NATO STANDARD

AOP-4240

FAST HEATING
TEST PROCEDURES FOR MUNITIONS

Edition A, Version 2

MARCH 2022

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

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NATO LETTER OF PROMULGATION

4 March 2022

1. The enclosed Allied Ordnance Publication AOP-4240, Edition A, Version 2, FAST HEATING TEST PROCEDURES FOR MUNITIONS, which has been approved by the nations in the CNAD AMMUNITION SAFETY GROUP (CASG – AC/326), is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 4240.

2. AOP-4240, Edition A, Version 2, is effective upon receipt and supersedes AOP-4240, Edition A, Version 1, which shall be destroyed in accordance with the local procedure for the destruction of documents.

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4. This publication shall be handled in accordance with C-M(2002)60.

Dimitrios SIGOULAKIS
Major General, GR (A)
Director, NATO Standardization Office

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS

Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.

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RECORD OF SPECIFIC RESERVATIONS

[nation]	[detail of reservation]
FRA	Reservation 1: Paragraph 2.2 – Test details: Test Method 1 (Standard) - Large Pool Fire When assessing an IM signature, France reserves the right, in its own programmes, to require that the liquid fuel/external fire test be performed on the item in the most detrimental configuration to safety. Reservation 2: Paragraph 2.2 – Test details: Test Method 2 - Fuel Burner Fire, and Test Method 3 - Mini Pool Fire When assessing an IM signature, France only accepts Test Method 1 (Large Pool Fire).
Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.	

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TABLE OF CONTENTS

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CHAPTER 1 INTRODUCTION

When reviewing requirements for this test, **SRD AOP-39.1** should first be read for guidance in the organization, responsibilities and conduct of full-scale testing.

1.1 ANNEXES

A. Best Practices

B. Historical Overview

1.2 RELATED DOCUMENTS

STANAG 4439	Policy for Introduction and Assessment of Insensitive Munitions (IM)
AOP-39	Policy for Introduction and Assessment of Insensitive Munitions (IM)
SRD AOP-39.1	Guidance on the Organization, Conduct and Reporting of Full-scale Tests
STANAG 4240	Fast Heating Test Procedures for Munitions
AASTP-03	Manual of NATO Safety Principles for the Hazard Classification of Military Ammunition and Explosives
United Nations	Manual of Tests and Criteria (ST/SG/AC.10/11)

1.3 AIM

The aim of this AOP is to specify the test requirements and procedures to provide evidence of the response of munitions and weapon systems to the threats represented from a very high rate of heating.

1.4 AGREEMENT

1. Participating nations agree that the requirements and methods incorporated in this AOP will be used for determining the response of munitions and weapon systems to heat fluxes which are typical of the fast heating to be generated within an engulfing incandescent flame envelope of a large liquid hydrocarbon fuel pool fire.

2. Participating nations further agree that national standards, orders, manuals and instructions implementing this AOP will include a reference to the STANAG 4240 for purposes of identification.

3. No departure may be made from this agreement without consultation with the NATO Tasking Authority. Nations may propose changes at any time to the NATO Tasking Authority where they will be processed in the same manner as the original agreement.

1.5 DEFINITIONS

For the purpose of this document, definitions of terms to be used to describe test details and events are given in the NATO Terminology Database (NATOTerm) that is available by reference for all Allied Publications.[1]

1.6 GENERAL

1. Effort to minimize the violence of the reaction of munitions to fast heating conditions that result from direct exposure to fires is a continuing commitment of weapons designers in order that the safety of personnel and materiel will not be unduly jeopardized.

2. This AOP addresses the situation where munitions and weapon systems are exposed to fire afloat and ashore, which can result in a significant compromise of safety. This can occur in peacetime as the result of an accident, dissident/saboteur activity, or on operations as a consequence of enemy action, which can result in a significant compromise of safety.

3. The objective of the Fast Heating Test is to determine the response of the munition(s) when subjected to a fast heating fire environment.

4. This test may also be used for Hazard Classification (HC) as required by AASTP-03 and UN Document ST/SG/AC.10/11 and any amendments thereto, and other applications not covered by these documents where the response of a munition to fast heating is required to be known or assessed. If a test is to be used for Hazard Classification, an agreement must be reached between Hazard Classification and Safety Authorities on the required test, number of test items, their configuration (e.g. packaged or unpackaged), and the number of tests to be performed.

[1] https://nso.nato.int/natoterm/

1.7 TEST LIMITATIONS

1. The Fast Heating Test is designed only to simulate the most intense heating conditions likely to be created in a hydrocarbon fuel pool fire. This test does not, however, simulate a particular in-service or accident scenario.

2. Test items filled with energetic materials that are involved in less intense fires, or exposed to lower rates of heating, may well remain quiescent for longer periods of time. The magnitude of any resulting response may be more violent than the response from exposure to high heating rates since more energetic materials reaching hazardous temperatures are confined in an unbreached enclosure.

3. Data obtained from this test should not be extrapolated with respect to either temperature or time in order to derive forecasts of performance in other situations that may involve lower temperature or heat flux levels. Rates of heat flow and thermal gradients within complex assemblies can become non-linear when changes of state and / or the loss of integrity of internal structures and components occur.

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CHAPTER 2 TEST SPECIFICATIONS

2.1 TEST ITEM CONFIGURATION

1. The test item configuration shall be the final production standard and in accordance with the condition as appropriate to the life cycle phase represented by the test, or representative as approved by the National Authority.

2. Guidance on variations to the production standard and condition (e.g. live vs inert, pre-conditioning, packaged vs unpackaged, single vs multiple test items, All-Up-Round vs component level) as given in SRD AOP-39.1 Annex B shall be considered.

2.2 TEST DETAILS

2.2.1 Test Methods

There are three methods for performing the Fast Heating Test for Munitions:

a. Method 1 (Standard) for determining the response of a munition when heated in a large pool of liquid burning hydrocarbon fuel. (Liquid Pool Fire, LPF);

b. Method 2 (Alternative) for determining the response of a munition when heated by a gas fuelled heating source. (Fuel Burner Fire, FBF);

c. Method 3 (Alternative) for determining the response of smaller munitions when heated in a small pool of liquid burning hydrocarbon fuel. (Mini Pool Fire).

2.2.2 Test Requirements

The test consists of engulfing the munition(s) in a fire and recording its reaction(s) as a function of time. To ensure sufficient and uniform thermal loading of the test item the following requirements on temperature, measurements, weather conditions and timing shall be met for all test methods. There is an additional requirement for Test Method 2 – FBF which addresses the calibration of the test setup for the correct heat flux.

a. **<u>Temperature.</u>** An average flame temperature of at least 800 °C, as measured by all valid external thermocouples will be considered a valid test. A thermocouple is regarded as invalid when its reading is influenced (increased, decreased or completely broken) by any reaction of the munition or its location has been moved during the measurements. This temperature is determined by averaging the temperature from the time the flame reaches 550 °C to the time all munition reactions are completed. Any deviation from this shall be recorded with appropriate time versus temperature data. The flame temperature shall reach 550 °C under 30 seconds after ignition as measured by all valid thermocouples.

b. **<u>Measurements.</u>** To provide a consistent, remote indication of the full development of the fire, a minimum of 6 thermocouples are required. These thermocouples shall be mounted 40-60 mm from the surface of the test item at positions fore, aft, starboard, port, above and below along a horizontal and vertical plane through the centerline of the test-item. Data shall be recorded at a sample rate greater than or equal to 1.0 Hz. Additional thermocouples may/should be positioned at the discretion of the National Authority.

c. **<u>Weather conditions.</u>** Fire tests should not be conducted in the rain, where localized heating irregularities could arise, giving spurious results that affect the test outcome. This test should also not be undertaken with excessive wind velocities in the test area (or inside wind barriers if such barriers are used), as this will prevent the test item from being fully engulfed by flames and will adversely affect the outcome of the test result. The use of mesh wind “curtains” as a wind barrier is preferred over solid walls or earthen burns. The wind curtains will allow ejected fragments to pass through with minimal effect on their trajectories. Solid barriers may cause a local increase in wind speed or deflection of wind direction. These are unacceptable test conditions.

ADVISORY NOTE: wind velocities greater than 10 km/h may result in temperature profiles that could invalidate a test, however, other factors (hearth size, test item size and location within the hearth) might still allow for acceptable temperature profiles and thus a valid test.

d. **<u>Timing.</u>** The zero-time base for the timing of test item reactions is the instant that all valid thermocouples reach 550 °C. This is an indication the test item has been engulfed by the fire. Verification of the time and degree of engulfment can be obtained from a combination of cine-film or video, and a timing device. The test is terminated upon completion of the reaction(s) of the munition(s) or when the fuel supply is exhausted and no sustained reaction (combustion, fragmentation, etc.) of the munition(s) is recorded as evidence of a Type VI response.

e. **<u>Additional requirements Test Method 2 – FBF.</u>** Heat flux in addition to the gas flame temperature must be used to characterize fires using alternative fuels in Test Method 2. A uniform spatial temperature distribution is required in an FBF, and measurements are dependent on instrumentation location, orientation and environmental conditions such as wind. Each new hearth/test facility design shall be calibrated to ensure the heat flux requirements are met. Once a hearth/test facility is qualified, further heat flux measurements are not required unless a change has been made to the configuration that would affect flame temperature or heat flux. Examples of changes include: gas nozzles, fuel type and shielding of radiation.

The following list of thermal requirements is provided to ensure that the environment is representative of that within a LFP. During calibration, the region within the burner that meets these requirements is determined. The region that qualifies is called the “hearth”. Items shall be tested in a region that meets all of these requirements:

(1) The average temperature must be greater than 800 °C and reach 550 °C within 30 seconds of ignition.

(2) Heating must be uniform.

(3) The total absorbed heat flux, as measured by a device of specified dimensions, must be greater than 80 kW/m^2 when averaged over a minimum 30 second period after a minimum temperature of 800 °C is achieved.

2.2.3 Test Set-Up

2.2.3.1 Test Method Specific

Each test method has a different physical setup to account for variations in the size of the test item or to reduce the amount of fuel required to undertake the test. Each test method has been designed to provide the same, comparable, flame-engulfing heating conditions.

a. In Test Method 1 - Large Pool Fire (LPF) is the test item surrounded by rich flames from a large open hearth containing liquid fuel. This test was formerly called “The Liquid Fuel/External Fire Test.” The large horizontal dimensions of the hearth ensure that the flames are fuel rich and hence heat transfer to the test specimen is highly radiative.

The hearth is the region within the fire where the temperature requirements are met. The hearth shall be large enough to allow at least 1 m clearance on each side of the test item and designed to provide a volume of flame which completely engulfs the test item throughout the trial. The liquid hydrocarbon fuel shall be contained within the hearth by an appropriate liner or pan, which does not interfere with the outcome of the test. The simplest design of a hearth can consist of a shallow, level pit, or a levelled area surrounded by a wall or embankment. The depth of the pit, or height of the wall or embankment, shall be sufficient to contain the required amounts of fuel and water as determined from Annex A. The depth of the pit shall not block fragment projection and accurate measurement of blast overpressure.

b. Test Method 2 - Fuel Burner Fire (FBF) has been introduced to allow other hydrocarbon fuels to be used by test centers when undertaking a Fast Heating Test. Research has shown that gaseous fuels (e.g. propane) can produce comparable absolute temperatures and heat fluxes to those of a pool of burning liquid hydrocarbon fuel, producing equivalent heating conditions to the test item. Testing and modelling has shown that the radiative and convective components of both gaseous propane and liquid hydrocarbon fuels are not always equivalent, but the total heating of the test item is equivalent when the correct test setup is used. The Fuel Burner Fire (FBF) allows for the alternate use of, and delivery of hydrocarbon fuels. The test specimen is surrounded by flames coming from fuels other than liquid pools.

Various designs of an alternative fuel facility are acceptable provided that the configuration allows for the required instrumentation and test requirements including hearth size, flame temperature and heat flux as well as clear recognition of the response types. The hearth is the region within the fire where both the temperature and heat flux requirements are met. The hearth shall be large enough to allow sufficient clearance on each side of the test item and designed to provide a volume of flame which completely engulfs the test item throughout the trial. It is imperative that any test configuration developed to use an alternative fuel, must be properly calibrated and characterized to show that the total heating of the item is equivalent to that observed with a LPF. Consideration should also be given to the possibility of the event causing significant damage to the FBF facility.

c. In Test Method 3 - Mini Pool Fire (MPF) are fuel rich flames and highly radiative heat transfer achieved by placing baffles around the much smaller hearth to restrict oxygen input. Where desired the MPF may be used to decrease pollution. Use of hydrocarbon fuel still results in more pollution than Test Method 2.

Limitations on its use are as follows:

(1) The test specimen must not be larger than 630 mm in any dimension nor exceed 50 kg in mass.

(2) The MPF test facility does not permit accurate measurement of overpressure and fragment projections that are essential in discriminating between the Type IV and Type V response types, and for the purpose of HC. If data on these aspects are required, the test item should be subjected to Test Methods 1 or 2.

Because there are no cost advantages in using the Mini Pool Fire test if the hearth were to be damaged severely as a consequence of the test, its use should be limited to test item predetermined as being unlikely to explode or detonate in the test, or whose Net Explosive Quantity is no more than would render acceptable minimal hearth damage after reaction.

The definitive drawing for the hearth, shown schematically in Figure 1, is UK P&EE(S) Drawing No 1 – RS-0034 Issue C entitled, “Mini Fuel Fire Mk2”; extracts are at Figure 2 and Figure 3. The hearth is the region within the fire where the temperature requirements are met. The hearth consists of a 2 x 2 x 0.4 m (deep) tank in 10 mm mild steel, and 4 removable wings loosely fitted to the tank by square hollow section steel posts in sockets at each corner. The 0.5 m vertical section of each wing above the lip of the tank is of heavy gauge expanded steel, as specified in Figure 3, framed in box section mild steel. Above this is a further 0.75 m of 8 mm mild steel plate, similarly framed but inclined inwards at 30° to the vertical, so as to form part of a short smokestack and downwards-facing black body radiator. The expanded steel section creates the air/fuel ratio necessary for fuel rich, soot-producing combustion.

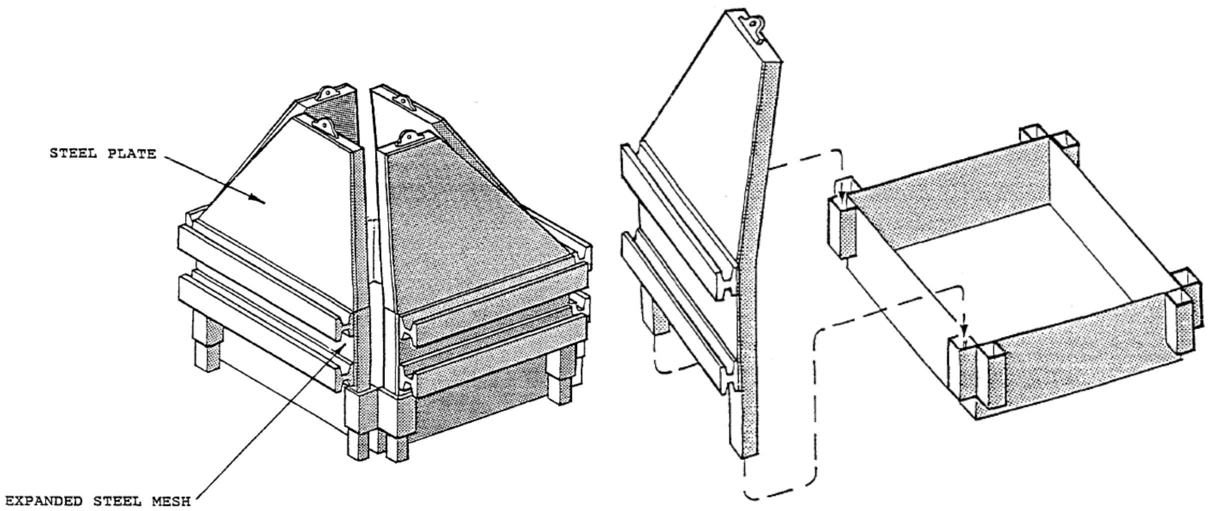


Figure 1: General Arrangement (schematic)

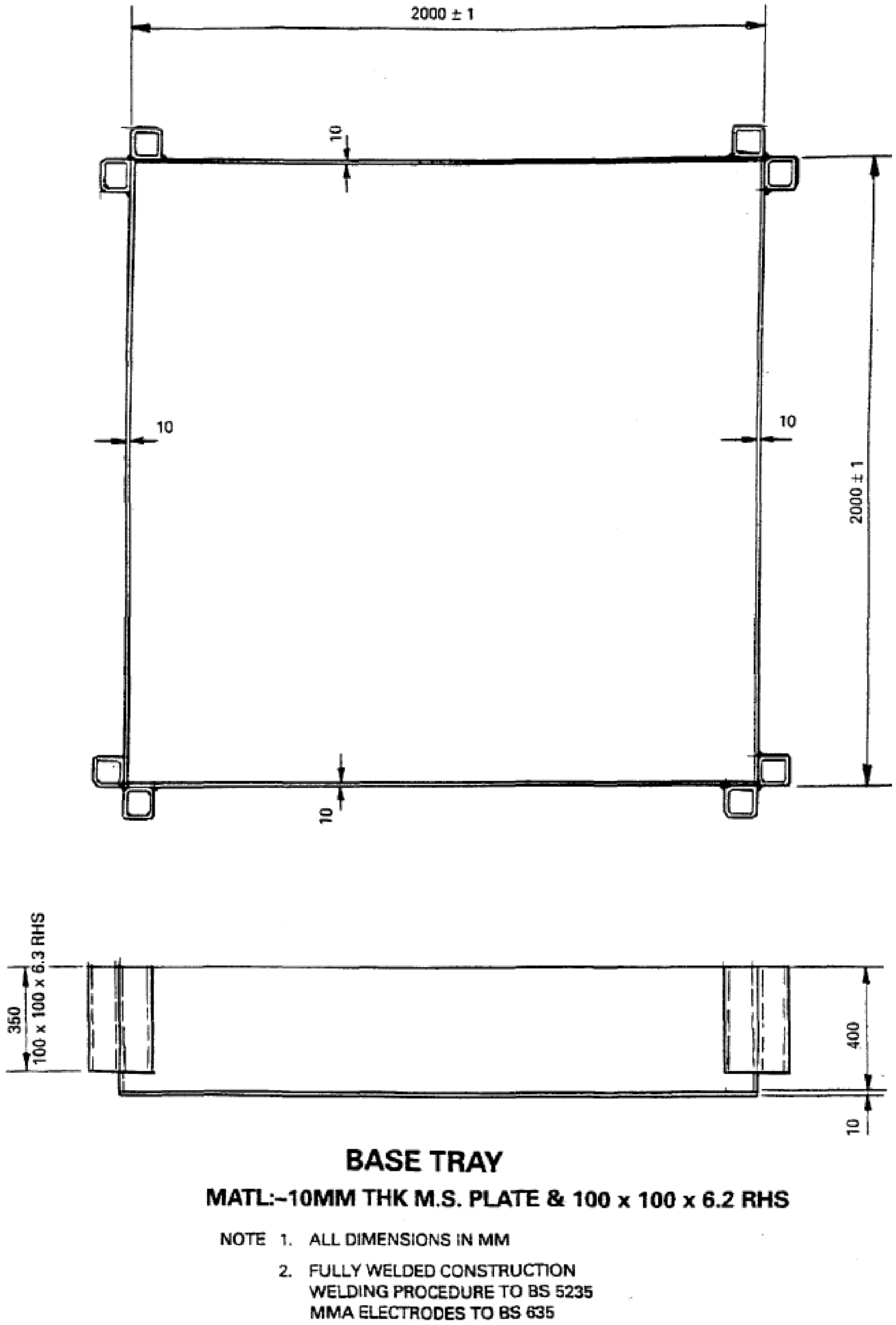


Figure 2: Specification hearth tank (not to scale)

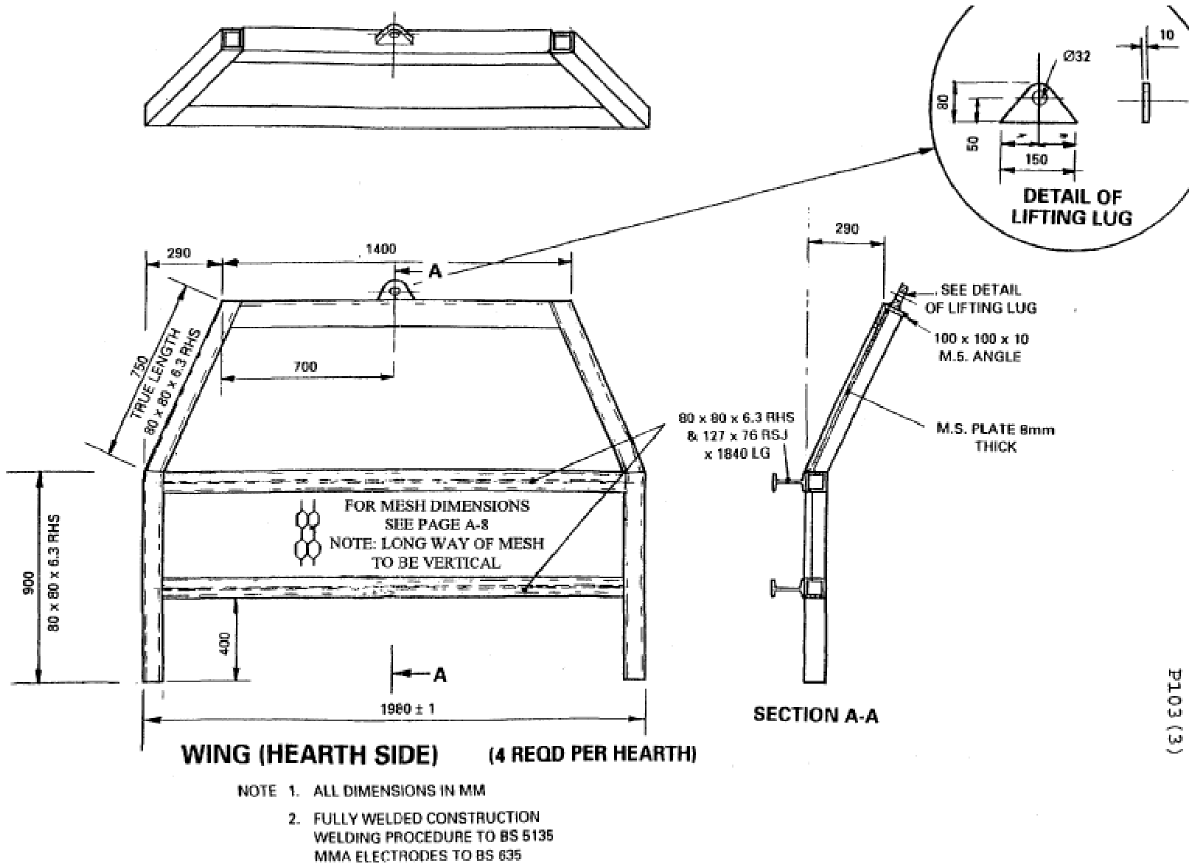
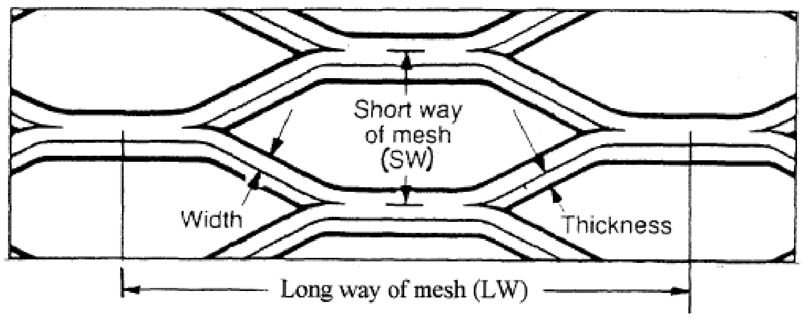


Figure 3: Specification hearth wing (not to scale)



Material Type	Nominal Size of Aperture mm		Nominal overall thickness mm		Approx weight uncoated kg/m^2
	LW	SW	Width	Thickness	
Carbon Steel	70	16	13	6.5	34

Figure 4: Specification hearth wing-mesh size (not to scale)

2.2.3.2 Test Method Independent

Each test method has a different physical setup as described in the previous paragraph. To ensure both a test setup and thermal loading of the test item which are as realistic as possible the following requirements shall be met for all test methods.

a. **General.** The test item condition and orientation shall be applied in coherence with the life cycle phase represented by the test, or representative as approved by the National Authority.

   Additional guidance on variations to the test conditions (positioning/orientation, restraints, conditioning, marking, reuse, etc.) as given in SRD AOP-39.1 Annex B shall be considered.

b. **Position and Mounting of the Test Item.** Unless otherwise specified by the Design or Test Authority, the test item shall be centered within the hearth area. In order to ensure the test item is not positioned in a cooler area of the flames the position shall satisfy the temperature, and for Test Method 2 heat flux, requirements. For the liquid pool tests, the lower surface of the test item should be high enough above the initial fuel surface to (a) allow full combustion below the test item; and (b) will not unduly increase the probability of emergence of the test item from the engulfing flames. As a guide, the initial height of the bottom of the test item above the fuel surface shall be no less than 0.5 m (this could be too low for a large hearth and may require appropriate adjustment) at the start of the test for Test Method 1 and 375 - 425 mm for Test Method 3.

   In a general manner, witness plates/screens shall not be in direct contact with the test item since this might alter the heat flow into the round test item and the confinement of the energetic material. Ideally, there should be at least 200 mm between the witness plate and the test item munition so as not to interfere with the uniform heating of the munition

   Suspension and Support. The methods used to position and hold the test item within the fire hearth could have an influencing effect on its response. The test item shall be supported on a stand that is sufficiently robust to prevent sagging or premature collapse. Unless otherwise specified, the test item shall be representatively supported such that any sagging would represent that which would occur in an actual incident. It should be noted that overhead structures for suspended test items should minimize blocking radiation heat transfer from the fire onto the test item.

Any additional support stands or props should make only minimum contact with the test item and must not screen it from the engulfing fire. The number of such extra supporting points must be kept to a minimum and should, where practical, be confined to positions where the casing of the test item is thickest.

c. **Restraints.** For test items that may become propulsive and compromise range safety, any restraining device shall not unduly screen the test item from incoming heat radiation from the flames.

d. **Support Tray.** If required, a perforated metal tray or grid may be arranged below the test item and sufficiently extends on all sides, by 1 m for the LPF, so that if the test item collapses, or its contents fall out, such contents will be held to remain (partially) exposed to the fire. The design, construction and position of such a tray is at the discretion of the Design or Test Authority but must be adequate to support the weight and impact of falling items. For Test Method 1, preferably, the positioning of such a tray or grid prior to initiation of the fire should be about 50 mm below the fuel surface so that it retains its strength and does not affect the combustion of the fuel. For Test Method 2 - FBF, the support trays should not block radiation.

e. **Thermal Insulation of Support and Restraining Rigs.** Components of the support and restraining structure can lose strength within a few minutes of the full fire developing (components of wall thickness of 6 mm could reach 700 °C within 2 min). To avoid unnecessary designs, some form of thermal insulation can be applied to the structural members. A suitable material is a mineral wool fiber (density 80-100 kg/m^3). This is obtainable in the form of preformed sections and slabs of 25 mm thickness, which can readily be shaped as required. Glass fiber is not suitable as it melts at the temperature obtained within the fire. Where lagging is used, it must be kept dry until the last practical moment.

f. **Instrumentation and measurements.** Type K thermocouples (nickel-chromium/nickel-aluminium conductors), sheathed in inert hermetically sealed insulation and capable of withstanding 1200°C, are highly recommended as well-adapted to measure fast heating test temperatures.

- The connections between the thermocouples and extension cable or interface unit must be made at least 5 m from the hearth, and on the upwind or crosswind sides. Extension cables may be of plastic covered copper.
- The temperatures of the thermocouples need to be monitored continuously. Simple direct indicating meters are sufficient for the purpose of this test.
- Sand filled bags have been found to give satisfactory protection to thermocouple cabling against ballistic fragments and heat resulting from the test. The MFT hearth and wings in themselves offer considerable protection.

It is also unlikely that electronic measurement devices will withstand the 850+ºC to which the test item is exposed; it may be possible to allow e.g. a motor to move a short distance on its stand to impact and indent a witness screen so that, from a measure of the depth of indent, the energy of the motor at impact can be calculated. This would probably require the motor to be restrained in some way (e.g. by a chain or steel cable or by being confined in a cage) to ensure that it did not leave the hearth, but the method of restraint must not affect the heat transfer to the munition or the confinement of the munition.

2.2.4 Number of Tests

Any of the selected methods shall be carried out as directed by the National Authority to provide appropriate information contributing to the munition's IM Signature required by AOP-39. Multiple tests (different test item configurations, multiple components, etc.) may be required to fully assess the munition.

2.3 DOCUMENTATION AND COMPLIANCE

1. A test directive, test plan and test report shall be produced and shall be agreed by the National Authority. Guidance on completion of documentation, responsibilities for completion and review are discussed in detail in SRD AOP-39.1.

2. It is essential that the test is conducted in accordance with the test directive; one of the responsibilities of the Project Team is to confirm compliance.

3. Where deviations from the agreed test directive and test plan, or the procedure agreed upon at the Trial Readiness Review prove necessary, these must be approved on behalf of the review body by the appropriate Project Team representative, taking advice as necessary from the safety advisor and technical specialists.

2.4 OBSERVATIONS AND RECORDS

Guidance on specific aspects of the conduct of testing, observations and data recording is discussed in more detail in SRD AOP-39.1. Unless noted as “optional”, for IM purposes, the following minimum observations must be made and records kept. Test recommendations, records and observations for HC testing and assessment are included in the UN Manual of Tests and Criteria and the Globally Harmonized System of Classification and Labelling of Chemicals, and are not optional.

a. Test item identification and configuration (model, serial numbers, number of test items, etc.); Type of energetic material and weight; Listing of environmental preconditioning test performed; Spatial orientation of the test item.

b. Test setup/configuration: Type of procedure; Type of fuel for the test, Thermocouple identification and locations; Method of suspension or mounting and/or restraint; Height of bottom of test item above surface of fuel; Distances from the test item to any protective wall or enclosure; Identification and location of any other instrumentation if used. For Method 2: pressures, flow rates, supply temperatures, and other adjustments.

c. Record of events versus time, from the ignition of the fuel to the end of the test.

d. Record of Thermal data: The time until flame temperature, as measured by all the valid temperature measuring devices, reaches 550 °C shall be recorded; Average temperature; Thermocouple readout (versus time) for all sensors.

e. Thermal flux measurements (versus time) to assess the intensity of munition(s) reaction(s) relative to the background fire for all sensors (optional); Note that heat flux measurements are required for calibration of the FBF test facility but are optional for any other testing.

f. Nature of any reactions by the test item.

g. Photo Imagery of the test item and the test setup before and after performing the test.

h. Nature and distribution of remains/residue and debris including: range, position, photographs, identification (as possible), and mass of each piece.

i. Meteorological data, in specific wind velocities and direction inside and outside the enclosure before the test, and any significant change in velocity/direction outside the enclosure (preferably well clear of the enclosure) during the test.

j. Indication of propulsion (video or other suitable means).

k. Audio and video records: A recording device shall be placed near the trial site to record all audio and enable correlation between visible events and indicated time.

l. Suitable blast or overpressure gauges should be positioned around the test item to record pressure-time history with a record of gauge location and height.

m. Witness plates and screens (optional) as a measure of projection severity; Photographs of witness plates and screens (if used). Number and depth of penetrations in fragment recovery panels (if used).

n. A complete data record shall be compiled to include pressure, sound, imagery, fragmentation, debris and propulsion information.

2.5 EVALUATION OF TEST RESULTS

Policy and procedures for evaluation of test results are given in:

a. AOP-39, Policy for Introduction and Assessment of Insensitive Munitions (IM);

b. AASTP-03, Manual of NATO Safety Principles for the Hazard Classification of Military Ammunition and Explosives.

ANNEX A BEST PRACTICES

A.1 RECOMMENDATIONS

A.1.1 Liquid Pools (LPF / MPF)

1. **<u>Fuels.</u>** Examples of fuels previously used in fast heating liquid pool tests include liquid hydrocarbon fuels: JP-4, JP-5, Jet A-1, F-24, AVCAT (NATO F-34, F-35 or F-44), commercial diesel fuel or commercial kerosene (Class C2 /NATO F-58). When other fuels are used, it is advised to calibrate the hearth to check whether it provides sufficient heat loading for the intended size of test items.

The quantity of fuel should be sufficient to maintain a fully developed/engulfed fire for the specified period, which is about 150% of the estimated time to reaction. Water (from a low-pressure hose) may be added, as required, to raise the fuel level to the correct distance below the test item, but the quantity of fuel over the water must be greater than 15 mm deep at all times during the test to prevent boiling of the water due to radiation from the fire.

As a general guide in calculating quantities of fuel, the rate of fuel surface regression due to combustion for all the required fuels and all sizes of hearth can be taken as 7 mm/minute for method 1 and 5 mm/minute for method 3.

2. **<u>Ignition.</u>** To ensure a rapid consistent build-up of flame area, the fuel should be ignited at opposite sides or corners of the hearth by means of suitable remotely operated flame-producing devices fired simultaneously.

Initiation of the flame producing devices should ensure the best "all fire" probability.

A flame producing system, which has been shown to be effective and reliable, consists of an electrically initiated igniter inserted into a small-bagged powder charge.

Suitable military devices are:

a. Igniter S/F, Electric (ADAC No 51204-01);

b. Simulator shell burst (ADAC No 23502-04) Charge, bagged, 2 oz G12, No MK 2; and

c. Simulator shell burst (ADAC No 23072-04) Charge, bagged, 4 oz NRN, No 12 MK1.

A bundle of cotton waste (1-2 kg), in which the charge/igniter unit has been folded into the top, is in the fuel at all ignition points and the petrol (gasoline) is gently poured over the waste and charge/igniter units. The charges will function even when completely soaked in petrol (gasoline) although not so reliably when soaked with kerosene or AVCAT or if rain saturates the bundles.

3. **Flame Spread Rate.** To enhance the rate of spread of the flame area, particularly in conditions of low ambient temperature, petrol (gasoline) is to be floated on the fuel at each of the ignition points (20-30 liters for the large pool and 10 liters for the mini pool).

The time delay between placing of the petrol (gasoline) and ignition of the fire should be kept to a minimum to avoid excessive loss by evaporation and dispersion in the fuel.

A.1.2 Alternate Fuel Burner

This section outlines a method to qualify an alternate fuel burner for Test Method 2 using heat flux as the principal thermal characteristic.

a. **Fuel.** fuel shall be introduced into the hearth/test facility that is appropriate to that particular type and can include but is not limited to the following: propane, butane, heptane, or other commercial liquefied gases.

b. **Ignition.** To ensure a rapid, consistent build-up of the flame area, the fuel should be ignited simultaneously on all sides of the test facility, from the fuel that is introduced. A suitable remotely operated ignition device(s) shall be used. Such a device(s) shall be capable of multiple ignitions to allow for flame re-ignition should a wind gust extinguish an area of flame.

c. **Average flame temperature.** The flame temperature is determined by averaging the temperature of all valid thermocouples from the time the flame reaches 550 °C and measured for 30 seconds at a sample rate of 1.0 Hz or greater. Temperature measurements are to be made on two orthogonal planes that are centered within the hearth. Each plane is divided into a grid on which the temperature measurements are made using thermocouples. The spacing between the measurement locations should be no more than one quarter of the length (or height) of the hearth in each direction. This gives a minimum of 25 temperature locations (5 wide x 5 high) in each plane for a total of 45 measurements (measurements along the vertical centerline are redundant). These measurements indicate the region within the fire that exceeds the 800 °C minimum requirement.

d. **Uniform heating.** The uniformity of the heating must be calculated for the region that meets the 800 °C requirement. The heating is considered uniform if the standard deviation of the average temperatures at all measured locations within this region is not greater than 10% of the overall average temperature in this region.

e. **Average total heat flux.** The measurement locations that meet both the temperature and uniformity requirement must be shown to meet the total absorbed heat flux requirement. The total absorbed heat flux is the sum of the absorbed radiative heat flux and the convective heat flux. Care must be taken when performing total heat flux measurements to account for reflected and emitted heat fluxes from the measurement device. For example, T is the absolute (Kelvin, not Celsius) temperature measured as a function of time by a slug calorimeter, the total absorbed heat flux is then:

$$q'' = \rho C \delta \frac{\partial T}{\partial t} + \varepsilon \sigma T^4$$

where ρ is the density of the slug material, C is the specific heat of the slug material and δ is the thickness of the slug. dT/t is the rate of change of the slug temperature, ε is the surface emissivity and σ is the Stefan-Boltzmann constant.

The total absorbed heat flux must be measured with a device that is larger than 2.5 cm in length (or diameter if a cylindrical or spherical device is used) and either be coated or oxidized to ensure a high surface emissivity so that the total absorbed heat flux is approximately the total heat flux.

An external separate thermocouple should be located within 10 cm of a heat flux measurement device. The total absorbed heat flux must be measured at each location in time and then averaged for a minimum of 30 seconds after the 800 °C temperature is met on the external separate thermocouple located next to the heat flux measurement device. Locations that exceed 80 kW/m^2 are considered valid for testing.

Appropriate heat flux measuring devices include plate thermometers, differential flame thermometers, differential heat flux sensors, and slug calorimeters. Heat flux definitions:

(1) *Total heat flux:* Thermal exposure, the incident radiative heat flux plus convective heat flux

(2) *Total absorbed heat flux:* absorbed radiative heat flux plus convective heat flux

(3) *Absorbed radiative heat flux:* radiative heat flux absorbed by an item, equal to the incident radiative heat flux times the emissivity of the item

(4) *Incident heat flux:* irradiance, the radiative heat flux impinging on the surface of an item.

f. **Heat Flux Principles.** This section provides more clarification on heat flux principles. Figure A-1 shows an item that is exposed to both radiation and convection. The incident radiation is the irradiance and is the radiative heat flux impinging on the surface. Since no surface is a perfect absorber, some of the incident radiation will be reflected and the rest will be absorbed. The amount that is absorbed is dependent on the absorptivity of the surface. This is further simplified by assuming that the absorptivity of the surface is equal to its emissivity, ε. So the absorbed radiation is equal to the emissivity (ε) times the irradiance.

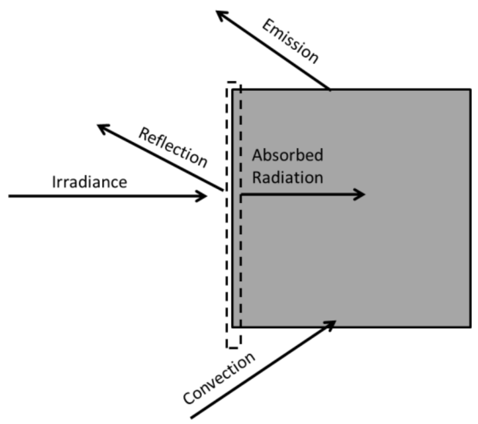


Figure A-1: Energy balance of heat transfer.

All surfaces emit radiation. The emission from a surface is equal to the surface emissivity, ε, times the Stefan-Boltzmann constant, σ, times the absolute temperature raised to the fourth power, or $\varepsilon\sigma T^4$. Due to the fourth power relationship, as temperature increases, emission increases dramatically.

The “total absorbed heat flux” is the sum of all the heat fluxes that actually make it into the item. It is the absorbed radiation plus the convection. The “net heat flux” is found from a complete energy balance of the item and is the sum of all heat fluxes entering the item minus all heat fluxes leaving the item. It is equal to the total absorbed heat flux minus the emission from the surface. This is what is measured by a slug calorimeter.

g. **Example Test Setup for Qualification.** Figure A-2 shows the grid used to calibrate the temperature field produced by a 2.43 m (8 ft) square burner. The grid used was 1.5 m (5 ft) wide and 1.5 m (5 ft) tall and the spacing of the thermocouples was 38 cm (1.25 ft). The uniformity of the hearth was found for the example shown in Figure A-2. The average temperature measured was 903 °C and the standard deviation was 61 °C or 7% of the average. After the temperature measurements were performed, the heat flux was measured within the burner at the same locations as the temperature measurements. This was done using a vertical rake that held multiple heat flux sensors as shown in Figure A-3. This rake was then moved throughout the burner at all the locations that met the temperature requirement and the tests were repeated to map out the heat flux field within the domain. Regions that meet both the temperature and heat flux requirements are considered to be within the hearth of the burner.

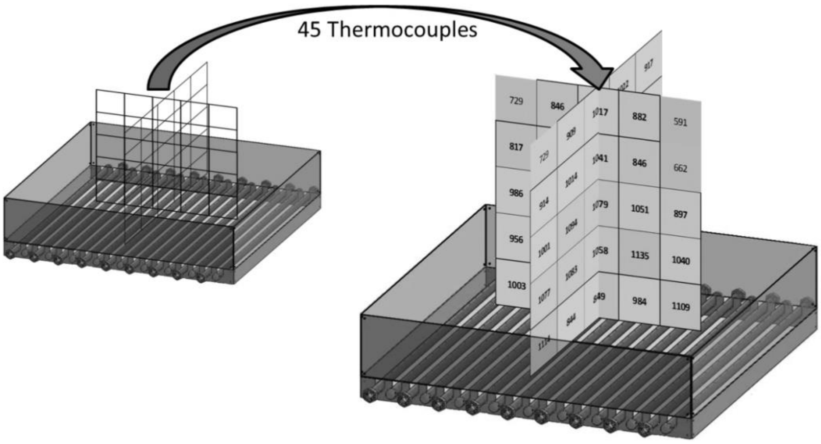


Figure A-2: Grid used to define hearth within burner.

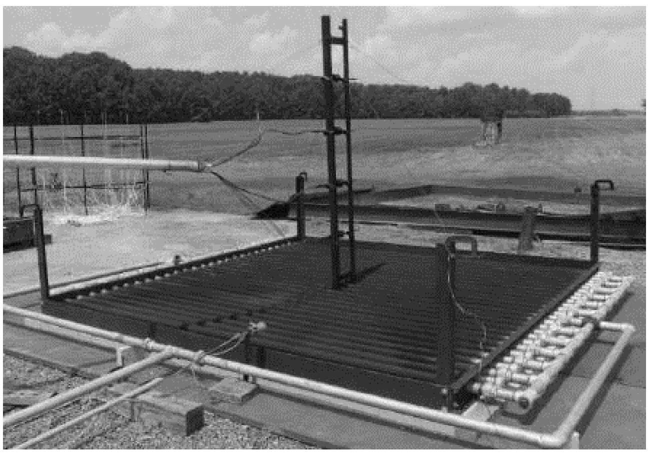


Figure A-3: Vertical rake for heat flux measurements.

h. **Calibration Results.** The test facility should maintain a log of the above qualification testing and a log of any changes to dimensions, materials, operating pressures, fuel supplies, etc., and the results of retests after a change. The log should be added as an appendix to test reports prepared for assessment or classification authorities.

i. **Pre-test validation.** It is advisable to perform a pre-test validation of the test apparatus prior to each planned test series or, at a minimum, on an annual schedule. The purpose of this process is to ensure that the test apparatus is working as intended.

ANNEX B HISTORICAL OVERVIEW

B.1 REVISION PROCESS

B.1.1 IM Test AOP Standardization Working Group (2020-2021)

1. In the time between April 2020 and April 2021, AOP-39, -39.1, -4240, -4241, -4382, -4396, -4496, and -4526 have been revised. The objectives of these revisions, executed by the IM Test AOP Standardization Working Group, were:

   a. Fix grammatical and spelling mistakes, clerical errors, and enforce a uniform structure, format, and wording across all AOPs for the sake of readability and ease-of-use.

   b. Ensure that the AOPs only contain requirements.

2. Altering any technical content was not permitted, because the group aspired to merely update each AOP's Version and not release entirely new Editions.

3. To achieve the second goal, guidance and best practices were to be moved into the SRD AOP-39.1. However, accomplishing this was not entirely possible. It was agreed that all AOP-specific guidance remains in each AOP's Annex A, while all guidance that applied to two or more AOPs was marked to be moved into the SRD.

4. The IM Test AOP Standardization Working Group also made notes about topics that could potentially be discussed at future gatherings of each AOP's respective Custodian Working Group.

5. A total of 26 meetings took place, all of them virtually. The involved people were the Custodians of the various documents as well as representatives of MSIAC and AC/326 SG/B.

B.1.2 Creation of AOP-4240 Edition A

1. Besides the periodically required review of a STANAG, the international community recognized the need for a more environmentally friendly test method to test and evaluate the fuel fire hazard. During the review of STANAG 4240, Edition 2, by the assigned Custodian Working Group, it was recognized that the test parameters of the existing Standard Liquid Fuel Fire Test and the Mini Fuel Fire Test required only minor updates to capture relevant test data. The main focus during the drafting of this new STANAG edition and its accompanying AOP was aimed at the inclusion of a new test method with the same thermal environment that allows for the use of less polluting fuels.

2. The aim of the Custodian Working Group was to identify and describe additional relevant characteristics of the hearth and the resulting thermal environment in this document. It was not intended to prescribe how a test facility must design their test setup. This leaves the option open for new technical innovations as they arise.

B.1.3 Changes from STANAG 4240 Edition 2

1. The Standard Liquid Fuel / External Fire Test specifications (from STANAG 4240 Edition 2) required minimal changes. Test facilities will not have to change their basic setup or procedures. Comparison of future results with historical data will continue. Additionally, the technical information provided in the test methods was clarified based on lessons learned from prior experience. This was viewed as an aid to current and future users in the test community. The most significant change made to Test Method 1 was the number of thermocouples, increased from 4 to 6, since wind was recognized as the predominant factor that affects a full flame engulfment of a test item.

2. The description in Test Method 2 provides an option for other fuel sources. Wherever possible, text from Test Method 1 was used to maintain consistency between the test methods. More importantly, all test parameters and requirements in Test Method 1 were also applied to Test Method 2. Both test methods must be considered to produce the same thermal environment, where only the source to achieve the test parameters for the thermal environment is different. The Custodian Working Group recognized that temperature alone, regardless of test method, is not sufficient to assure the same heat load (thermal environment) for the test item.

3. Few among the contributing nations within the Custodian Working Group routinely use the Mini Fuel Fire Test but all test parameters remain valid for future use. The specifications for this Test Method 3 required very little updating.

B.2 BACKGROUND AND TEST ORIGIN

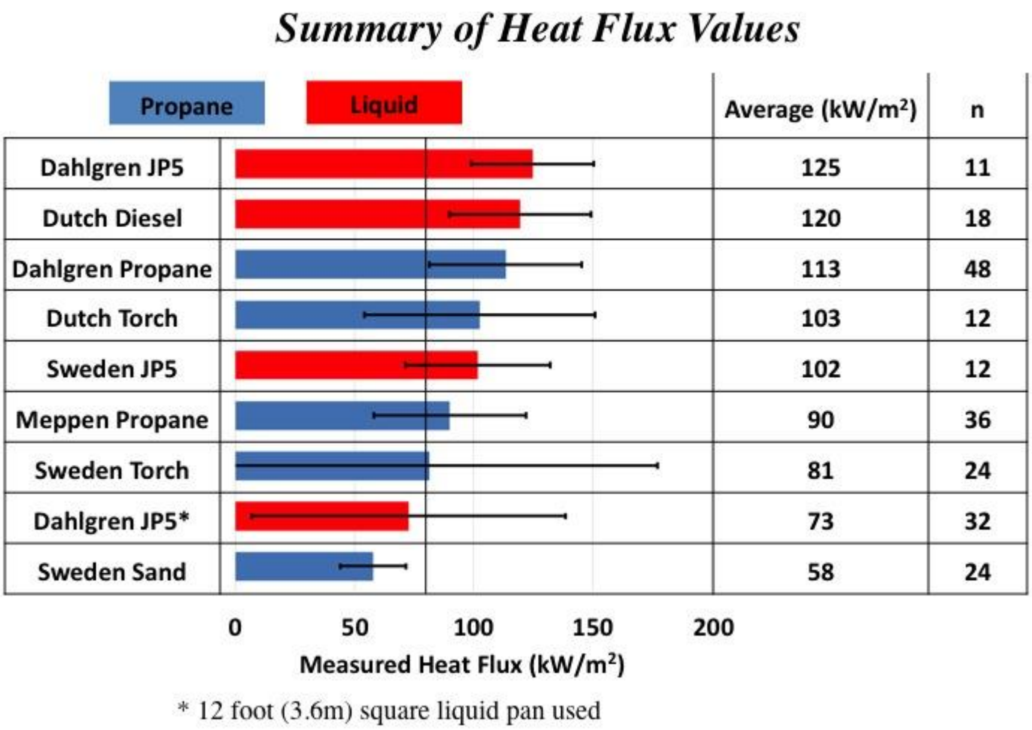
1. Several test setups based on different design principles where constructed by five nations over a several-year period. They all focused on the use of fuel sources other than kerosene-based fuels, principally propane, and used various ways of spraying, blowing or evaporating the fuel into the hearth. Results of testing conducted with these methods were compared with results using the old Standard Liquid / External Fire Test. Measured data were shared and discussed in multiple Working Group meetings to determine the requirements that must be specified in this test requirement document to assure the delivery of the same heat load and thermal environment if an optional test method would be used.

2. All of the designed test setups successfully achieved the temperature rise time within 30 seconds and an average hearth temperature above the minimum temperature of 800 °C. Most variations in the measured temperature data were a result of weather conditions (wind) or measurements taken outside the domain of the hearth.

3. There is also a spatial uniformity requirement for these fires. This must be specified to avoid very local heating due to hot spots that are more likely to occur with forced-flow heating compared to the buoyant flame produced in a liquid pool fire. Tests performed on both liquid fuel (kerosene) and gas-burning (propane) fires showed that hot spots were sufficiently avoided when the standard deviation of the average temperatures at all the locations within the hearth was less than 10% of the average temperature within the hearth.

4. Heat flux, in addition to temperature, was recognized as the most suitable test parameter to characterize an acceptable fire that produces the necessary heat load and thermal environment. Since most heat flux measuring devices may shield the heat when placed between the heat source and the test item, Test Method 2 includes a calibration section that describes how a test facility shall demonstrate that a suitable test setup can produce the required heat load and thermal environment when the test item is fully exposed to the hearth.

5. Testing was conducted to determine the heat load and establish the requirement for this thermal characteristic for several types of fuel fires. Heat flux was measured in various liquid pool fires from three nations with the use of different types of hydrocarbon fuels (JP5 kerosene and commercial diesel). The results from these tests are shown in Figure B-1 below. Test data from the liquid pool fires that are the baseline for valid testing were used as a basis of comparison. Heat flux values were measured between 80 and 150 kW/m^2. The 80 kW/m^2 heat flux threshold was thus selected as the minimum satisfactory level for the optional test method based on this data set.



Note 1: The heat flux at each of the n locations was averaged for 30 seconds. The n different average values were then averaged to give an overall average heat flux for that fire.

Figure B-1: Measured heat flux values in existing hearths.

6. In general, heat flux varies in time and depends on the temperature difference between two bodies. In a fuel fire test, the heat flux will increase rapidly as the hearth becomes fully developed. For that reason, the heat flux shall be measured from the moment the 800 °C is reached and then averaged over the next 30 seconds. This 30 second averaging was chosen to level out sudden fluctuations and is considered long enough to give enough data points to be statistically significant.

B.3 REFERENCES

D. Pudlak, K. Tomasello, “Revisions and Improvements to the NATO Insensitive Munitions Test Doctrine Portfolio”, NATO AC326 SG/B Spring Meeting, April 15-16, 2021

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