Propane as a Surrogate for Kerosene in Fuel Fire Tests

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Purpose

1. To introduce **STANAG 4240**.
2. To provide the **results** of a recent meeting.
3. To share the **lessons learned**.
4. To propose a **way forward**.

STANAG 4240 Liquid Fuel/External Fire Munition Test Procedures

Fuel fire tests are performed in accordance with STANAG 4240, Liquid Fuel/External Fire, Munition Test Procedures.

- Developed from MIL-STD-2105B.
- Harmonized with UN Orange Book so the IM and HC could be satisfied with one test.
- Included in STANAG 4629 and AAS3P series.

  Note: The title specifies liquid as fuel; kerosene is used in this brief to mean all listed liquid hydrocarbon fuels.

Issue

Because of environmental concerns, some countries would like to use propane instead of kerosene. The advantages of using propane are:

- Cleaner burning; no large black cloud
- Cleaner combustion by-products
- Presumed advantage of seeing the test item
- Presumed similarity of heating compared to kerosene
- Presumed repeatable heating properties
- Presumed lower operating costs
- Anticipate that all countries will eventually be required to stop kerosene fueled safety tests

Recent Meeting

The **Fuel Fire Expert's Meeting** was held at WTD 91, Meppen, Germany from 2 to 4 February 2010 to consider a request by Germany to use propane as a surrogate for kerosene in liquid fuel fires. Five nations gave **technical presentations**, all attendees **participated in discussions**, and **proposed a way forward**.

Loop Hole

The proposal to use propane is based on a loop hole in NATO STANAGs:

- STANAG 4240 does not authorize propane, nor other non-liquid fuels.
- However, STANAG 4439 and AOP-39 (Guidelines for IM Assessments) state:

> *Where environmental concerns dictate, alternate fuel such as propane, or natural gas may be used if testing verifies that the overall test item heating rate, uniformity of spatial heating to the test item and type of radiation heat transfer duplicate those of the hydrocarbon fuel fire.*

Fuel Fire Experts Meeting

Germany requested approval to use propane and volunteered to host an Experts Meeting to:

- Review the current work in this area.
- Observe the operation of a propane fueled test apparatus.
- Develop revisions to STANAG 4240 to allow alternate fuels, especially propane.

Agenda

The agenda included presentations by:

- USA
- Sweden
- France
- Germany
- Canada

Summary of Presentations

Agreements

- Purpose
  - Standardized test
  - IM Test harmonized with HC
- Environmental Issues
  - Environmentally friendly is the goal
  - No European regulation limiting using kerosene fire
- Heat Flux is the critical parameter
- The ratio of radiative vs convective heating is not considered critical as long as the heat transfer rate is achieved, except for those items with exposed reactive surfaces
- Current temperature profile is OK
- AOP-39 criteria needed clarification
- Propane will be acceptable if the new AOP-39 criteria is met

Summary of Presentations

Work to Be Done

- Cannot achieve comparison between kerosene and LPG fire with current STANAG 4240, because of lack of data
- Need better instrumentation
- Facility design
- Evaluate the cost effectiveness
- The variability of kerosene fires must be compared with that of LPG fires
- Acceptance of test results from other test centers
- An improved document is required to capture the technical issues

Work Completed

- AOP-39 updated

Proposed Change to AOP-39, Annex H, Appendix 7, 2.4:

Statement developed from the meeting:

Where environmental concerns dictate, alternate fuel such as propane, or natural gas may be used if testing verifies that the overall heat load to the test item must match what would be achieved from a liquid fuel fire at the established ramp and average temperature. For those items with exposed reactive surfaces (energetic materials, intumescent paints; not including packaging) the radiative conditions should match that of a kerosene fire.

Final wording included in AOP-39 Ed. 2:

Where environmental concerns dictate, alternate fuel such as propane, or natural gas may be used if testing verifies that the overall heat load to the test item matches what would be achieved from a liquid fuel fire at the established ramp and average temperature. For those items with exposed reactive surfaces (energetic materials, intumescent paints; not including packaging) the radiative conditions should match that of a liquid fuel fire.

Major Accomplishments

1. Reviewed and discussed all national concerns relative to this concept.
2. Agreed that the AOP-39 statement regarding criteria for use of alternate fuels was close, but needed clarification.
3. Agreed that propane will be acceptable if the criteria are met.
4. Agreed that STANAG 4240 does not specify sufficient instrumentation to measure the parameters necessary to verify that the criteria is met.

Major Accomplishments Cont.

5. Created a list of technical issues to be addressed.
6. Agreed on a change to the criteria for use of alternate fuels that could be immediately incorporated into AOP-39, Ed. 2.
7. Agreed on the way forward for improving STANAG 4240.

The Way Forward

The task at hand is to continue working collaboratively to accomplish the following:

1. Reformat the STANAG 4240 in accordance with AAP-3J.

The Way Forward, Cont.

2. Develop a guidance document, AOP-TBD, to include the new instrumentation requirements for improved standardized diagnostics to quantify the thermal load and any other changes resulting from this meeting. This effort will require the working group to:
   a. Research currently available sources.
   b. Schedule workshops until project completion.

Technical Discussions

Since Heat Flux was agreed to be the most critical parameter, plate gauges were proposed as a method for measuring. Additional instrumentation ideas:

- Use of 6 thermocouples (TC) and 6 flux gauges. Co-located left, right, top, bottom, front, and rear. (Possibility of back calculation to gas temperature)
- For large test items, 6 TC might not be enough.
- Distances and sampling rates will be determined at a later date.

Technical Discussions, Cont.

Causes of reaction violence:

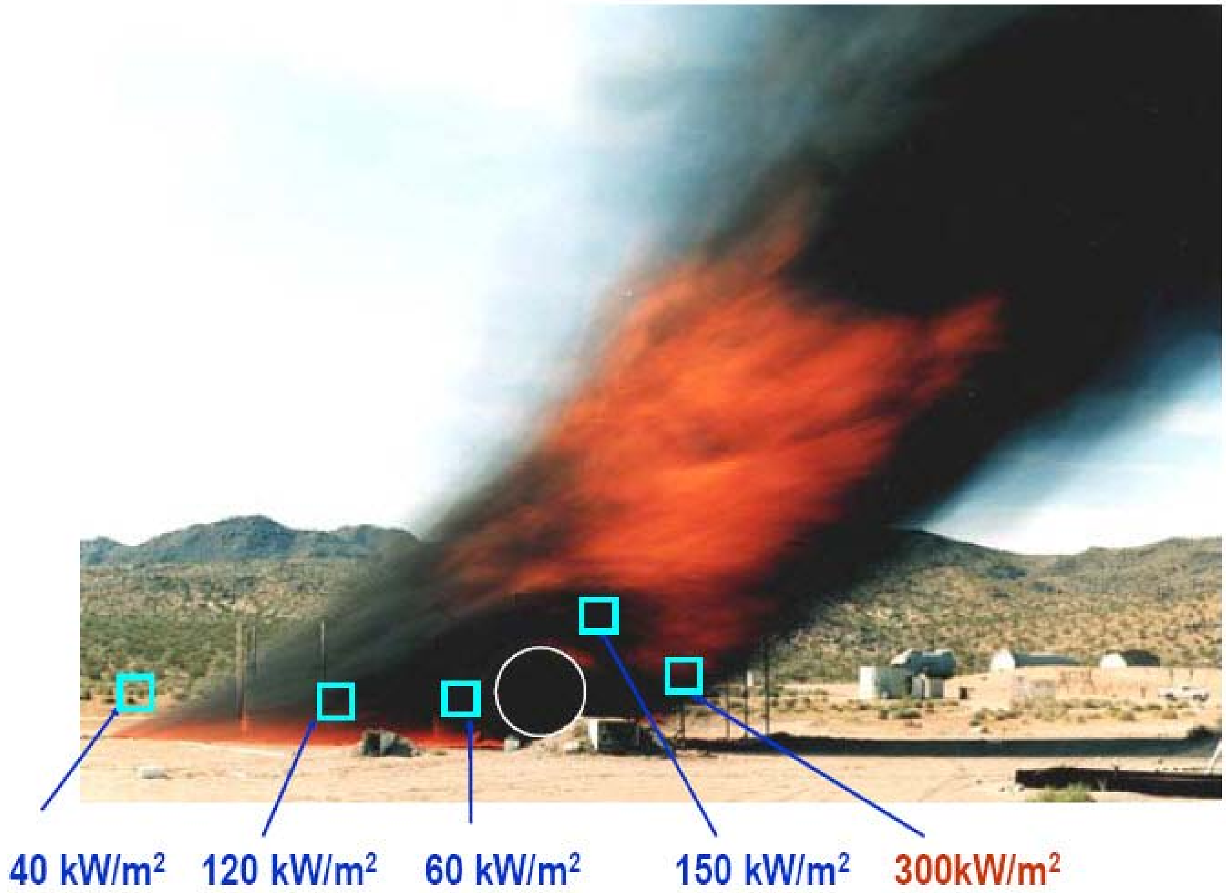
- Confinement
- Lack of mitigation devices
- Heating rate
- Ignitability
- Combustion behavior
- Design of ammunition (e.g., combustible casing)
- Available surface area for FCO
- Sensitivity of the energetic material

What Did We Learn?

Heat flux

- Heat flux is the critical parameter in fuel fires
- Heat flux measured in typical liquid fuel fires ranges from 20 to 400 kW/m^2
- Heat flux is rarely measured in Munitions Fuel Fire Tests
- Heat flux instrumentation is readily available, but will add to test costs

Mock Fuselage Tests—Heat Fluxes



Sandia National Laboratories

What Did We Learn?

Wind

- Wind is the most significant contributor to variations within and between fuel fires.
- Even light winds cause a significant affect on a fuel fires.

Calm & Windy Fire Images

Test 1 – 0.85 m/s

Test 2 – 5.76 m/s

Sandia National Laboratories

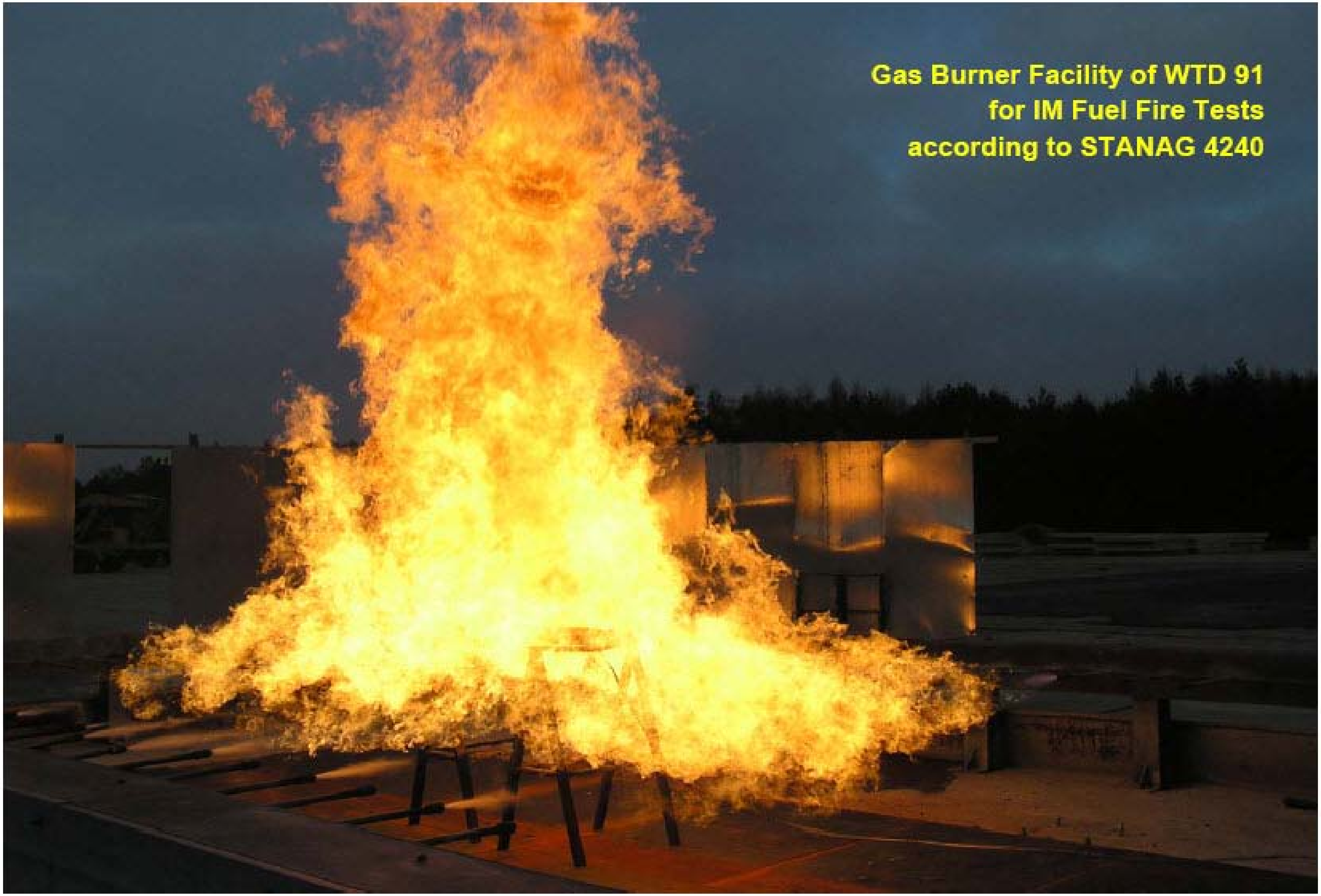
What Did We Learn?

Optical depth

- If you can see the object, then the object can see you.
- Since you are cold, it is getting less thermal radiation.

One optical depth is the distance where the item can not be seen in the infrared spectrum.

- For JP8, one optical depth is approximately 6 to 10 cm, flame coverage is 3 optical depths or approximately 20 to 30 cm.
- Using simple scaling, propane requires 3 times the depth, so total flame coverage is then approximately 60 to 100 cm.


Gas Burner Facility of WTD 91
for IM Fuel Fire Tests
according to STANAG 4240

What Did We Learn?

Anatomy of a liquid fire vs propane fire:

- A liquid fuel fire consists of a test item suspended over a pool of liquid fuel.
- Heating is a combination of radiative and convective heating from the flames and soot above, and the pool of liquid fuel below.
- Since there is insufficient oxygen for combustion, the bottom of the test item is heated by boiling oil at <150°C, while the top is heated at 800 to 1000°C.

What Did We Learn?

- A propane fire consists of a test item suspended in an apparatus surrounded by multiple propane burners.
- The burners in the Meppen Facility are aimed below the item and tend to engulf the item in flames averaging 800 to 1000°C.
- The effect of hot spots need further investigation.

Questions?

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Back up slides

Presentations

Canada

- Environmental issues with kerosene on ground and water (fuel spillage)
- Cost effectiveness with liquid petroleum gas (LPG)
- Difficulty to access kerosene facilities
- Smaller ammunition can be tested with LPG fires
- Flexibility of the test configurations for LPG
- Modifying STANAG 4240, e.g., Annex A, modifying test setups, putting effort into AOPs

Presentations

France

- Recognizes advantage of LPG fire for smaller net equivalent weight (NEQ) ammunition and moderate reactions
- Necessary coexistence with fuel fire for hazard classification issue, even having environmental constraints
- No European regulation limiting using kerosene fire
- The variability of kerosene fire has to be compared with that of LPG fire
- LPG standardization difficulties
- Cost effectiveness for LPG has to be proven

Presentations

Germany

- Heat transfer is nearly the same (LPG vs kerosene)
- Temperature gradients can be matched
- Maximum temperature, that can be reached by LPG is higher than that by kerosene
- Environmental “friendly” need for alternatives
- Cost effective once established and relatively low life cycle cost (LCC)

Presentations

Sweden

- Cost efficiency for LPG (reduction of fuel costs, shorter run times)
- Fast turnover of testing for LPG
- High flexibility with LPG
- LPG testing is more repeatable and environmental friendly
- Improved evaluation of test items with LPG (e.g., High Speed Video)
- Kerosene and LPG fire deliver almost the same results on the test items

Presentations

USA

- Supports LPG fire as long as heating rates, uniformity of spatial heating and heat transfer to the test item are equivalent to a kerosene fire
- The ratio of radiative vs convective heating is not considered critical as long as the heat transfer rate is achieved
- Cannot achieve comparison between kerosene and LPG fire with current STANAG 4240, because of lack of data:
  STANAG 4240 allows 4 TC in forward, aft, starboard, and port, and requires that the average of 4 temperatures is greater than 800°C to call it a valid test
- The new document needs to capture harmonization efforts between IM and HC testing
- The new document needs to contain standardization to assure comparison and acceptance among test sites

Presentations

USA Cont'd

The current document will require an amendment for path forward. Before developing a new document we need answers to the following questions:

- What is the purpose of the test?
- What causes reaction violence?
- What is the thermal load?
- How do we develop a standard instrumentation technique for measuring thermal load? (Perhaps on ITOP level?)
- What are the spatial variations?
- What is the absorbed flux (surface emissivity changes)?
- Was there optical depth to ensure consistent radiation load?
- What are the scaling issues?
- How to measure the load? For instance, heat flux as well as temperature
- What burner design to achieve the desired thermal load?
- Is there uncertainty to allow comparisons? Natural variables associated with wind, facility design variances?
- What is the cost of replacement?
- Is there a measurement of fragment throw and energy?

Presentations

MSIAC (Munitions Systems Information and Analysis Center)

- Lots of data from existing test results (90% kerosene, 5% LPG, 5% wood in MSIAC database)
- Acceptance of test results from other test centers

Discussion Towards a Way Forward

- What is the purpose of the test?
  - Trying to get an answer on the reaction of the ammunition under standardized test conditions.
  - Maintain harmonization between IM and HC in terms of heating rates and classification.
- We agree with the current temperature profile (that includes the temperature ramp and average minimum temperature).
- However, improved standardized diagnostics are required to quantify the thermal load.
- For those items with exposed reactive surfaces (energetic materials, intumescent paints; not including packaging) the radiative conditions should match that of a kerosene fire.
- We recognize that this Fast Cook Off Test is used as a standardized test, acknowledging that not every possible accident is totally duplicated. Some accidents might be harsher, some might be less harsh. There are different accident scenarios identified throughout the life cycle: transport, storage, and tactical use.