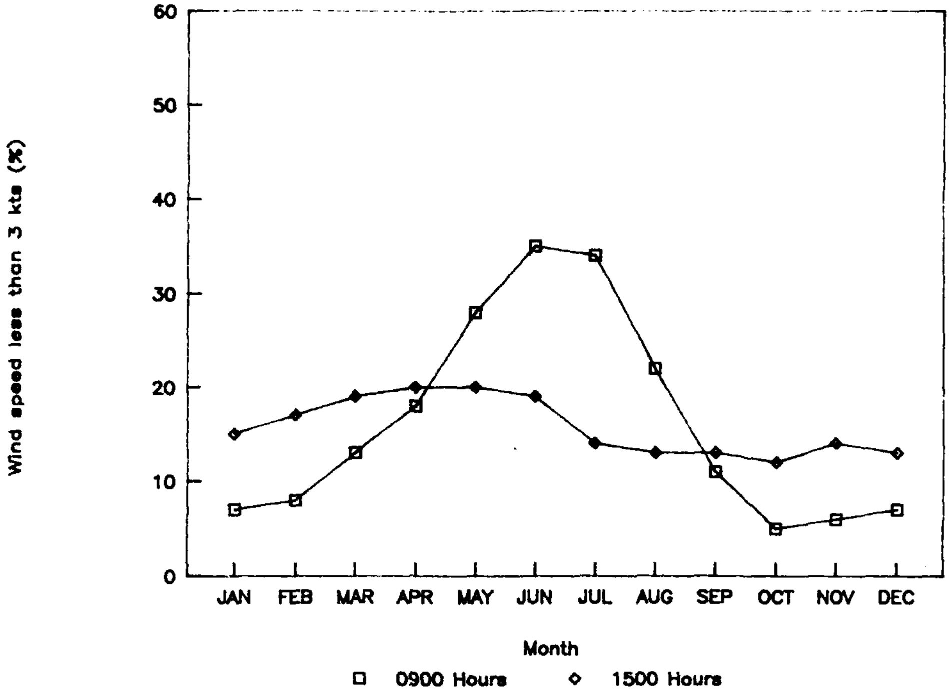

Figure 17: Percentage of occurrences of wind speeds less than three knots, by month - Woomera.

Two other factors should be considered when comparing these three sites. Firstly, the potential for a fast cookoff test to cause bushfires in the neighbouring vegetation. For this reason, EOD-Salisbury has elected not to conduct fast cookoff tests in the months of December, January or February. Hence, wind speed results for these months are ignored in the subsequent discussion. Secondly, the burning of large quantities of aviation fuel always generates a thick column of dense black smoke, so that an environmental impact study should be conducted prior to selection of an alternate test site.

4.4 Discussion

Given that each of the sites can provide all of the support required to conduct full scale fast cookoff tests, the preferred site based on wind conditions (excluding the summer results) is clearly Mangalore (ie P&EE, Graytown). Early in the morning, particularly in winter, is the optimum time to conduct fast cookoff tests.

The preferred site in South Australia is Price (ie P&EE, Port Wakefield). Again, winter months are preferred, with mornings only marginally better than afternoons at this time of year. In order to investigate the applicability of Price's records to P&EE, Port Wakefield, EOD-Salisbury has recorded a number of wind speeds at P&EE, Port Wakefield during November 1990 and March to May 1991. These results, obtained from an anemometer and a chart recorder, together with those for Price for the same days are given in Table 8 below. Readings are taken at 0900 h at both locations.

Table 8: Wind Speeds at 0900 h - Price and P&EE, Port Wakefield

Date	Price (knots)	Port Wakefield (knots)	Date	Price (knots)	Port Wakefield (knots)
3/11 (1990)	-	6	27/4 (1991)	-	4
4/11	-	1 (60 mins)	28/4	-	2 (120 mins)
5/11	15	10+	29/4	5	5
6/11	5	10+		5	1 (90 mins)
7/11	5	7	1/5	5	9
8/11	15	10+	2/5	5	9
9/11	10	10+	8/5	5	6
16/11	5	5	9/5	5	2 (90 mins)
17/11	-	10+	10/5	5	3 (5 mins)
18/11	-	9	11/5	-	7
19/11	5	6	12/5	-	7
20/11	10	10+	13/5	10	6
12/3 (1991)	5	5+	14/5	5	4
13/3	10	5+	15/5	5	3 (10 mins)
14/3	5	2 (15 mins)	16/5	5	1 (150 mins)
15/3	10	5+	17/5	5	2 (30 mins)
23/4	10	8	18/5	-	5
24/4	15	10+	19/5	-	5
25/4	-	10+	20/5	-	2 (45 mins)
26/4	-	5	21/5	5	3 (5 mins)

Notes on Table 8:

i. Values 5+ or 10+ indicate a result in excess of these values. The chart recorder connected to the anemometer output was set to 5 knots or 10 knots full scale during this recording.

ii. The number of minutes given for all Port Wakefield results less than or equal to 3 knots indicates how long the wind speed was below three knots around that 0900 h reading.

iii. No records are available for Price on weekends or public holidays as these records are gathered by Cheetham Salt Pty Ltd.

iv. The Price records are all in 5 knot multiples: as stated earlier, these records are estimates made by an observer to a set of guidelines, and if the observer is not sufficiently confident to state a precise value, he typically estimates to the nearest 5 knots.

No definitive conclusions can be drawn from Table 8, given the small sample size of comparisons, however there is reasonably good agreement between wind speed estimates at Price and records from P&EE, Port Wakefield, considering their locations and the nature of the Price estimates. Further, data in Table 8 suggests that the monthly figure for Price's 'percentage less than 3 knots' may be conservative (lower than what actually occurs at P&EE), since Price's estimates seem to be '5 knots' for anything above

'0 knots'. That is, only the '0 knots' readings will contribute to the 'percentage less than three knots' summary at Price: anything slightly above 0 knots is estimated at 5 knots. This lends more support to the use of Price's results to represent wind speed conditions at P&EE, Port Wakefield.

Obviously, it would be preferable to have wind speed data available directly from P&EE, Port Wakefield. There is an approved anemometer at P&EE, but it is not used for continuous recording, only monitored during appropriate trials.

Data in Table 8 also highlights both the care which must be taken when interpreting meteorological data, and a major difficulty encountered when conducting full scale fast cookoff tests. That is, at any given time when the wind speed is less than 3 knots, how long will that condition remain? From the time a decision is made to proceed with a test until the test is completed requires a *minimum* of 30 minutes (15 minutes to add final fuel and igniters to the pit, and 15 minutes for the test itself). From Table 8, although wind speeds at 0900 hours were at or below 3 knots on 11 occasions, 4 of these occurrences lasted less than 30 minutes and 1 was marginal. The officer in charge of the test has no way of knowing how long this 'relatively calm' period will last when he decides to proceed with the test, however once that decision is made and fuel is added, the test must proceed within a short time frame, whether or not the wind speed has increased. From considerations of safety, once the fuel is added the pit must be guarded day and night until the test is conducted. A long delay may be detrimental to the test item, and will significantly increase the cost of the test.

Results from the third potential test site, Woomera, were surprising to the authors. From our experience at both Port Wakefield and Woomera, we expected Woomera's results to be significantly better than Port Wakefield's. This was not the case: at both 0900 h and 1500 h, conditions at Price were, on average, preferable to Woomera.

In summary, on the data available, the preferred test site for fast cookoff tests in Australia is P&EE, Greytown, Victoria, with winter mornings being the optimum time of year to test. Within South Australia, P&EE, Port Wakefield, is preferred over Woomera, and winter mornings or afternoons are often acceptable. These recommendations are based on meteorological data from stations closest to these locations, which give the percentage of days per month that the 0900 hours and 1500 hours wind speed is equal to or less than three knots.

What is not available is any indication of conditions at times other than these, although some assumptions can be made. For example, it would be reasonable to assume that conditions in the early mornings (prior to, say, 0600 h) at P&EE, Greytown would be relatively calm due to the constant low surface temperature. The wind speed data presented also does not give any indication of how long the 'relatively calm' conditions prevail. This is a constant problem for the officer in charge of the test.

5. *Summary*

This report has considered three aspects of fast cookoff testing in Australia: test specifications, distribution of temperatures within the fire, and potential test sites based on meteorological conditions.

Particularly in the US and the UK, test specifications have changed very little in technical detail, despite the numerous titular changes and the many drafts and reissues. Theoretically, the current overseas situation is that virtually all NATO nations should be testing in accordance with NATO STANAG 4240. In practice, the US are still widely using MIL-STD-2105A(NAVY), which differs only slightly from the STANAG.

In Australia, the DI(G) on Insensitive Munitions lists STANAG 4240 as the fast cookoff *test specification. This specification* has the advantage that the height of the test item can be selected to match the hottest region of the fire, however it is recommended that the thermocouples be placed at 200 mm from the test item, as per MIL-STD-2105A(NAVY), to provide a more accurate measure of flame temperature. This is only a minor deviation from the STANAG, but will result in a significantly better test.

An examination of temperature distributions in large aviation fuel fires has shown that in nil wind conditions, temperatures at a given height above fuel are hottest in the centre of the fire and decrease moving towards the fire's edge. Temperature also increases with increasing height above fuel, up to at least approximately 1.5 m. In conditions where the wind speed lies in the range from 3.0 to 4.5 knots, temperature increases with height above fuel up to a point, and then decreases with HAF. This point varies, depending on the size of the fire and the wind speed.

Based on the results of Section 3, it is recommended that:

i. Fast cookoff tests should not be conducted in conditions where the wind speed *in the pit area* exceeds 3 knots.

ii. Tests should be conducted in a pit of at least 9 m square.

iii. The test item should be suspended such that its horizontal centreline is 600 mm above the initial fuel surface (higher only for bulky test items).

iv. Thermocouples to measure flame temperature should be placed at 200 mm from the test item.

Options for reducing the windspeed in the pit were also discussed in Section 3, including a fire wall or windbreak, or the use of an excavated pit. Subject to the number of tests likely to be carried out in Australia in the next decade, these options could be investigated as they have the potential to reduce the cost of full scale fast cookoff testing in the medium and longer term.

Of the potential sites considered, and based on limited meteorological information, the preferred location for a fast cookoff test site is P&EE, Graytown, followed by P&EE, Port Wakefield, and thirdly DSC, Woomera. However, given that suitable conditions do occur during the year at each of these sites, other factors must be also considered in choosing a preferred test site. These include the expected frequency of tests, current workload at each site and its capacity to cope with additional tests, the environmental impact of fast cookoff tests at each site, and cost implications such as transport of materiel and personnel, and infrastructure requirements not already in existence.

6. Acknowledgements

The tests described in Sections 3 and 4 required major contributions from a number of personnel and organisations, and their efforts are gratefully acknowledged. In particular, the authors wish to thank staff from P&EE, Port Wakefield, EOD-Salisbury's Drawing Office and Workshop, and Messrs Evans, Footner, Fraser, Braithwaite and Bull from EOD-Salisbury.

7. References

1. Defence Instruction (General) LOG 07-10, 'Insensitive Munitions', 10 Nov 93.
2. Australian Ordnance Council Proceeding 188.91, 'Insensitive Munitions. Recommended Australian Defence Organisation Policy', 5 Feb 91.
3. US Military Standard, MIL-STD-1648A(AS), 'Criteria and Test Procedures for Ordnance Exposed to an Aircraft Fuel Fire', 30 Sep 82.
4. US NAVSEA INSTRUCTION, NAVSEA INST 8010.5B, 'Insensitive Munitions Program Planning and Execution', OPR 662, 5 Dec 89.
5. US Military Standard, MIL-STD-2105A(NAVY), 'Hazard Assessment Tests for Non-Nuclear Munitions', 8 Mar 91.
6. UK Ordnance Board Proceeding 42242, 'Environmental Testing of Armament Stores', 14 Jun 83.
7. UK BR 8541, 'Safety Requirements for Armament Stores for Naval Use', Feb 88.
8. UK Ordnance Board Divisional Note 1/84.
9. UK Ordnance Board Proceeding 42657, 'Insensitive Munitions Pillar Proceeding', 25 Sep 90.
10. NATO MAS Standardisation Agreement, STANAG 4240, 'Liquid Fuel Fire Test for Munitions', 6 Aug 91.
11. Bader, B. E., 'Heat Transfer in Liquid Hydrocarbon Fuel Fires', Chemical Engineering Progress Symposium Series, Vol 61, No 56, pp. 78 - 90, 1965.
12. Gordon, W. and McMillan, R. D., 'Temperature Distribution within Aircraft Fuel Fires', Fire Technology, Feb 1965, pp. 52 - 61.
13. Alger, R. S., Corlett, R. C., Gordon, A. S. and Williams, F. A., 'Some Aspects of Structures of Turbulent Pool Fires', Fire Technology, 15, pp. 142 - 156.
14. Gregory, J. J., Keltner, N. R. and Mata, R., 'Thermal Measurements in Large Pool Fires', Journal of Heat Transfer, Vol 111, May 1989, pp. 446 - 454.
15. Schneider, M. E. and Kent, L. A., 'Measurements of Gas Velocities and Temperatures in a Large Open Pool Fire', Sandia National Laboratories Report SAND-87-0095C, 1987.
16. Schneider, M. E., Keltner, N. R. and Kent, L. A., 'Thermal Measurements in the Nuclear Winter Fire Test', Sandia National Laboratories Report SAND88-2839, 1989.

17. 'Bureau of Meteorology - Surface Wind Analysis, Percentage Occurrence of Speed Versus Direction Based on ... Years of Records', Stations 088109 Mangalore Composite, 022015 Price (Ocean Salt) and 016001 Woomera AMO, Bureau of Meteorology.

18. Private communication, Barrington (EOD-Salisbury) / Stock (Bureau of Meteorology, Kent Town, SA), 29 Jan 93.

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On the conduct of fast cookoff tests in Australia

AUTHOR(S)
L.M. Barrington and K.J. Schebella

CORPORATE AUTHOR
DSTO Materials Research Laboratory
PO Box 50
Ascot Vale Victoria 3032

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ABSTRACT

The conduct of full scale fast cookoff or liquid fuel fire tests in Australia is becoming increasingly important as Australia moves to adopt and implement an official policy on Insensitive Munitions. EOD-Salisbury has considerable experience in the development and conduct of these tests, and some relevant findings are summarised here. This report is presented in five Sections:

Section 1 introduces the official Australian Insensitive Munitions policy,

Section 2 discusses the various fast cookoff test specifications which exist both internationally and in Australia,

Section 3 describes the results of a number of trials conducted to measure the spatial distribution of temperature within a liquid fuel fire, in order to firstly establish an upper wind limit for such tests, and secondly to locate the 'hottest' region of the fire,

Section 4 examines meteorological (wind) conditions at three potential fast cookoff test sites in Australia, and

Section 5 briefly summarises the report's findings.

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L.M. Barrington and K.J. Schebella

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