NORTH ATLANTIC TREATY ORGANIZATION
ORGANISATION DU TRAITÉ DE L'ATLANTIQUE NORD

# NATO IM PORTFOLIO UPDATE W/ FOCUS ON THE INSENSITIVE MUNITIONS – HAZARD CLASSIFICATION (IM-HC) HARMONIZATION EFFORT & POTENTIAL IMPACT ON THE DDESB COMMUNITY (E.G. UN ORANGE BOOK, US TB700-2, ETC.)

## (International Explosives Safety Summit (IESSE)

Jan 21-23, 2026
Phoenix, Arizona
Phoenix Convention Center

NATO IM CWG Chair
*Daniel J. Pudlak*

# Preface

- <u>Recall my presentations this morning regarding:</u>

"Implementation of Improved 'Metrics' & 'Method' for Hazardous Fragment Evaluation for Both IM & HC Purposes"

...which discussed the:

- ✓ Mathematical Corrections & Improvements to the Hazardous Fragment Energy Curves (8J, 20J & 79J) originally found in TB700-2 (and adopted by IM community).
- ✓ New / Proposed 'Energy-Density' Methodology, which provides more accurate scientific evaluation of fragment hazardousness, rather than legacy 'Energy' method.

  - **<u>Purpose</u>** - To inform HC / Safety Community of these improvements, and for consideration of adoption.

# Preface

- Similarly, purpose of this presentation is to inform the HC / Safety community of the:
  - Improvements made to the NATO IM Standards which improve the IM Evaluation Process;
  - Harmonization Effort which harmonizes IM & HC standards;
    - ✓ Improving the efficiency in which munition safety test data is obtained & utilized
    - ✓ Reduces overall costs for harmonized IM-FHC testing
    - ✓ Better informs the decision-making process due to Whole Body of Evidence (WBE)
      - **WBE** – Provides both IM & HC Authority Panels (and stakeholders) with more comprehensive evaluation of munition's safety, enabling better decision-making.

# IM-HC HARMONIZATION EFFORT
## - *Purpose & Goals* -

- ✓ **Purpose** – To harmonize the 'Munition Safety-Related Evaluation Tests & Criteria' that are common amongst the NATO community.

- ✓ **Goal** - To identify the 'Munition Safety-Related Evaluation Tests & Criteria' that are common amongst the NATO community and develop a standardized 'Harmonized Test Plan' that entails the details (e.g. requirements, criteria, configurations, aim-points, threat rates/velocities/etc.) of how to test harmoniously, in a consistent manner, for all laboratories of all NATO member nations.

# IM-HC HARMONIZATION EFFORT
## - *Benefits* -

- **Reduce Cost**
  - Primary Goal (50%)
  - Secondary Goal (25%)
- **Reduce Time**
  - Primary Goal (50%)
  - Secondary Goal (25%)
- **Reduce Risk**
  - Wartime Risk Reductions
    - Off-Shore Sales
    - Sharing Munition
  - RDT&E Programmatic Risk Reduction
    - COVID-19 Pandemic
    - Ukraine-Russia War
    - Long-Range Weapons Requirements
  - Production / Acquisition Risk Reduction
  - Logistical & Operational Risk Reduction

# IM-HC HARMONIZATION EFFORT
# - *Progression* -

## NATO IM Portfolio Progression that led to IM-HC Harmonization

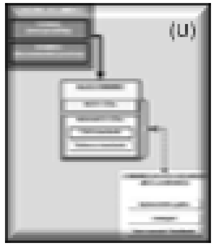
2010
- **NATO IM Portfolio Structural Revision**
  - Created new AOPs (Requirements Document)
  - Revised STANAGs (Policy Document)
  - Created SRD (Guidance Document)
- **Creation of AOPs from STANAGs**
  - 8 new documents (6 Test AOPs, Overarching AOP-39 & associated SRD):
    - AOP-39, AOP-39.1, AOP-4240, AOP-4241, AOP-4382, AOP-4396, AOP-4496, AOP-4526
  - Created Annex M (Document Modification History)

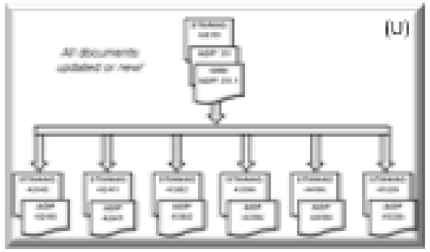
2019
- **Revision of entire NATO IM Portfolio**
  - ✓ All 8 new AOPs Promulgated in 2021-2022
    - ✓ Improved: Consistency, Accuracy, Relevancy, Readability and Clarity compared to first iterations of AOPs & old STANAGs
    - ✓ Created new tool/matrix that simplified revision of portfolio with multiple documents

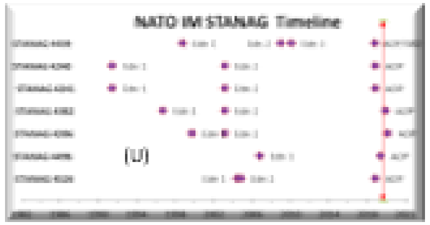
2021
- **Harmonization of IM-HC-S3**

2022
  - Currently revising AOP-39
    - New Custodian – Franck Dupuis (FRA)
    - Incorporate latest changes to portfolio, ensure relevancy & reduce redundancy
  - New Overarching AOP-4864 under development
    - New Chair/Custodian – Daniel Pudlak (USA)
    - Harmonize IM, HC, S3, etc.
    - Reduces cost, schedule, test assets required
    - Incorporate risk assessment

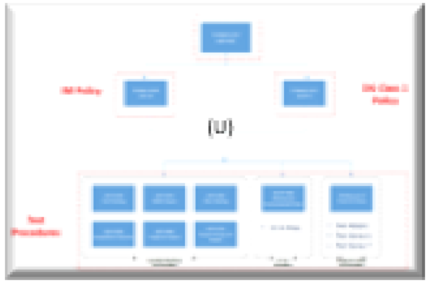
2025



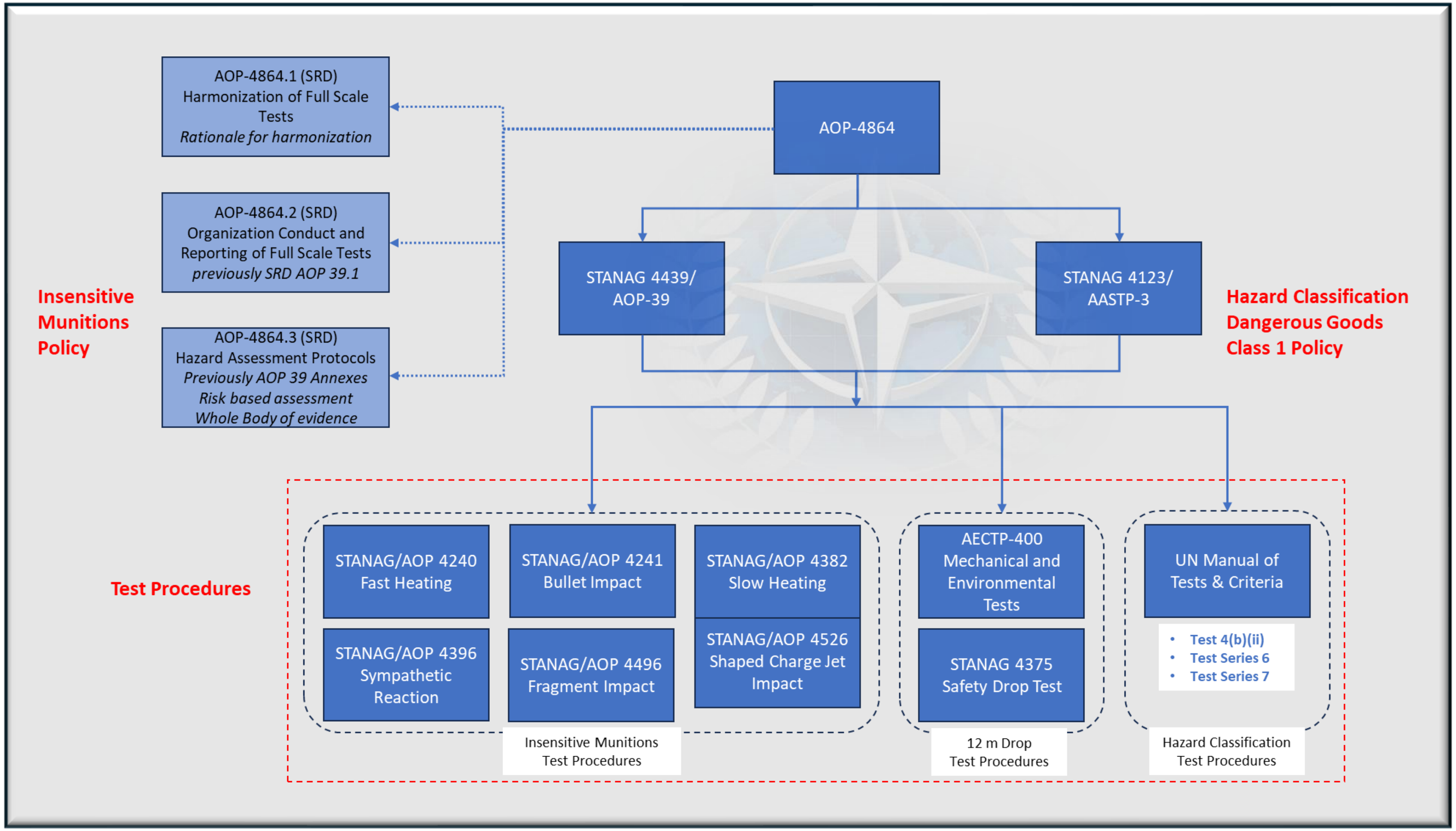







# IM-HC HARMONIZATION EFFORT

## - *New Portfolio Structure* -



# IM-HC HARMONIZATION EFFORT
## *- Harmonizable Tests -*

- **AOP-39 (IM Testing)**
  - STANAG/AOP 4240 (Fast Heating)
  - STANAG/AOP 4241 (Bullet Impact)
  - STANAG/AOP 4382 (Slow Heating)
  - STANAG/AOP 4396 (Sympathetic Reaction)
  - STANAG/AOP 4496 (Fragment Impact)
  - *STANAG/AOP 4526 (Shaped Charge Jet Impact)

- **UN Manual of Tests & Criteria (Orange Book)**
  - Test 4(b)(ii)
  - Test Series 6
  - Test Series 7

- **AECTP-400**
  - Mechanical Environmental Tests
    - 12m Drop
    - *…anything else?*

*Since SCJI is not currently a HC requirement, the initial AOP-4864 draft will not include it. However, future revision will include SCJI test, as discussion with HC Liaisons indicate that IM test results from SCJI tests are shared/used by HC SMEs, and they concur that this data should be included in HC assessment.

# AOP-4864

## *- Chapter 1 - Highlights -*

- **AOP-4864 Highlights** - This AOP serves as the policy document, and follows the same format as the recently revised AOPs, including the same/similar chapters, sections, sub-sections, and appendices.

- **Chapter 1:**

  - **AIM**:  The aim discusses the purpose and benefits of harmonizing IM & HC..

  - **Scope**:  The scope discusses the different disciplines of IM, HC & S3, and their similarities and differences.  It also enforces the need to apply this methodology at the 'earliest stages of munition design, as well as thorough the lifecycle of the munition.

  - **General**:  This section discusses the 'integrated approach towards the data acquisition and evidence to support IM scoring and HC assessments', and how it ensures efficient use of test assets and material resources, maximizing the availability of data and evidence to support these assessments.

# AOP-4864

## *- Chapter 2 - Highlights -*

- **AOP-4864 Highlights** - This AOP serves as the policy document, and follows the same format as the recently revised AOPs, including the same/similar chapters, sections, sub-sections, and appendices.

- **Chapter 2:**

  - **Overview** – Discusses that 'There is a certain amount of overlap and gaps between the threat environments and testing requirements of these disciplines', and how this harmonized approach ensure the best possible use of the info and resources.

  - **Table 1** – Includes 'Relevant UN Classification Procedures & Test Methods, and the NATO Test Methods Producing Similar Environments'.

  - **Sections 2.2 & 2.3** - Calls out the test requirements (by documents), and provide an overview of the Harmonized Approach, noting that the test set-up, configurations, etc. should be in accordance with the Threat Hazard Assessment (THA), etc. Finally, a comment is made, noting the prioritization with respect to importance of IM scoring / HC assessment

# AOP-4864.1 (SRD)
# *- Highlights -*

- **AOP-4864.1 (SRD) Highlights** – The SRD serves as the guidance document for the AOP, providing sufficient details to successfully execute a harmonized IM, HC & S3 suite of tests.

- **Chapter 1:** The content in the sections of Chapter 1 is similar to AOP-4864, providing guidance on how to execute a harmonious test series.

- **Chapters 2-6**: Each subsequent chapter discusses the details of the how to harmonize each of the 5 IM tests that are possible to harmonize with HC. Each individual section describes the details, provides considerations, and summarizes the best 'Methods' described in the respective IM test that enables harmonious testing, and satisfies both requirements, for IM & HC purposes.

  - The following is the guidance for the best methods to use to achieve harmonization:
    - ✓ **Chapter 2 (Fast Heating)** – To harmonize, use either AOP-4240 Method 1.
    - ✓ **Chapter 3 (Sympathetic Reaction)** – To harmonize, follow AOP-4396 with a few modifications to satisfy the UN Manual of Test requirements.
    - ✓ **Chapter 4 (Bullet Impact) -** To harmonize the test set-up, the guidance in AOP-4241 Method 1 should be followed, with the addition that the test item should be secured in a holding device capable of restraining the item against dislodgement by the projectiles as required by UN test series 7(d): substance and 7(j): article or component.
    - ✓ **Chapter 5 (Slow Heating) -** To harmonize use AOP-4382 Test Method 3.
    - ✓ **Chapter 6 (Fragment Impact) -** To harmonize Fragment Impact (FI) threat can be harmonized by using test Method 1 of AOP-4496.

  - More detailed harmonization guidance, for each individual test, can be found in each respective chapter, including guidance on test set-up, configurations, metrics, etc.

# AOP-4864
# - *Related Documents* -

**Related Documents:**

| | |
|---|---|
| **SRD AOP-4864.1** | **Guidance on the Harmonization of Full-Scale Tests** |
| **SRD AOP-4864.2** | Guidance on the Organization, Conduct and Reporting of Full Scale Tests |
| **SRD AOP-4864.3** | Process for Evaluating Hazards |
| **STANAG 4439 / AOP-39** | Policy for Introduction and Assessment of Insensitive Munitions (IM) |
| **STANAG / AOP-4240** | Fast Heating Test Procedures for Munitions |
| **STANAG / AOP-4241** | Bullet Impact Test Procedures for Munitions |
| **STANAG / AOP-4382** | Slow Heating Test Procedures for Munitions |
| **STANAG / AOP-4396** | Sympathetic Reaction Test Procedures for Munitions |
| **STANAG / AOP-4496** | Fragment Impact Test Procedures for Munitions |
| **STANAG 4123 / AASTP-03** | Hazard Classification of Military Ammunition and Explosives |
| **STANAG 4297 / AOP-15** | Guidance on the Assessment of the Safety and Suitability for Service of Non-Nuclear Munitions for NATO Armed Forces |
| **United Nation ST/SG/AC.10/11** | Manual of Tests and Criteria |
| **STANAG AOP - 4375** | Safety Drop Test for Munitions |

# AOP-4864

# *- Related Documents -*

Future Portfolio Including **Affected / Associated Documents:**

| STANAG-4864 | Policy and Methods to Assess the Response to Extreme but Credible Threats |
|---|---|
| AOP-4864 | Policy and Methods to Assess the Response to Extreme but Credible Threats |
| AOP-4864.1 (SRD) | Guidance on the Harmonization of Full-Scale Tests |
| AOP-4864.2 (SRD) | Guidance on the Organization, Conduct and Reporting of Full Scale Tests |
| AOP-4864.3 (SRD) | Process for Evaluating Hazards |
| AOP-4864.4 (SRD) | Whole Body of Evidence |
| AOP-4864.5 (SRD) | Risk Assessment |
| STANAG 4439 | Policy for Introduction and Assessment of Insensitive Munitions (IM) – Policy Document |
| STANAG / AOP-4240 | Fast Heating Test Procedures for Munitions |
| STANAG / AOP-4241 | Bullet Impact Test Procedures for Munitions |
| STANAG / AOP-4382 | Slow Heating Test Procedures for Munitions |
| STANAG / AOP-4396 | Sympathetic Reaction Test Procedures for Munitions |
| STANAG / AOP-4496 | Fragment Impact Test Procedures for Munitions |
| STANAG / AOP-4526 | Shaped Charge Jet Impact Test Procedures for Munitions |
| AOP-39 | Policy for Introduction and Assessment of Insensitive Munitions (IM) – Requirements Document |
| STANAG 4123 | Hazard Classification of Military Ammunition and Explosives – Policy Document |
| AASTP-03 | Hazard Classification of Military Ammunition and Explosives – Requirements Document |
| **United Nation ST/SG/AC.10/11** | **Manual of Tests and Criteria (New Test Series 7)** |
| **STANAG 4297 / AOP-15** | **Guidance on the Assessment of the S & S & S of Non-Nuclear Munitions for NATO Armed Forces** |

# AOP-4864.3 Hazard Protocols (SRD)
# - *Highlights* -

❖ **AOP-4864.3 Highlights** - This SRD serves as a guidance document, providing protocols for hazard assessment that were previously found in the Annexes of AOP-39.1.

❑ **Chapter 1:**

- **AIM**: The aim discusses a series of hazard assessment protocols which can be used to assess the response of a munition to certain extreme but credible threats.
- **Examples of these protocols:**

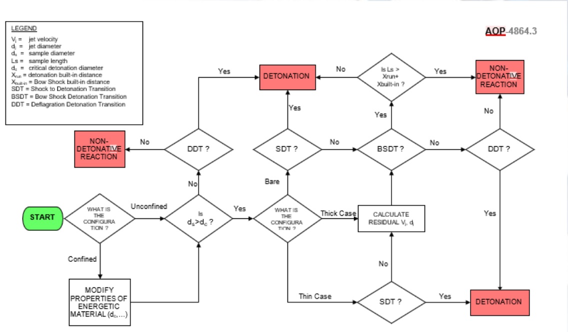



Figure 13: Shaped Charge Jet Impact Hazard Protocol – Solid Energetic Materials Branch (Part 2)

5-5 Edition A Version 1

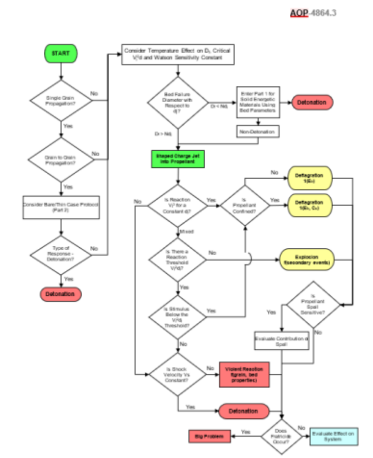



Figure 14: SCJ Impact Protocol – Propellant Beds Branch (Part 3)

5-6 Edition A Version 1

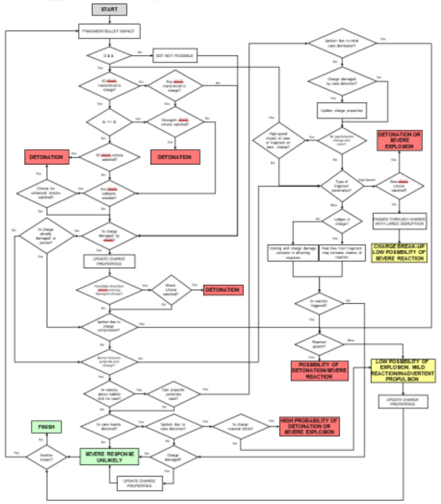



Figure 4: Detailed Hazard Protocol – Bullet / Fragment Impact

# AOP-4864.4 WBE (Future SRD)
## *- Highlights -*

- **AOP-4864.4 Highlights** - This new SRD will serve a guidance document for the new 'Whole Body of Evidence' methodology, and improved Risk Assessment.

- **Chapter 1:**
  - **AIM**: The aim will be to provide a list of approved methodologies (tests, methods, analyses, models) that can aid in developing a Whole Body of Evidence that supports the process of evaluating munition safety, and further aids in the assessment of risk.
  - **Whole Body of Evidence**: This is still TBD, but initial list includes:
    - Small-scale testing;
    - Component-level testing;
    - FEA / Numerical Modeling;
    - Incorporation of new / additional instrumentation (e.g. witness plates/screens) to increase data acquisition to mitigate unknowns (e.g. fragment debris trajectories).
  - **Risk Assessment**: This is still TBD, but the following is an example of one methodology:
    - High-Fidelity IM Scoring Methodology (High-FIMSM)

# Whole Body of Evidence

NATO IM-HC CWG spent many meetings discussing what the WBE:

- Is
- Does
- Should look like on paper (AOP/SRD)

....and how it should be used

During the process of developing AOP-4864, and its associated SRD, discovered much of it was already created by our fore-fathers (NIMIC/MSIAC) back in the 1980’s.

# AOP-4864.3 Description of 'Whole Body of Evidence'

## 1.6 GENERAL

### 1.6.1 Introduction

1. Full-scale testing involves small statistical samples that may not provide adequate confidence in the likely response of a munition. To address the problems of full-scale testing, and to increase confidence in IM assessments, a detailed understanding of the reactive behavior of energetic materials is required along with an understanding of their interaction with hazard stimuli in conjunction with hardware characteristics and full-scale configurations. The evidence required to support response predictions can be determined by analyzing the initiation and reaction mechanisms that the various stimuli are known to induce in the energetic materials.

2. A hazard assessment protocol is an ordered procedure that results in a flow chart directing the user through the evaluation of a hazard area. Once a threat stimulus has been identified and quantified, hazard protocols identify the response "paths" that this stimulus is likely to instigate and must, therefore be considered, and also the information required in order to perform an assessment of the hazard. Since such an assessment is based on a logical process and is conducted for a munition in a real environment, subject to real threats, it will have more value than the results of a small number of go/no- go full-scale hazard tests.

3. Each protocol consists of a decision tree flow chart that examines the science of successive events in the hazard/munition interaction. In this way, it characterizes the stimulus, then its interaction with the munition, and finally the response of the munition. Each box (decision point) in the flow chart identifies the information required, and in what order, to make a decision and follow the process to the next box. In the simplest terms, then, a hazard assessment protocol is nothing more than an orderly process for viewing the hazard areas, and defining what information is needed to assess the response of munitions to those hazards.

### 1.6.2 Context

1. Traditional methods of hazard analysis depend on standard go/no-go or pass/fail tests, and the experience and judgment of cognizant individuals. Inevitably, this approach places emphasis on large scale tests of major components or the full-scale munition. Such full-scale tests have several disadvantages. They contribute very little to the understanding of the fundamental mechanisms occurring in each hazardous situation. They are extremely costly and hence only a few are undertaken. Interpretation of their results is complicated by the problems associated with the statistical probability of an inadvertent reaction with the small number of tests which are conducted. The test design is for a "pass", with the response giving no indication of how far the stimulus is from conditions that could induce a very different response. There is no guarantee that you will see all the possible response mechanisms.

2. Limiting the assessment process to some standard pass/fail test may reduce time and costs, but there is no guarantee that the test represents the range of munition + environment + stimuli that the munition is likely to see. There is little mechanistic understanding involved that would allow the response of the munition to some other combination of environment and stimuli to be predicted (in terms of both initiation and output). The probabilistic nature of hazard occurrence is an issue. For example, if the probability of seeing an explosion is one in a thousand, the probability of seeing an explosion in two tests is 0.02%. In fact, it would take 2,944 tests to be 95% certain of seeing one explosion. So, while pass/fail tests are appealing in a simplistic sense – it either passed or failed – they do not provide a useful predictive capability, or a worthwhile degree of assurance to National Authorities that their results represent the true IM level of a munition. Confidence can be increased by using other methods.

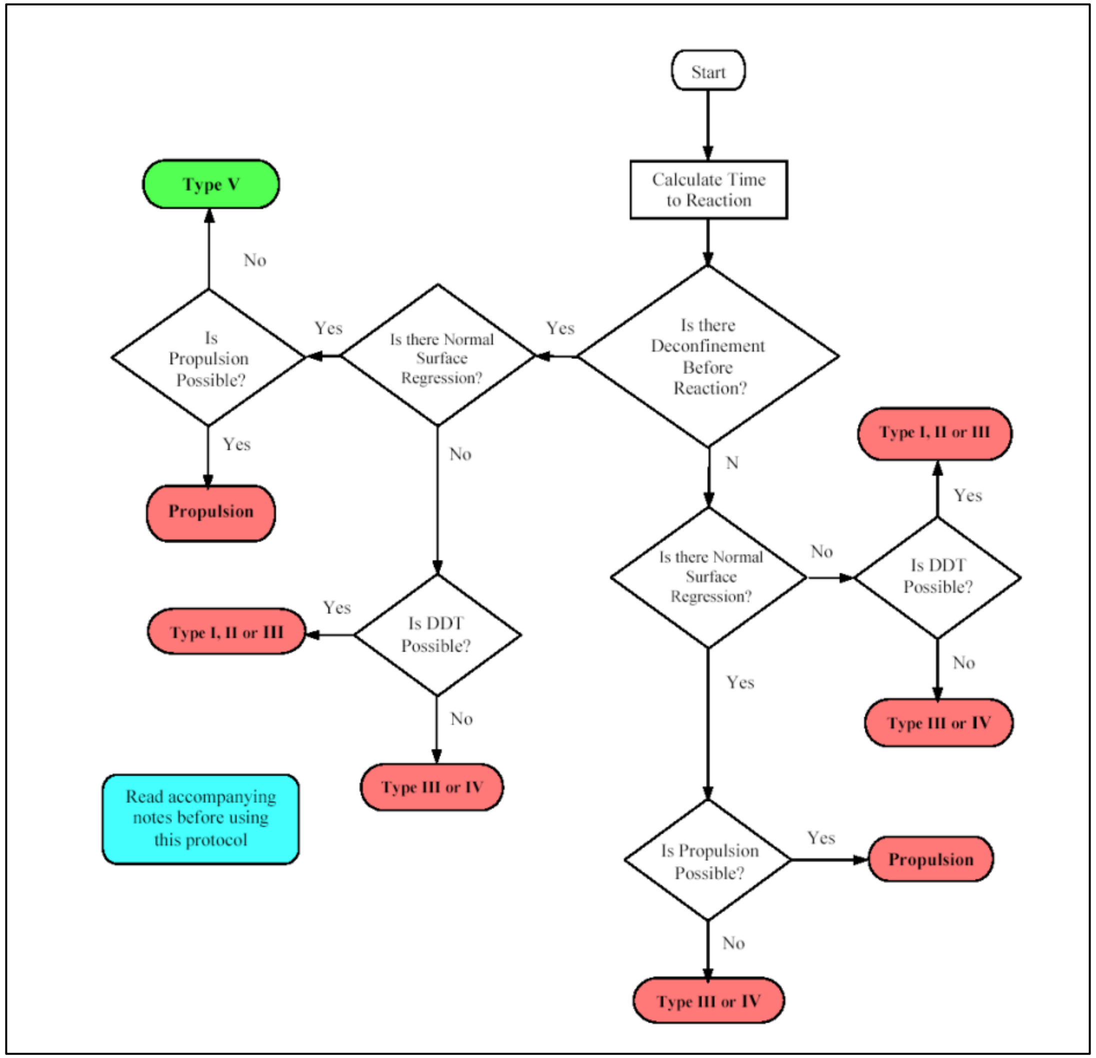
3. A need for some full-scale tests will probably always exist; to confirm the reaction level prediction or where no better techniques exist. However, in developing this methodology it is anticipated that substantial munition design and development and assessment can occur based on the results of laboratory and small-scale tests, theoretical analyses and numerical modelling. Significantly fewer full- scale tests will be required for confirmation of the methodology's predictions.

### 1.6.3 Background

4. The Technical Cooperation Program (TTCP) Conventional Weapons Action Group 11 (WAG-11) was formed in a climate where it was felt by the international community of technical experts that the mechanistic understanding of the phenomena involved in energetic materials hazard assessment had advanced to the point where a science based methodology was possible. The detailed protocols presented here are primarily the output of the WAG-11 programme that ran from 1987 to 1994.

5. From the beginning, it was recognized that in outlining such a methodology, in addition to the benefits described above, areas of technical deficiency would be clearly identified for future research, and that the protocols would need to be continually updated as new knowledge emerged. They were passed to the NATO Insensitive Munitions Information Center (NIMIC, now MSIAC) in 1995, and this organization has continued to update and extend their scope and relevance, holding a series of workshops to tap the collective expertise of the international technical community. The simplified protocols and lists of relevant tests and techniques are largely the product of these workshops.

# Hazard Protocol Example from AOP-4864.3




***Note similarity to Hazard Classification processes / protocols...**

# Tables from AOP-4864.3

Table 1: Examples of tools available and data required to analyse fast / slow heating reaction paths.

| Key Factors / Reaction Mechanisms | Tools for Analysis | Properties Required |
|---|---|---|
| Time to ignition | Thermochemical Limits Test (TLT)<br>Ignition Temperature Test<br>Unconfined Thermal Ignition Test<br>One Dimensional Time to Explosion (ODTX)<br>Differential Scanning Calorimetry (DSC)<br>Thermogravimetric Analysis (TGA)<br>Accelerated Reaction Calorimetry (ARC)<br>Reactive Heat Flow Models | Kinetics and thermochemistry of EM Decomposition as a function of temperature and pressure<br>Thermal properties of munitions EM<br>Thermal properties of munitions inert individual components<br>Extrapolation of the above to munition full size dimensions<br>Detailed munitions design<br>Damage dependency |
| Effect of Confinement on Energetic Material Reaction | Thermo Analytical Techniques<br>Finite Elements Analysis Models<br>Computational Fluid Dynamics Models<br>Effect of Confinement on EM Reaction<br>Variable Confinement Cook-off Test (VCCT)<br>Tube Test (Fast/Slow Heating Versions)<br>Hot Cell<br>Pyrolysis Test<br>Scaled Thermal Explosion eXperiment (STEX) | Mechanical physical and thermal properties of munitions EM<br>Mechanical physical and thermal properties of munitions individual inert components<br>Mechanical physical and thermal properties of munitions assembly and packaging<br>Kinetics and thermochemistry of EM Decomposition as a function of temperature and pressure<br>Mechanical and thermal properties of case, liner and EM<br>Extrapolation to munitions full size dimensions<br>Detailed munitions design |
| Burning | Closed Bomb (and Variations of)<br>Strand Burner<br>DSC | Mechanical physical and thermal properties of munitions EM<br>Burning rate as a function of temperature and pressure<br>Damage Dependency |
| Deflagration to Detonation Transition (DDT) | Tube Test, Internal Ignition Version<br>UN Test Series 5<br>Hybrid Combustion Bomb<br>Closed Bomb<br>Run-to-detonation Distance (of Damaged Material)<br>Critical Diameter<br>Dynamic Case Resistance | Mechanical physical and thermal properties of munitions EM<br>Burning rate as a function of temperature and pressure<br>Damage dependency |
| Violence of Response | dP/dt Information<br>Case Fragmentation Models | Burning rate as a function of temperature and pressure |
| Propulsion | Closed Bomb<br>Strand Burner<br>Ballistic Models | Burning rate<br>Detailed munitions design |

AOP-4864.3

Table 2: Examples of tests that can be used to generate the data required in Table 1.

| Data Required | Properties | Test to be Carried Out | General Points |
|---|---|---|---|
| Kinetics and thermo chemistry of EM physical changes or decomposition | Porosity | - Density Measurements | - Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |
| | Pore size | - Refractive Matching Fluid<br>- Atomic Force Microscopy<br>- Scanning Electron Microscopy (SEM) | |
| | Particle size | - Microsonic Techniques | |
| | Crystal quality | - SEM<br>- Microscopical Techniques<br>- X-ray Diffraction<br>- Density measurement test | |
| | Chemical reaction rate | - Adiabatic bomb calorimeter<br>- Thermo analytical techniques:<br>- Differential Scanning Calorimetry (DSC)<br>- Dynamic Mechanical Thermal Analysis (DTMA)<br>- Thermo Mechanical Analysis (TMA)<br>- Thermo Gravimetric Analysis (TGA)<br>- Differential Thermal Analysis (DTA)<br>- Dilatometry | |
| Burning rate | Burn rate (Undamaged and damaged material) | - Strand burner<br>- Closed bomb<br>- Hybrid combustion bomb | - Over a suitable temperature, pressure dimensions and geometries range including ones resulting from mechanical or/and thermal damages<br>- Not measured routinely |
| | Friability: Propensity to fracture/damage | - Shotgun test (Friability test)<br>- Bullet damage test<br>- Hopkinson bar<br>- Failure modulus test<br>- Taylor impact test<br>- Fracture toughness | |
| | Damage Characterisation | - Sectioning microscopy<br>- X-Ray tomography<br>- Closed bomb (Surface area)<br>- Neutron and X-Ray diffraction<br>- Coefficient of Thermal Expansion | - Highly dependent on damage characteristics<br>- Fractures<br>- Porosity<br>- Dewetting |
| Mechanical physical and thermal properties of munitions individual inert components | | - Thermal expansion measurements<br>- Thermo analytical techniques<br>- Differential Scanning Calorimetry (DSC)<br>- Dynamic Mechanical Thermal Analysis (DTMA)<br>- Thermo Mechanical Analysis (TMA)<br>- Thermo Gravimetric Analysis (TGA)<br>- Differential Thermal Analysis (DTA)<br>- Dilatometry<br>- Mechanical properties analysis<br>- Uniaxial Tensile/Compressive Testing (Low Strain Rates)<br>- Servohydraulic Mechanical Test (at rates from 1 to 500 /s) | Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |
| Thermal physical and mechanical properties of munitions EM | | - Same as in Mechanical physical and thermal properties of munitions individual inert components<br>- AOP-7 test category 102-02-xxx | Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |
| Mechanical physical and thermal properties of munitions assembly and packaging | | - Same as in Mechanical physical and thermal properties of munitions individual inert components<br>- Mechanical properties analysis<br>- Hopkinson Bar (at Rates from 100 to 104/s)<br>- Components bond strength<br>- AOP-7 Series 102.01 tests<br>- Compatibility test in an environment representative of IM tests | Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |
| Detailed munitions design | | - Technical Data Package<br>- X-Ray<br>- Munitions disassembly | - Geometry and physical size<br>- Loading density<br>- External confinement<br>- Gas tightness<br>- Free volume<br>- Casing type |

# Many of these tests look familiar? Same tests as Orange Book.

Table 1: Examples of tools available and data required to analyse fast / slow heating reaction paths.

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| Violence of Response | dP/dt Information<br>Case Fragmentation Models | Burning rate ... pressure |
| Propulsion | Closed Bomb<br>Strand Burner<br>Ballistic Models | Burning rate<br>Detailed munitions design |

AOP-4864.3

Table 2: Examples of tests that can be used to generate the data required in Table 1.

| Data Required | Properties | Test to be Carried Out | General Points |
|---|---|---|---|
| Kinetics and thermo chemistry of EM physical changes or decomposition | Porosity | - Density Measurements | - Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |
| | Pore size | - Refractive Matching Fluid<br>- Atomic Force Microscopy<br>- Scanning Electron Microscopy (SEM) | |
| | Particle size | - Microsonic Techniques | |
| | Crystal quality | - SEM<br>- Microscopical Techniques<br>- X-ray Diffraction<br>- Density measurement test | |
| | Chemical reaction rate | - Adiabatic bomb calorimeter<br>- Thermo analytical techniques:<br>- Differential Scanning Calorimetry (DSC)<br>- Dynamic Mechanical Thermal Analysis (DTMA)<br>- Thermo Mechanical Analysis (TMA)<br>- Thermo Gravimetric Analysis (TGA)<br>- Differential Thermal Analysis (DTA)<br>- Dilatometry | |
| Burning rate | Burn rate (Undamaged and damaged material) | - Strand burner<br>- Closed bomb<br>- Hybrid combustion bomb | - Over a suitable temperature, pressure dimensions and geometries range including ones resulting from mechanical or/and thermal damages<br>- Not measured routinely |
| | Friability: Propensity to fracture/damage | - Shotgun test (Friability test)<br>- Bullet damage test<br>- Hopkinson bar<br>- Failure modulus test<br>- Taylor impact test<br>- Fracture toughness | |


| Burning rate | Burn rate (Undamaged and damaged material) | - Strand burner<br>- Closed bomb<br>- Hybrid combustion bomb |
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| Data Required | Properties | Test to be Carried Out | General Points |
|---|---|---|---|
| | Damage Characterisation | - Sectioning microscopy<br>- X-Ray tomography<br>- Closed bomb (Surface area)<br>- Neutron and X-Ray diffraction<br>- Coefficient of Thermal Expansion | - Highly dependent on damage characteristics<br>- Fractures<br>- Porosity<br>- Dewetting |
| Mechanical physical and thermal properties of munitions individual inert components | | - Thermal expansion measurements<br>- Thermo analytical techniques<br>- Differential Scanning Calorimetry (DSC)<br>- Dynamic Mechanical Thermal Analysis (DTMA)<br>- Thermo Mechanical Analysis (TMA)<br>- Thermo Gravimetric Analysis (TGA)<br>- Differential Thermal Analysis (DTA)<br>... ve Testing (Low ...<br>... est (at rates from 1 ... | Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |
| ... al and thermal ... inert components | | | Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |

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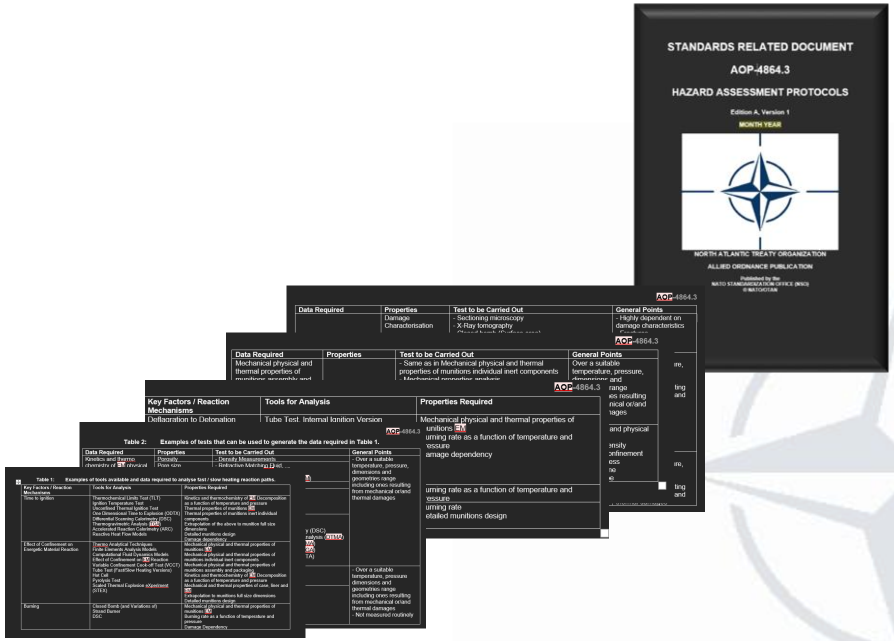
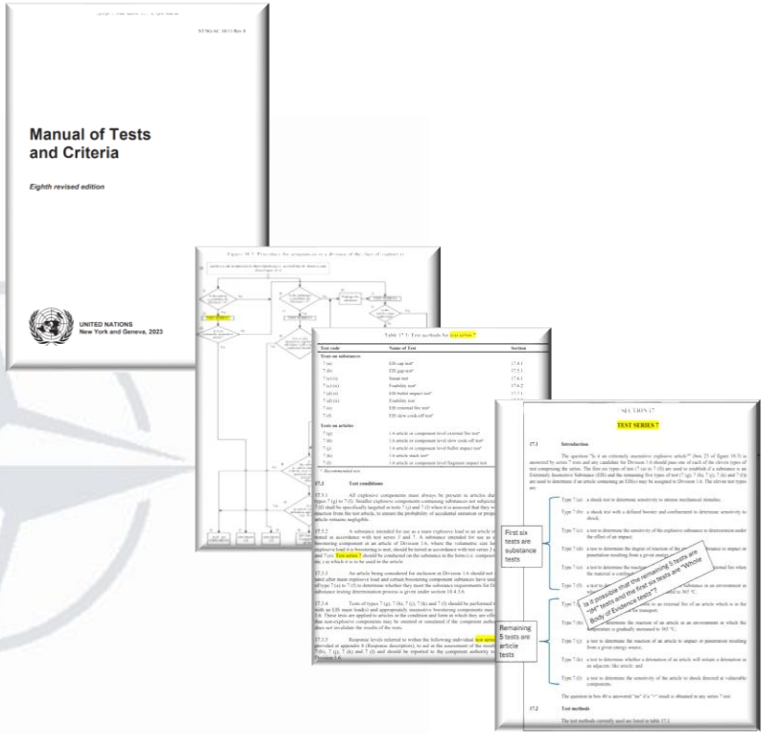
| Data Required | Properties | Test to be Carried Out | General Points |
|---|---|---|---|
| Mechanical physical and thermal properties of munitions assembly and packaging | | - Same as in Mechanical physical and thermal properties of munitions individual inert components<br>- Mechanical properties analysis<br>- Hopkinson Bar (at Rates from 100 to 104/s)<br>- Components bond strength<br>- AOP-7 Series 102.01 tests<br>- Compatibility test in an environment representative of IM tests | Over a suitable temperature, pressure, dimensions and geometries range including ones resulting from mechanical or/and thermal damages |
| Detailed munitions design | | - Technical Data Package<br>- X-Ray<br>- Munitions disassembly | - Geometry and physical size<br>- Loading density<br>- External confinement<br>- Gas tightness<br>- Free volume<br>- Casing type |

# Comparing AOP-39 to Orange book



# SECTION 17

## TEST SERIES 7

### 17.1 Introduction

The question "Is it an extremely insensitive explosive article?" (box 23 of figure 10.3) is answered by series 7 tests and any candidate for Division 1.6 should pass one of each of the eleven types of test comprising the series. The first six types of test (7 (a) to 7 (f)) are used to establish if a substance is an Extremely Insensitive Substance (EIS) and the remaining five types of test (7 (g), 7 (h), 7 (j), 7 (k) and 7 (l)) are used to determine if an article containing an EIS(s) may be assigned to Division 1.6. The eleven test types are:

Type 7 (a): a shock test to determine sensitivity to intense mechanical stimulus;

Type 7 (b): a shock test with a defined booster and confinement to determine sensitivity to shock;

Type 7 (c): a test to determine the sensitivity of the explosive substance to deterioration under the effect of an impact;

Type 7 (d): a test to determine the degree of reaction of the explosive substance to impact or penetration resulting from a given energy source;

Type 7 (e): a test to determine the reaction of the explosive substance to an external fire when the material is confined;

Type 7 (f): a test to determine the reaction of the explosive substance in an environment in which the temperature is gradually increased to 365 °C;

Type 7 (g): a test to determine the reaction to an external fire of an article which is in the condition as presented for transport;

Type 7 (h): a test to determine the reaction of an article in an environment in which the temperature is gradually increased to 365 °C;

Type 7 (j): a test to determine the reaction of an article to impact or penetration resulting from a given energy source;

Type 7 (k): a test to determine whether a detonation of an article will initiate a detonation in an adjacent, like article; and

Type 7 (l): a test to determine the sensitivity of the article to shock directed at vulnerable components.

The question in box 40 is answered "no" if a "+" result is obtained in any series 7 test.

### 17.2 Test methods

The test methods currently used are listed in table 17.1.

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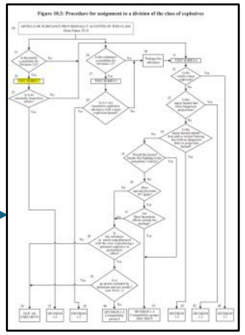

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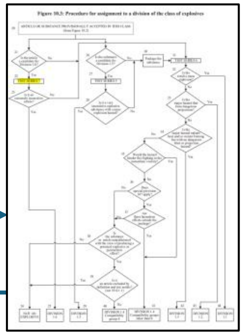
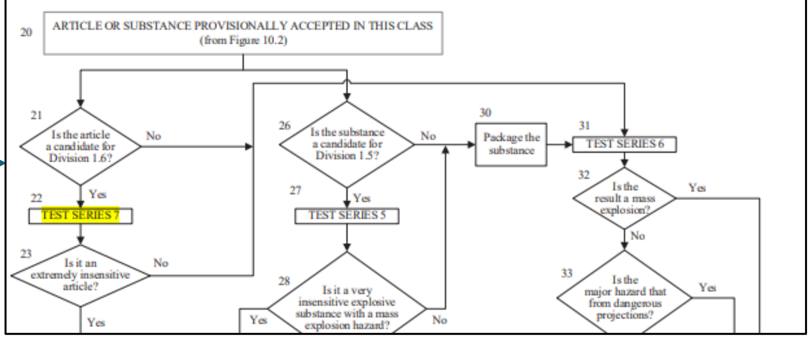


**Figure 10.3: Procedure for assignment to a division of the class of explosives**



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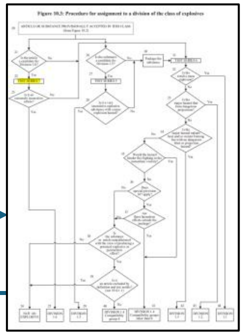

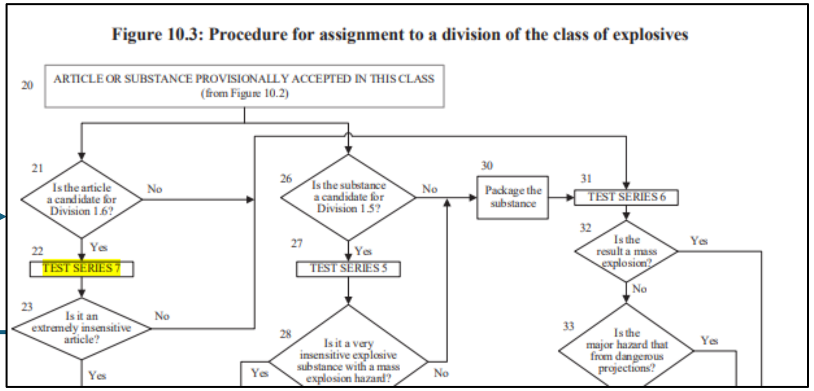


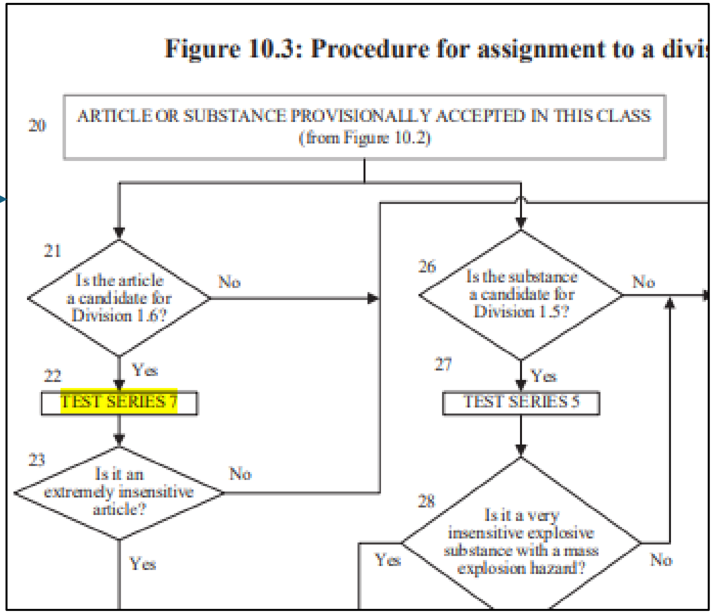

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**First six tests are substance tests**

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Type 7 (f): a test to determine the reaction of the explosive substance in an environment in which the temperature is gradually increased to 365 °C;

**Remaining 5 tests are article tests**

Type 7 (g): a test to determine the reaction to an external fire of an article which is in the condition as presented for transport;

Type 7 (h): a test to determine the reaction of an article in an environment in which the temperature is gradually increased to 365 °C;

Type 7 (j): a test to determine the reaction of an article to impact or penetration resulting from a given energy source;

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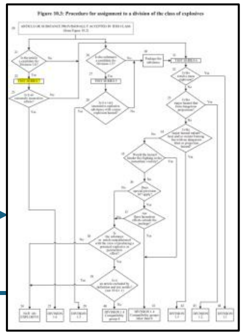

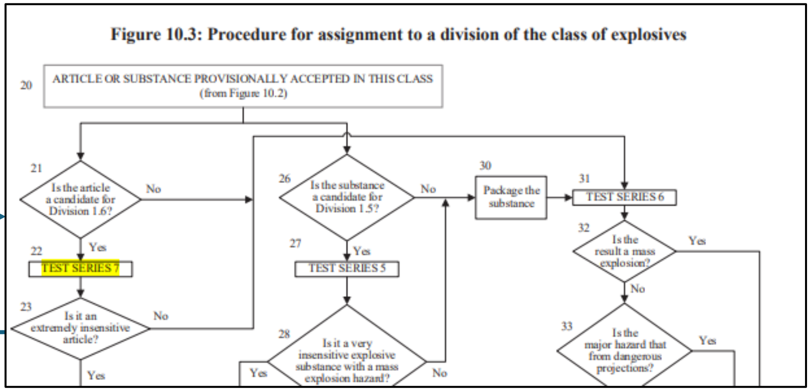


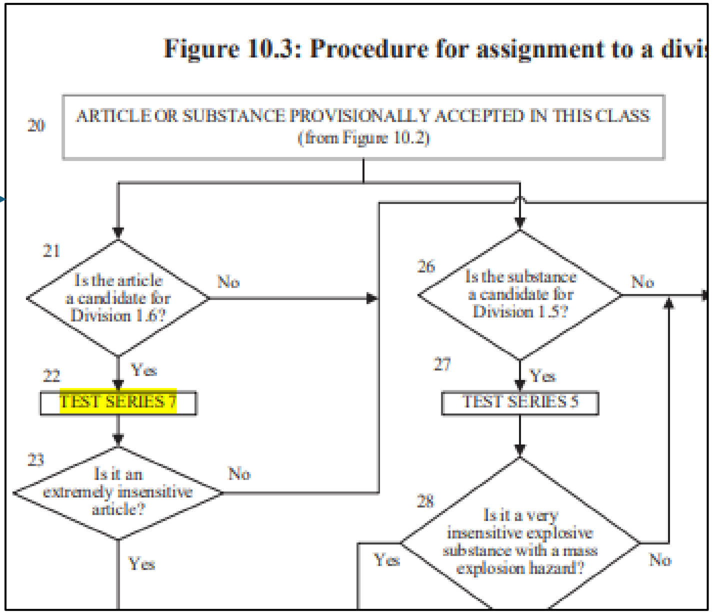

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Type 7 (f): a test … stance in an environment in … to 365 °C;

**Remaining 5 tests are article tests**

Typ… to an external fire of an article which is in the … transport;

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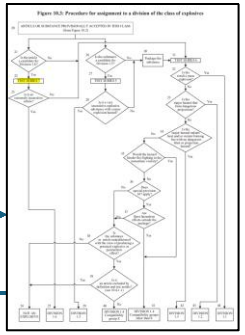
The question in box 40 is answered "no" if a "+" result is obtained in any series 7 test.

**Is it possible that the remaining 5 tests are "IM" tests and the first six tests are "Whole Body of Evidence tests"?**

### 17.2 Test methods

The test methods currently used are listed in table 17.1.



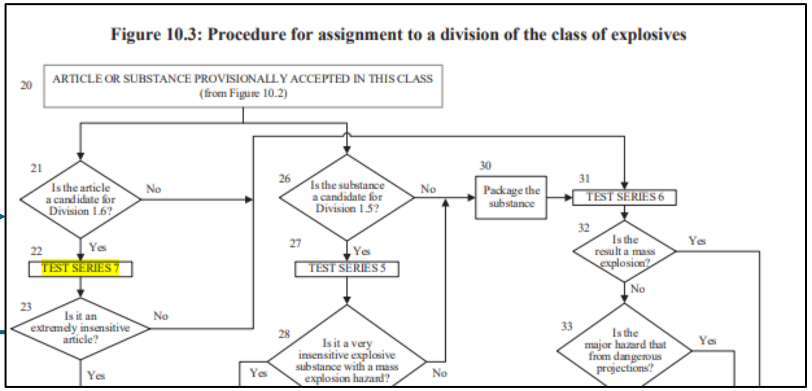


Figure 10.3: Procedure for assignment to a division of the class of explosives

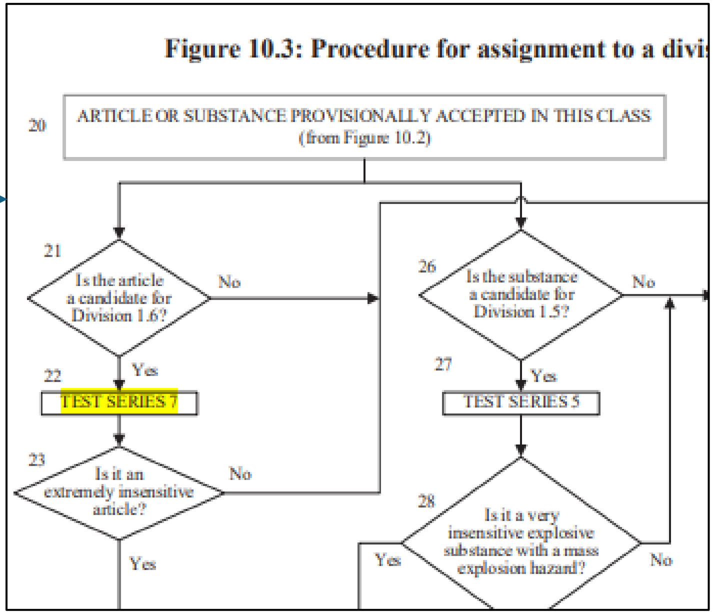


Figure 10.3: Procedure for assignment to a divi

**Table 17.1: Test methods for test series 7**

| Test code | Name of Test | Section |
|---|---|---|
| **Tests on substances** | | |
| 7 (a) | EIS cap test[a] | 17.4.1 |
| 7 (b) | EIS gap test[a] | 17.5.1 |
| 7 (c) (i) | Susan test | 17.6.1 |
| 7 (c) (ii) | Friability test[a] | 17.6.2 |
| 7 (d) (i) | EIS bullet impact test[a] | 17.7.1 |
| 7 (d) (ii) | Friability test | 17.7.2 |
| 7 (e) | EIS external fire test[a] | 17.8.1 |
| 7 (f) | EIS slow cook-off test[a] | 17.9.1 |
| **Tests on articles** | | |
| 7 (g) | 1.6 article or component level external fire test[a] | 17.10.1 |
| 7 (h) | 1.6 article or component level slow cook-off test[a] | 17.11.1 |
| 7 (j) | 1.6 article or component level bullet impact test[a] | 17.12.1 |
| 7 (k) | 1.6 article stack test[a] | 17.13.1 |
| 7 (l) | 1.6 article or component level fragment impact test | 17.14.1 |

[a] *Recommended test.*

## 17.3 Test conditions

17.3.1 All explosive components must always be present in articles during Series 7 testing of types 7 (g) to 7 (l). Smaller explosive components containing substances not subjected to tests of type 7 (a) to 7 (f) shall be specifically targeted in tests 7 (j) and 7 (l) when it is assessed that they will cause the most severe reaction from the test article, to ensure the probability of accidental initiation or propagation of a Division 1.6 article remains negligible.

17.3.2 A substance intended for use as a main explosive load in an article of Division 1.6 should be tested in accordance with test series 3 and 7. A substance intended for use as a larger (dimensionally) boostering component in an article of Division 1.6, where the volumetric size limit relative to the main explosive load it is boostering is met, should be tested in accordance with test series 3 and tests of type 7 (c) (ii) and 7 (e). Test series 7 should be conducted on the substance in the form (i.e. composition, granulation, density etc.) in which it is to be used in the article.

17.3.3 An article being considered for inclusion in Division 1.6 should not undergo Series 7 testing until after main explosive load and certain boostering component subtances have undergone appropriate tests of type 7 (a) to 7 (f) to determine whether they meet the substance requirements for Division 1.6. Guidance on substance testing determination process is given under section 10.4.3.6.

17.3.4 Tests of types 7 (g), 7 (h), 7 (j), 7 (k) and 7 (l) should be performed to determine if an article with an EIS main load(s) and appropriately insensitive boostering components may be assigned to Division 1.6. These tests are applied to articles in the condition and form in which they are offered for transport, except that non-explosive components may be omitted or simulated if the competent authority is satisfied that this does not invalidate the results of the tests.

17.3.5 Response levels referred to within the following individual test series 7 test prescriptions are provided at appendix 8 (Response descriptors), to aid in the assessment of the results of tests of types 7 (g), 7 (h), 7 (j), 7 (k) and 7 (l) and should be reported to the competent authority to support assignment to Division 1.6.

Cap Test

**17.4 Series 7 type (a) test prescription**

***17.4.1 Test 7 (a): EIS cap test***

17.4.1.1 *Introduction*

This shock test is designed to determine the sensitivity of an EIS candidate to intense mechanical stimulus.

17.4.1.2 *Apparatus and materials*

The experimental set-up for this test is the same as for test 5 (a) (see 15.4.1).

17.4.1.3 *Procedure*

The experimental procedure is the same as for test 5 (a) (see 15.4.1).

17.4.1.4 *Test criteria and method of assessing results*

The result is considered "+" and the substance should not be classified as an EIS if in any trial:

(a) The witness plate is torn or otherwise penetrated (i.e. light is visible through the plate) - bulges, cracks or folds in the witness plate do not indicate cap sensitivity; or

(b) The centre of the lead cylinder is compressed from its initial length by an amount of 3.2 mm or more.

Otherwise, the result is considered "-".

17.4.1.5 *Examples of results*

| Substance | Result |
|---|---|
| HMX/inert binder (86/14), cast | - |
| HMX/energetic binder (80/20), cast | + |
| HMX/aluminium/energetic binder (51/19/14), cast | - |
| RDX/TNT (60/40), cast | + |
| TATB/Kel-F (95/5), pressed | - |

# Gap Test

**17.5 Series 7 type (b) test prescription**

***17.5.1 Test 7 (b): EIS gap test***

17.5.1.1 *Introduction*

This test is used to measure the sensitivity of an EIS candidate to a specified shock level, i.e. a specified donor charge and gap.

17.5.1.2 *Apparatus and materials*

The set-up for this test consists of an explosive charge (donor), a barrier (gap), a container holding the test charge (acceptor), and a steel witness plate (target).

The following materials are to be used:

(a) United Nations Standard detonator or equivalent;

(b) 95 mm diameter by 95 mm long pellet with a density of 1 600 $kg/m^3$ ± 50 $kg/m^3$ of either 50/50 pentolite or 95/5 RDX/WAX;

(c) Tubing, steel, seamless, with an outer diameter of 95 ± 7.0 mm, a wall thickness of 9.75 mm ± 2.75 mm and an inner diameter of 73.0 mm ± 7.0 mm and with a length of 280 mm;

(d) Sample substances, machined to a diameter which is just under the diameter of the steel tubing. The air gap between the sample and tubing wall should be as small as possible;

(e) Polymethyl methacrylate (PMMA) rod, of 95 mm diameter by 70 mm long;

(f) Mild steel plate, 200 mm × 200 mm × 20 mm;

(g) Wood block, 95 mm diameter and 25 mm thick, with a hole drilled through the centre to hold the detonator.

17.5.1.3 *Procedure*

17.5.1.3.1 As shown in figure 17.5.1.1, the detonator, donor, gap and acceptor charge are coaxially aligned above the centre of the witness plate. A 1.6 mm air gap is maintained between the free end of the acceptor charge and the witness plate with suitable spacers which do not overlap the acceptor charge. Care should be taken to ensure good contact between the detonator and donor, donor and gap and gap and acceptor charge. The test sample and booster should be at ambient temperature for the test.

17.5.1.3.2 To assist in collecting the remains of the witness plate, the whole assembly may be mounted over a container of water with at least a 10 cm air gap between the surface of the water and the bottom surface of the witness plate which should be supported along two edges only.

17.5.1.3.3 Alternative collection methods may be used but it is important to allow sufficient free space below the witness plate so as not to impede plate puncture. The test is performed three times unless a positive result is observed earlier.

17.5.1.4 *Test criteria and method of assessing results*

A clean hole punched through the plate indicates that a detonation was initiated in the sample. A substance which detonates in any trial is not an EIS and the result is noted as "+".

## Susan Impact Test

**17.6 Series 7 type (c) test prescriptions**

**17.6.1 *Test 7 (c) (i): Susan impact test***

17.6.1.1 *Introduction*

The Susan Impact test is used to assess the degree of explosive reaction under conditions of high velocity impact. The test is conducted by loading the explosives into standardised projectiles and firing the projectiles against a target at a specified velocity.

17.6.1.2 *Apparatus and materials*

17.6.1.2.1 51 mm diameter, 102 mm long explosives billets, fabricated by normal techniques, are employed.

17.6.1.2.2 The Susan test employs the test vehicle shown in figure 17.6.1.1. The projectile has an assembled weight of 5.4 kg and contains slightly less than 0.45 kg of explosive. The overall dimensions are 81.3 mm in diameter by 220 mm long.

17.6.1.2.3 The projectiles are fired from a 81.3 mm smooth-bore gun. The gun muzzle is positioned about 4.65 m from the 64 mm thick, smooth-surface, armour steel target plate. Projectile impact velocity is obtained by adjusting the propellant charges in the gun.

17.6.1.2.4 A schematic drawing of the firing range showing the target-gun layout and the relative positions of the diagnostic equipment is shown in figure 17.6.1.2. The flight path is about 1.2 m above ground level.

17.6.1.2.5 The test site is equipped with calibrated blast gauges and recording equipment. The air blast recording system should have a system frequency response of at least 20 kHz. Measurements are made of impact velocities and air shock blast over-pressure. Air blast is measured at a distance of 3.05 m from the impact point (gauges (C) in figure 17.6.1.2).

17.6.1.3 *Procedure*

17.6.1.3.1 The propellant charge in the gun should be adjusted to produce a projectile velocity of 333 m/s. The projectile is fired and the impact velocity and air blast, produced as a result of its reaction on impact, are recorded. If a velocity of 333 m/s (+10 %, -0 %) is not obtained, the amount of propellant is adjusted and the test repeated.

17.6.1.3.2 Once an impact velocity of 333 m/s is obtained, the test is repeated until accurate pressure-time records are obtained from at least five separate shots. On each of these accurate shots, the impact velocity should be 333 m/s (+10 %, -0 %).

17.6.1.4 *Test criteria and method of assessing results*

The maximum air blast overpressure that is determined from each air blast is recorded. The average of the maximum pressures obtained from the five accurate shots is determined. If the average pressure obtained by such a procedure is greater than or equal to 27 kPa, then the substance is not an EIS explosive and the result is noted as "+".

**Friability Test**

**17.6.2 *Test 7 (c) (ii): Friability test***

17.6.2.1 *Introduction*

The friability test is used to establish the tendency of a compact EIS candidate to deteriorate dangerously under the effect of an impact.

17.6.2.2 *Apparatus and materials*

The following apparatus is required:

(a) A weapon designed to shoot 18 mm diameter cylindrical test pieces at a velocity of 150 m/s;

(b) A Z30C 13 stainless steel plate, 20 mm thick with a front face roughness of 3.2 microns (AFNOR NF E 05-015 and NF E 05-016 standards);

(c) A 108 ± 0.5 $cm^3$ manometric bomb at 20 °C;

(d) A firing capsule containing a heating wire on 0.5 g of black powder with a mean particle size of 0.75 mm. The composition of the black powder is 74 % potassium nitrate, 10.5 % sulphur and 15.5 % carbon. The moisture content should be less than 1 %;

(e) A cylindrical sample of compact substance of diameter 18 ± 0.1 mm. The length is adjusted so as to obtain a mass of 9.0 ± 0.1 g. The sample is brought to and maintained at a temperature of 20 °C;

(f) A fragment recovery box.

17.6.2.3 *Procedure*

17.6.2.3.1 The sample is projected against the steel plate at an initial velocity sufficient to give an impact velocity as close as possible to 150 m/s. The mass of fragments collected after the impact should be at least 8.8 g. These fragments are fired in a manometric bomb. Three tests are carried out.

17.6.2.3.2 The curve of pressure against time p = f (t) is recorded; this enables the curve (dp/dt) = f' (t) to be constructed. From this curve the maximum value $(dp/dt)_{max}$ is read off. This enables the value $(dp/dt)_{max}$, corresponding to an impact speed of 150 m/s, to be estimated.

17.6.2.4 *Test criteria and method of assessing results*

If the average maximum $(dp/dt)_{max}$ value obtained at a speed of 150 m/s is greater than 15 MPa/ms, the substance tested is not an EIS and the result is noted as "+".

17.6.2.5 *Examples of results*

| Substance | Result |
|---|---|
| HMX/inert binder (86/14), cast | - |
| HMX/energetic binder (80/20), cast | + |
| HMX/aluminium/energetic binder (51/19/14), cast | - |
| RDX/TNT (60/40), cast | + |
| TATB/Kel-F (95/5), pressed | - |

**Bullet Impact Test**

**17.7 Series 7 type (d) test prescriptions**

***17.7.1 Test 7 (d) (i): EIS bullet impact test***

17.7.1.1 *Introduction*

The bullet impact test is used to evaluate the response of an EIS candidate to the kinetic energy transfer associated with impact and penetration of a given energy source, i.e. a 12.7 mm projectile, travelling at a specified velocity.

17.7.1.2 *Apparatus and materials*

17.7.1.2.1 Explosive test samples fabricated by normal techniques are employed. The samples should have a length of 20 cm and a diameter to allow a close fit into a seamless steel pipe having an inside diameter of 45 mm (± 10 % variation), a wall thickness of 4 mm (± 10 % variation) and a length of 200 mm. The pipes are closed with steel or cast iron end caps, at least as strong as the tube, torqued to 204 Nm.

17.7.1.2.2 The bullet is a standard 12.7 mm armour-piercing bullet with a projectile mass of 0.046 kg, and is fired at the service velocity of about 840 ± 40 m per second from a 12.7 mm gun.

17.7.1.3 *Procedure*

17.7.1.3.1 A minimum of six test articles (explosive substance in a capped steel pipe) should be fabricated for the tests.

17.7.1.3.2 Each test article is positioned on a suitable pedestal at a convenient distance from the muzzle of the gun. Each test article must be secured in a holding device upon its pedestal. This device must be capable of restraining the item against dislodgement by the bullet.

17.7.1.3.3 A test consists of the firing of one projectile into each test item. There should be at least three tests with the test article oriented such that its long axis is perpendicular to the line of flight (i.e. impact through the side of the pipe). There should also be at least three tests with the test article oriented such that its long axis is parallel to the line of flight (i.e. impact through the end cap).

17.7.1.3.4 The remains of the test container are collected. Complete fragmentation of the container is indicative of explosion or detonation.

17.7.1.4 *Test criteria and method of assessing results*

A substance which explodes or detonates in any trial is not an EIS and the result is noted as "+".

17.7.1.5 *Examples of results*

| Substance | Result |
|---|---|
| HMX/inert binder (86/14), cast | - |
| HMX/energetic binder (80/20), cast | + |
| HMX/aluminium/energetic binder (51/19/14), cast | - |
| RDX/TNT (60/40), cast | + |
| TATB/Kel-F (95/5), pressed | - |

Slow Fragment Impact Test?

**17.7.2 *Test 7 (d) (ii): Friability test***

17.7.2.1 *Introduction*

The friability test is used to evaluate the response of an EIS candidate to the kinetic energy transfer associated with impact and penetration of a given energy source travelling at a specified velocity.

17.7.2.2 *Apparatus and materials*

The following apparatus is required:

(a) A weapon designed to shoot 18 mm diameter cylindrical test pieces at a velocity of 150 m/s;

(b) A Z30C 13 stainless steel plate, 20 mm thick with a front face roughness of 3.2 microns (AFNOR NF E 05-015 and NF E 05-016 standards);

(c) A 108 ± 0.5 $cm^3$ manometric bomb at 20 °C;

(d) A firing capsule containing a heating wire on 0.5 g of black powder with a mean particle size of 0.75 mm. The composition of the black powder is 74 % potassium nitrate, 10.5 % sulphur and 15.5 % carbon. The moisture content should be less than 1 %;

(e) A cylindrical sample of compact substance of diameter 18 ± 0.1 mm. The length is adjusted so as to obtain a mass of 9.0 ± 0.1 g. The sample is brought to and maintained at a temperature of 20 °C;

(f) A fragment recovery box.

17.7.2.3 *Procedure*

17.7.2.3.1 The sample is projected against the steel plate at an initial velocity sufficient to give an impact velocity as close as possible to 150 m/s. The mass of fragments collected after the impact should be at least 8.8 g. These fragments are fired in a manometric bomb. Three tests are carried out.

17.7.2.3.2 The curve of pressure against time p = f (t) is recorded; this enables the curve (dp/dt) = f' (t) to be constructed. From this curve the maximum value $(dp/dt)_{max}$ is read off. This enables the value $(dp/dt)_{max}$, corresponding to an impact speed of 150 m/s, to be estimated.

17.7.2.4 *Test criteria and method of assessing results*

If the average maximum $(dp/dt)_{max}$ value obtained at a speed of 150 m/s is greater than 15 MPa/ms, the substance tested is not an EIS and the result is noted as "+".

17.7.2.5 *Examples of results*

| Substance | Result |
|---|---|
| HMX/inert binder (86/14), cast | - |
| HMX/energetic binder (80/20), cast | + |
| HMX/aluminium/energetic binder (51/19/14), cast | - |
| RDX/TNT (60/40), cast | + |
| TATB/Kel-F (95/5), pressed | - |

Fast Heating Test (Operational Configuration)

**17.8 Series 7 type (e) test prescription**

**17.8.1 *Test 7 (e): EIS external fire test***

17.8.1.1 *Introduction*

The external fire test is used to determine the reaction of an EIS candidate to external fire when it is confined.

17.8.1.2 *Apparatus and materials*

Explosive test samples fabricated by normal techniques are employed. The samples should have a length of 20 cm and a diameter to allow a close fit into a seamless steel pipe having an inside diameter of 45 mm (± 10 % variation), a wall thickness of 4 mm (± 10 % variation) and a length of 200 mm. The pipes are closed with steel or cast iron end caps, at least as strong as the tube, torqued to 204 Nm.

17.8.1.3 *Procedure*

17.8.1.3.1 The experimental procedure is the same as for test 6 (c) (see 16.6.1.3) except as noted in paragraph 17.8.1.3.2 below.

17.8.1.3.2 The test is conducted as:

(a) One fire engulfing fifteen confined samples, stacked in three adjacent piles of two samples banded on top of three samples; or

(b) Three fires in which five samples are laid out horizontally and banded together.

Colour photographs are taken to document the condition of the samples after each test. Cratering and the size and location of confining pipe fragments are documented as an indication of the degree of reaction.

17.8.1.4 *Test criteria and method of assessing results*

An explosive substance which detonates or reacts violently with fragments thrown more than 15 m is not an EIS and the result is noted as "+".

17.8.1.5 *Examples of results*

| Substance | Result |
|---|---|
| HMX/inert binder (86/14), cast | - |
| HMX/inert binder (85/15), cast | - |
| HMX/energetic binder (80/20), cast | + |
| HMX/aluminium/energetic binder (51/19/14), cast | - |
| RDX/inert binder (85/15), cast | + |
| RDX/TNT (60/40), cast | + |
| TATB/Kel-F (95/5), pressed | - |

Slow Heating Test

**17.9 Series 7 type (f) test prescription**

**17.9.1 *Test 7 (f): EIS slow cook-off test***

17.9.1.1 *Introduction*

This test is used to determine the reaction of an EIS candidate to a gradually increasing thermal environment and to find the temperature at which reaction occurs.

17.9.1.2 *Apparatus and materials*

17.9.1.2.1 Explosive test samples fabricated by normal techniques are employed. The samples should have a length of 200 mm and a diameter to allow a close fit into a seamless steel pipe having an inside diameter of 45 mm (± 10 % variation), a wall thickness of 4 mm (± 10 % variation) and a length of 200 mm. The pipes are closed with steel or cast iron end caps, at least as strong as the tube, torqued to 204 Nm.

17.9.1.2.2 The sample assembly is placed in an oven which provides a controlled thermal environment over a 40 °C to 365 °C temperature range and can increase the temperature of the surrounding oven atmosphere at the rate of 3.3 °C per hour throughout the temperature operating range and ensure, by circulation or other means, a uniform thermal environment to the item under test.

17.9.1.2.3 Temperature recording devices are used to monitor temperature at 10 minute or less intervals; continuous monitoring is preferred. Instrumentation with an accuracy of ± 2 per cent over the test temperature range is used to measure the temperature of:

(a) The air within the oven; and

(b) The exterior surface of the steel pipe.

17.9.1.3 *Procedure*

17.9.1.3.1 The test item is subjected to a gradually increasing air temperature at a rate of 3.3 °C per hour until reaction occurs. The test may begin with the test item pre-conditioned to 55 °C below the anticipated reaction temperature. The onset temperature at which the sample temperature exceeds the oven temperature should be recorded.

17.9.1.3.2 After the completion of each test, the pipe or any fragments of pipe are recovered in the test area and examined for evidence of violent explosive reaction. Colour photographs may be taken to document the condition of the unit and the test equipment before and after the test. Cratering, and the size and location of any fragments, may also be documented as indications of the degree of reaction.

17.9.1.3.3 Three tests are conducted for each candidate substance unless a positive result is observed earlier.

17.9.1.4 *Test criteria and method of assessing results*

A substance which detonates or reacts violently (fragmentation of one or two end caps and fragmentation of the tube into more than three pieces) is not considered an EIS and the result is noted as "+".

17.9.1.5 *Examples of results*

| Substance | Result |
|---|---|
| HMX/inert binder (86/14), cast | - |
| HMX/energetic binder (80/20), cast | + |
| RDX/TNT (60/40), cast | + |
| TATB/Kel-F (95/5), pressed | - |

**Fast Heating Test (Logistical Configuration)**

**17.10 Series 7 type (g) test prescription**

***17.10.1 Test 7 (g): 1.6 article or component level external fire test***

17.10.1.1 *Introduction*

The external fire test is used to determine the reaction of a possible Division 1.6 article to external fire as presented for transport.

17.10.1.2 *Apparatus and materials*

The experimental set-up for this test is the same as for test 6 (c) (see 16.6.1.2).

17.10.1.3 *Procedure*

17.10.1.3.1 The experimental procedure for this test is the same as for test 6 (c) (see 16.6.1.3), except that, if the volume of single item exceeds 0.15 $m^3$, only one item is required.

17.10.1.3.2 Colour still photographs are taken to document the condition of the test item and the test equipment before and after the test. Explosive substance remains, fragmentation, blast, projections, cratering, witness screen damage, and thrust are documented as an indication of the article's response level.

17.10.1.3.3 Colour video for the duration of each trial can be vital to assessment of response. In sitting the camera(s), it is important to ensure that the field of view will not be obstructed by any of the test facilities or instrumentation and that the field of view will include all necessary information.

17.10.1.3.4 To classify complex articles containing multiple EIS main explosive loads, external fire testing at the individual main load component level should be conducted to fully characterise the article's response level.

17.10.1.4 *Test criteria and method of assessing results*

If there is a response level more severe than burning as outlined in appendix 8, the result is noted as "+" and the items are not classified as Division 1.6 articles.

Slow Heating Test

### 17.11 Series 7 type (h) test prescription

#### 17.11.1 *Test 7 (h): 1.6 article or component level slow cook-off test*

17.11.1.1 *Introduction*

This test is used to determine the reaction of a candidate Division 1.6 article to a gradually increasing thermal environment and to find the temperature at which reaction occurs.

17.11.1.2 *Apparatus and materials*

17.11.1.2.1 The test equipment consists of an oven which provides a controlled thermal environment over a 40 °C to 365 °C temperature range and can increase the temperature of the surrounding oven atmosphere at the rate of 3.3 °C per hour throughout the temperature operating range, minimize hot spots, and ensure (by circulation or other means) a uniform thermal environment to the item under test. Secondary reactions (such as those caused by exudate and explosive gases contacting the heating devices) invalidate the test, but these can be avoided by providing a sealed inner container to surround bare articles. A means of relief should be provided for the increased air pressure generated during the test due to heating.

17.11.1.2.2 Temperature recording devices (permanent record types) are used to monitor temperature continuously or, at least, every 10 minutes. Instrumentation with an accuracy of ± 2 % over the test temperature range is used to measure the temperature at:

(a) The atmosphere air gap adjacent to the unit under test; and

(b) The exterior surface of the unit.

17.11.1.3 *Procedure*

17.11.1.3.1 The test item is subjected to a gradually increasing, at a rate of 3.3 °C per hour, air temperature until unit reaction occurs. The test may begin with the test item pre-conditioned to 55 °C below the predicted reaction temperature. Temperatures and elapsed test time are measured and recorded.

17.11.1.3.2 Colour still photographs are taken to document the condition of the test item and the test equipment before and after the test. Explosive substance remains, fragmentation, blast, projections, cratering, witness plate damage, and thrust are documented as an indication of the article's response level. Colour video for the duration of each trial can be vital to assessment of response. In sitting the camera(s), it is important to ensure that the field of view will not be obstructed by any of the test facilities or instrumentation and that the field of view will include all necessary information.

17.11.1.3.3 The test is conducted twice unless a positive result is obtained earlier. To classify complex articles containing multiple EIS main explosive loads, slow cook-off testing at the individual main load component level should be conducted to fully characterise the article's response level.

17.11.1.4 *Test criteria and method of assessing results*

If there is a response level more severe than burning as outlined in appendix 8, the result is noted as "+" and the items are not classified as Division 1.6 articles.

Bullet Impact Test

17.12 **Series 7 type (j) test prescription**

17.12.1 ***Test 7 (j): 1.6 article or component level bullet impact test***

17.12.1.1 *Introduction*

The bullet impact test is used to evaluate the response of a candidate Division 1.6 article to the kinetic energy transfer associated with the impact and penetration by a given energy source.

17.12.1.2 *Apparatus and materials*

Three 12.7 mm gun are used to fire service 12.7 mm armour-piercing ammunition with a projectile mass of 0.046 kg. Standard propellant loads may require adjustment to achieve projectile velocities within tolerance. The guns are fired by remote control and protected from fragment damage by firing through a hole in a heavy steel plate. The firing gun muzzle should be at a maximum range of at least 10 m from the test item to assure stabilization prior to impact, and at a maximum range of 30 m from the test item depending upon the explosive weight of the test item. The test item should be secured in a holding device capable of restraining the item against dislodgement by the projectiles.

17.12.1.3 *Procedure*

17.12.1.3.1 The candidate Division 1.6 article is subjected to a three-round burst fired at 840 ± 40 m/s velocity and 600 rounds/minute rate of fire. The test is repeated in three different orientations striking the test item in the most vulnerable areas as assessed by the competent authority These are areas for which an assessment of the explosive sensitivity (explosiveness and sensitiveness) combined with knowledge of the article design indicate the potential producing the most violent response level.

17.12.1.3.2 Colour still photographs are taken to document the condition of the test item and the test equipment before and after the test. Explosive substance remains, fragmentation, blast, projections, cratering, witness plate damage, and thrust are documented as an indication of the article's response level.

17.12.1.3.3 Colour video for the duration of each trial can be vital to assessment of response. In sitting the camera(s), it is important to ensure that the field of view will not be obstructed by any of the test facilities or instrumentation and that the field of view will include all necessary information.

17.12.1.3.4 To classify complex articles containing multiple EIS main explosive loads, bullet impact testing at the individual main load component level should be conducted to fully characterise the article's response level.

17.12.1.4 *Test criteria and method of assessing results*

If there is a response level more severe than burning as outlined in appendix 8, the result is noted as "+" and the items are not classified as Division 1.6 articles.

**Sympathetic Reaction Test**

**17.13 Series 7 type (k) test prescription**

**17.13.1 *Test 7 (k): 1.6 article stack test***

17.13.1.1 *Introduction*

This test is used to determine whether a detonation of a candidate Division 1.6 article, as offered for transport, will initiate a detonation in an adjacent, like article.

17.13.1.2 *Apparatus and materials*

The experimental set-up is the same as for test 6 (b) (see 16.5.1.2), with one trial conducted confined, and another unconfined. The test should only be conducted on detonable candidate Division 1.6 articles; the test 7 (k) article stack test is waived for non-detonable candidates for Division 1.6 (evidence is available to demonstrate that the article cannot support a detonation). Where the article is designed to provide a detonation output, the article's own means of initiation or a stimulus of similar power shall be used to initiate the donor. If the article is not designed to detonate but is capable of supporting a detonation, the donor shall be detonated using an initiation system selected to minimise the influence of its explosive effects on the acceptor article(s).

17.13.1.3 *Procedure*

The experimental set-up is the same as for test 6 (b) (see 16.5.1.3). The test is performed twice unless detonation of an acceptor is observed earlier. Colour still photographs are taken to document the condition of the test item and the test equipment before and after the test. Explosive substance remains, fragmentation, blast, projections, cratering, witness plate damage, and thrust are documented and used to assess whether or not any acceptor has detonated (including partially). Blast data may be used to supplement this decision. Colour video for the duration of each trial can be vital to assessment of response. In sitting the camera(s), it is important to ensure that the field of view will not be obstructed by any of the test facilities or instrumentation and that the field of view will include all necessary information. Comparing data from the two stack test trials to data from a single donor calibration shot, or to a calculated donor detonation pressure, can be useful in assessing the response level of acceptors.

17.13.1.4 *Test criteria and method of assessing results*

If detonation in the stack is propagated from the donor to an acceptor, the test result is noted as "+" and the article cannot be assigned to Division 1.6. Acceptor article response levels assessed as no reaction, burning, deflagration or explosion as outlined in appendix 8 are considered as negative results and noted as "-".

Fragment Impact Test (Logistical Configuration)

**17.14 Series 7 type (l) test prescription**

***17.14.1 Test 7 (l): 1.6 article or component level fragment impact test***

17.14.1.1 *Introduction*

This test is used to determine the response of an article in its transport configuration to a localised shock input representative of a fragment strike typical of that produced from a nearby detonating article.

17.14.1.2 *Apparatus and materials*

To reduce variability due to yaw, a gun system is recommended for firing a standard 18.6 g steel fragment in the shape of a right-circular cylinder with a conical nose, as detailed in figure 17.14.1, at a candidate Division 1.6 article. The distance between the firing device and the test item should ensure that the fragment is ballistically stable at impact. Barricades should protect the remote control gun system from the potential damaging effects of the test item's reaction.

17.14.1.3 *Procedure*

17.14.1.3.1 The test is repeated in two different orientations, striking the test item in the most vulnerable areas as assessed by the competent authority. These are areas for which an assessment of the explosive sensitivity (explosiveness and sensitiveness) combined with knowledge of the article design indicate the potential for producing the most violent response level. Typically, one test would be conducted targeting a non-EIS boostering component and the second test would target the centre of the main explosive load. The orientation of impact should generally be normal to the outer surface of the article. The fragment impact velocity should be 2530 ± 90 m/s.

17.14.1.3.2 Colour still photographs are taken to document the condition of the test item and the test equipment before and after the test. Explosive substance remains, fragmentation, blast, projections, cratering, witness plate damage, and thrust are documented as an indication of the article's response level.

17.14.1.3.3 Colour video for the duration of each trial can be vital to assessment of response. In sitting the camera(s), it is important to ensure that the field of view will not be obstructed by any of the test facilities or instrumentation and that the field of view will include all necessary information.

17.14.1.3.4 To classify complex articles containing multiple EIS main explosive loads, fragment impact testing at the individual main load component level should be conducted to fully characterise the article's response level.

17.14.1.4 *Test criteria and method of assessing results*

If there is a response level more severe than burning as outlined in appendix 8, the result is noted as "+" and the items are not classified as Division 1.6 articles.

# IM-HC HARMONIZATION EFFORT

## *- IM-HC-S3 Comparison Template -*

| Harmonized Tests | Detail | IM (Test) | UN (Test) | Safety (Test) | EQMB (Test) | Etc. (Test) |
|---|---|---|---|---|---|---|
| Requirements (e.g. Stimulus) | Temperature | Min, Max, Avg. | Min, Max, Avg. | Temperature | Min, Max, Avg. | |
| | X | | | X | | |
| Data Collection | Temperature | | | Temperature | | |
| | Pressure | | | Pressure | | |
| | Y | | | Y | | |
| Equipment Used | Pressure Gauges | | | Pressure Gauges | | |
| | Thermocouples | | | Thermocouples | | |
| | Z | | | Z | | |
| Test Set-Up | | | | | | |
| | | | | | | |
| Configurations | | | | | | |
| | | | | | | |

EXAMPLE

# Whole Body of Evidence (WBE) - Table

| Whole Body of Evidence | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test** | **Priority:** High, Medium, Low | Large Scale Gap Test (LSGT) | Burn to Violent Reaction (BVR) | Tube Test | Vented STEX | Modeling | Arena test | Witness plates (HC) | Thermal Test | VCCT | Other test ideas add here | | |
| **Nation** | | | | | | | | | | | | | |
| Austria | | | | | | | | | | | | | |
| Australia | | | | | | | | | | | | | |
| Belgium | | | | | | | | | | | | | |
| Canada | | | | | | | | | | | | | |
| Denmark | | | | | | | | | | | | | |
| Finland | | | | | | | | | | | | | |
| France | | | | | | | | | | | | | |
| Germany | | | | | | | | | | | | | |
| Netherlands | | | | | | | | | | | | | |
| Norway | | | | | | | | | | | | | |
| South Africa | | | | | | | | | | | | | |
| Sweden | | | | | | | | | | | | | |
| Turkiye | | | | | | | | | | | | | |
| United Kingdom | | | | | | | | | | | | | |
| United States | | | | | | | | | | | | | |

***<u>Simple table with just a list of tools</u>***

# Whole Body of Evidence (WBE) - Table

| Whole Body of Evidence | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Test** | **Priority:** High, Medium, Low | Large Scale Gap Test (LSGT) | Burn to Violent Reaction (BVR) | Tube Test | Vented STEX | Modeling | Arena test | Witness plates (HC) | Thermal Test | VCCT | Other test ideas add here | | | Test / Threat |
| **Nation** | | - | | | + | + | | | | + | | | | FH |
| Austria | | - | | | + | + | | | | + | | | | SH |
| Australia | | | | | | + | | | | | | | | BI |
| Belgium | | + | | | | + | | | | | | | | FI |
| Canada | | | | | | + | | | | | | | | SR |
| Denmark | | | | | | - | | | | | | | | SCJI |
| Finland | | | | | | | | | | | | | | |
| France | | AOP-LSGT | | | | | | | | | | | | |
| Germany | | | | | | | | | | | | | | |
| Netherlands | | | | | | | | | | | | | | |
| Norway | | | | | | | | | | | | | | |
| South Africa | | | | | | | | | | | | | | |
| Sweden | | | | | | | | | | | | | | |
| Turkiye | | | | | | | | | | | | | | |
| United Kingdom | | | | | | | | | | | | | | |
| United States | | | | | | | | | | | | | | |

Tube Test – Internal Ignition
Tube Test – FI
Tube Test – BI
Tube Test – SCO(A)
Tube Test – SCO (Electirc)
Tube Test – FCO (A)
Tube Test – FCO (Electric)
Arena Test
Fleurette Test

NATO IM-HC CWG working on this now.

# Conclusion

- Purpose of this presentation is to inform the HC / Safety community of the:
  - Improvements made to the NATO IM Standards which improve the IM Evaluation Process;
  - Harmonization Effort which harmonizes IM & HC standards;
    - ✓ Improving the efficiency in which munition safety test data is obtained & utilized
    - ✓ Reduces overall costs for harmonized IM-FHC testing
    - ✓ Better informs the decision-making process due to Whole Body of Evidence (WBE)
      - **WBE** – Provides both IM & HC Authority Panels (and stakeholders) with more comprehensive evaluation of munition's safety, enabling better decision-making.
  - Looking to further harmonize, where applicable.