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Slow Heating Testing Survey and Historical Events Review

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This report describes the results of an international review of the STANAG 4382 Slow Heating, Munitions Test Procedures, as well a review of heating rates and durations associated with actual fire events. The purpose of the slow heating test is to assess the reaction, if any, of munitions and weapon systems to a gradually increasing thermal environment. To perform the review, MSIAC created a questionnaire in conjunction with the custodian of this STANAG, the United States, and sent it to subject matter experts including test centers in most of the AC/326 nations. The questionnaire questions deal with the test purpose, test procedure, heating rate, actual events, oven design, oven standardization, temperature preconditioning, energetics melting, reaction temperature, test item restraints, test item orientation, instrumentation, and number of tests. This report provides an analysis of the answers received, summarizes best practice and provides some recommendations to potentially support an amendment of STANAG 4382. These recommendations are being discussed within the NATO AC/326 SG/B Slow Heating Custodial Working Group (SH CWG). The working group has already reviewed the review results and is currently drafting updates to STANAG 4382 NATO documentation, which includes the technical content of the STANAG that is being migrated into a new AOP 4382.

INTRODUCTION

This report describes the results of an international review of the STANAG 4382 Slow Heating, Munitions Test Procedures, as well a review of heating rates and durations associated with actual fire events. The purpose of the slow heating test is to assess the reaction, if any, of munitions and weapon systems to a gradually increasing thermal environment. To perform the review, MSIAC created a questionnaire in conjunction with the custodian of this STANAG, the United States, and sent it to subject matter experts including test centers in most of the AC/326 nations. Moreover, an analysis of similar standards has been done in order to achieve more consistency in the recommendations. From a NATO point of view, the requirements for the slow heating test are defined within three documents: STANAG 4439, STANAG 4382 and AOP-39. The test 7 (h) from the “UN – Manual of Tests and Criteria” specifies a slow cook-off test for the classification into hazard division 1.6. The questionnaire questions deal with the test purpose, test procedure, heating rate, actual events, oven design, oven standardization, temperature preconditioning, energetics melting, reaction temperature, test item restraints, test item orientation, instrumentation, and number of tests. This report provides an analysis of the answers received, summarizes best practice and provides some recommendations to potentially support an amendment of STANAG 4382.

BACKGROUND

In 2015, MSIAC carried out a review of STANAG 4496 related to the fragment impact test This review was managed the same way as this current one, and resulted in a list of recommendations that are currently being discussed in a custodian working group to update STANAG 4496. Following the review of the bullet and fragment impact tests, MSIAC proposed to perform a similar review for the slow heating test, on behalf of the United States who is the custodian for this STANAG.

REQUIREMENTS

From a NATO point of view, the requirements for the slow heating test are defined within three documents: STANAG 4439 [1], STANAG 4382 [2] and AOP-39 [3]. The test 7 (h) from the “UN – Manual of Tests and Criteria” [4] specifies a slow cook-off test for the classification into hazard division 1.6.

Analysis of the requirements

The table hereafter compares the STANAG 4382, AOP-39, and the UN Manual of Tests and Criteria test 7(h) regarding the slow heating test:

Table 1: Differences between the STANAG 4382, AOP-39 and UN orange book test 7(h)

	STANAG 4382 ed.2	**AOP 39 Ed. 3**	**UN 7 (h)**
Alternative procedure	Yes		No
Number of tests	2		2
Item configuration	Bare or logistical, as agreed by the national authority	Bare or logistical	Logistical
Test Procedure	Yes		Yes
Heating rate	3.3°C/hr		3.3°C/hr
Preconditioning Temperature	50°C for 8 hours or until equilibrium at 50°C		°C below the predicted reaction temperature
Maximum Temperature			365°C
Reaction level acceptable	Burning or no reaction		Burning or no reaction

The main difference between the documents is related to the item configuration:

- In logistical configuration for the UN document. This seems logical, as this document relates to the transport classification of the article;
- Bare or packed, as agreed by national authority, in the STANAG, which seems logical as the national authority is able to define when a fire is more likely to impact the munitions during the life cycle.

An alternative procedure is provided in the STANAG: if no analysis has been done, a rate of 25°C per hour should be used as a default rate. With respect to temperatures specified, there are 2 main differences: the preconditioning temperature is different (higher for the UN) and the UN defines a maximum temperature. The STANAG provides more details on the test procedure and includes a basic test set-up description. Neither the STANAG nor the UN document provides a detailed example of test set-up. In addition, there are redundancies between the STANAG 4382 and the AOP-39, especially in the observations and reports part. They should be avoided to allow these 2 documents to remain independent. Indeed, the AOP-39 is linked to the STANAG 4439, and it is not automatically updated when there is a change in one of the STANAGs that defines the test procedure, like the STANAG 4382. The 3rd edition of AOP-39 includes Appendices which provided intermediate updates of all the IM full scale tests not referenced from STANAG 4382 and the contents of the Slow Heating appendix needs to be included in the review of STANAG 4382.

MSIAC was requested to support AC/326 SG/B, which was agreed by the MSIAC SC, to review all these documents to remove redundancies or contradictions and to clarify where the information should reside. As a result, most of the redundancies will no longer exist in the updated documents. The review includes drafting of a Standards Related Document to provide guidance on common aspects of IM testing, reporting and documenting. Other IM full scale tests STANAGs have recently been reviewed in conjunction with this MSIAC review and changes to STANAG 4382 need to reflect a common structure and content with these other STANAGs

QUESTIONNAIRE

The questionnaire was conducted through the MSIAC web site. A notice was sent to the MSIAC nation representatives for distribution, as well as a large group of identified laboratories and test sites from previous survey responses. The questions deal with the test purpose, test procedure, heating rate, actual events, oven design, oven standardization, temperature preconditioning, energetics melting, reaction temperature, test item restraints, test item orientation, instrumentation, and number of tests. For each question, a breakdown of the responses is provided with additional comments.

Origin of the Answers

MSIAC has received answers from 11 nations. Within these answers, one nation acknowledged the fact that they were not performing this test. Therefore, only the 34 responses from 10 nations were taken into account for the analysis. Answers were analyzed from 7 NATO nations (Canada, France, Germany, The Netherlands, UK, Norway and the USA) and 3 partner nations (South Africa, Sweden and Finland). 62% of the answers come from governmental test centers and 38% from private test centers. If should be noted that the majority of responses represented group responses, rather than individuals.

The following chart shows the origin of the answers by nations:

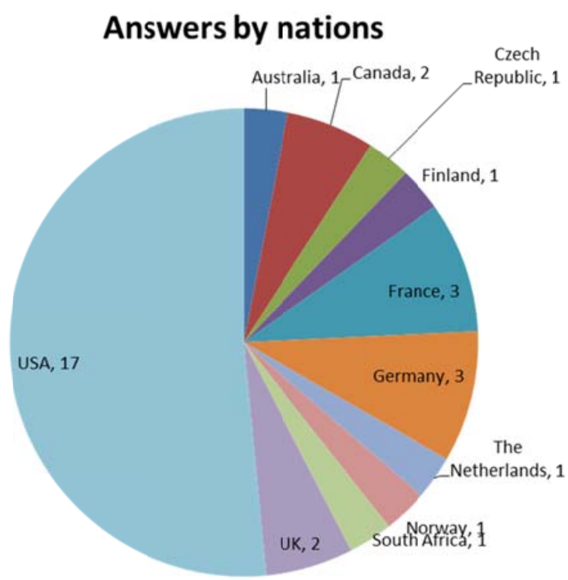

Figure 1: Number of answers received by nations

The following table presents the complete list of test centers and national authorities who replied (duplicates indicate multiple individuals from the same organization):

Table 2: List of facilities and nations who replied to the survey

Organization	Country	Status
DOS	Australia	Government
DRDC Valcartier	Canada	Government
GD-OTS Canada	Canada	Private
AC/326	Czech Republic	Government
Test Firing Center	Finland	Government
AC/326 – DGA	France	Government
NEXTER Munitions	France	Private
Airbus Safran Launchers	France	Private
WTD91	Germany	Government
MBDA Systems	Germany	Private
MBDA Systems	Germany	Private
Centre of Excellence Weapons and Ammunition	Netherlands	Government
AC/326	Norway	Government
AC/326	South Africa	Government
Bofors Test Center	Sweden	Private
QinetiQ	United Kingdom	Private
BAE Systems	United Kingdom	Private
US Army IM Board	United States of America	Government
NSWC Dahlgren D	United States of America	Government
Redstone (Army)	United States of America	Government
Eglin Air Force	United States of America	Government
Eglin Air Force	United States of America	Government
AFLCMC/EBDP	United States of America	Government
NAWC China Lake	United States of America	Government
NSWC Dahlgren D	United States of America	Government
NSWC Dahlgren D	United States of America	Government
NAWC China Lake	United States of America	Government
NAWC China Lake	United States of America	Government
DDESB	United States of America	Government
YPG ATC	United States of America	Government
NAWC China Lake	United States of America	Government
NSWC Crane	United States of America	Government
NSWC Crane	United States of America	Government
NSWC Crane	United States of America	Government

TEST PURPOSE

The survey participants were asked about the purpose of the test. They were asked if the test purpose was to provide an extreme heat rate different from the fast cook-off test, if the test purpose is to characterize the munition being tested, and/or if the test purpose is to simulate a real life accident scenario. Additionally, they were asked to comment as to the reason that the slow heating test was developed. The majority agreed with all three statements, but a larger number agreed that the test purpose was to characterize the munition being tested. Figure 2 presents circle graphs of the responses.

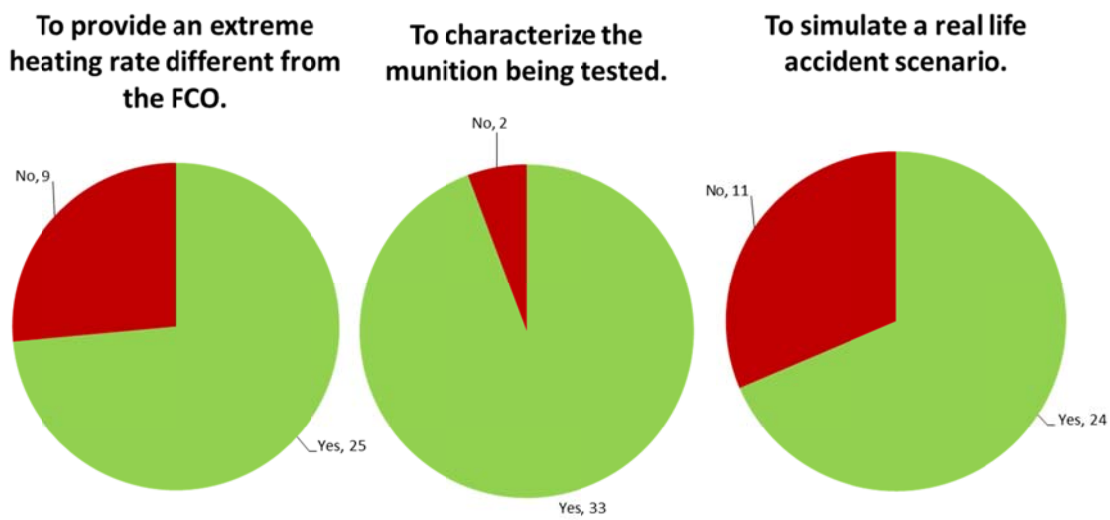

Figure 2: Test purpose responses

For What Reason Was the Slow Heating Test Developed?

A large number of comments were received. These comments were:

- The primary reason for doing any IM test is to characterize the munition – to find out what it might do in the real world and then figure out a way to minimize the impact of the reaction.
- Simulate the slow heating of a test item due to heating from an adjacent building
- It should be performed to simulate a real life accident scenario but with the heating rate now in use (3.3°C/h). I doubt that it actually does so.
- The test forms a hypothetical scenario which is worst case. Other additional more specific testing is required to relate to specific scenarios that fall between FCO and SCO. Over time, we have been able to improve the reaction of munitions to this "severe" environment. We would have never gotten to where we are today without testing to the extremes. SCO aids in down selection of design concepts or materials early on in the design process
- It may not necessarily be reality but it will be a standard comparator that can be referenced for all customers and munitions requiring testing.
- Tests performed to fulfill the customer requirements.
- To simulate a fire in a storage hold that slowly heats a nearby or adjacent storage hold, presumably on a ship, or in a depot or railcar.
- Anecdotally, it was to serve as a worse case test to simulate a series of fires occurring aboard a ship with multiple below deck magazines. I've seen anecdotal statements that "one US Navy ship burned for three days", but no other rationale on how this SCO cook-off environment can exist (in its current extreme form) anywhere else.
- Originally several rates were tested providing thermal characteristics for a munition. Due to financial constraints, this slowly evolved into using only the most extreme slow rate achievable as a "bookend" to the Fuel-fire test.
- The 6°F or C/hr heating rate was intended to achieve heating in a near-isothermal condition to reduce the influence of item size, mass, and other physical features; and was based on the limitation of test equipment available in that era.
- The test already existed – it was just adapted to SCO. Prior to that it was used to test to ensure a munition didn't auto ignite under very extreme conditions prior to a certain temperature or within a certain period of time. At that time, the reaction wasn't

important, just the time to reaction. And, the heating rate was the slowest that could be tested at the time.

- Developed to provide a scenario in which the test item is heated at a much slower rate than in a fast cook-off test
- It has been established than in the case of fire on the ship deck, neighboring magazines can be slow heated as low as 6°F/hr.
- Historically SCO was imposed by the US in UN Manual of Tests and Criteria 2nd Edition (HD 1.6) and then introduced in the IM policy (MIL-STD 2105 and STANAG 4382).

TEST PROCEDURE

The survey participants were asked about the test procedure. They were asked if they conduct the SCO test as required by the STANAG 4382 primary test procedure, and if they have a separate nationally approved procedure. Additionally, for what reason was a specific nationally approved procedure developed. The vast majority of responders conduct SCO tests as required by the STANAG 4382 primary test procedure. Germany and France provided the designation of their nationally agreed test procedures. Additionally, the US Navy NAWCWD and the US Navy NSWC Crane divisions provided the designations of their locally agreed test procedures and reasoning for developing these locally agreed procedures. Figure 3 presents circle graphs of the responses.

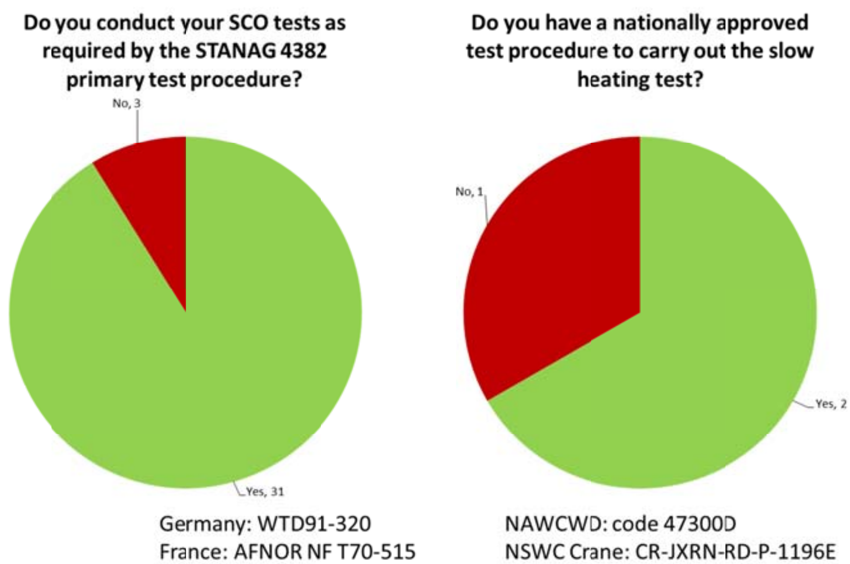

Figure 3: Test procedure responses.

Nationally Approved Specific Procedure

When asked for what reason was this nationally approved specific procedure developed, the comments received were:

- Confirm that our trials plan meet the requirement and has objective review and acceptance from all parties concerned.
- This is a procedure created to give clear concise steps to conduct a slow cook off test per latest requirements as well as other Hazard Classification Tests

Locally Approved Specific Procedure

The comments associated with local specific procedures were:

- Procedures developed to meet STANAG requirements, safety requirements (local and national), environmental requirements, and gather quality test data at a reasonable cost
- Simpler design and it is easier to control the temperature if the outside temperature is cold

Another interesting related comment was that some test areas use the test set-up defined in the former MIL-STD 2105B (12 January 1994). It is described as a very convenient and efficient definition. Figure 4 presents a diagram of the slow heating test configuration from MIL-STD 2105B.

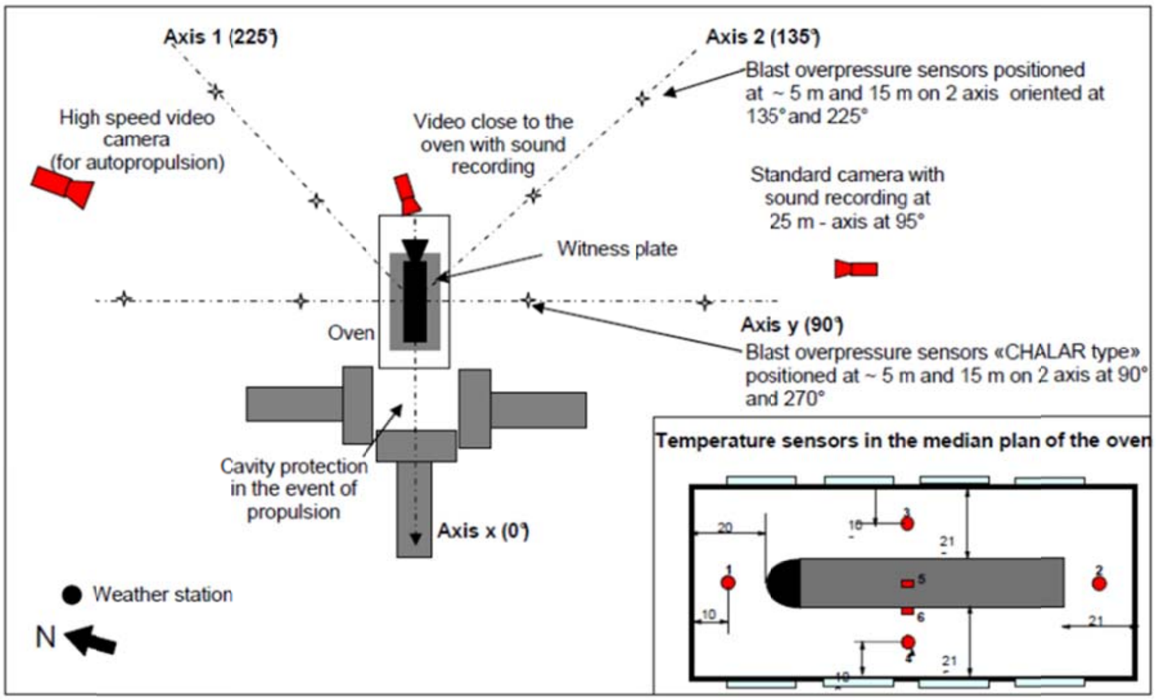

Figure 4: MIL-STD 2105B configuration of the slow heating test.

HEATING RATE

The survey participants were asked about the test heating rate. They were asked if the heating rate should be changed and if item size should be a consideration in defining a slow heating rate. Specifically, they were asked to comment on what heating rate they use, what heating rate should be used in procedure 1, why should this rate be used, should size be a consideration, and whether they had any information on duration or rates of actual real world slow heating events. About half of the responders agreed that the heating rate should be changed. However, several responders were unsure or stated that it depends on the test intent. The majority of the responders thought that item size should not be a consideration in defining the rate. Figure 5 presents circle graphs of the responses.

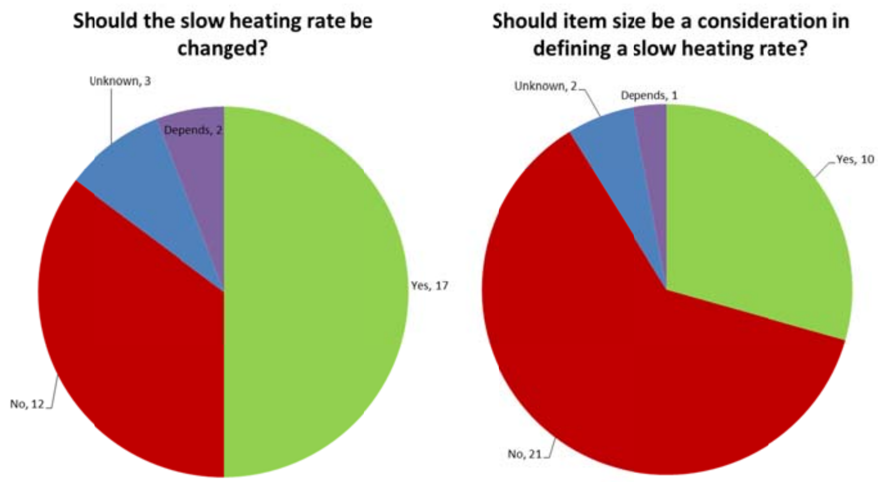

Figure 5: Heating rate responses

What Rates Are Currently Used?

The comments received were:

- Majority response: 3.3°C/hr
- Sometimes faster rates – up to 100 °F/hr – are used for evaluation of mitigation systems to ensure they will work for more than the standard rate which may or may not be real world.
- Whatever the customer wants …but almost always 3.3°C/hr
- As requested by customers…typically 6°F/hr or 50°F/hr.
- Either 3.3°C/hr or 25°C/hr
- We use 3.3°C/hr for standard tests for qualification. For routine, we often use an intermediate rate, to allow us to run one test per day.

What Range of Rates is Accessible with your Heating Equipment?

The comments received were:

- Less than 3.3°C/hr and greater than 25°C/hr
- This is very dependent on the size of the item under test. We can test at almost any rate if the item is not extremely large.
- Nearly any rate can be programmed. Low rates are easily accommodated, but high rates are limited by the number of heating elements. At this time, an upper limit of 150 amps to the elements.

What Should be the Heating Rate be in Procedure 1?

The comments received can be divided into three responses: keep the original rate, the rate should be based on "real world data" and that the rates should be worst and the most likely.

Should keep the original rate:

- It should remain at 3.3°C/hr.

Should be based on "real world data":

- It should be realistic to the scenario that a slow cook-off test is simulating. This should be based on real world data, past occurrences, and SME evaluations of what is and

what is not a realistic heating rate in real world incidents. A suggested heating rate with some supporting data is 45-50 degrees F per hour.
- The heating rate should be changed to a rate that is consistent with reaching cook-off temperature within a reasonable time for a fire to be extinguished. If the worst case is 24 hours, then the heating rate should be determined based on the item reaching cook-off temperature in 24 hours.

Should be worst case and most likely:
- The problem with the current rate is that we don't know if it will produce the worst reaction. No, it's not "real world". But, the real world rate for any munition will be highly dependent on the life cycle of that item. There should probably be at least two rates – a worst case rate and a most likely rate (one set by the specific program depending on the life cycle assessment).

Why This Rate?

The received comments are:
- Maintain compatibility and comparability with previous test data.
- We should be assessing for IM compliance over a range of slow rates, rather than just at a single point. Having a single point may enable developers to focus on passing just that single requirement, whereas passing over a range of rates might make them more focused on a better IM solution.
- A suggested heating rate with some supporting data is 45-50 degrees F per hour.
- With modern day fire fighting equipment aboard ships, fires should be completely extinguished in less than xx-hours. I do not know what that reasonable timeframe is but we should be able to determine it from the experts. The example I cited above was for a 24-hour fire. Using a cook-off temperature of 180-Deg C, starting at 50-Deg C, 130 divided by 24 hours equals 5.5-Deg C per hour.
- Various energetic materials will have their worst case reaction at different rates. There will not be one rate value that will invoke the worst case reaction in all or most articles or even components. Retaining rates of 3, 4, 5° C etc. will only be valuable for scientific research. A real fire will be extinguished well before any reaction occurs (and won't last for two days).

Should Size be a Consideration?

The received comments are:

- The size of the item to be tested is not foreseeable. It is as big as it is.
- The rate should be based on what can be expected in a real world application.
- It might be necessary/prudent to tailor the heating rate(s) to item size in order to assess the effectiveness of reaction mitigation features across a range of credible stressing conditions (see previous comment).
- We already have an artificial rate…don't make it worse by adjusting the rate based on size. How does that relate to anything real?
- We should remain standardized for all, rather than variable.
- Worst case should be used, whatever that rate is.

OVEN DESIGN

The survey participants were asked about test oven design information, including oven construction material and thickness, the oven heating system, the oven airflow and oven photographs. They were also asked about oven design issues that affect the testing and potential test outcome, including the item spacing to the oven wall, the observed temperature homogeneity while testing and about protection for energetic material exuded out of the item.

General Oven Design Information

Figures 6-17 present provided photographs and diagrams of various testing facility oven designs. The oven designs vary significantly and it is clear that test areas use different designs depending on the scale and type of test item. Below are the comments received on general oven design:

- Our oven designs are tailored for individual items.
- Design for oven: Square oven or cylinder oven dependent on dimension of asset being tested.
- It's an expandable design constituted of a metallic pipe surrounding the munition, this pipe being covered with an electric blanket. This set is enclosed itself in a thermal insulated box.
- We have various ovens.

Figure 6: NSWC China Lake, US Navy.

Figure 7: Qinetiq, UK.

Figure 8: Bundeswehr Technical Center for Weapons and Ammunitions, Germany.

Figure 9: Yuma Proving Grounds, US Army.

Figure 10: Explosives Centre, Finnish Defence Forces, Finland

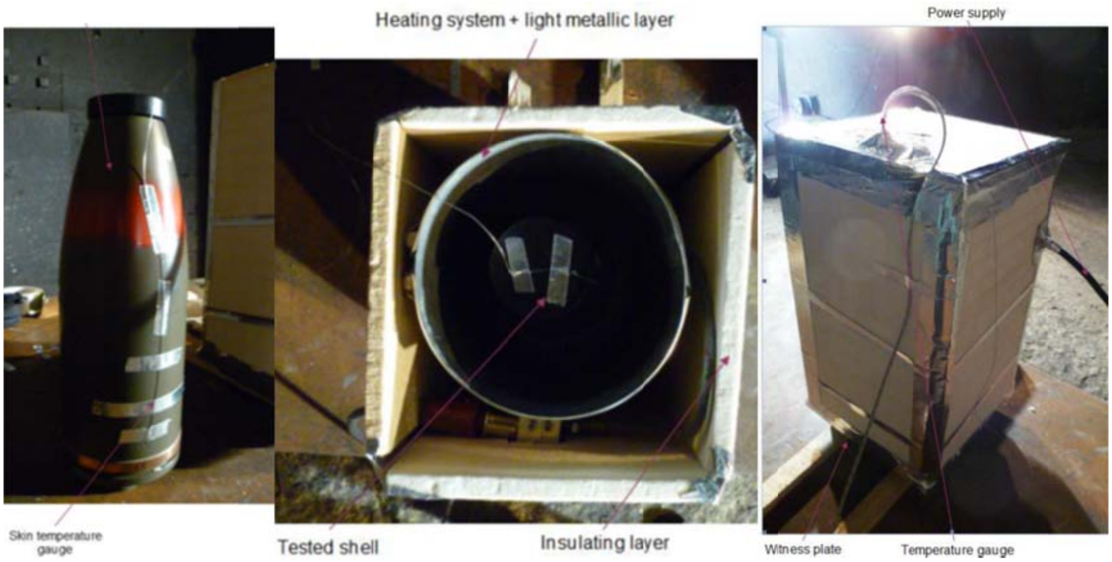

Figure 11: NEXTER Munitions, France.

Figure 12: GD-OTS, Canada.

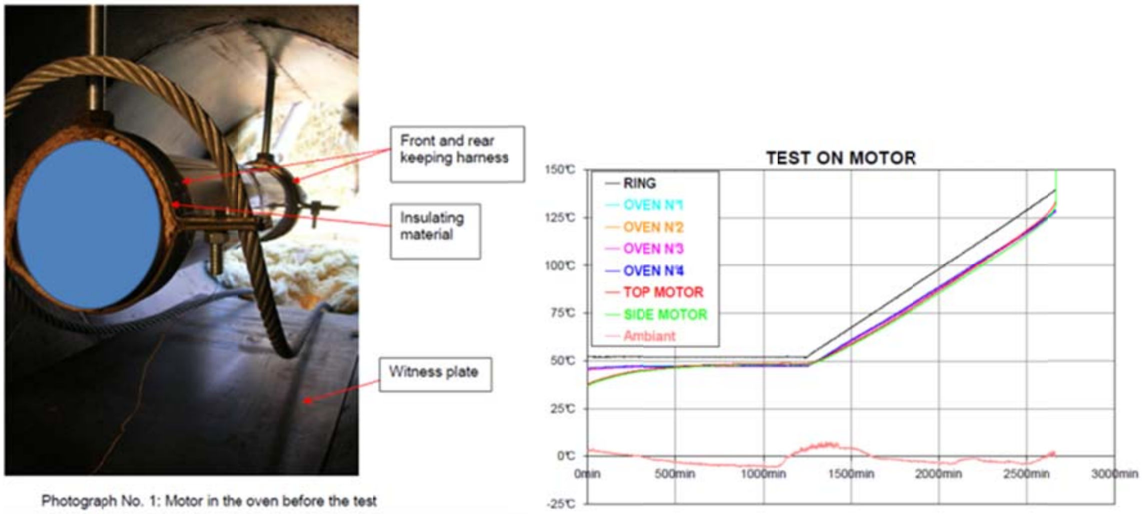

Figure 13: Airbus Safran Launchers, France.

Figure 14: BAE, UK.

Figure 15: BAE, UK.

Figure 16: MOD NLD / KCW&M, Netherlands.

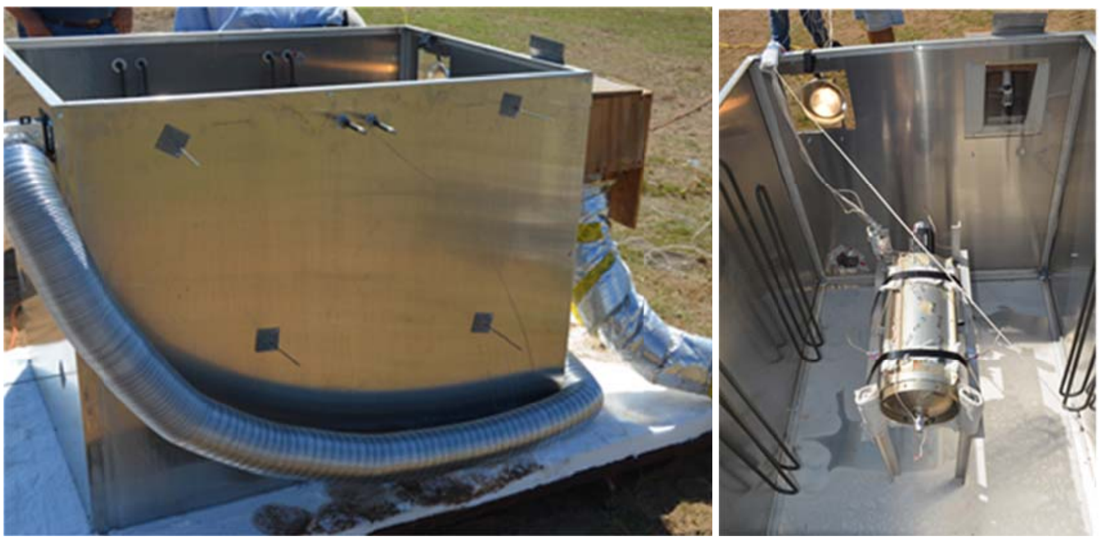

Figure 17: Redstone Test Center ATEC, USA.

Oven Material and Thickness

A very large variety of materials and thicknesses are used for the oven construction. Below is a listing of the different responses:

- 16 and 18 gage steel depending on the size of the oven for structural integrity.
- 4 inch thick insulation material.
- Usually we use large air conditioning pipe/tube or “chicken wire” and frame. For insulation we use mineral wool (thickness 10-20cm), aluminium foil and tape.
- Made from 4 ft x 8 ft x 3’’ Home Insulation sheeting polyisocyanurate R3 assembled with aluminum tape. The oven is mounted on a steel frame/table.
- Regular steel, around 1mm thick.
- The ovens used are thin double walled aluminium designed with fibreglass or other form of insulation. These ovens are custom built for size and are all deemed as sacrificial.
- Double wall design: 1” thick, foil-faced, fiberglass duct board lined with single layer of 1” Ceramic Thermal blanket rated to 2400F. (“Soft” oven design with no hard surfaces present to interfere with potential fragment flight) for the inner box, which is covered

with an outer box made from the same duct board allowing 3 inches airspace between the inner and outer to allow for circulation.

- Standard Stone Wool inside steel grid.
- 1/16” aluminium walls with a 1” aluminium angle skeleton to produce a box which is then covered with high temperature insulation as needed and then covered by a clear tarp to protect the insulation from dew or rain.
- Double-wall construction with inner wall of 1-in thick fiberglass duct-board and outer wall of 2-in thick rigid polystyrene foam.
- Usually steel sheet, appx 1/16” (China Lake) or appr 1/8” (Eglin)
- Bespoke oven created for each individual test scenario.
- Mild steel with insulating material sandwich between inner and outer layer.
- Double-wall design (i.e. inner chamber/outer chamber). Inner chamber constructed from 1-inch thick duct board. Outer chamber constructed from 1 ½ inch thick foam insulation.
- We use reinforcement mats for the framework of the oven and 200 mm thick mineral wool for insulation. The oven is protected from wind and rain with polyethylene foil.
- Heat resistant wool. Thickness is very much dependent on the outer conditions, i.e. thicker insulation in the winter time than in the summer time.
- Oven material and thickness 1mm steel plate on light frames, rockwool insulation
- Thin steel sheet metal, see NAWCWD 473000D for detail info
- Ceramic, approx. 3 inches.

Heating Systems and Airflow

There appears to be much less variation in the heating systems, with two main approaches: internal heat source convection oven, or external heat source convection oven both using electric heating elements. Almost all responses indicated that they used forced airflow in order to try and achieve temperature homogeneity. So the primary difference between the two heating systems approaches is the location of the heat source: internal for convection ovens and external for heat source convention ovens which employ a pipe to transfer the heat.…are that for the internal heat source convection ovens, the electric heating elements are within the oven, and for the external heat source convection oven, the electric heating elements are in a separate unit from the oven and heated air is piped into the oven.

Below are some associated comments from the survey:

- Heating system is like large “fan-oven”.
- Convection oven heated by four 120 Volt, 500W strip heaters protected by thin aluminium witness plates. The heaters may me reusable from test to test.
- Electrical resistances.
- One or more heating elements off the ground and away from the item under test within the oven system and fan assisted for air circulation.
- (4) 500 Watt heating elements.
- Hielkema Air Heaters.
- Typically 3 each tubular heaters controlled by a Watlow control device that regulates the time that the heaters receive voltage, thereby, providing heat to the box.

Wall Distance

All survey responders indicated that they maintained the distance between the test item and the oven wall to be >200mm per the STANAG requirement.

Temperature homogeneity

The STANAG lists a requirement for temperature homogeneity to be within 5°C. Most respondents indicated that this requirement was not difficult to meet, except for large test items.

Associated comments are:

- When testing new items, dry run with inert dummy is always performed to ensure a valid test.
- Temperature homogeneity has almost always been kept below 5°C. On very rare occasions, this tolerance has been exceeded.
- Typically we can meet the required homogeneity. However, we have had problems with relatively large, elongated items (e.g., large surface-launched rocket motors).
- Usually 4-7°C. If insulation is not done well, it can be 10°C or more.
- Usually less than 5°C but with strip heaters the oven wall, especially on the bottom can be at least 30°C hotter.
- Why should there be uniform temperature? Based on what real world rationale?

Protection for Exuded Energetic Materials

The survey asked if any protection was used to prevent exuded energetic material being prematurely ignited on contacting the oven wall. . About 40% of the respondents indicated that they did use some protection, as seen in Figure 18.

Associated comments were:

- A "drip tray" is located below the test item to avoid energetic material dropping onto the heating element.
- We have a tray added to the inside of the oven so fill that exudes out of the case can be insulated from the hotter oven wall.
- Depends on the test item, in some occasions, "trays" are added to prevent melted EM to have contact with oven walls
- We put thermally insulated receptacle below tested munition. In the aim to avoid a prompt ignition when energetic material fall on the oven wall.
- Our ovens are built of heat resistant wool which is insulating and do not act like a hot surface. We try also to insulate the fixtures in the ovens which hold the test item
- I understand why the concern exists about exuded material: it makes the test look bad. As we don't have a valid rationale for the test, how do you make the assumption that you won't have hot spots on the floor? What if the fire is in the portion of the ship right under the weapon? Then the floor will be the hottest part.
- We consider the pyrolysis gases as having more influence on premature ignitions.

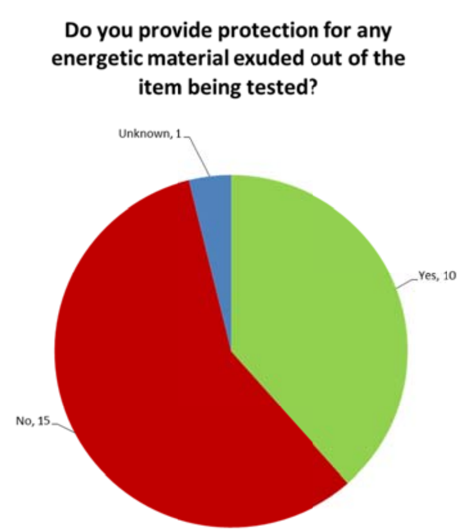

Figure 18: Protection from exuded energetic material.

OVEN DESIGN ISSUES

The survey asked that any issues with the oven designs be raised. The primary topics discussed by the respondents were that the oven should be: 1) very well Thermally insulated and 2) designed so as not to significantly confine the reaction, fragmentation or blast.

Thermal issues

Comments associated with thermal insulation are:

- Forced air flow ovens have resulted in varying responses from the same munition. It is believed the air inlet is creating localized hotspots.
- The convective oven wall is much hotter than the oven air so when fill contacts it ignites. This not only causes a slightly earlier reaction but ignites the remaining fill in the case in a location that may not be realistic.
- We use heat resistant wool as construction material and place most metal parts (heating elements, fans etc.) beneath the test item.
- The ultimate SCO oven material would be a heat resistant, light colored (better “in oven camera” coverage) affordable, light weight / density and environmental friendly plate.
- Air flow in our test set up does not have high velocity. On my opinion that does not have significant influence to test item and test result.
- Several different cameras that look through a window in the oven and the most difficult problem is determining how to keep the camera cool to keep the internal view camera alive. I have had successes and failures, but I haven’t found the perfect answer for that yet.

Confinement and Fragment Flight Issues

Comments associated with confinement and fragment flight are:

- Heavy wall construction can influence the flight of fragments.
- I feel that the greatest issue is ensuring that the design of the oven truly provides the minimum confinement that can be achieved practically, in order to minimize suppressive effects on the ejection of debris and attenuation/focusing of blast
- Oven walls should be constructed of foam/fiber panels with minimal structural integrity to lessen their effect of slowing fragment projections
- Even if the confinement exacerbates oven throw distance we do not believe it throws test item parts farther.
- Confinement will always be an issue, but items can be compared using the same test setup and a “calibration” shot can be used to measure/determine the full detonation properties of the test item.
- Oven design should have minimal effect on the projection of fragments from the oven.

OVEN STANDARDIZATION

The survey asked whether the oven design should be standardized. The results split fairly evenly as seen in Figure 19. The problem with standardizing the design is that different munition types require different considerations. Differing sizes of munitions required different sized ovens. Rocket motors will need to be restrained to prevent flight in case of a strong propulsive reaction. Also, munitions tested inside a shipping container or canister can affect the oven design. One thing to consider is the use of the oven itself as a surrogate shipping container or canister. This could avoid duplicate confinement. Another point to discuss will be the consideration of the effect of heating bands on the reaction if material is extruded out of the test item. Heating bands create localised hot surfaces which are eliminated if forced air is used. So, guidance could be provided to use forced air if energetic extrusion is anticipated. External conditions affect the design as well: if it’s very cold outside additional insulation will be needed. Recommendations could be developed for oven design to limit masking of primary blast and fragment effects whilst limiting the potential of secondary fragmentation.

TEMPERATURE PRECONDITIONING

The survey participants were asked about temperature preconditioning. The STANAG states that prior to commencement of the heating condition (rate), the test item should be preconditioned at 50°C for 8 hours or until the test item reaches thermal equilibrium at 50°C, whichever occurs first. The survey asked if they did precondition per the STANAG, whether a melt cast energetic should be pre-soaked differently and should the preconditioning requirement be changed.

Preconditioning Responses

As seen in Figure 19, almost all responded that they precondition per the STANAG. About half of the respondents thought that melt cast energetic should be pre-soaked identically to non-melt materials, whereas about ¼ of respondents thought that they should be pre-soaked differently. About 1/3 of respondents thought that the requirement should be changed and about 1/3 of respondents thought that it should remain the same.

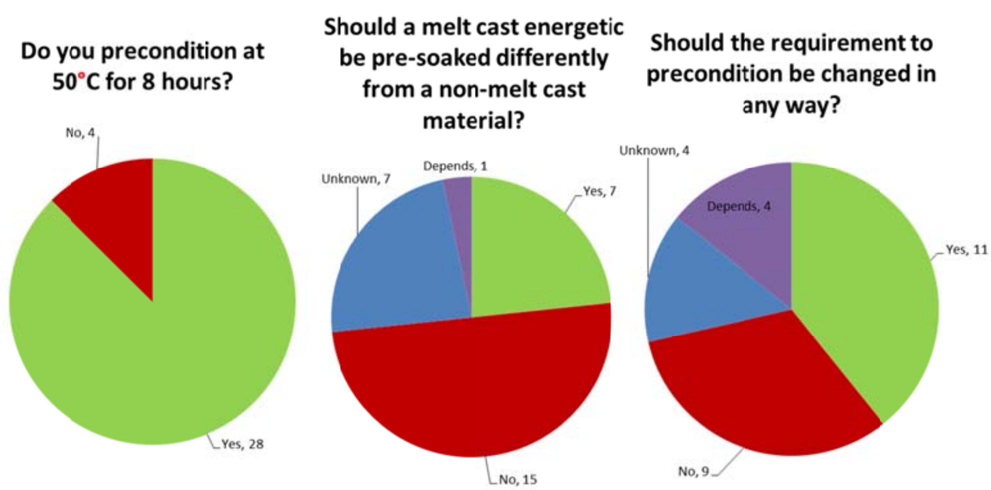

Figure 19: Temperature preconditioning.

Should a Melt Cast Energetic be Pre-soaked Differently?

Comments associated with pre-soaking melt cast energetic are:

- It is useful to have the same starting temperature for all f munition types. Especially as we are performing the tests in autumn and winter times and the munition cools down before the test starts.
- I don't see any reason to. During firing tests we would also condition these energetics to 120ºF (~50º C) before firing.
- If the soaking temperature is much lower than the typical melt temperature (i.e. around 80°C for the TNT which is the lowest of the melting explosive used) as it is the case now, the soaking should be the same.
- If the test is to be used as characterization test, the material should be soaked just above the melting point until all material has melted.
- If it is intended to be used a real-life surrogate, then all pre-soaks are no longer needed.

Should the Requirement to Precondition be Changed?

Comments associated with potentially changing preconditioning are:

- Some guidance should be provided on the minimum time to precondition. Smaller items may reach thermal equilibrium in 8 hours but larger items definitely will not. I think the STANAG should provide a guide for pre-conditioning time based on item size (diameter, weight, amount of container/item insulation).
- The only reason I can see for it is if it affects the onset of self-heating and if self-heating is a driver of the reaction severity.
- Consider making it even higher if that can be shown to not change results.
- We do not see the need to change this. Preconditioning should be performed to ensure that initial temperatures are identical from test to test, regardless of the ambient air and oven walls temperature. The preconditioning temperature should however be much lower than the temperature at which degradation begins in the energetic materials or other materials.
- I'm not aware of the history of why 50°C was chosen as the soak temperature.
- I would consider establishing and documenting the need for preconditioning at 50 deg. What is gained by doing this? Why 50 degrees? What does it represent in the munitions life cycle or threat profile? How does a potential thermal threat scenario map to this requirement?
- I think that one should take a look at the entire heating rate profile so that it would better fit one of the most common accident scenarios.

MELTING

The survey participants were asked whether melting of energetics during a test should affect the testing requirement. As seen in Figure 20, about 75% of respondents think that melting of energetics during a test should not affect the requirement.

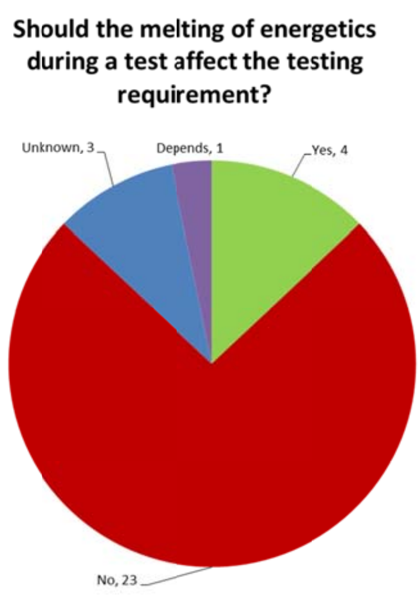

Figure 20: Melting energetics.

PROPULSION

As seen Figure 21, almost half of the respondents stated that they do not restrain items to prevent propulsion. More than half said that they do restrain potentially propulsive items if they believe that they pose some safety risk. Many of the described restraint methods allow some

item movement, providing the testing facility has some information on propulsive potential of the item.
Some of the received comments are:

- Test item is normally strapped to the test stand with steel banding.
- The motor is placed in relatively open but strong steel cage to prevent the motor from flying away during reaction due to the onset of thrust – this is a general requirement of the test site.
- Mostly by using vertical orientation when testing rocket motor or propulsive items.
- System dependent, range safety dependent. Tethering, catch boxes, barrier walls, thrust cells, are used as needed
- We only restrain items in instances where propulsion of the case might present a range-safety hazard. Typically this is uniquely associated with items that have live rocket motors.
- In spite of a nearest neighbor at 20 miles, we must be prepared for a propulsive event that takes ordnance off the station boundaries.
- We normally always allow propulsion in IM tests. We handle that with our risk areas.

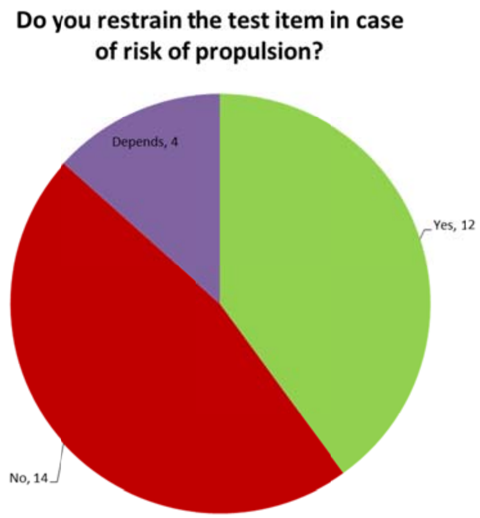

Figure 21: Item restraint from propulsion.

ITEM ORIENTATION

When asked about item orientation during testing, the majority stated that the test orientation is usually representative of the orientation during most or all of the item logistics life-cycle. Often, this is the horizontal orientation, which can facilitate the assessment of the debris hazard posed by end caps, plugs, etc. that might be ejected from the test item. Vertical orientation can impede the ejection of these pieces of debris by directing downward into the oven floor or directing them straight up, which can result in a misleadingly short apparent ejection range. The latter can pose problems evaluating the results if video coverage is poor; or the reaction occurs at night-time.

INSTRUMENTATION

The survey requested information on instrumentation used for the slow heating testing. The responses were very similar from all of the respondents in terms of the instrumentation that was normally used: digital data acquisition recorders, video coverage, microphones, witness plates, pressure gauges and thermocouples. Typically type K thermocouples are used for temperature measurement and piezoelectric pressure gauges for blast overpressure measurement. One test facility listed bikini pressure gauges for blast measurement.

Number of Thermocouples

The STANAG is somewhat inconsistent in that it states “A minimum of four thermocouples should be used to be sure that the oven is uniformly heated and to monitor the surface temperature of the test item.”, but goes on to state “In general, there should be at least two thermocouples mounted on opposite surfaces of the test item, one each in the air space near the air inlet and exit, and one each in the air space on opposite sides of the round (see Figure 1).”, implying at least 6 thermocouples should be used. The number of thermocouples used by test facilities appears to vary greatly from 4 to 100.
Below are some of the responses:

- 4 as per the STANAG.
- 6 (minimum) installed in accordance with the STANAG to assess compliance with the heating conditions and provide an indication of reaction of the test item.
- Between 8 – 16: near the oven wall, near the item, and when possible inside the item (charging tubes).
- Typically fifteen. This includes the typical air temp at various points near the item, oven wall temp, skin temp in several locations including just outside the oven wall, and one or two internal to the item to detect self heating.
- Ten to thirty thermocouples are typical. Some dictating factors include, size of the oven (ensure temperature homogeneity), specific test information about a location, efficiency of heat transfer, STANAG requirement, engineering considerations, etc. We are equipped to use as many as 100 thermocouples.

VISUALIZATION ISSUES

A number of respondents described visualization issues:

- Occasionally an internal camera will fail or be obscured by fill exudate prior to initiation. This will compromise diagnostics.
- A minimum of four cameras are used. Two are fielded to view the test store inside the oven and two are deployed to view the outside of the oven.
- We use two cameras outside and one camera inside the oven to record the reaction of the munition.
- Cameras are used external to the event. Disposable internal cameras are often used, as many as four in a single test.
- We have a camera outside oven, shooting through window to inside oven, to the test item. It has been very useful and has given information during test and just before reaction.
- The window allows the ability to confirm reaction of the item but our current set-up does not allow for visualization of the test item reaction, since we prefer using a general surveillance camera. A system using bigger window, mirrors, and high speed camera is possible. Trigger is an issue with some instruments, although we used bridge-wire to acquire data (ex.: pressure) at a higher speed rate during reaction.

SUMMARY OF RECOMMENDATIONS

This is a summary of the recommendations, the explanations have been provided in the core of this document:

- Develop a group consensus as to the intent of the test and document it.
- Query all of the MSIAC nations to provide information on actual event durations and rates.
- Based on consensus test intent and supporting data, develop a consensus as to changing rate or leaving the rate unchanged.
- Clarify the minimum number of required thermocouples and thermocouple positioning.

- Observations of events inside the oven.
- Develop and provide a best practice oven design examples for different types and scales of test items.
- Characterize the heating equipment and perform calibration testing.
- Provide a best practices example test configuration.
- Remove redundancies or contradictions and clarify where the information should sit between the STANAG 4382 and the AOP-39 (AC/326 SG/B has already begun this process).

ACTUAL EVENTS HEATING RATES

There were 32 responses that the individuals had no information on the duration or rates of actual slow heating incidents. As a result, during the NATO AC/326 SG10-11 April 2017 /B Slow Heating Custodial Working Group (SH CWG) meeting, MSIAC was requested to conduct a review of actual event heating rates and durations and share any available historical information from the MSIAC safety database regarding real-life slow heating events and potential thermal threats. A search of the MSIAC MAD-X accident database provided no applicable information. A report search resulted in a large number of references [5-32], including the previous 2003 MSIAC report “Assessing Thermal Threats” [33] that was published in 2003. The review results provided many examples of fire durations and very few actual temperature rate measurements. As a result, fire modelling results of actual events are required in order to estimate credible actual or minimum heating rates. The vast majority of fire events are complete within a day. Some events have occurred over multiple days, but it needs to be recognized that these events are all multiple fires that have occurred sequentially. The individual fire events associated with these multiple day fires appear to be complete in much shorter times. The summary inferred actual fire events temperature rise rates remains the same as that assessed in the 2003 MSIAC report [33]. A summary of this assessment is presented in figure 22. This review, and the previous assessment conclude that actual credible adjacent compartment fires could produce rates as low as 25°C/hr. Lower rates appear very difficult to justify based on actual fire events and associated thermal modelling. Dr. David Hubble from NSWCDD, USA recently completed a similar study, which included supporting fire modelling [34]. The results and conclusions appear to be very similar.

Heating Source	• Torching • EM Burning • Exhausts • Pyrotechnics	• Fuel Fire • Wood fire • Propane burner • Building Fire	• Hot Breach • Gun Battlecarry • Launcher • Nuclear plant • Aircraft debris • Remote fire • Aerodynamic Heating • Adjacent compartment fire	• Solar Heating • Steam leak
Regime	Fast Cookoff (FCO)		Intermediate Cookoff (ICO)	Slow Cookoff (SCO)
Temperatures (Order of magnitude)	1000 to 2000 °C	~1000 °C	100 to 300 °C	~ 100 °C
Heating rates (Order of magnitude)	50 to 100 °C/sec	1 to 20 °C/sec	25°C/hr to 50 °C/min	< 20 °C/hr

Figure 22: Thermal threat categorization.

CONCLUSIONS

This study and the associated historical events assessment was an efficient way to identify recommendations to further improve the STANAG 4382. These recommendations are being discussed with AC/326 SG/B who has already chartered a working group to review and update the STANAG. The working group has already reviewed the survey results. According to the new requirements in the NATO documentation, the technical content of the STANAG will be migrated into an AOP.

ACKNOWLEDGEMENT

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