NATO STANDARD

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SYMPATHETIC REACTION TEST PROCEDURES FOR MUNITIONS

Edition A, Version 1

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NORTH ATLANTIC TREATY ORGANIZATION

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NATO LETTER OF PROMULGATION

18 December 2020

1. The enclosed Allied Ordnance Publication AOP-4396, Edition A, Version 1, SYMPATHETIC REACTION TEST PROCEDURES FOR MUNITIONS, which has been approved by the nations in the CNAD AMMUNITION SAFETY GROUP (CASG – AC/326), is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 4396.

2. AOP-4396, Edition A, Version 1, is effective upon receipt.

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

for

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

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TABLE OF CONTENTS

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CHAPTER 1 INTRODUCTION

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

1.1 ANNEXES

A. Best Practices
B. Historical Overview

1.2 RELATED DOCUMENTS

STANAG 4439	Policy for Introduction and Assessment of Insensitive Munitions (IM)
AOP-39	Policy for Introduction and Assessment of Insensitive Munitions (IM)
SRD AOP-39.1	Guidance on the Organization, Conduct and Reporting of Full-scale Tests
STANAG 4396	Sympathetic Reaction Test Procedures for Munitions
AOP-4526	Shaped Charge Jet Test Procedure for Munitions
AASTP-03	Manual of NATO safety principles for the Hazard Classification of military ammunition and explosives
United Nations Document (UN)	Recommendation on the Transport of Dangerous Goods - Manual of Tests and Criteria.ST/SG/AC.10/11

1.3 AIM

The aim of this AOP is to specify the test requirements and procedures to provide evidence of the potential for munitions or weapon systems to sympathetically react to the worst-case credible reaction of an adjacent munition or weapon system.

1.4 DEFINITIONS

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

1.5 GENERAL

1. Effort to minimize the violence of a chain reaction event caused by sympathetic reactions of munitions is a continuing commitment of weapon designers and explosives safety practitioners to ensure that the safety of personnel and material will not be unduly jeopardized.

2. This Standard addresses the situation where munitions and weapon systems are positioned in close proximity to each other. In such conditions, a reacting munition (donor) may transmit blast, shock, thermal effects, fragments, or other debris, to other munitions (acceptors) in the vicinity. This can occur in peacetime as a result of an accident or as a result of hostile actions from a dissident/saboteur or enemy action. These events can result in a significant safety compromise.

3. The objective of the sympathetic reaction test is to determine the response of an acceptor test item(s) when exposed to the worst-case credible reaction of an identical donor test item. This test uses a worst-case credible configuration experienced in its life-cycle as defined in a THA. It is anticipated that the results of this test will be used to develop mitigation techniques to reduce the violence and consequences of reactions caused by accidents or hostile actions.

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

1.6 TEST LIMITATIONS

1. The sympathetic reaction tests are designed only to simulate the effects of the reaction of a munition on identical munitions in close proximity.

2. This document does not include the procedures for assessing the effects of the reactions of different types of munitions stored or placed in close proximity in storage, transportation or tactical (operational) use. If required, a suitable procedure could be developed from the procedure given in this Standard.

3. The test only represents a particular set of conditions as it is not possible to cater to the wide range of life-cycle configurations.

CHAPTER 2 TEST SPECIFICATIONS

2.1 TEST ITEM CONFIGURATION

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

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

2.2 TEST DETAILS

1. Test Methods

   a. If the donor munition is designed to detonate, initiate the donor munition(s) in the design mode. This may be done using plastic explosive to initiate the donor's booster or using electrical means to initiate the donor's detonator. It is essential that full detonation is achieved.

   b. For munitions that are not designed to detonate, initiate the donor munition(s) with a credible threat that produces a worst-case response (for example, a shaped charge jet as defined in AOP-4526, an explosive charge,-etc.). Credible threats and any deviations shall be approved by national authorities.

   Note: For munitions, especially small munitions tested in the packaged configuration, multiple munitions within the donor test item may be initiated together. This may be deemed a worst-case credible threat if identified by a THA and approved by national authorities.

2. Test Requirements

   a. The test configurations shall be based on the THA or other approved analysis methods, and likely to produce the worst-case response of the acceptor test items. The test shall have a sufficient number of live (donor and acceptor) test items to meet the minimum total volume requirement of 0.15 m^3 and provide adequate data for IM signature determination and HC assignment when satisfying both purposes. Inert items shall not be used to meet the 0.15 m^3 volume requirement. A smaller total volume may be used if a technical justification indicates the same conclusions will result and is approved by national authorities. Conversely, extra acceptors such that the minimum total volume requirement is exceeded may be a means to generate HC evidence that a Division 1.1 mass explosion hazard is not present.

b. The donor munition shall be positioned and oriented to induce the worst-case response from the acceptors as per the THA or approved analysis methods. This layout should be approved by national authorities.

c. When protection methods (e.g., shields, screens, barriers, etc.) are used in the life cycle phase represented by the test to reduce the likelihood of a sympathetic reaction, these devices shall be included in the test configuration.

d. External Confinement: If an existing external confinement is likely to alter the test result, the confinement should be simulated in at least one of the two minimum required tests. Any confinement should represent that of a typical storage/transport confinement. Based on the information provided in Annex A, confinement thickness will depend on the lifecycle situation the specific test is supposed to simulate (guidance of at least 1 meter deep in all directions around the test item to allow for harmonization with HC requirements), and is typically represented in the palletized configuration, based on the logistical lifecycle cited in the THA. The confinement should include the packaging, unitization, and palletization material as per the packaging, unitization and palletization drawings. Common materials as per these drawings should be used to accurately represent the confinement of the fielded munition, however inert munitions and mass simulants may be used if a technical justification indicates the same conclusions will result and is approved by the national authorities. **Safety concerns shall prohibit the use of sand, dirt or similar loose granular material for simulating external confinement.** Both partial and complete confinement test configurations are possible.

3. <u>Test Set-Up</u>

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

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

4. Number of tests

A minimum of two tests shall be conducted.

Note: A baseline test may be necessary to determine the blast, fragmentation and penetration signature of the donor test items and the fragmentation and spatial distribution of inert acceptors. Guidance on this test procedure is given in paragraph B.4 in SRD AOP-39.1.

2.3 DOCUMENTATION AND COMPLIANCE

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

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

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

2.4 OBSERVATIONS AND RECORDS

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

a. Test item identification and configuration (model, serial numbers, number of test items, etc.); type of energetic material and weight; list of environmental preconditioning tests performed; spatial orientation of the test item;

b. Test setup/configuration: Method of mounting and/or restraint; distances from the test item to any protective wall or enclosure; identification and location of any other instrumentation if used;

c. Record of events versus time through the end of the test;

d. Nature of any test item responses (donor and acceptor(s));

e. Imagery of the item under test and the test setup before and after the test;

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

g. List of environmental preconditioning tests performed;

h. Confirmation that the donor reacted as required;

i. Blast signature of the donor (if a baseline test is performed);

j. If a donor signature with adjacent inert item(s) is performed before the test, comparison of residue and debris between inert (baseline test) and active items (test items);

k. Meteorological data (wind speed, direction) during the test;

l. Indication of propulsion (video or other suitable means);

m. Video and sound track;

n. Positioning and record of blast or pressure gauges around the test item, including a record of their location and height;

o. Suitable blast or pressure gauges should be positioned around the test item and the location and height of the gauges recorded (not useful for tests in configurations with external confinement);

p. Witness plates and screens (optional) as a measure of projection severity, including photographs of witness plates and optional screens.

2.5 EVALUATION OF TEST RESULTS

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

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

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

ANNEX A BEST PRATICES

Disclaimer – These Annexes include additional information, recommendations and preferences to be considered when setting up the test and configuring the tests items. The pictorials (pictures, schematics, drawings, etc.) in the Figures in A.1 are examples used to support the textual explanation of the mathematical findings from the investigation of the origins of the SR numerical requirements, as well as aid in the guidance for setting up the test item configurations. The pictorials in A.2 are examples visually illustrating Confined/Unconfined Load Configurations and the concept of how the insult (shock/debris) propagates from the donor(s) to/through the acceptor(s) based on the numerical requirements. The pictorials are only examples, and they are not to scale.

A.1. RECOMMENDATIONS FOR TEST SET-UP & EXAMPLES OF CONFIGURATIONS

STANAG 4396 Ed 2, Section 8a. 'Sample Section' states that: 'The test requires sufficient packages or articles to give a minimum total volume of 0.15m^3, with a minimum of one donor and two acceptor packages'. Section 9b. 'Number and Layout of Munitions' further clarifies that: 'The volume of the stack must be at least 0.15m^3 minimum. If the volume of the donor and one acceptor package exceeds 0.15m^3, two acceptors are required, but three are desirable.

US DOD took the action from the Fall 2018 meeting to investigate the origins of these technical requirements to provide clarity and reasoning for the SRCWG to accept these legacy metrics and include them in the new AOP. Per [4] DA PAM 746-1, Pallets and Storage Aids for Army Use, 29 August 2018, amongst the 6 common pallet types used for shipment and storage, [5] MIL-DTL-15011 details one of two pallets specified for palletization in MIL– STD–147 and the only reusable–type pallet to be used for NATO shipments, and is also deemed the 'pallet used for ammunition worldwide shipment and storage'. While several other pallet types, such as the NN-P-71 Pallet (Figure A-1, Left), are suitable for ammunition use, the MIL-DTL-15011 Style 1 Pallet (Figure A-1, right) best meets NATO requirements for ammunition shipment and storage for several reasons, including: material type, load rating, 4-way entry, etc.).

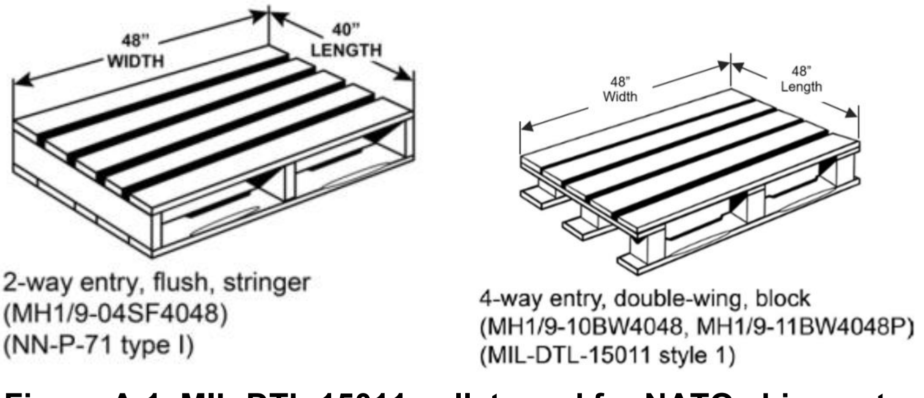

Figure A-1. MIL-DTL-15011 pallet used for NATO shipments

Note that the aerial dimension of the NATO pallet is 40in x 48in (1.0m x 1.2m). Upon further review of several ‘Unitization’ (Pallet) drawings used for shipping and storing common (high production, cross-service use) munitions, it was found that 40in x 48in is a typical/average aerial dimension of most ammunition pallets. Some munitions utilize smaller, larger, or other shaped pallets for unique reasons, but the majority of ammunition is palletized on pallets matching the aerial dimensions of the NATO pallet. Depending on the munitions being stacked, and other load requirements (e.g. weight, ammo quantity, etc.), the pallet is typically stacked ~38in-52in high, and the standard NATO pallet height is 40in.

For simplicity, 40in(L) x 48in(W) x 40in(H) is used to calculate the volume of a common pallet load.

- $V_{PALLET\ LOAD}$ = 40in x 48in x 40in = 44.44ft^3 ≈ 1.25m^3

A ‘Sample Selection’ of 1/8 of this Pallet Load Volume is 0.15m^3:

- 44.44ft$^{3/}$8 = 5.55ft^3 ≈ 5.3ft^3 ≈ 0.15m^3

*Note the similarity of 1/8 of a pallet load, which is 5.55ft^3, to the legacy SR test volumetric requirement of 5.3ft^3 ≈ 0.15m^3. It is presumed that this is where the volumetric requirement of 0.15m^3 (5.3ft^3) originates, and it was accepted by the SRCWG that this is the technical reasoning supporting this legacy metric.

To evaluate this similarity to common munitions, the analysis was performed with three different common munitions that are typically packaged in three common families of ammunition containers.

Typically medium caliber ammunition (20cal, 30cal, 40cal, 50cal, grenades, mines, demo etc.) are packaged in rectangular ammo boxes, as illustrated in Figure A-2 (left). Large caliber ammunition (mortars, tank, propelling charges, etc.) are typically packaged in either tall rectangular containers, stored vertically in only one layer (Figure A-2, right), or in long cylindrical containers, stored horizontally in several layers (Figure A-2, middle).

Figure A-2. Examples of typical palletized loads for 3 common munitions

Examples of Test Set-up and Configurations

The following are three examples encompassing the typical range of common (highly produced, cross-service use) palletized munitions. Each example respectively represents the 3 common munition types (and associated containers type). These examples are provided here-in to serve as guidance when designing the test set-up and test item'(s) configurations(s).

<u>Example 1: Palletized load of 40mm Grenades packaged in small ammo boxes.</u>

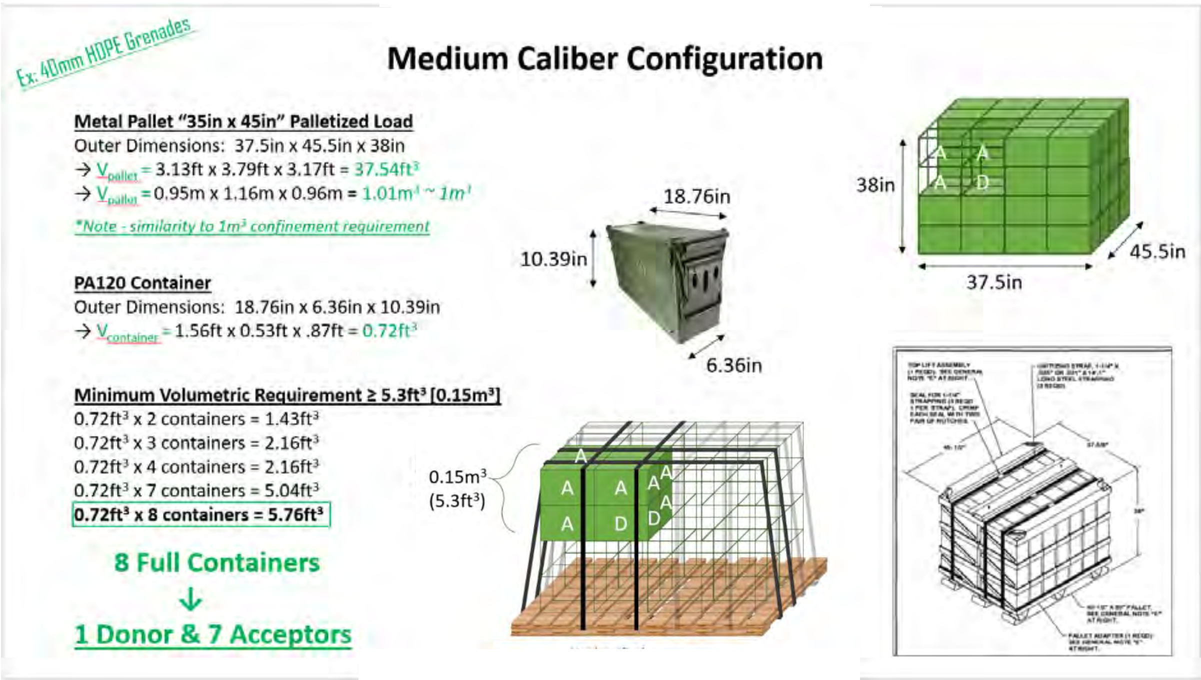

Figure A-3. Palletized load of 40mm Grenades packaged in small ammo boxes

Note that the palletized load for this particular medium caliber round is slightly different/smaller than the standard 40in x 48in x 40in pallet dimensions used earlier. This is why it is important that the specific test item under evaluation be addressed individually. The Threat Hazard Assessment (THA) will include, or call out, the palletization/unitization drawing as illustrated above. Using the dimensions provided from this drawing, as well as the container drawings, the sampling size can be calculated for each unique test item.

For this particular analysis, 8 containers are needed to achieve the $0.15m^3$ ($5.3ft^3$) requirement. This would result in a test including 1 donor and 7 acceptors.

Note – quite often it is realized, through up-front experimental engineering testing/computational analysis that the reaction of the item does not propagate beyond the container. In this case, a single package test can be conducted for official scoring.

Example 2: Palletized load of 120mm Mortars packaged in tall rectangular containers, vertically.

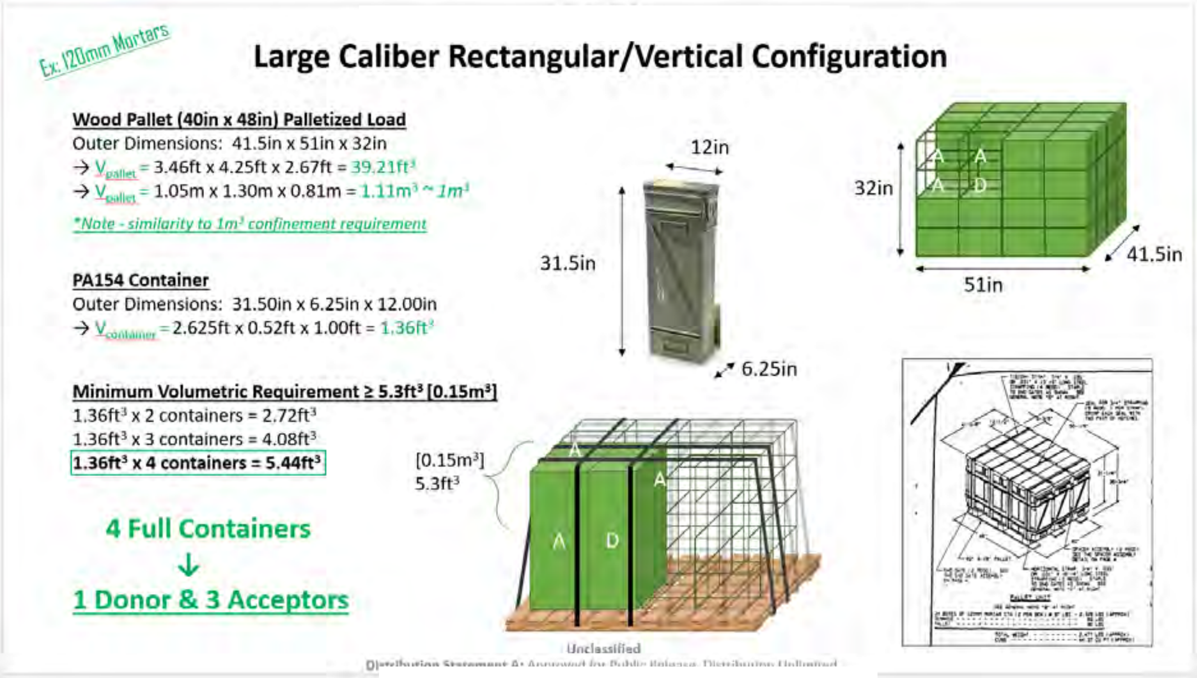

Figure A-4. Palletized load of 120mm Mortars packaged in tall rectangular containers, vertically

Note that the aerial (LxW) dimensions (40in x 48in) of the palletized load for this particular large caliber round is the same as the common pallet example used earlier. However, due to system requirements, as well as several palletization/unitization requirements, these containers are stacked vertically, and only one layer high. Therefore, the height of this load is slightly different/smaller than the 40in height used earlier. Also note that the width dimensions (41.5in) of the unitized load (containers) is smaller than that of the aerial dimensions of the pallet. This is due to the palletization/unitization materials configured to brace/secure the load on the pallet. Therefore, it is important to identify the actual dimensions/configuration of the unitized load, and not just use the pallet dimensions, when configuring the sampling size for the SR test.

For this particular analysis, 4 containers are needed to achieve the $0.15m^3$ ($5.3ft^3$) requirement. This would result in a test including 1 donor and 3 acceptors. Note that there are potential scenarios in which an identical pallet(s) of identical munition(s) may be stacked above or below this pallet, whether in a warehouse or on a ship/truck/plane, etc. If the THA identifies that this munition produces a worst case threat vertically, rather than horizontally (i.e. end to end, rather than side to side), the THA should identify this as the worst case (or most credible) threat. Since this case would involve munitions from a second (or potentially third) pallet, this case/configuration would have to be presented to the technical authority for consideration and approval.

<u>Example 3: Palletized load of 120mm Tank Cartridges packaged in long cylindrical containers, horizontally.</u>

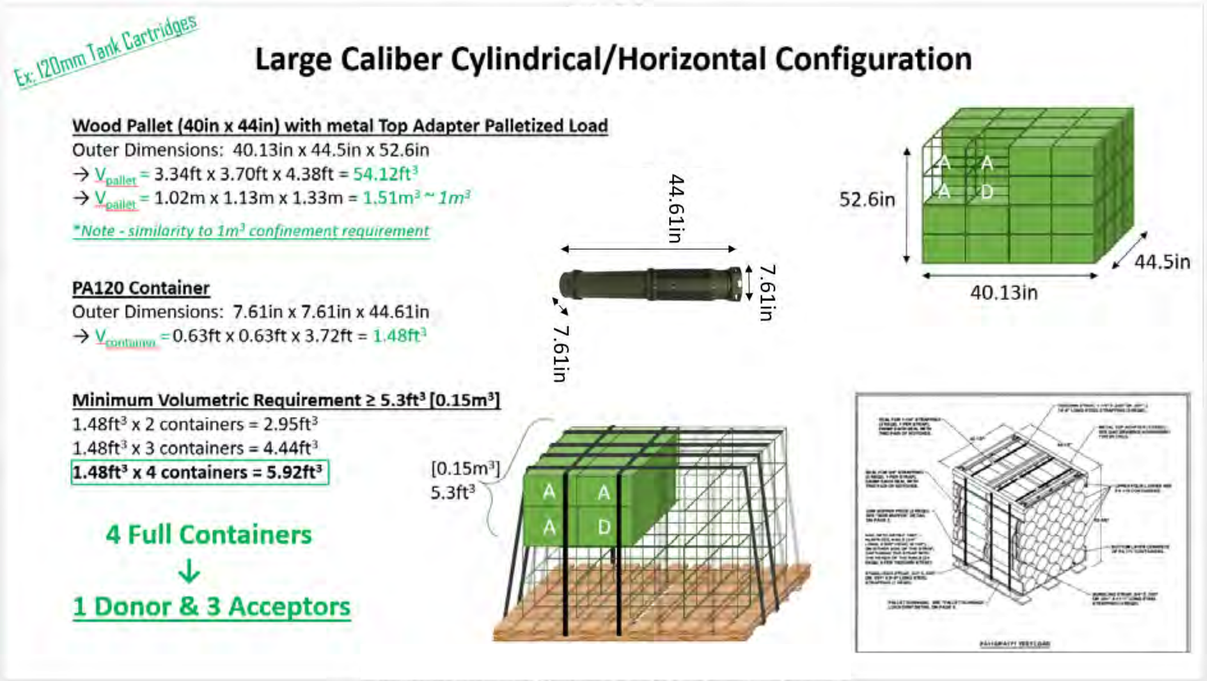

Figure A-5. Palletized load of 120mm Tank Cartridges packaged in long cylindrical containers, horizontally

Note that the unitization height dimension is larger than the container stack by a few inches. This is due to the bracing and strapping system used to secure the load on the pallet. If/when testing a configuration of this munition, and representing the outer surfaces/corners of the pallet, these unitization/palletization materials (braces, straps, etc.) should be taken into account when calculating the 'sample size'.

For this particular analysis, 4 containers are needed to achieve the 0.15m^3 (5.3ft^3) requirement. This would result in a test including 1 donor and 3 acceptors.
Note that this particular large caliber munition is packaged in a cylindrical container, horizontally on the pallet. Similar caveats apply here as the vertical configuration in Example 2. If the THA indicates that a worst case scenario can result from end-to-end placement, a technical justification must be presented to, and approved by, the technical authorities to test accordingly. The THA may not necessarily state that this would be the worst case scenario, however, if it can be deduced that end-to-end (or any other potential orientation(s) can create a worse case configuration, then it should be considered for testing. The 5.3ft^3 (0.15m^3) volumetric requirement applies to munitions, not just a pallet. While this palletization drawing may only indicate that the containers are unitized side-to-side, it is possible that the pallet will be stored/shipped adjacent to another pallet, with the containers facing end-to-end. The 5.3ft^3 (0.15m^3) volumetric requirement should be comprised of munitions that represent the worst case scenario, which may involve adjacent containers from more than just one pallet.

Based on the sampling sizes calculated using these common pallets, it is evident that the $0.15m^3$ ($5.3ft^3$) requirement is a sampling size of a fraction of a pallet. In general, $0.15m^3$ ($5.3ft^3$) is approximately 1/8 of the common palletized load. For the large caliber munitions, 4 containers were required to meet the $0.15m^3$ ($5.3ft^3$), which also satisfies the minimum of 2 (or preferably 3) acceptors requirement. For the medium caliber munition, 8 containers were required to meet the $0.15m^3$ ($5.3ft^3$) requirement, which has been common practice, and does provide a better sampling size of the pallet than just 2 or 3 acceptors.

Note that for extra-large munitions (e.g. rockets, missiles, etc.) the $0.15m^3$ ($5.3ft^3$) requirement does not typically meet the 2 or 3 acceptors requirement. This is understood, as the quantity of the larger, more expensive munition systems are merely a fraction of the common medium and large caliber munitions of interest with respect to Insensitive Munitions.

Non-Packaged Munitions, Un-Unitized Munitions & Bare Munitions

Not all munitions are ‘packaged’, and not all munitions are palletized the same way. Care must be taken to address each individual munition’s Logistical & Operational Configurations per their lifecycle in their THA. Figure A-6 below illustrates artillery shells on a pallet.

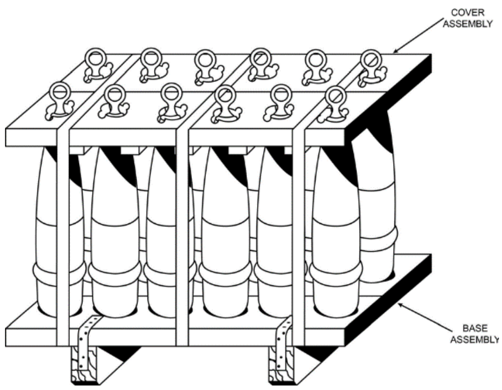

Figure A-6. Non-Packaged Munitions

Within the lifecycle of a munition, a pallet of munitions may be broken-down and left with a partial pallet load of munitions, palletization and unitization materials (e.g. strapping, dividers, etc.) may be removed, and the munition will eventually be removed for carry and operational use. These configurations must also be considered for sympathetic reactions, however, the most credible response from the most credible threat must be the configuration tested for official scoring.

A.2 CONFINEMENT

1. Test without external confinement

Configuring Acceptors and Donors

Using a similar scenario as the medium caliber example above, this section will describe/provide guidance on how to configure the acceptors and donors for IM & HC purposes.

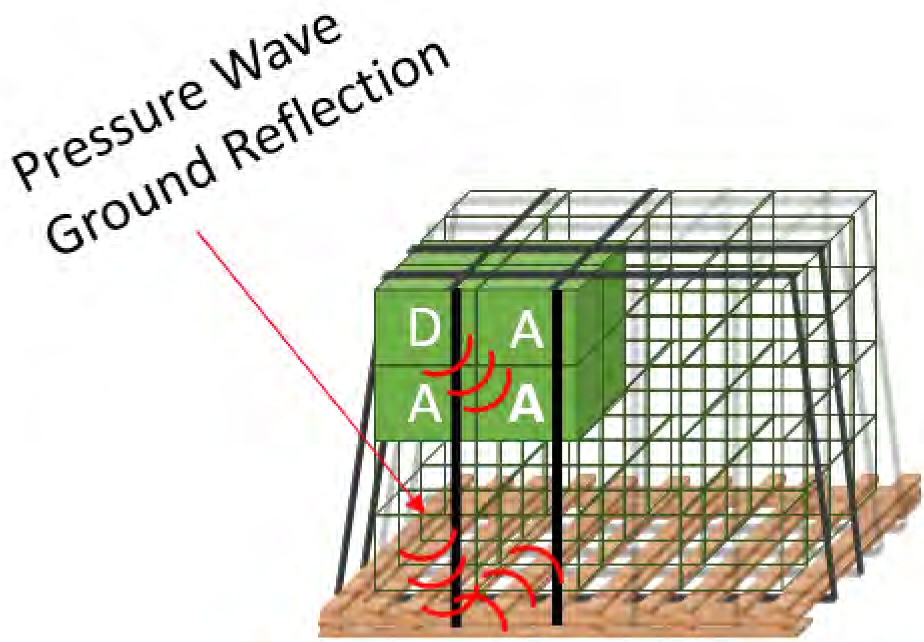

Figure A-7. Example of Configuration without external confinement

One manner of configuring the 8 containers would be to place the acceptors in as many adjacent positions to the donor as possible. As seen in Figure A-7 above, the sampling size was configured in a way to represent the donor on the outside of the pallet load, where it would be susceptible to threats outside of the pallet (fire, heat, bullet/fragment/shaped-charge, impacts, etc.). The acceptors were arranged in a manner that represents the corner of a pallet. This test would help in evaluating how the acceptors on the corner of a pallet react due to a donor reacting from the outer surface of the pallet. It can also help in evaluating how the acceptors at the corner of a pallet react to a donor reacting from an adjacent pallet initiating and setting off the donor. For Insensitive Munitions purposes, this is the preferred configuration, as there is little to no confinement, which allows the fragment debris and overpressures from the acceptors to project about the test arena, providing the evidence needed to evaluate the overall reaction violence of the acceptor munitions. This configuration would suffice for the ‘Unconfined’ test (without external confinement).

2. Test with external confinement

External Confinement is described as the typical materials or items surrounding a munition or of stack of munitions during storage. When performing the confined test for the harmonized IM/HC test as one of the two required tests, the configurations must meet HC requirements. That is preferred by the IM community to represent the munition’s defined palletized/unitized load as possible. The test should be conducted with containers, not sand bags, and the containers should be filled with the best replication of the actual munitions as possible. For example, aluminum rods, steel spheres, etc., of same mass and inert dunnage (foam packaging, etc.) will suffice if inert munitions are not achievable to attain. Sand-filled containers are a last resort option as they can extremely hinder the fragment debris and overpressure projection that would normally propagate outward. Sand-filled containers can present a safety hazard as their debris might cover/bury live test items during post-test operations. A technical justification must be presented to the technical authorities to approve the use of sand-filled containers. However, it must be noted that this is NOT the preferred method.

The requirement for ‘1m thick in all directions’ was questioned, and again resulted in finding no known historical/technical reasoning for the specific metric. Using the Standard NATO Pallet as a common pallet load, the following analysis was performed:

Common pallet load dimensions: 40in(L) x 48in(W) x 40in(H)

- 40in(L) = 1.016m
- 48in(W) = 1.219m
- 40in(H) = 1.016m
- Avg. thickness = 1.084m

*Note the similarity of the average thickness of a pallet (1.084m) to the external thickness requirement of 1m. It is apparent that the technical reasoning for this is to evaluate the response of the acceptors centralized in a confinement of pallet loads 1m thick in all directions.

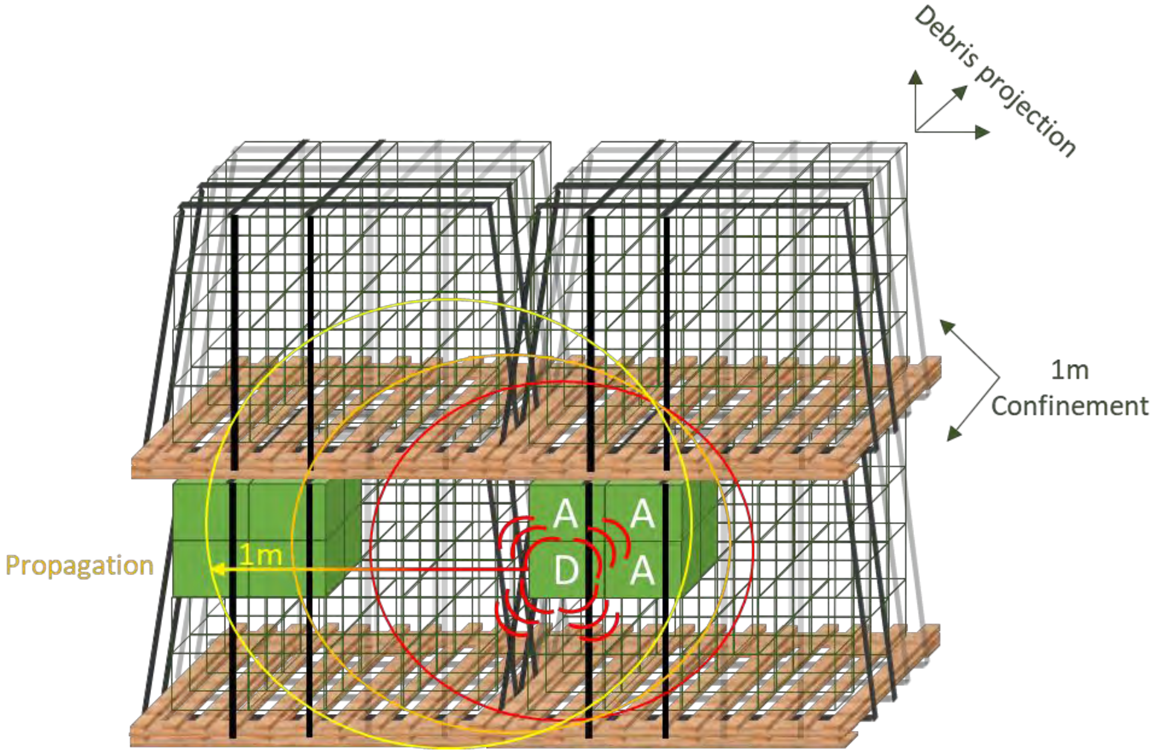

Figure A-8. Example of propagation through Confined Load

For Hazard Classification purposes, it is preferred to represent the 0.15m^3 (5.3ft^3) in the center of the pallet(s), or a manner in which the donor and acceptors are surrounded by other containers/pallets. This would provide the confinement around the donor and acceptors needed to allow the Hazard Classifiers to evaluate the reaction of the acceptors when subject to a confined donor initiating. Since the UN requirement is at least 1m of confinement in all directions of the 0.15m^3 (5.3ft^3) sample, typically a full pallet of containers (with inert rounds) will be required to conduct this test. For smaller pallets, adjacent pallets will have to be incorporated to meet the 1m thickness requirement. Note that the adjacent unitization/palletization materials (braces, straps, etc.) must be taken into account for this type of configuration.

When testing in the configuration with external confinement for HC purposes, it is preferred to place the donor in a manner that projects downward to the acceptors, which typically results in a worst case by exacerbating the confinement. Figure A-8 illustrates a cross-section of the external confinement for stacked pallet loads and propagation through the confined pallet load.

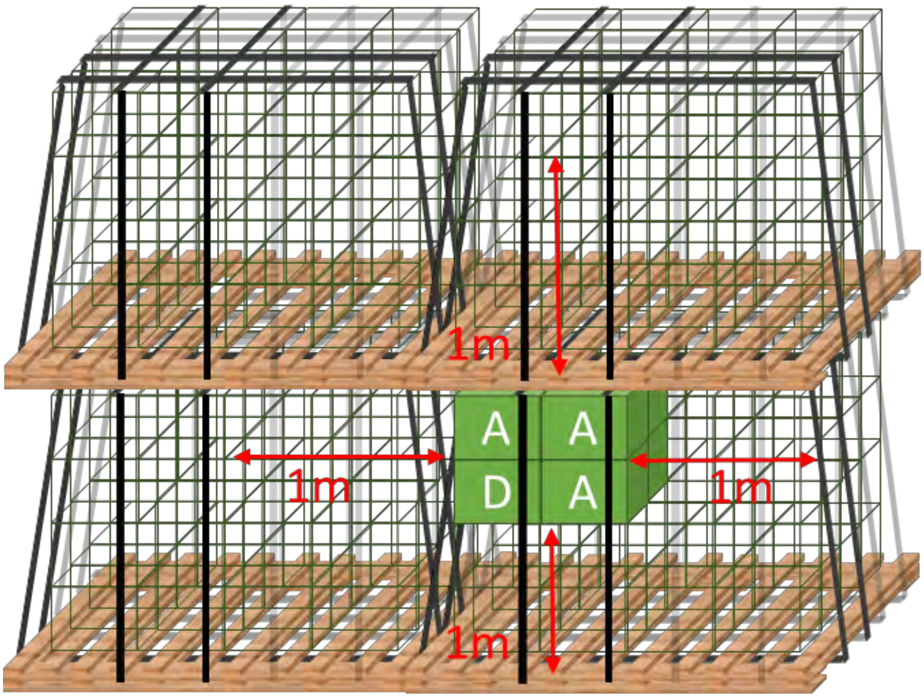

Figure A-9. Example of Configuration with ≥ 1m external confinement

A.3 INITIATION CONSIDERATIONS

The initiation method for the sympathetic reaction test should mimic the worst-case credible reaction. The selection of this reaction is aided by the system's Threat Hazard Analysis (THA).

For detonating munitions, this normally means detonation in the design mode. The safety of fuzing systems frequently makes this difficult. For systems where safety concerns exist, the fuze may be replaced by a mass simulant and an alternate initiation train. This initiation train should mimic, as far as possible, the initiation input provided in the design mode. The use of plastic explosives to fill fuze wells, or to be used in a manner of Unexploded Ordnance (UXO) demolition, is discouraged as this can change the output of the donor.

For munitions that are not designed to detonate such as rocket motors, smoke shells, flares, etc. care must be taken in designing tests. Some of these materials have a greater detonation velocity and smaller critical diameter than some main charge explosives. If the materials are larger than the detonation critical diameter, the use of igniters (even if in design mode) are not normally the worst-case credible reaction. When a design mode for detonation does not exist, the munition shall be initiated with a credible threat that produces the worst-case response of the munition (shaped charge jet as defined in AOP-4526 or explosive charge assessed as the most credible threat). If AOP-4526 Shaped Charge Jet Munition Test Procedure is followed for the test, it is often possible to provide test scores for both the SR and SCJ threats.

A.4 REFERENCES

[1] D. Pudlak, ‘Guidance on Sympathetic Reaction Test Item Configuration & Set-up’, MSIAC Database, Fall SRCWG Meeting Proceedings.

[2] D. Pudlak, B. Fuchs, ‘Guidance on Sympathetic Reaction Test Item Configuration & Set-up’, National Defense Industrial Association, Insensitive Munitions & Energetic Materials Symposium Proceedings, Oct 21-24, 2019.

[3] Recommendations on the TRANSPORT OF DANGEROUS GOODS, Tests and Criteria, First Edition (Orange Book)

[4] DA PAM 746-1, Pallets and Storage Aids for Army Use, 29 August 2018

[5] MIL-DTL-15011, Detail Specification, Pallets, Material Handling, Wood Post Construction, 4-way Entry

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ANNEX B HISTORICAL OVERVIEW

B.1 REVISION PROCESS

1. Creation of AOP-4396

In 2010 NATO's Ammunition Safety Group (AC/326) empowered their munition Subgroup B (Ammunition Systems Design & Assessment) to establish Custodian Working Groups for each of the IM related STANAGs as a means of reviewing and updating the IM test requirements where needed. Several nations participated in these Working Groups to address the individual IM test requirements in succession, including fast heating, bullet impact, shaped-charge jet impact, fragment impact, slow heating and finally sympathetic reaction. Each topic required multiple meetings to produce the desired end product – a draft AOP document that contained the revised, updated test requirements. These new AOPs would then become companion documents to their respective STANAGs with the STANAG as the lead or referencing document only.

There were four Sympathetic Reaction Custodian Working Group (SR CWG) meetings during the period April 2018 – September 2019. These meetings were conducted to review and update the test requirements of STANAG 4396 and create AOP-4396. The SR CWG deliberations included very lengthy discussions, sometimes supported by detailed technical investigations, on many topics related to this test and its procedural requirements. Indeed, it became apparent that there were discrepancies amongst the members regarding several aspects of the test conduct and assessment, including: selecting the quantity of munitions for the test, the test configuration(s), donor parameters, etc. Additionally, the SR CWG encountered several terms/definitions and statements in the previous STANAG that were deemed misleading/insufficient to relay the specific intentions of the new AOP-4396. The following topics were addressed:

a. Purpose & Goals of an SR test
b. Definitions/terminology
c. Test Configurations, Conditions and procedures
    - Number of donor & acceptor test items
    - Packaged vs Unpackaged
    - Confinement (Confined vs. Unconfined)
    - Donor/Acceptor Orientation and Spacing
d. Initiation Methods
e. Number of tests
f. Test type/configuration

2. Changes from STANAG 4396 ed 2

Many changes to the documented test requirements are apparent when comparing the STANAG (Edition 2) and the new AOP. An improved standardized format was used for all of the new IM test AOPs that were established. IM and Hazard Classification test harmonization was considered during the formulation of the updated SR test requirements. The most significant changes in this update are summarized below.

1. Purpose & Goals of an SR test

STANAG referred to a worst-case credible reaction in the statement of the test purpose without mention of worst-case credible threats or hazards.

AOP requires the use of a Threat Hazard Analysis (THA) to guide the design of this test, especially with respect to threats, test configurations, number of tests and other aspects of the test procedures. A THA is a systematic investigation of credible events, safety-related or resulting from hostile actions, that a munition is expected to experience over its lifetime, paired with the resultant potential endangerments posed by those situations acting on the munition's vulnerabilities.

AOP focuses clearer on *initiating* a munition (to achieve worst-case response) and evaluating whether its effects propagate (sympathetically) to an adjacent munition causing the same level of response (i.e., sympathetic reaction). This focuses on a reaction propagation *decrease* in severity from one test item to its neighbor as an indication of progress or an acceptable outcome.

2. Test Configurations

a. Packaged vs Unpackaged

Test configurations should represent the Logistical or Operational Configurations of the munition's Lifecycle per the THA. Not all munitions are 'Packaged'. Some are transported in several layers of unitization (outer containers, inner boxes/sleeves, dunnage, etc.), others are bare (e.g. artillery) or in their final launchers when deployed.

b. Confined vs. Unconfined

STANAG required 1 Confined & 1 Unconfined test.
The terms 'confined' and 'unconfined' were deemed unclear and were respectively replaced by 'with external confinement' and 'without external confinement'.

AOP focuses on worst-case response from a worst-case credible threat. Level of confinement is now based on technical analysis justifying worst-case threats, responses and appropriate test configurations. If testing harmoniously, it is recommended to perform one 'unconfined' (without external confinement) test and one 'confined' (with external confinement) test.

c. External confinement

Should consist of inert materials at least 1m thick in all directions. This is a legacy requirement from the previous STANAG. Based on a technical analysis conducted by the US members of the SRCWG, the metric presumably represents the depth of a standard NATO pallet which is approx. 1m x 1m x 1m by volume. The intention is to represent a munition packaged on a pallet in a stack of pallets (one on each side of the pallet).

STANAG allowed sand to be used as confinement material.

AOP prohibits sand, dirt or similar loose granular material for simulating external confinement for several reasons, including:

a. Safety – Sand is unsafe for test facilities as it hides live energetics post-test.
b. Technical – Sand absorbs shock and hinders fragment ejection.

Inert material must physically and geometrically represent the fielded munition.

a. Identical simulants are preferred.
b. Mass simulants are acceptable.

Palletization and Unitization materials should be included.

a. E.g. Wooden dividers often used to separate rows of containers. These should be included as distance is a major factor regarding detonation propagation.
b. Metal strapping often used to strap containers together. These should be included as the restraint affects the release of gases and fragmentation from the response.

d. Donor/Acceptor Orientation and Spacing

For IM purposes, typically donor is preferably positioned at top of $0.15m^3$ stack to observe ground reflection of pressure waves and fragment throw.

For HC purpose, both are desired, however if testing harmoniously, donor should be stacked at the bottom to cover both concerns.

3. Initiation Methods

a. STANAG focused on 3 initiation methods:

i. If designed to detonate, detonate the donor in the design mode.
ii. For rocket motors and gun propellants, initiate the donor with a credible threat (for example, Shaped Charge Jet (SCJ)) that produces the worst case donor reaction.
iii. For all others, use the normal means of initiation.
iv. It was mentioned in an advisory note that the test was generally not required for IM if the item will not detonate.

b. AOP focuses on 2 initiation methods:

i. If the donor munition is designed to detonate, initiate the donor munition(s) in the design mode (same as previous STANAG).

ii. The second and third items above are combined, which means that for munitions that are not designed to detonate (all other munitions), the donor munition(s) must be initiated with a credible threat that produces a worst-case response (for example, a shaped charge jet as defined in AOP-4526, an explosive charge, etc.). The use of the SCJ defined in AOP-4526 will ensure better harmonization among nations. If an explosive charge is considered as the most credible threat, its characteristic (material, size, shape, location on the munition, etc.) shall be approved by National Authorities.

iii. Unlike the STANAG, for which 'the test is generally not required for IM if the munition will not detonate', the test is now required in the AOP even if the munition will not detonate.

4. Response Evaluation Methods

There were discrepancies amongst Nations regarding the assessment of the SR test. AOP focuses on propagation of the same (any level) response from one munition to another.

a. Detonation to Detonation
b. Partial Detonation to Partial Detonation
c. Explosion to Explosion
d. Deflagration to Deflagration
e. Burn to Burn

5. Terminology

It was agreed that any new definitions should be proposed and added to the NATOTerm database.

B.2 BACKGROUND & TEST ORIGIN

1. Hazard Classification historical reference

For several decades, the Safety Community has been characterizing how ammunition sympathetically responds when initiated by adjacent munitions. Original assessments were conducted due to intentional (i.e., hostile) and unintentional (i.e., accidental) "chain-reaction" events that occurred in ammunition depots, battlefields and aboard naval vessels, resulting in catastrophic responses, often "mass explosions".

At the end of the World War I, the US DOD had considerable quantities of High Explosive (HE) ordnance remaining, and initially began conducting Sympathetic Detonation testing in 1922 when there was a need to identify the optimal distance to store an adjacent pile of HE ordnance from a detonating pile of HE ordnance such that the adjacent pile would not detonate.

While many countries had individual concentrated efforts to address this chain-reaction events, particularly in the 1960's/70's, the United Nations originally introduced a 'Stack Test' in 1988. This was used by the Hazard Classification Community to assign hazard divisions to "explosive products/articles'.

Under Test Series 6, Type (b), taken from the source document] 'Recommendations on the TRANSPORT OF DANGEROUS GOODS, Tests and Criteria, First Edition (Orange Book) [3], the Stack Test was defined as a 'Test on a stack of packages of an explosive product or a stack of non-packaged explosive articles for the purpose of determining: (i) Whether burning or explosion in the stack is propagated from one package to another or from a non-packaged article to another: and (ii) In what way the surroundings could be endangered in this event'.

In the Orange Book, Section 41.3 Application of Test Series states that this test is: '…applied to packages of explosive substances and articles in the condition and form in which they are offered for transport. Where explosive articles are to be carried without packaging, the tests are applied to the non-packaged articles'.

In the Orange Book, Section 41.3.3 states that: 'If the exterior of the package is undamaged by internal detonation and/or ignition' during a single pack test, 'test 6(b) is waived'; and 'If the contents of the package fail to explode, or explode so feebly as would exclude propagation of the explosive effect from one package to another in test 6(b), test 6(b) is waived'.

While the Orange Book does not provide details regarding how to set-up and conduct the Test Series 6(b) Stack Test, TB 700-2, US DOD Ammunition & Explosives Hazards Classification Procedures, includes: Introduction, Apparatus & Materials, Procedure, and Criteria & Method of Assessing Results.

2. Insensitive Munitions historical reference

The catastrophic events aboard US Navy ships during the 1960's and 70's focused attention on the various types of hazards posed by ordnance stored or deployed in close proximity. The concept of developing, producing and deploying "insensitive munitions" thus became an apparent necessity. An IM initiative began in the US in the 1980's to formulate test requirements to qualify munitions as "insensitive." Some of these requirements were taken from established system safety test methods and others originated to counter new threats or hazards.

These new IM test requirements in the US were initially documented in DOD-STD-2105 in September 1982 (later becoming MIL-STD-2105). This document cited fast cook-off, slow cook-off, bullet impact, fragment impact and sympathetic detonation as mandatory requirements for IM compliance. This requirements document was later adopted by NATO as IM became an important safety issue among the NATO nations. STANAGs for each of the individual IM tests were then written collaboratively, agreed upon by the NATO nations and promulgated for IM testing and munition IM certification.

Sympathetic detonation test procedures for munitions were first published in STANAG-4396, edition 1, in the early 1990's. It was revised in June 2002 when IM test requirements were updated in edition 2. An important distinction was cited in this test concerning the severity of the chain-reaction event, the "sympathetic" response of the adjacent munition. It thus became a *sympathetic reaction* test vs. a *sympathetic detonation* test to replicate and assess catastrophic real-world events. STANAG 4396 then continued to be followed until this current update with this AOP becomes effective.

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