# Harmonization and Improvements to Fast Heating Test Procedures – IMEMG Proposals

*IMEMG FCO Working Group*

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*www.imemg.org*

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# INTRODUCTION

- IMEMG

**21 company groups from 7 countries:**

# INTRODUCTION

- CONTEXT

  - Fast Heating objectives
    - Hazard classification with respect to large liquid fuel fire
  - STANAG 4240
    - Applied in most of tests centres
  - Future changes
    - International push to develop/institute alternative fire
    - Some test centre already investigating alternative fire tests, *BUT no standard*

*No confidence at the beginning and now new AOP in preparation…*

# IMEMG Fast Heating Working Group - Goals :

- Harmonize Fast Heating test procedures and acceptance criteria
  - Identify key test methodology criteria in STANAG 4240
  - Compare test facilities in Europe (DE, FR, NO, SE, SP, UK) : fuel types, temperature, item position, mounting, sensors, wind barrier
- Look for new alternative solutions
  - Reduce environmental problems due to the burning of liquid fuels (smoke, lead, soil pollution)
  - Save costs : test cost + avoid test duplication due to different methods from different countries
- Evaluate equivalence of liquid fuel and alternative solutions
  - Compare test methods and results : temperatures, heat fluxes, etc.
  - Propose calibration criteria and method for Fast Heating tests

# STANDARD FIRE TEST

- Main objectives (STANAG 4240 ed.2):
  - ✓ Testing in a **realistic configuration** (item packaging / configuration & position / support …)
  - ✓ Ensuring **correct heating** of test item, corresponding to a hot LFF (hydrocarbon) :
    - Rapid & full engulfment
    - Appropriate temperatures and fire duration
  - ✓ Getting **relevant evidence** (measurements) → reaction level & time assessment of tested item

Liquid Fuel Fire
(Courtesy of SBTC, Sweden)

- Other recommandation:
  - ✓ **Test repeatability** is required → for comparison between tests (≠ objects and / test centers)

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# STANDARD FIRE TEST

- Standard Fire Test – analysis and comments :
  - ✓ **Heating conditions** : test repeatability and uniformity difficult to ensure
    - **Fire-to-fire dispersion** → average flame temperatures [800 - 1100°C]
    - **Spatial dispersion within a single fire** → typically +/- 100°C
  - ✓ **Wind** identified as critical test parameter / one of the most difficult constraint in FH testing :
    - T°C ➚ : wind can activate combustion (bringing O2 to flame)
    - T°C ➘ : potential emergence of item from flame envelope

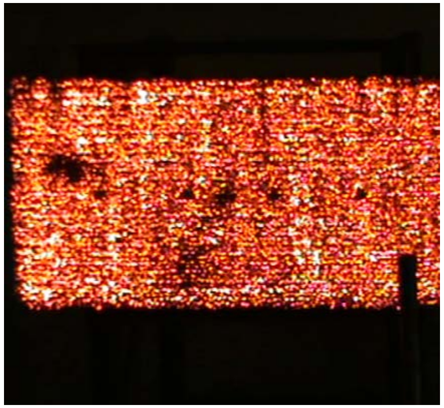
      **=> Improvement necessary (wind screen efficiency / compatibility with fragments mapping for reaction assessment)**
  - ✓ STANAG not adapted for munitions with short reaction times (<30s)

# Alternative Fire Test

- General idea

  - ➢ Replace kerosene by less polluting fuels
  - ➢ LPG burners, propane jets, sand-bed burners, radiant panels, etc.
    - Very different alternative test setups experimented throughout the world
    - Large or small scale facilities

LPG Fire
(Courtesy of WTD91, Germany)



Radiant panel
(Courtesy of Herakles, France)

Propylene gas burners
(Courtesy of Nexter, France)

A challenge

→ Consistency of IM results shall be guaranteed whatever the fire test method

And an opportunity

→ To get a better control of fire heating parameters (lower spatial dispersion, better repeatability)

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# SFT/AFT comparison

- Flame temperature cannot be the only metric
  - What about heat fluxes ?

| | SFT | AFT |
|---|---|---|
| Flame characteristic | Buoyant, turbulent diffusion flame | Turbulent diffusion or pre-mixed flame |
| Flame temperature [°C] | [600-1100°C] | [xxx-1200°C] |
| Heat transfers | Mainly radiative [soot]<br>Low influence of item external surface emissivity due to pollution by soot | Depending on test setup:<br>• Incident and absorbed radiative HF<br>• Convective exchanges depending on burners position, flow rates, etc. |
| HF values | 10kW/m²-400kW/m² [1] | 127-136kW/m² Propane [1] |

- **Target value of 100 - 150kW/m²** seems to be globally acknowledged
- **How to ensure similar IM signature ?**
  - Flame temperature and total heat load received by the test item
  - Spatial heat flux distribution
  - Impact of predominant heat transfer mode ?

*[1] IMEMTS 2013, T16003_Yagla*
*Experimental development of propane burners for fast cook off testing*

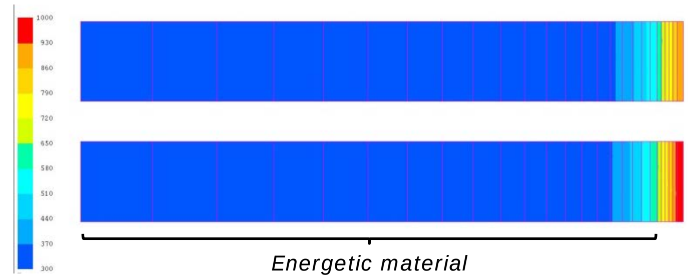
# SFT/AFT comparison

- Rough sensitivity study

**Objective: to compare reaction times and case temperatures at reaction for fires with similar global heat fluxes but different exchange parameters**

➢ Cylindrical test object
  - ϕ 150mm
    *Steel Case* 1,5mm
    *Heat Shield* 5mm
    *Energetic material*

➢ Finite Element model (axi)




'AFT' type parameters

'SFT' type parameters

➢ Energetic material reaction: $T_{ignition} = 500K$

➢ Wall heat flux approximated by:

$$\varphi = h.(T_f - T_w) + \varepsilon_w.(\varepsilon_f.\sigma.T_f^{\,4} - \sigma.T_w^{\,4})$$

**Range (1): [76-202] kW/m²**

(1) peak value with Twall=300K

# SFT/AFT comparison

- Rough sensitivity study

  - Parameters range

$$\varphi = h.(T_f - T_w) + \varepsilon_w.(\varepsilon_f.\sigma.T_f^{\,4} - \sigma.T_w^{\,4})$$

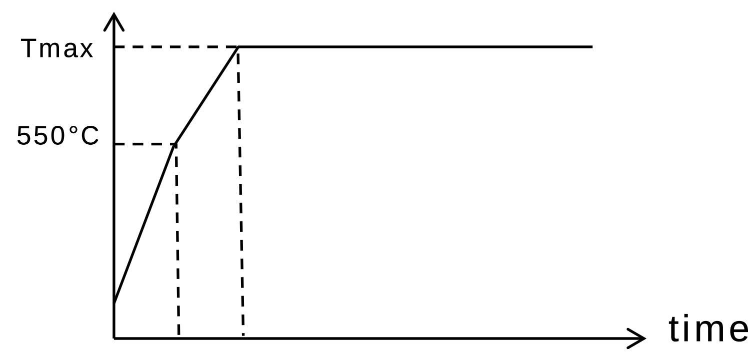
**Heating parameters**

| Parameter | Value |
|---|---|
| TF MAX [°C] | [800-1100] |
| HF [kW/m²] | [76-202] |

| Parameter | "SFT" | "AFT" |
|---|---|---|
| $\varepsilon_f$ [-] | [0.9-1] | [0.3-0.5] |
| $\varepsilon_w$ [-] | 0.9 | 0.5 |
| h [W/m²K] | 20 | *Calculated such as HF_AFT=HF_SFT* |

**TF profile**

| Parameter | Value |
|---|---|
| time 550°C [s] | [5-30s] |
| time TF_MAX [s] | [15-60] |



# SFT/AFT comparison

- Rough sensitivity study
  - Reaction time results

T550°C=5s / t550°C=30s

| Case | A | B | C | D | |
|---|---|---|---|---|---|
| **STANAG [1] reaction time [s]** | HF 76kW/m² (TF max 800°C) | **HF 83kW/m² (TF max 800°C)** | **HF 184kW/m² (TF max 1100°C)** | HF 202kW/m² (TF max 1100°C) | **Delta B-C** |
| SFT | 147s / 150s | **131s / *n.e.* [2]** | **82s / 91s** | 76s / *n.e.* | 49s |
| AFT (ε=0,5) | 175s / 174s | **167s / *n.e.*** | **93s / 96s** | 90s / *n.e.* | 74s |
| AFT (ε=0,3) | 185s / *n.e.* | - | 97s / *98s* | - | |
| **Delta SFT – AFT (ε=0,5)** | 28s | 36s | 11s | 14s | |

[1] *STANAG reaction time = reaction time – time to reach 550°C*
[2] *n.e = not evaluated*

- Effect of initial heating rate: limited in both cases
- Effect of fire heat flux : significant dispersion of reaction times in both cases
- Comparison "SFT"/"AFT" (similar HF level): higher reaction times with less radiative fires (all the more as flame temperatures are low)

# SFT/AFT comparison

- Rough sensitivity study
  - Case temperature results: link with reaction violence

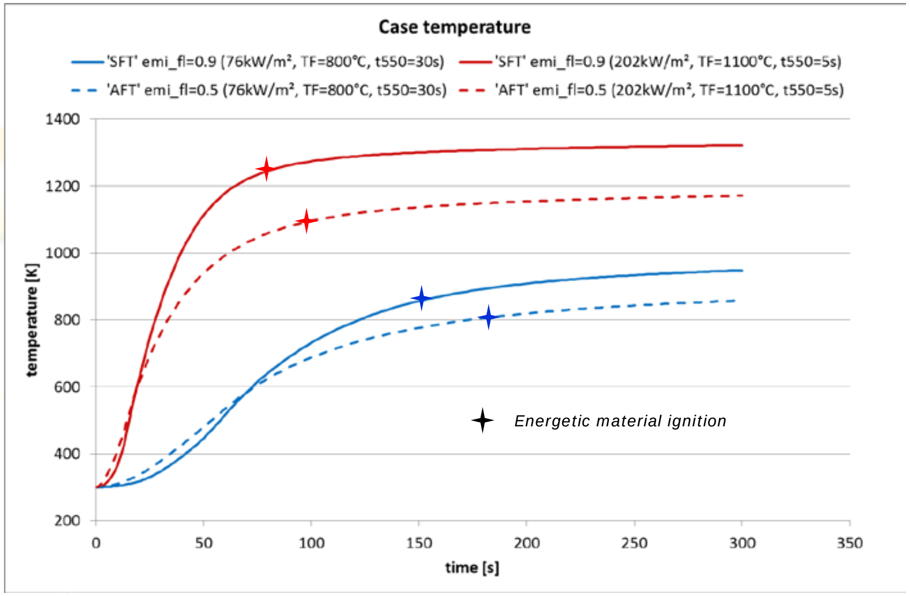
T550°C=5s / t550°C=30s

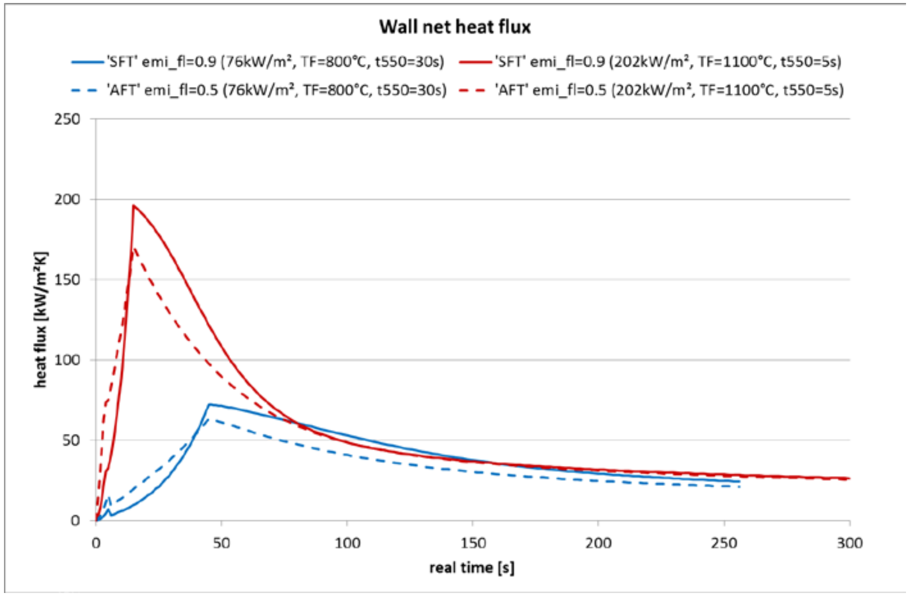
| Case | A | B | C | D | |
|---|---|---|---|---|---|
| **Case temperature at reaction [°C]** | HF 76kW/m² (TF max 800°C) | **HF 83kW/m² (TF max 800°C)** | **HF 184kW/m² (TF max 1100°C)** | HF 202kW/m² (TF max 1100°C) | **Delta B-C** |
| SFT | 620 / 620 | **659 / *n.e.*** | **918 / 917** | 974 / *n.e.* | 259°C |
| AFT (ε=0,5) | 548 / 549 | **559 / *n.e.*** | **801 / 799** | 815/ *n.e.* | 242°C |
| AFT (ε=0,3) | 529 / *n.e.* | - | 767 / *764* | - | |
| **Delta SFT – AFT (ε=0,5)** | 72°C | 100°C | 117°C | 159°C | |

- Effect of initial heating rate: limited effect, in both cases
- Effect of fire heat flux : significant dispersion of case temperatures in both cases
- Comparison "SFT"/"AFT" (similar HF level): lower case temperatures with less radiative fires (all the more as flame temperatures are high)

# SFT/AFT comparison

- Rough sensitivity study
  - Synthesis
    - Reaction time & temperature case dispersion
      - Function of heat flux history, flame temperature, convective/radiative ratio, emissivities, …




- Rough analysis… but highlights some difficulties with FH analysis
- Behavior probably different for smaller objects

## SFT/AFT comparison

- Fire Tests equivalence

➢ LFF=real threat // AFT=equivalent approach

- Comparable HF data achieved on some tests
- Dispersion observed in both cases (fire-to-fire and spatial dispersion)

➢ Reaction may occur before steady state conditions are reached, thus:

- Equivalence needs to be validated for all phases (ignition and hot phases)
- Importance of radiative inputs (radiation > convection in buoyant flames)

=> Acceptance criteria = f(TF, HF and heat transfer mode)

# FH calibration

- TEST CALIBRATION

**BASE DEVICE REQUIREMENTS**

ROBUST

CHEAP

EASY TO SOURCE

EASY TO USE

HARMONIZED

=> Simple object

**TYPE OF MEASUREMENTS**

FLAME TEMPERATURE

HEAT FLUX
NET ABSORBED / INCIDENT

CONVECTIVE / RADIATIVE RATIO

TIME-DEPENDENT
(FROM T0)

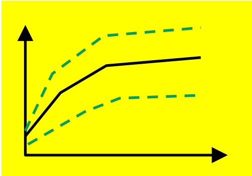
SPATIAL FIELD

=> Combination of thermocouples and calorimeter object

**CRITERIA**

UPPER BOUNDARIES

LOWER BOUNDARIES



- Total Heat Flux Gages (Gardon, Schmidt-Boelter, radiometers)
- Coaxial thermocouples
- Sandia Hemispheric Heat Flux Gages (HFG)
- Differential Flame Thermometer (DFT)
- Calorimeters
- Directional Slug Calorimeter (DSC)
- Plate Thermometer (PT)
- Adiabatic Surface Temperature (AST) Probe
- ARL Container
- Two paired thermocouples
- Transpiration radiometers
- Transverse Seebeck coefficient heat flux gage
- ...

# FH procedures – IMEMG proposals

- CONCLUSION
  - STANAG 4240 ed.2
    - Test repeatability and uniformity difficult to ensure
    - Wind control needs to be improved
  - Alternative fire tests
    - Cost reduction is unclear at the moment (function of size, inert/live, setup)
    - Opportunity to get a better control on fire dispersion
  - AFT calibration process = key point
    - Harmonized calibration device compulsory to obtain comparable measurements

Live test with gas burners
(Courtesy of Hirtenberger, Austria)

**The consistency of IM test results shall be guaranteed whatever the fire test method**

**Live tests comparison is essential to increase confidence (from small ammunition to large rocket motors)**

# THANK-YOU FOR YOUR ATTENTION

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