Insensitive Munitions – Industry Problems and Solutions

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ABSTRACT

This paper describes some of the problems in implementing insensitive munitions requirement by US industry and solutions that have been applied. Mr. Graham has worked in this area for over 43 years, and the views expressed are his own. All information is unclassified and releasable to the public.

1.0 INTRODUCTION

Industry is in the business of making a profit! In order to achieve this goal, high quality, responsive work is required. Industry is willing to invest their own internal funds to achieve a program that will ultimately bring a profit to the company. There are many bright, clever engineers and scientists in private industry that are anxious to provide what the government needs to achieve insensitive munitions. But there are issues that need resolution to be most efficient at this process.

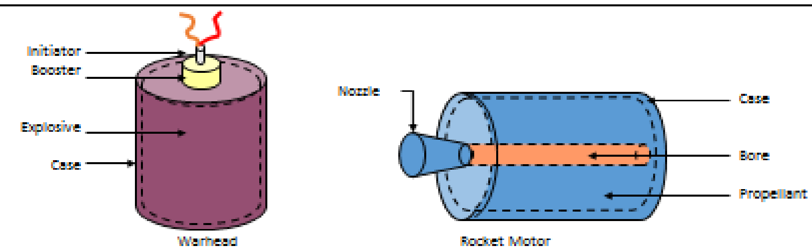
2.0 DEFINITIONS

The phrase "Insensitive Munitions" seems to be incongruous. "Munitions" implies weapons that are sensitive to their boosters or igniters; while "Insensitive" implies that the weapons aren't. So to start out, some definitions are in order.

- Munition – An assembled ordnance item that contains explosive material(s) and is configured to accomplish its intended mission.
- Insensitive munition – Munitions which reliably fulfil (specified) performance, readiness and operational requirements on demand, but which minimize the probability of inadvertent initiation and violence of subsequent collateral damage to the weapon platform (including personnel) when subjected to unplanned stimuli.
- Burning – The least violent type of explosive event. The energetic material ignites and burns, non-propulsively. The case may open, melt or weaken sufficiently to rupture nonviolently, allowing mild release of combustion gases. Debris stays mainly within the area of the fire. The debris is not expected to cause fatal wounds to personnel or to be a hazardous fragment beyond 50 ft.
- Hazardous fragment – For personnel, a hazardous fragment is a piece of the reacting weapon, weapons system or container having an impact energy of 58 ft-lb [79 J] or greater.
- Deflagration – Reaction driven by thermal conduction in an energetic material. For solids and liquids, no utilization of atmospheric oxygen is required. The reaction wave is subsonic in the energetic formulation and the reaction products flow in a direction opposite to the reaction front.

- Detonation – Chemical reaction induced by a compression wave and driven by the expansion wave in the products. A shock wave is formed that propagates at a steady velocity if the formulation is above its critical diameter. The velocity of the shock wave in the explosive (detonation velocity) is supersonic, and the reaction products travel in the direction of the shock wave.
- Critical diameter – The diameter of a long, unconfined right circular cylinder of energetic formulation that just sustains a steady detonation. Propagation of detonation fails below critical diameter.
- Sympathetic reaction – The detonation of a munition or an explosive charge induced by the detonation of another like munition or explosive charge.
- Explosive - Substances or mixtures of substances which are capable of undergoing exothermic chemical reaction at extremely fast rates to produce gaseous and/or condensed reaction products at high pressure and temperature.

There are numerous potential hazards associated with munitions. They are sensitive to thermal and shock or impact stimuli, with potential responses ranging from none to very severe combinations of reactions. Figure 1 illustrates.



Stimuli	Some Potential Responses	
• Impact & Shock – Drop – Bullets – Fragments – Shaped-charge jets • Thermal – Fires – Slow heating – Hot spall fragments	• None • Ignition • Burning • Propulsion • Explosion • Detonation • Heat – Radiant – Hot gases – Plasma	• Blast – Shockwaves – Overpressure • Fragments – Small, high-speed – Large, lower speed • Combinations of the above

Figure 1. Potential Hazards from Munitions

Over the years, insensitive munitions has grown from a single service program to a universal program subject to US public law (Figure 2). We need to make munition systems that are safe for our military personnel and their associated materiel, throughout the whole munition lifecycle. This is quite a challenge!

> **"The Secretary of Defense shall ensure, to the extent practicable, that munitions under development or procurement are safe throughout development and fielding when subjected to unplanned stimuli."**

Figure 2. United States Code, Title 10, Chapter 141, Section 2389, ensuring safety regarding insensitive munitions. [1]

3.0 THE "SIMPLIFIED" IM PATHWAY

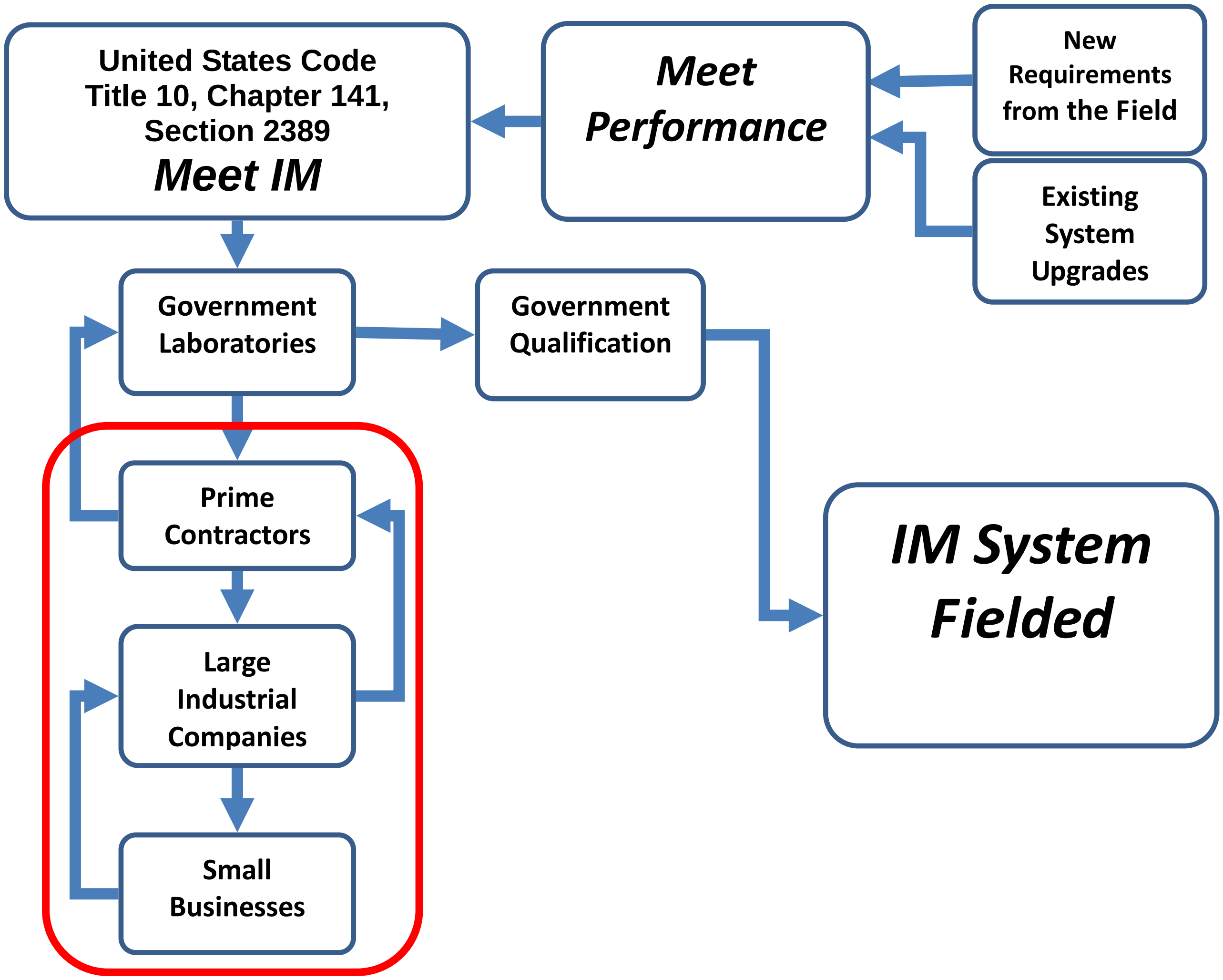


Figure 3. The Simplified IM Pathway

Figure 3 shows a simplified pathway from munition requirements to munition fielded system. There are several sources for requesting production of IM systems. One is the upgrade of legacy munitions that do not meet the IM requirements. The services have prioritized lists of legacy weapons and may choose to improve top priority weapons. Another pathway is new requirements from the field. Mission requirements change as new threats appear, and new, improved weapons are needed. Program offices generally handle and fund these requests, typically to government laboratories.

The government laboratories and program offices work together to define system requirements and may do some early research on ways to improve the munition responses to the IM threats. Soon after this assessment is completed, typically a request for proposal is issued, asking companies to bid on the manufacture of the new, improved munition. Typically, prime contractors respond to the request, and one or more primes are awarded a contract.

Prime contractors typically are system integrators, so subsystems such as rocket motors and/or warhead development are subcontracted to large industrial companies. These large industrial companies have system engineering design groups and generally a cadre of scientists and/or engineers dedicated to IM technologies. Sometimes the technology aspects are further subcontracted to small companies specializing in one or more aspects of IM technologies. Technology information is generated, and if done properly, IM features are factored into the munition design early in the design/development phase. As the design progresses, information is fed back to the prime contractors for incorporation into the final integrated system design.

Along the way, there may be IM modeling and/or tests on components to assure that the component has the required level of IM responses. Mitigation features can be incorporated into the component or system design, particularly if the combination of fill plus case provides inadequate IM responses. Some of this work may be funded using a company's internal funds, particularly if the solution is propriertary. Note that the US code states "…to the extent practicable…". A general reduction in the adverse responses to IM threats may be acceptable if no technology currently exists.

Note that engineering design is no easy feat. In addition to IM sensitivity reductions, performance must be equal or increased. System safety, hazard classification, and qualification requirements also play into the design. Testing has to be done by the prime and the government to assure requirements are met. Ultimately, a design is developed that generally satisfies the government requirements. The system must then be briefed and approved by a system safety review board to be qualified for service use.

Assuming the system is qualified for service use, and there is funding available, one or more industrial partners that developed the system may be awarded a contract for production, finally allowing the possibility of meeting the corporate goal of making a profit.

4.0. PROBLEMS EXIST – WHAT ARE SOME POTENTIAL SOLUTIONS?

The design path is tortuous, and there are many problems for the industrial partners that have to be overcome. A poll was taken of some industrial companies, asking them to identify the problems that had in developing IM-compliant munitions. Their list of problems and their potential solutions follow.

4.1. Performance vs. Sensitivity

Problem: Performance always wins**.** New and/or improved systems require at least equivalent performance to the system being replaced and generally, more performance is required. " IM requirements compete with performance requirements. In many cases it has been difficult to come up with insensitive high-performance explosives and propellants. There is a need to identify other ways to meet performance requirements than with high energy propellants and explosives".

Problem: Not considering the whole system. "There has been an inordinate focus on propellant and explosive formulation rather than a system solution approach that includes case design, grain design, closure design and mitigation methods and systems".

Solution: IM solutions require a <u>systems</u> approach. System design features such as the placement of the igniter, propellant and warhead explosive selection, case material, and the launch container design are important in preventing "cheap kills" on valuable assets. **<u>There is not one simple solution</u>**. Combinations of system components are required for the mitigation of violent reactions**.** One needs to look at overall system solutions that leverage beneficial interactions between components to meet IM requirements.

System designers tend to remove every bit of parasitic weight in an effort to increase performance. Every nut and bolt adds weight. For rocket motors, performance can be increased by **lightening the system and increasing the operating pressure**. Here, replacement of metal cases with composites is of value. Composites can be stronger than metal cases, are lighter, and can provide IM benefits in both impact and thermal threats due to their failure modes.

To improve the "IM-ness" of a system, mitigation methods and devices are also important. A partial list of passive and active mitigation methods are shown in Tables 1 and 2. Note that passive methods are preferred and active methods carry a number of restrictions. Also note that for best performance and IM value and potentially lowest weight impact, mitigation techniques should be part of the initial design and not a strap-on afterthought.

Passive	Active
Preferential Insulation Treatment	**Thermally Initiated Vent System (TIVS)**
Memory Metal Alloys and Bimetallics	**Explosive Bolts**
Bore Mitigants	**Impact Switches**
Pulse Motor	**Thermal Switches**
Composite Cases	**Case Bar Cutter**
Slotted Cases	**External Thermite Case Penetrator**
Case Embrittlement Concepts	**Internal Thermite Case Penetrator**
Hybrid Cases	**Explosive Case Separator**
Steel Strip Laminate Cases	**Multihazard Threat Mitigation System**
Metal Matrix Composite Cases	
Roll Bonded Cases	
Shear Vent Patch Strip	
Packaging	
Shock absorbing materials	

Table 1. Some Passive and Active Mitigation Techniques for Rocket Motors

Reduced Sensitivity Explosive(s)	**Venting Holes**
Warhead System Design	**Composite Overwraps**
Composite Case Design	**Shielding**
Dual Explosive Warhead	**Bomb Fuze Thermal Protection**
Reactive Case Warhead	**Ordnance Flying Plate Lead/ Boosters**
Case Stress Riser Groove	**Ordnance Vented Boosters**
Warhead Liners	

Table 2. Mitigation Options for Warheads

(Appendix A. gives added information on mitigation methods.)

4.2 System solutions are necessary.

Problem: "System solutions are required." Munition systems can be sensitive to various threat stimuli leading to adverse reactions that can injure or kill personnel, damage materiel, and severely impact operations.

Solution: System design features such as the placement of the igniter, propellant and warhead explosive selection, case material, and the launch container design are important in preventing "cheap kills" on valuable assets. **There is not one simple solution**. Combinations of system components are required for the mitigation of violent reactions**.**

Munition designers need to incorporate IM features into the system design early in the design phase. IM mitigation afterthoughts tend to be less thorough and almost always add weight, reducing performance.

4.3. Booster Explosives

Problem: "There is a lack of qualified insensitive booster explosives."

Solution: Legacy booster explosives typically are pressed, and contain a high concentration of sensitive ingredients, in particular nitramines such as RDX or HMX. PBXN-5 and CH-6 have poor cook-off performance PBXN-7 has good cook-off performance, but lower than desired output for initiating insensitive main charges. PBXW-14 included TATB in the formulation and passed all small-scale characterization tests. It is less sensitive than PBXN-7 and has equivalent performance. More recently, Sandia National Laboratory has developed DAAF (3,3' Diaminoazoxy furazan) [2]. It has the following properties:

Detonation Velocity 7.93 km/s @ ρ= 1.685 g/cm^3	**No impurities, high onset of decomposition**
CJ pressure = 306 kbar	**1-Step process**
Critical diameter < 3mm	**Particle size (~28µm)**
Drop height > 320cm, Friction >36 kg	**Good performance**
Heat of Formation ΔH_f = +106 kcal/mol	**Fast synthesis: 4 Hours**
High pressed density 97% TMD	**Non-hazardous waste**

Table 2. DAAF Properties

OSD counts this as a major success from the JIMTP program. [3].

4.4 Modeling

Problem: "There is an inability to model slow and fast cookoff reactions with sufficient fidelity."

Solution: Enhance the chemistry model in software codes. OSD funds a program each year to the US national laboratories to improve computer models. They have been challenged to predict the violence of reaction of a large rocket motor subjected to thermal insults. Thus far, prediction of reaction violence has not yet been obtained. Onset of runaway reaction is predictable, however. Further work is necessary. The good news is that industry is encouraged to take classes provided by the national laboratories on these increasingly complex models, at little or no cost. Models can be provided to authorized facilities, and technical assistance is freely provided.

4.5 Performance degradation

Problem: "Using less sensitive IM explosives results in performance degradation."

Solution: The industrial community response was to relax the IM requirements, especially with regard to fragment impact and shaped-charge jet impact. I do not see this happening. The problems are not insolvable – just very difficult. Continued work into system solutions will no doubt prevail.

4.6 Pass-Fail Testing

Problem: "IM testing is typically worst on worst and does not allow for incremental improvements. The requirement is all or none –pass or fail. This is a very demanding requirement that pushes off the table a lot of design solutions that move you significantly to the right direction but don't get across the line."

Solution: "A more balanced and system level approach would seem to be warranted." However, it is the opinion of the author that incremental IM improvements are of value, especially where no obvious technology is available. Each IM test is described in a NATO STANAG. (See reference list for citations [7-13].

4.7. Collaboration of Government with Industry

Problem: Until relatively recently, government seemed to want to be in control of IM solutions and industry was pretty much left in the cold.

Solution: Government has seen that industry can be a valuable partner. The National Warheads and Energetics Consortium (NWEC) was started to provide an organization of industry partners working IM solutions. Currently there are over 170 industrial entities that are part of this consortium [4]. The Defense Ordnance Technology Consortium (DOTC) is the government version of this organization [5]. DOTC is a collaborative partnership between the DoD and the NWEC. Commissioned by OSD (AT&L) as a DoD initiative in 2002, DOTC was established to facilitate collaboration between government, industry and academia in the advancement of munitions technologies.

DOTC is available for the use by all service laboratories, program offices, and other agencies for the development and prototyping of advanced concept warheads, energetics, fuzes and other related enabling weapon system technologies. A key feature of DOTC is the Other Transaction Agreement (OTA) that expedites the procurement process outside of the FFAR environment. Proposals to DOTC for funding must include a non-traditional industrial or academic partner – ultimately expanding the breadth of the IM program.

Figure 4 shows the organization of the DOTC. Three technology managers cover the breadth of IM. A call for proposals is developed by the government and promulgated once per year. A unique feature of the DOTC process is that if a proposal is not funded in a particular year, it goes into "the basket" where it remains for 3 years. If a government entity needs something that is in the basket, it can be withdrawn from the basket and quickly funded, since it has already gone through the vetting process.

Figure 5 summarizes the key features of DOTC. As stated earlier, streamlined acquisition is a key feature. Collaboration between industry and government is also facilitated.

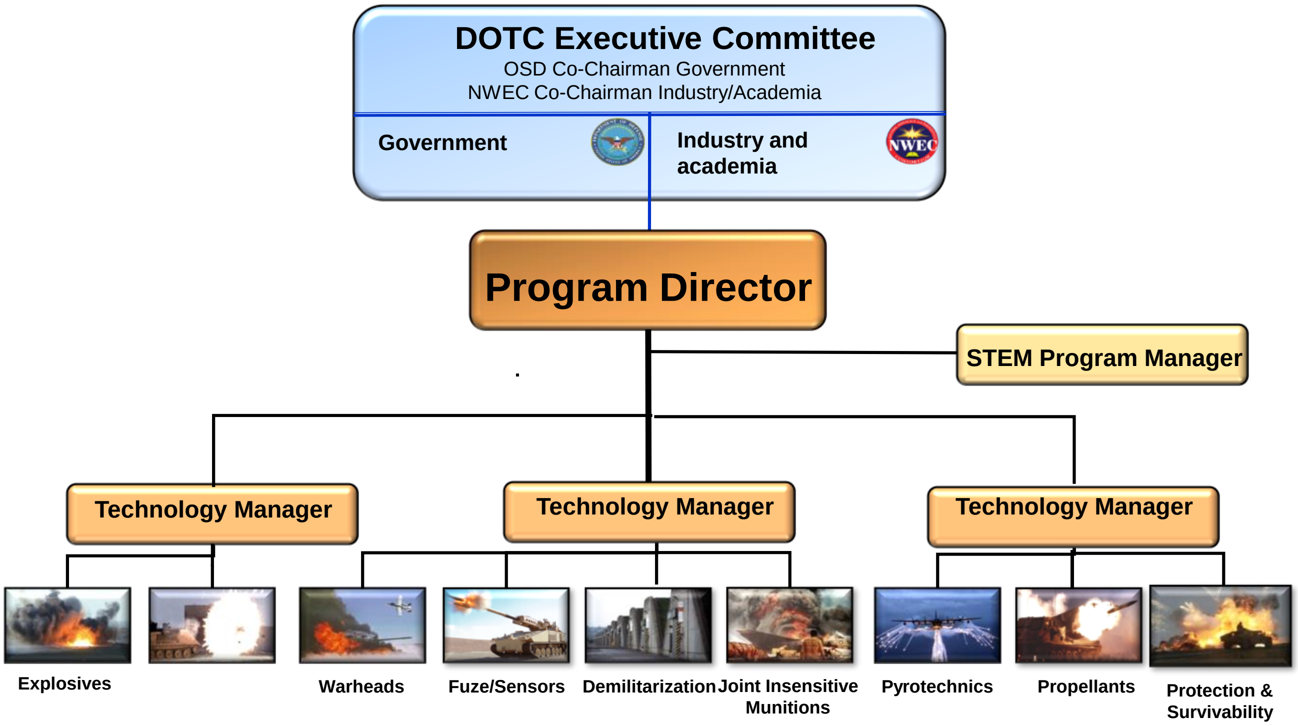


Figure 5. DOTC Organization. Providing enhanced collaboroation with Industry.

FEATURES	BENEFITS
Open Membership	Affords opportunity for all interested members of industry and academia to participate by imposing reasonable membership requirements.
Streamlined Acquisition	Existing contract and flexible business processes reduce duplicative FAR-based upfront contract processes, thus reducing overall development and fielding time for prototype materiel solutions.
Collaborative and Competitive Environment	Enables Government and Consortium members to collaborate in an upfront technology planning process. Consortium members (or teams of members) then compete in response to government Request for Project Proposals in anticipation of technology development funding against the tech development plan/projects. The Government solicits, evaluates, selects and awards.
Targeted Research Investment	Provides Consortium members early insight into technology requirements which in turn allows them to focus their Independent Research and Development (IRAD) resources on items that matter to the Government.
Small Business and Non-traditional Participation	Enables greater participation by small and non-traditional defense contractors that can bring innovative technologies and solutions to both the Government and the Consortium member organizations.
Resource Leveraging	Allows Government and Consortium members to leverage their financial resources and employ each others' facilities, technology and human capital investments to achieve critical mass.
Single-Point Contracting	Reduces proposal preparation, contract award, and congressional reporting burdens on both the Government and Consortium members.
No Protests Allowed	Prohibits formal protests against the Government's project selections/awards.
DoD / Industry, Academia Partnering	Minimizes ordnance technology development duplication across Services, Agencies and Industrial/Academic enterprise components.

Figure 6. DOTC Features.

5.0 RESOURCES

Industry members need access to information on IM mitigation techniques and databases of results of IM tests. For both US and other NATO members, one of the best ways to access this information is through the use of the Munitions Safety Information Analysis Center (MSIAC) in Brussels, Belgium. Once you join, they have numerous databases, and focus officers that specialize in the various areasx of IM. A list of focus officers is provided in Table 3. MSIAC personnel can explain to you how to join and the process for accessing the member site.

In the US, each US service maintains an IM review board, that evaluates IM systems solutions. A good procedure is to brief the appropriate board early in the design phase with proposed IM solutions. The boards are a wealth of information and can help steer you toward acceptable solutions and save much unproductive work. The author can provide contact information.

MSIAC Contact	Area of Expertise	E-mail	Telephone
Roger Swanson	Project Manager	r.swanson@msiac.nato.in	+32 2 707 5495
Michael Longie	System & Database	m.longie@msiac.nato.int	+32 2 707 5583
Thomas Taylor	Munitions Safety, Transport	t.taylor@msiac.nato.int	+32 2 707 5636
Dr. Michael W. Sharp	Munitions Systems	m.sharp@msiac.nato.int	+32 2 707 5558
Dr. Ernst Christian Koch	Energetic Materials	e-c.koch@msiac.nato.int	+32 2 707 5630
Emmanuel Schultz	Propulsion Technology	e.schultz@msiac.nato.int	+32 2 707 5447
Angeline Liekens	Information Specialist	a.liekens@msiac.nato.int	+32 2 707 3947
Manfred Becker	Warhead Technology	m.becker@msiac.nato.int	+32 2 707 5426
DianeVanoverstraeten	Office Manager	d.Vanoverstraeten@msia	+32 2 707 5416

Table 3. MSIAC Contact List

Also in the US, the National Warheads and Energetics Consortium (NWEC) [4] is comprised of traditional and non-traditional government contractors, small and large businesses, for-profit and not-for-profit entities, academic organizations, and their affiliated organizations, to conduct research and development leading to technology demonstrations in the field of warheads and energetics in cooperation with the Government's Defense Ordnance Technology Consortium (DOTC) [5].

Members of the National Warheads and Energetic Consortium receive many benefits, including:

- Industry and academic members have the opportunity to become active partners in the development of ordnance technology requirements and work closely with government program sponsors to develop research and development funding priorities.
- Direct access to government funding sponsors and technology managers as well as information regarding on-going research and development activities, future research and development requirements and strategic visioning.
- The ability to compete for funding executed under Section 845 for Prototypes Other Transactions Agreement that provides greater flexibility than traditional FAR-based contracts. The competition for funding under this agreement is only available to NWEC members in good standing.
- Unparalleled outreach and networking opportunities with other industry and academia members, as well as government stakeholders, during annual membership meetings, technology subcommittee meetings and various other conferences and forums.

Since its establishment, the NWEC membership has grown and diversified. NWEC members research and development efforts are advancing the state-of-the-art of ordnance technologies needed to improve weapon systems and system upgrades to support future war fighting capabilities. If interested in becoming a member, please contact Mr. Bill Ervin at billervin@comcast.net.

Since the "harmonization" of hazard classification and IM, there are tests that satisfy both IM and hazard classification requirements. In the US, a good source of information is the hazard classifier for the particular service that you are designing your system for. The document commonly called "TB 700-2" lists hazard classifiers and their contact information (See Tables 4 and 5)[6].

US Army	US Navy	US Air Force	Dept. of Energy
US Army Technical Center for Explosives Safety 1C Tree Road Building 35 McAlester, OK 74501-9053 ATTN: JMAC-EST	Naval Ordnance Safety and Security Activity Farragut Hall 38217 Strauss Avenue Ste 108 Indian Head, MD 20640-5151	Air Force Safety Center 9700 Avenue G SE Kirtland AFB, NM 87117-5670 ATTN: SEWC	National Nuclear Security Administration Office of Mission Safety PO Box 5400 Albuquerque, NM 87185 ATTN: NNSANA-SH

Table 4. Service Hazard Classification Authorities

US Army			
Explosive Safety Office US Army Research, Development and Engin eering Command Army Research Laboratory Aberdeen Proving Ground, MD 21005-5066 ATTN: FOR-LOA-T	System Safety Office US Army Research, Development and Engineering Center Picatinny, NJ 07806-5000 ATTN: FDAR-QES-C	Safety Office US Army Aviation and Missile Command Redstone Arsenal, AL 35898-5000 ATTN: AMSAM-SF	Safety and Health Office US Army Research, Development and Engineering Command Edgewood Chemical Biological Center 5183 Blackhawk Rd Aberdeen Proving Ground MD 21010-5423 ATTN:FDCB-OPC-RH
US Air Force			
Ogden Air Logistics Center 6033 Bm Lane Bldg 1247 Hill AFB, UT 84056 ATTN: CO-ALC/GHGE	Systems Safety Air Armament Center 1001 North Second Street Suite 366 Eglin AFB,FL 32542-6838 ATTN: AAC/SES		

Table 5. Additional Delegated Hazard Classification Authorities

6.0 SUMMARY AND CONCLUSIONS

For many years, industry seemed to be relatively left out of the IM process. Currently, government relies heavily on industry – prime contractors, large industrial companies, and increasingly on small businesses. The key for industry to make a profit is to consider the whole system and successfully design in IM solutions early in the design phase.

7.0 REFERENCES

[1] United States Code, Title 10, Chapter 141, Section 2389. Ensuring safety regarding insensitive munitions.

[2] Francois, et al., DAAF, {[http://www.dtic.mil/ndia/2007im_em/ABriefs/Francois.pdf}

[3] Gonzalez, JIMTP, http://www.dtic.mil/ndia/2012munitions/JoseGonzalez.pdf

[4] NWEC information, http://www.nwec-dotc.org/membership.html

[5] Geiss, D., DOTC Briefing, private communication.

[6] For the latest hazard classification information, see , Department Of Defense Ammunition And Explosives Hazard Classification Procedures, TB 700–2/NAVSEAINST 8020.8B/TO 11A–1–47/DLAR 8220.1, 30 July 2012.

[7] NATO STANAG 4396, Sympathetic Reaction, Munition Test Procedures

[8] NATO STANAG 4240, Liquid Fuel/External Fire, Munition Test Procedures

[9] NATO STANAG 4382, Slow Heating, Munitions Test Procedures

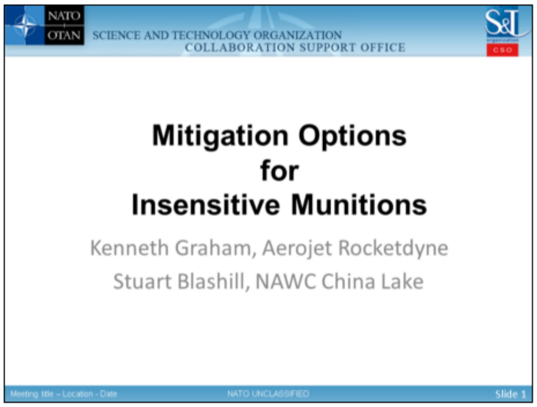
[10] NATO STANAG 4241, Bullet Impact, Munition Test Procedures

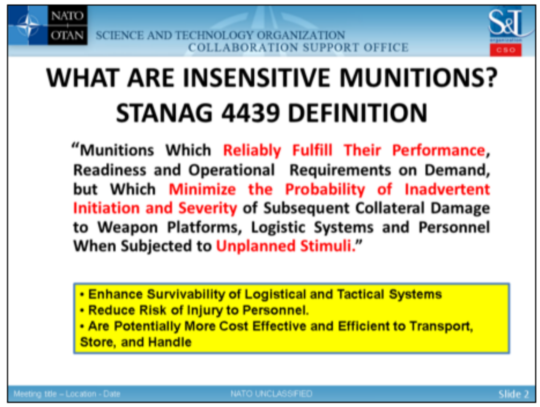
[11] NATO STANAG 4375, Safety Drop Munition Test Procedures

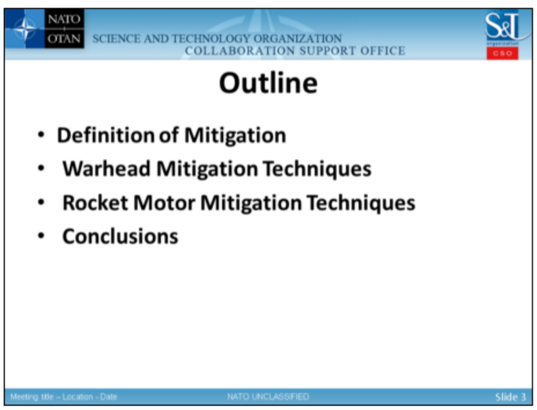
[12] NATO STANAG 4496, Fragment Impact, Munition Test Procedures

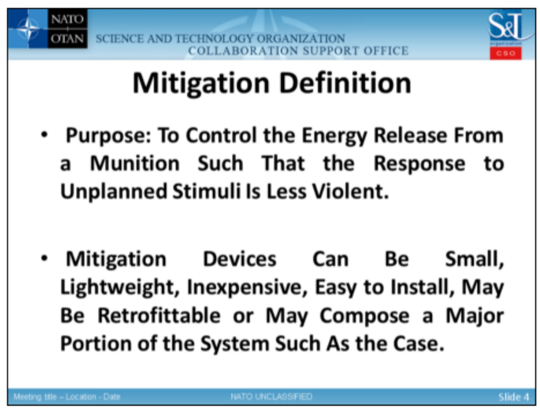
[13] NATO STANAG 4439, Policy for Introduction and Assessment of Insensitive Munitions (IM)

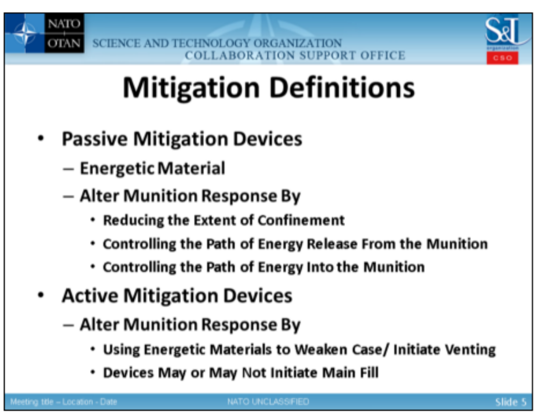
APPENDIX A. MITIGATION METHODS FOR WARHEADS AND ROCKET MOTORS











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WARHEADS

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Warhead Mitigation Techniques

- Reduced Sensitivity Explosive(s)
- Warhead System Design
- Composite Case Design
- Dual Explosive Warhead
- Reactive Case Warhead
- Case Stress Riser Grove
- Warhead Liners
- Venting Holes
- Composite Overwraps
- Shielding
- Bomb Fuze Thermal Protection
- Ordnance Vented Boosters
- Ordnance Flying Platelead/ Boosters

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Composite Case Construction

- Sandwich Layer of Fragmenting Material Between Two Composite Shells
- 2-D Hydrocode Studies Show That Shock Wave Due to Fragment Impact and "Case Slap" Can Be Smeared by Using Layers of Different Materials
- During SD and Fragment Impact, Sandwich Construction Should Break up Causing Further Diffusion of Shock Waves

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Composite Case Construction (cont'd)

- Advantages
  – More Weight Efficient Than an All Steel Warhead Possibly Allowing for Better Missile Kinematics and Range
  – Positive Effect in Preventing Adverse Reaction in Fragment Impact (Results Less Clear for SD and Slow Cookoff)
  – Allows for Alternate Fragment Materials
- Disadvantages
  – Cost

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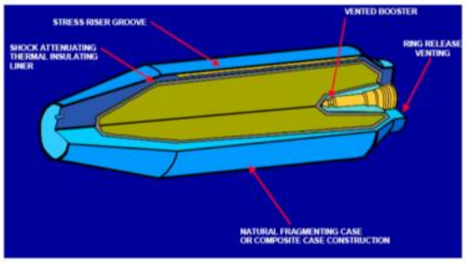
Warhead System IM Design



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Dual Explosive Warhead

- Fabricate Explosive Charge With Outer Layer of Insensitive Explosive and Center Core of High Performance Explosive
- Outer Insensitive Explosive Will Act As an Attenuator to Protect Bulk of Fill From Shock and Impacts With Minimal Reduction in Performance

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Dual Explosive Warhead (cont'd)

- Two Pairs of Explosives Demonstrated in Generic 100 Lb. Warheads
  - Demonstrated SD Compliance With One Explosive Pair – Horizontal / Vertical and Stacked
  - Demonstrated BI/FI Compliance With Second Explosive Pair
  - Minimal Impact on Fragment Velocities or Blast Pressure.
- Adds Cost and Complexity

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Reactive Case Warhead

- Surround the Explosive Charge With Outer Layer of Porous Aluminum Pressed Powder and Reactive Metal Case
- Aluminum Powder Acts As Attenuator to Protect Explosive Fill From Shock and Impacts and Will Contribute to Air Blast With Minimal Reduction in Performance
- Adds Cost and Complexity
- Only Applicable to Selected Warheads.

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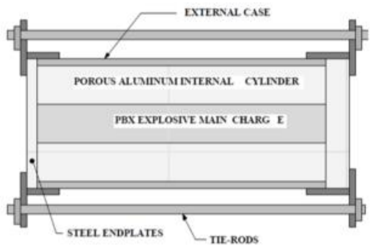
Generic Reactive Case Warhead



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Reactive Case Warhead Test Summary Examples

IM Test	No. Tests	Reactive Case Response	Baseline Comparison
Bullet Impact	2 Tests with 2 Explosives	3 Burns 1 Deflagration	2 Deflagrations 2 Deflagrations
Fragment Impact	5 Tests	3 Explosions 1 Deflagration 1 Burn	4 Detonations 1 Deflagration
Sympathetic Detonation	1 Test	NO Propagation	Propagation Predicted

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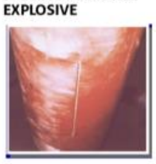
Case Stress Riser Groove

- CUT DEPTH CONTROLLED TO ACHIEVE CONSTANT CASE THICKNESS UNDER CUT
- DESIRED CASE BURST PRESSURE DEPENDENT ON SPECIFIC MAIN FILL EXPLOSIVE
- LOWERS CASE BURST PRESSURE
- CONTROLS CASE FRACTURE
- PRIMARILY USED ON NATURALLY FRAGMENTING WARHEADS



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Warhead Liners

- Warhead Cavities Lined to Prevent Direct Contact Between the Explosive and Case
- Liner May Provide Additional Protection in Shock and Thermal Environments
- Many Types and Applications of Liners Exist
  - Outgassing / Inhibiting Liner Systems
  - Dual Liner Systems
  - Shock Attenuating Liner Systems
  - Energetic Material Liner Systems
  - Microballoon Liners

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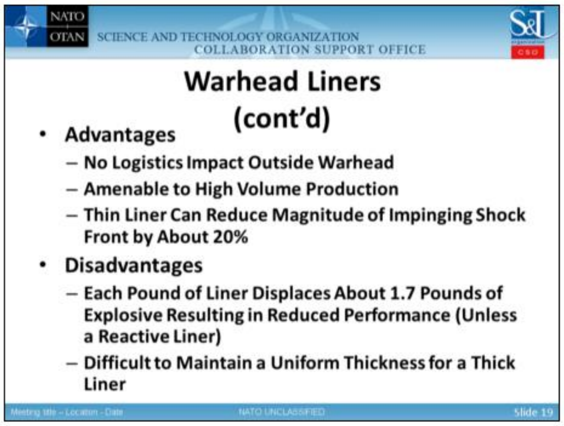
NATO
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COLLABORATION SUPPORT OFFICE
Warhead Liners (cont'd)
• Advantages
– No Logistics Impact Outside Warhead
– Amenable to High Volume Production
– Thin Liner Can Reduce Magnitude of Impinging Shock Front by About 20%
• Disadvantages
– Each Pound of Liner Displaces About 1.7 Pounds of Explosive Resulting in Reduced Performance (Unless a Reactive Liner)
– Difficult to Maintain a Uniform Thickness for a Thick Liner
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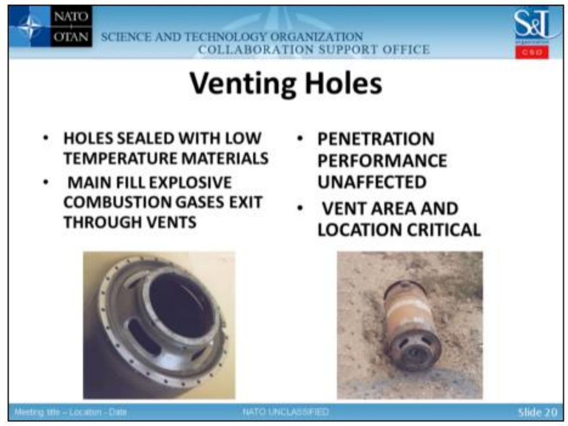
NATO
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COLLABORATION SUPPORT OFFICE
Venting Holes
• HOLES SEALED WITH LOW TEMPERATURE MATERIALS
• MAIN FILL EXPLOSIVE COMBUSTION GASES EXIT THROUGH VENTS
• PENETRATION PERFORMANCE UNAFFECTED
• VENT AREA AND LOCATION CRITICAL
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Composite Base Plates
• Used Extensively in Anti-Air Warhead Designs
• Carry Missile Loads at Operating Temperatures – at Explosive Reaction Temperatures Have Little Strength
– Allows for Easy Venting During Both Slow and Fast Cookoff
• Advantages
– Passive
– Strength Degrades Quickly With Temperature – Glass Transition Temperature ~275° for Many Fiber / Matrix Systems
• Disadvantages
– Cost
– May Not Be Effective If Reaction Begins in the Nose
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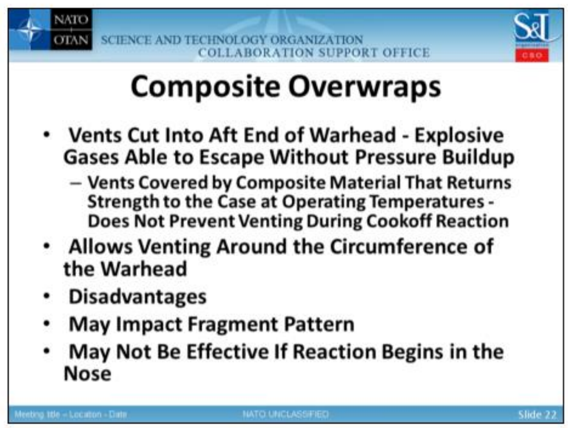
NATO
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COLLABORATION SUPPORT OFFICE
Composite Overwraps
• Vents Cut Into Aft End of Warhead - Explosive Gases Able to Escape Without Pressure Buildup
– Vents Covered by Composite Material That Returns Strength to the Case at Operating Temperatures - Does Not Prevent Venting During Cookoff Reaction
• Allows Venting Around the Circumference of the Warhead
• Disadvantages
• May Impact Fragment Pattern
• May Not Be Effective If Reaction Begins in the Nose
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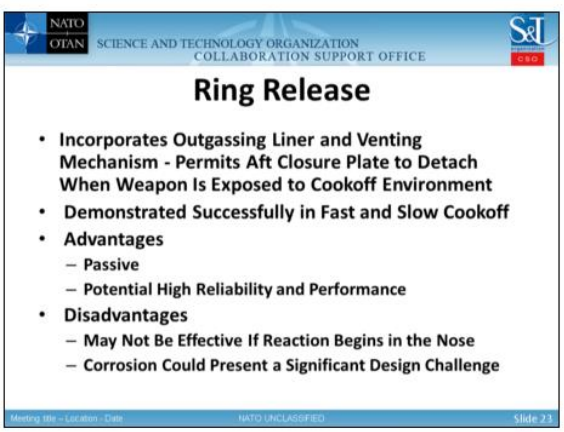
NATO
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COLLABORATION SUPPORT OFFICE
Ring Release
• Incorporates Outgassing Liner and Venting Mechanism - Permits Aft Closure Plate to Detach When Weapon Is Exposed to Cookoff Environment
• Demonstrated Successfully in Fast and Slow Cookoff
• Advantages
– Passive
– Potential High Reliability and Performance
• Disadvantages
– May Not Be Effective If Reaction Begins in the Nose
– Corrosion Could Present a Significant Design Challenge
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Shielding / Container Hardening
• Shock Mitigation
• Can Break Donor Warhead Fragments Into Small Pieces
• Reduced Fragment Velocities
Warhead Shield Filled With Shock Absorbing Material
SIDE SHIELDING
Shielded Metal Containers
Fins And Wings As Container Shielding
Meeting title – Location - Date
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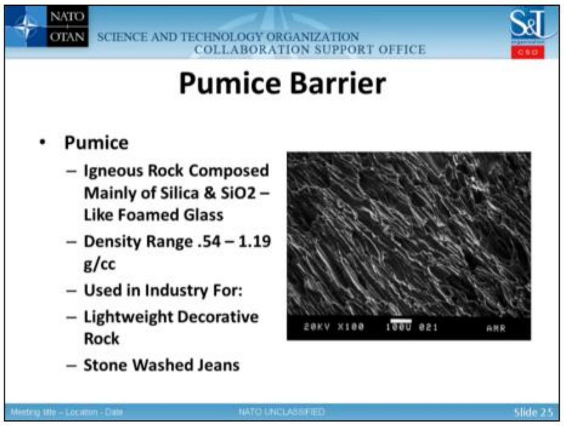
NATO
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COLLABORATION SUPPORT OFFICE
Pumice Barrier
• Pumice
– Igneous Rock Composed Mainly of Silica & SiO2 – Like Foamed Glass
– Density Range .54 – 1.19 g/cc
– Used in Industry For:
– Lightweight Decorative Rock
– Stone Washed Jeans
20KV X100 100U 021 AMR
Meeting title – Location - Date
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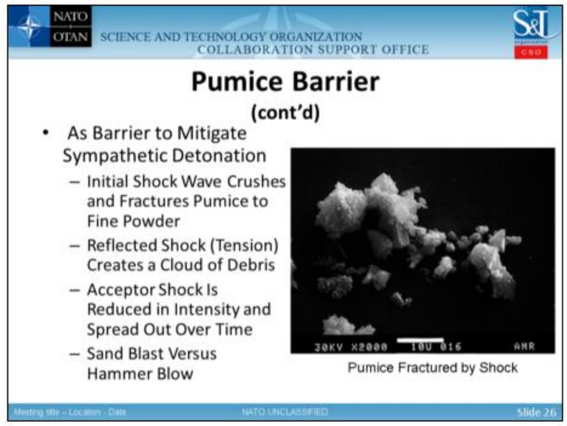
NATO
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COLLABORATION SUPPORT OFFICE
Pumice Barrier
(cont'd)
• As Barrier to Mitigate Sympathetic Detonation
– Initial Shock Wave Crushes and Fractures Pumice to Fine Powder
– Reflected Shock (Tension) Creates a Cloud of Debris
– Acceptor Shock Is Reduced in Intensity and Spread Out Over Time
– Sand Blast Versus Hammer Blow
30KV X2000 10U 016 AMR
Pumice Fractured by Shock
Meeting title – Location - Date
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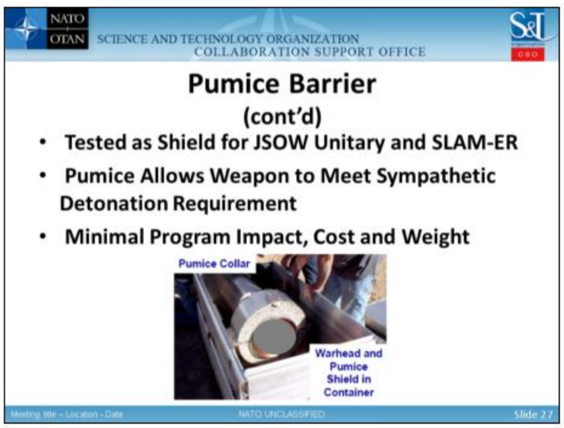
NATO
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COLLABORATION SUPPORT OFFICE
Pumice Barrier
(cont'd)
• Tested as Shield for JSOW Unitary and SLAM-ER
• Pumice Allows Weapon to Meet Sympathetic Detonation Requirement
• Minimal Program Impact, Cost and Weight
Pumice Collar
Warhead and Pumice Shield in Container
Meeting title – Location - Date
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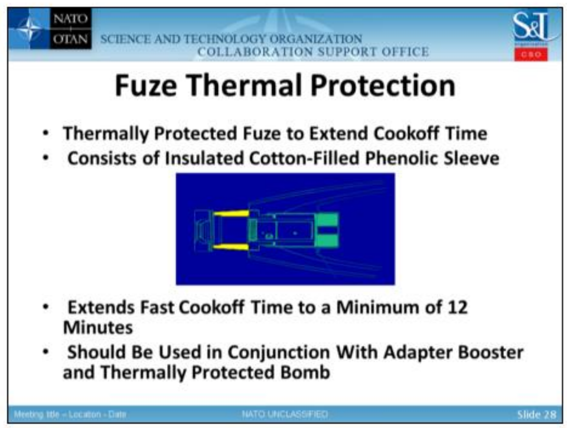
Slide 27


NATO
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COLLABORATION SUPPORT OFFICE
Fuze Thermal Protection
• Thermally Protected Fuze to Extend Cookoff Time
• Consists of Insulated Cotton-Filled Phenolic Sleeve
• Extends Fast Cookoff Time to a Minimum of 12 Minutes
• Should Be Used in Conjunction With Adapter Booster and Thermally Protected Bomb
Meeting title – Location - Date
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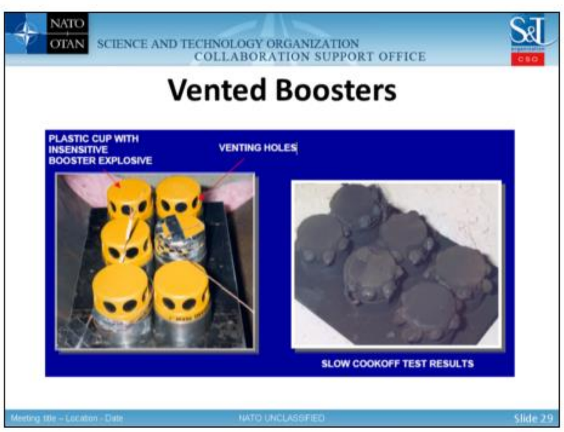
Slide 28


NATO
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COLLABORATION SUPPORT OFFICE
Vented Boosters
PLASTIC CUP WITH INSENSITIVE BOOSTER EXPLOSIVE
VENTING HOLES
SLOW COOKOFF TEST RESULTS
Meeting title – Location - Date
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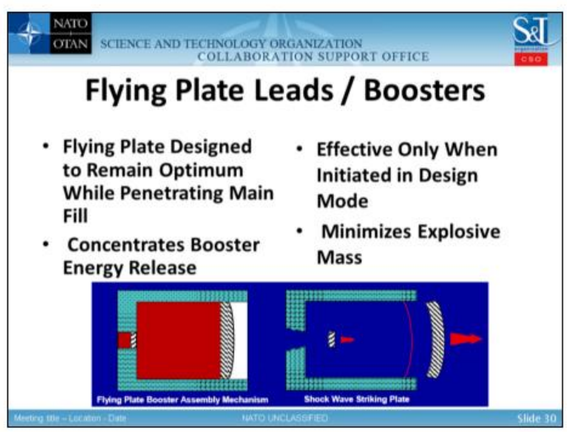
Slide 29


NATO
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COLLABORATION SUPPORT OFFICE
Flying Plate Leads / Boosters
• Flying Plate Designed to Remain Optimum While Penetrating Main Fill
• Concentrates Booster Energy Release
• Effective Only When Initiated in Design Mode
• Minimizes Explosive Mass
Flying Plate Booster Assembly Mechanism
Shock Wave Striking Plate
Meeting title – Location - Date
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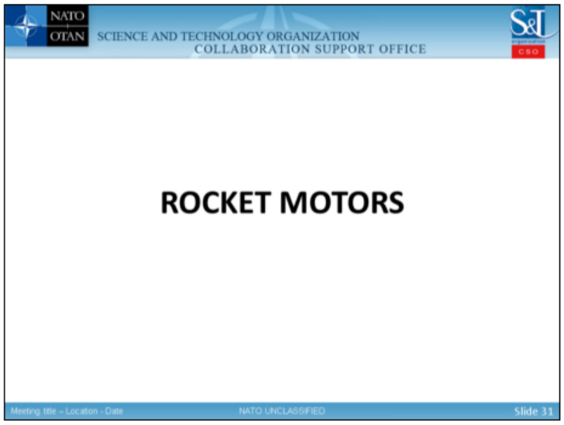
NATO
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COLLABORATION SUPPORT OFFICE
ROCKET MOTORS
Meeting title – Location - Date
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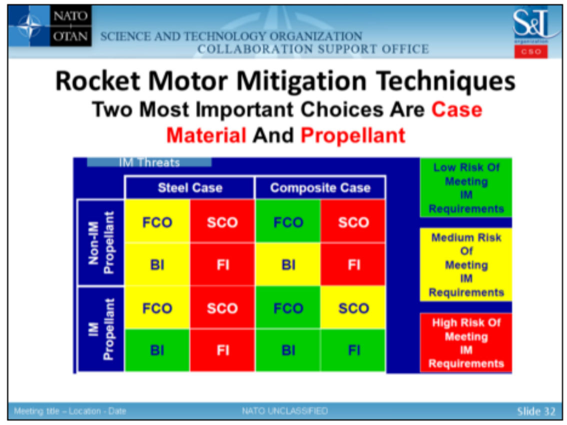
NATO
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COLLABORATION SUPPORT OFFICE
Rocket Motor Mitigation Techniques
Two Most Important Choices Are Case Material And Propellant
IM Threats
Steel Case
Composite Case
Non-IM Propellant
IM Propellant
FCO SCO FCO SCO
BI FI BI FI
FCO SCO FCO SCO
BI FI BI FI
Low Risk Of Meeting IM Requirements
Medium Risk Of Meeting IM Requirements
High Risk Of Meeting IM Requirements
Meeting title – Location - Date
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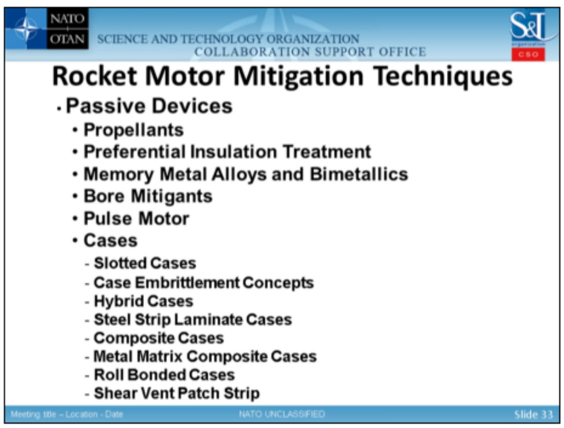
NATO
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COLLABORATION SUPPORT OFFICE
Rocket Motor Mitigation Techniques
• Passive Devices
• Propellants
• Preferential Insulation Treatment
• Memory Metal Alloys and Bimetallics
• Bore Mitigants
• Pulse Motor
• Cases
- Slotted Cases
- Case Embrittlement Concepts
- Hybrid Cases
- Steel Strip Laminate Cases
- Composite Cases
- Metal Matrix Composite Cases
- Roll Bonded Cases
- Shear Vent Patch Strip
Meeting title – Location - Date
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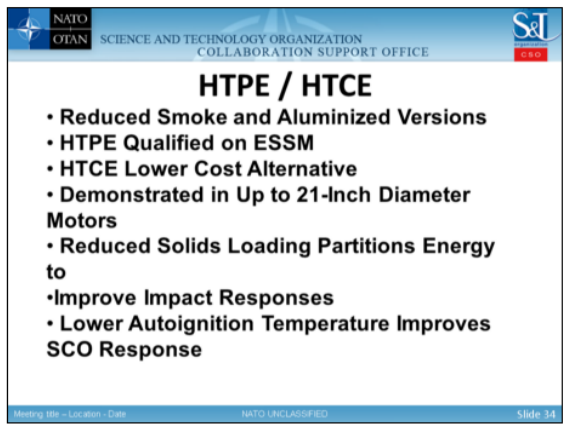
NATO
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COLLABORATION SUPPORT OFFICE
HTPE / HTCE
• Reduced Smoke and Aluminized Versions
• HTPE Qualified on ESSM
• HTCE Lower Cost Alternative
• Demonstrated in Up to 21-Inch Diameter Motors
• Reduced Solids Loading Partitions Energy to
•Improve Impact Responses
• Lower Autoignition Temperature Improves SCO Response
Meeting title – Location - Date
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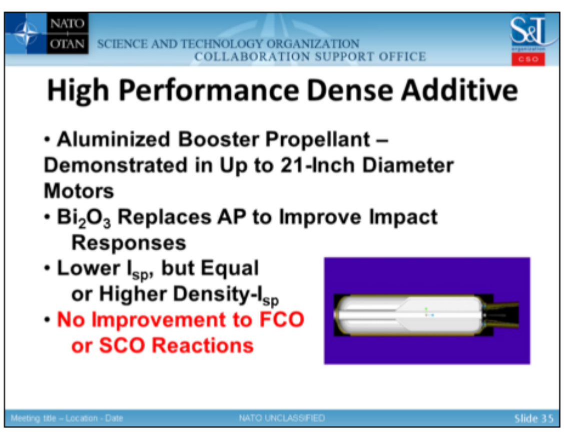
NATO
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COLLABORATION SUPPORT OFFICE
High Performance Dense Additive
• Aluminized Booster Propellant – Demonstrated in Up to 21-Inch Diameter Motors
• Bi_2O_3 Replaces AP to Improve Impact Responses
• Lower I_{sp}, but Equal or Higher Density-I_{sp}
• No Improvement to FCO or SCO Reactions
Meeting title – Location - Date
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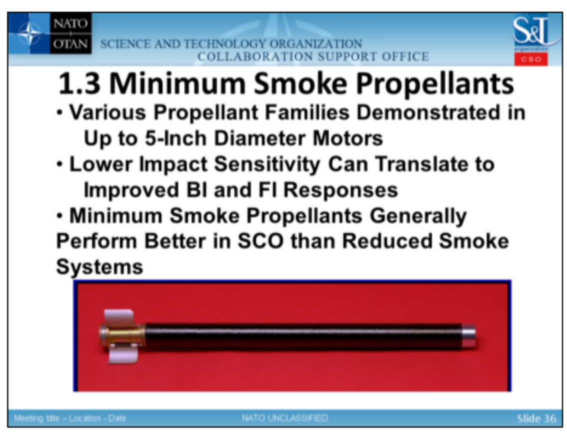
NATO
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COLLABORATION SUPPORT OFFICE
1.3 Minimum Smoke Propellants
• Various Propellant Families Demonstrated in Up to 5-Inch Diameter Motors
• Lower Impact Sensitivity Can Translate to Improved BI and FI Responses
• Minimum Smoke Propellants Generally Perform Better in SCO than Reduced Smoke Systems
Meeting title – Location - Date
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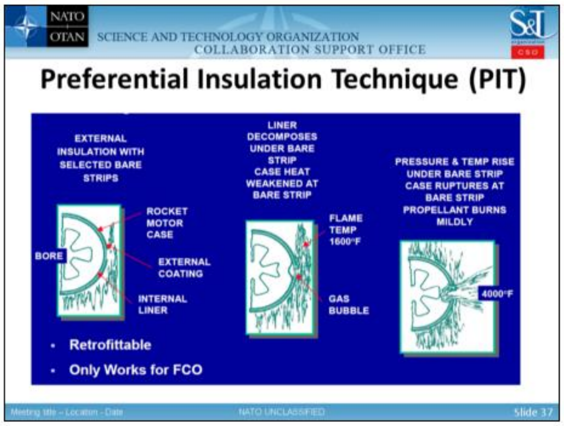
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Preferential Insulation Technique (PIT)
EXTERNAL INSULATION WITH SELECTED BARE STRIPS
ROCKET MOTOR CASE
BORE
EXTERNAL COATING
INTERNAL LINER
LINER DECOMPOSES UNDER BARE STRIP CASE HEAT WEAKENED AT BARE STRIP
FLAME TEMP 1600°F
GAS BUBBLE
PRESSURE & TEMP RISE UNDER BARE STRIP CASE RUPTURES AT BARE STRIP PROPELLANT BURNS MILDLY
4000°F
• Retrofittable
• Only Works for FCO
Meeting title – Location - Date
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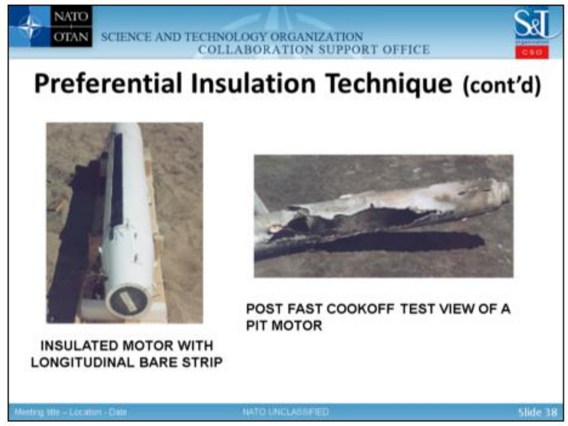
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Preferential Insulation Technique (cont'd)
INSULATED MOTOR WITH LONGITUDINAL BARE STRIP
POST FAST COOKOFF TEST VIEW OF A PIT MOTOR
Meeting title – Location - Date
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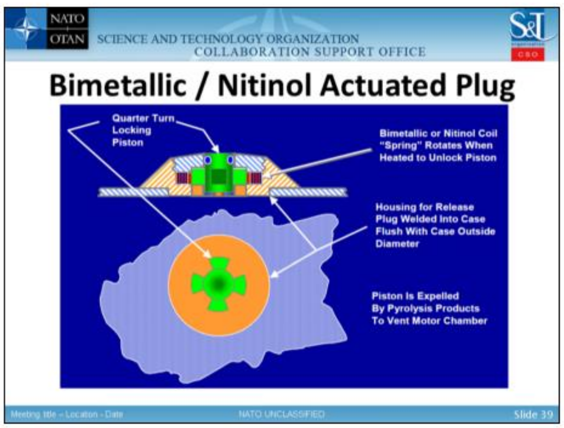
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Bimetallic / Nitinol Actuated Plug
Quarter Turn Locking Piston
Bimetallic or Nitinol Coil "Spring" Rotates When Heated to Unlock Piston
Housing for Release Plug Welded Into Case Flush With Case Outside Diameter
Piston Is Expelled By Pyrolysis Products To Vent Motor Chamber
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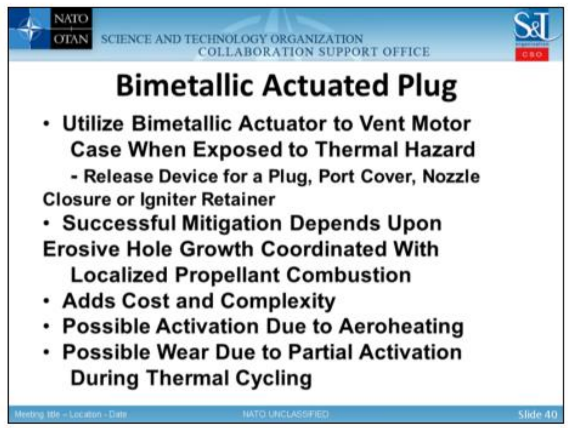
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Bimetallic Actuated Plug
• Utilize Bimetallic Actuator to Vent Motor Case When Exposed to Thermal Hazard
- Release Device for a Plug, Port Cover, Nozzle Closure or Igniter Retainer
• Successful Mitigation Depends Upon Erosive Hole Growth Coordinated With Localized Propellant Combustion
• Adds Cost and Complexity
• Possible Activation Due to Aeroheating
• Possible Wear Due to Partial Activation During Thermal Cycling
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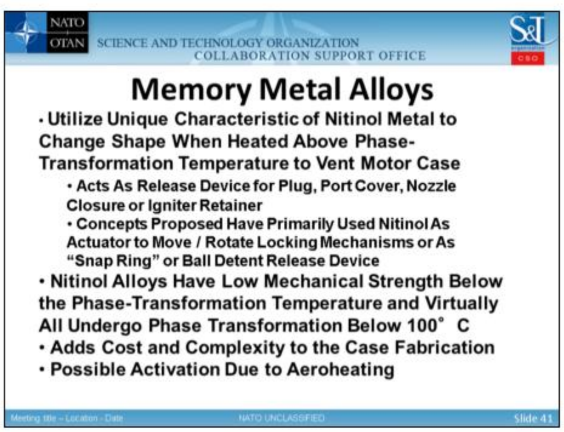
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Memory Metal Alloys
• Utilize Unique Characteristic of Nitinol Metal to Change Shape When Heated Above Phase-Transformation Temperature to Vent Motor Case
• Acts As Release Device for Plug, Port Cover, Nozzle Closure or Igniter Retainer
• Concepts Proposed Have Primarily Used Nitinol As Actuator to Move / Rotate Locking Mechanisms or As "Snap Ring" or Ball Detent Release Device
• Nitinol Alloys Have Low Mechanical Strength Below the Phase-Transformation Temperature and Virtually All Undergo Phase Transformation Below 100° C
• Adds Cost and Complexity to the Case Fabrication
• Possible Activation Due to Aeroheating
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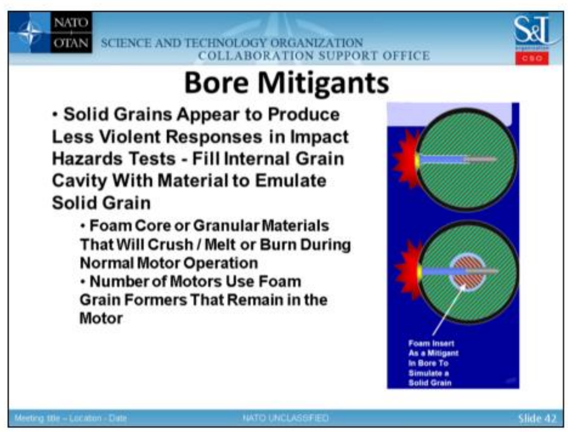
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Bore Mitigants
• Solid Grains Appear to Produce Less Violent Responses in Impact Hazards Tests - Fill Internal Grain Cavity With Material to Emulate Solid Grain
• Foam Core or Granular Materials That Will Crush / Melt or Burn During Normal Motor Operation
• Number of Motors Use Foam Grain Formers That Remain in the Motor
Foam Insert As a Mitigant In Bore To Simulate a Solid Grain
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Bore Mitigants (cont'd)

- Subscale Impact Testing (BVR) Indicates That Materials With Density Greater Than 0.1 Appear to Be Effective
- Bullet Impact Tests on 8-Inch Motors Inconclusive
- Bullet Impact Tests on 2.75 Inch Motors Show Reduction in Violence
- Mitigant Must Be Tailored for Ignition Transient Desired

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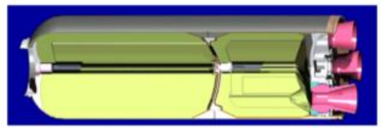
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE

Pulse Motor

- Hard-Barrier Between Propellant Grains Partitions Energy
- Can Force One of the Grains to a FCO-Type Reaction



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NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE

Slotted Steel Cases

- Preferentially Weaken Motor Chamber by Slots That Can Contribute to Crack Propagation in Impact Tests and Provide Venting in Thermal Hazards Tests
  - Series of Slots Would Be Machined or Chemically Milled Into the Motor Chamber in the Longitudinal Direction
  - Slots Filled With a Polymer Material
  - Replacement Structure May or May Not Be Required Depending on the Case Strength
  - Slots Vent to Reduce Case Confinement and Prevent Pyrolysis Products From Crushing the Propellant Grain

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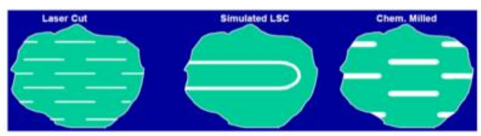
Slotted Steel Cases (cont'd)

- Prototype Motors Have Been Tested From 2.75-Inch to 14 Inches Diameter
  - Virtually All Tests Have Demonstrated Some Reduction in Reaction Violence to All IM Environments
- Requires Extensive Engineering to Customize the Process to Any Specific Rocket Motor



Meeting title – Location - Date NATO UNCLASSIFIED Slide 46

NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE

Case Embrittlement Concepts

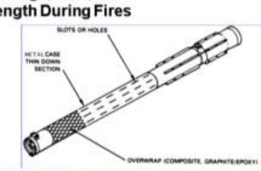
- Utilize Chemical Agent to Embrittle or Weaken Motor Case When Heated by a Thermal Threat
  - Sealed Container Filled With Suitable Agent Designed to Dispense Agent in Contact With the Motor Case When Exposed to FCO and SCO Environments
  - Mercury, Cadmium, and Zinc Embrittle Steel
  - Gallium and Mercury Embrittle Aluminum
- Number of Preliminary Tests Run to Locate Suitable Candidate Agents
  - None Were Found to Be Promising for Steel
  - Gallium Tested Against Aluminum Plate Samples and a Crude Dispensing Device Was Tested Without Success

Meeting title – Location - Date NATO UNCLASSIFIED Slide 47

NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE

Hybrid Cases

- Use Combination of Metal and Composite Materials to Minimize Confinement During Fast Cookoff, Slow Cookoff, and After Impact Events
  - Enables Attachment of Lugs, Fins, etc. to Metal With Loss of Composite Strength During Fires
  - Thin Metal Tube With / Without Slots
  - Slots Establish Critical Crack Length



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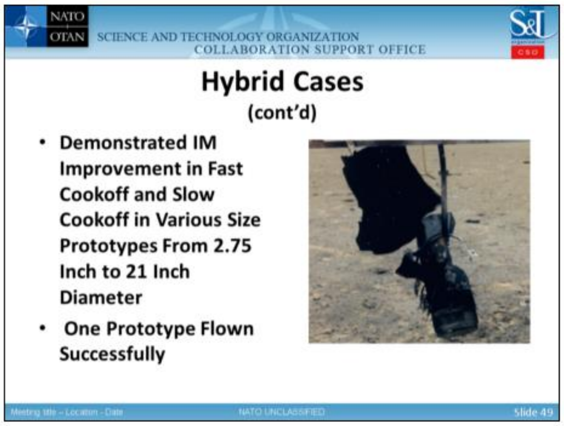
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Hybrid Cases
(cont'd)
• Demonstrated IM Improvement in Fast Cookoff and Slow Cookoff in Various Size Prototypes From 2.75 Inch to 21 Inch Diameter
• One Prototype Flown Successfully
Meeting title – Location - Date
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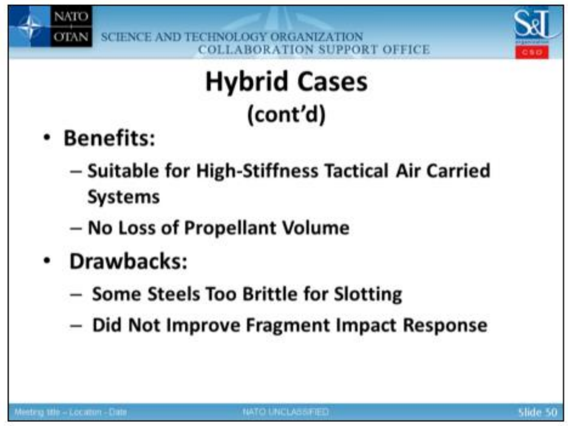
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Hybrid Cases
(cont'd)
• Benefits:
– Suitable for High-Stiffness Tactical Air Carried Systems
– No Loss of Propellant Volume
• Drawbacks:
– Some Steels Too Brittle for Slotting
– Did Not Improve Fragment Impact Response
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NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Steel Strip Laminate Motor Case
BONDED AFT END RING
STRIP LAMINATE TUBE
BONDED FORWARD END RING
• Demonstrated in 8" Generic Motors and a Variety of Prototypes for U.S. Systems Used by UK
• In UK Fleet
• Works for Fast Cook Off and Slow Cookoff
• Drawbacks
– Cost
– Not For All Propellant / Case Combinations
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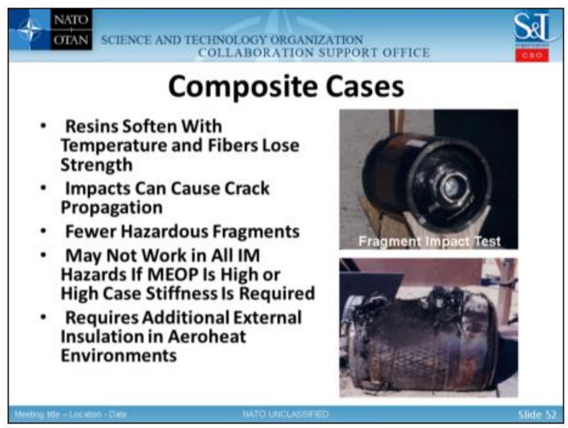
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Composite Cases
• Resins Soften With Temperature and Fibers Lose Strength
• Impacts Can Cause Crack Propagation
• Fewer Hazardous Fragments
• May Not Work in All IM Hazards If MEOP Is High or High Case Stiffness Is Required
• Requires Additional External Insulation in Aeroheat Environments
Fragment Impact Test
Meeting title – Location - Date
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NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Composite Case Captive Carry Qualification Program (C4Q)
• Developed Process to Qualify Composite Airframe Rocket Motor for Carriage and Release from Navy Aircraft
• Integrated Existing 6.2-Level Technology
• Performed Developmental and Environmental
• Testing
• Obtained Flight Clearance
• Demonstrated Composite Performance in Captive Carry Flight Tested
Meeting title – Location - Date
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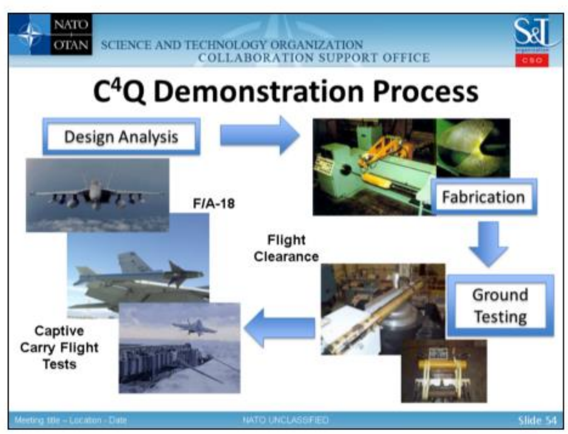
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
C4Q Demonstration Process
Design Analysis
Fabrication
F/A-18
Flight Clearance
Ground Testing
Captive Carry Flight Tests
Meeting title – Location - Date
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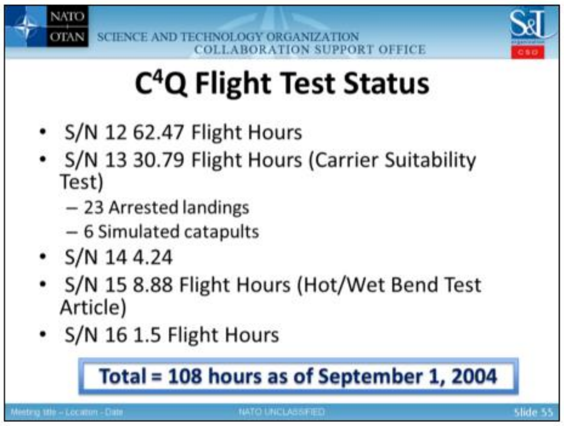
Slide 54


NATO
OTAN
SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
C4Q Flight Test Status
• S/N 12 62.47 Flight Hours
• S/N 13 30.79 Flight Hours (Carrier Suitability Test)
– 23 Arrested landings
– 6 Simulated catapults
• S/N 14 4.24
• S/N 15 8.88 Flight Hours (Hot/Wet Bend Test Article)
• S/N 16 1.5 Flight Hours
Total = 108 hours as of September 1, 2004
Meeting title – Location - Date
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COLLABORATION SUPPORT OFFICE
Metal Matrix Composite Case
• Aluminum with Nextel® Fibers
• Developed for and Tested in Gun-launch Configuration
– One Motor Static Tested
– One Motor Proof Tested to Equivalent of 12,000g Gun Launch Loads
– Passed BI and FCO
• Under Investigation for Other Applications
Metal Matrix Case
High Pressure Nozzle Assembly
End Burning Propellant Grain
Meeting title – Location - Date
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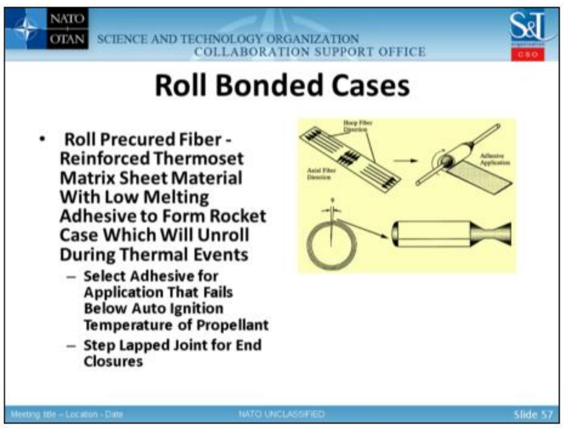
NATO
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COLLABORATION SUPPORT OFFICE
Roll Bonded Cases
• Roll Precured Fiber - Reinforced Thermoset Matrix Sheet Material With Low Melting Adhesive to Form Rocket Case Which Will Unroll During Thermal Events
– Select Adhesive for Application That Fails Below Auto Ignition Temperature of Propellant
– Step Lapped Joint for End Closures
Meeting title – Location - Date
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COLLABORATION SUPPORT OFFICE
Roll Bonded Cases (cont'd)
• 8" Cylindrical Analog Motors Fabricated With a Case Burst Pressure of 3650 PSI
– Lap Joint Bonded End Closure
– Subjected to Cookoff Testing
– Did Unwrap in Temperature Range of Interest (250F - 350F)
• Inexpensive Manufacturing Process
• Drawbacks:
– Additional Work on End Closures and Adhesives Required
– Unsuitable for Small Systems Due to Prepreg Stiffness
– Aeroheating Considerations May Prohibit Use on Air Launched Systems
Meeting title – Location - Date
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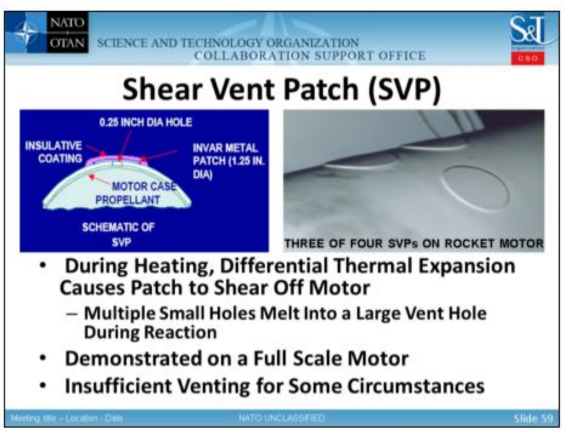
NATO
OTAN
SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Shear Vent Patch (SVP)
0.25 INCH DIA HOLE
INSULATIVE COATING
INVAR METAL PATCH (1.25 IN. DIA)
MOTOR CASE
PROPELLANT
SCHEMATIC OF SVP
THREE OF FOUR SVPs ON ROCKET MOTOR
• During Heating, Differential Thermal Expansion Causes Patch to Shear Off Motor
– Multiple Small Holes Melt Into a Large Vent Hole During Reaction
• Demonstrated on a Full Scale Motor
• Insufficient Venting for Some Circumstances
Meeting title – Location - Date
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NATO
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SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Rocket Motor Mitigation Techniques
• Active Devices
– Thermally Initiated Vent System (TIVS)
– Explosive Bolts
– Impact Switches
– Thermal Switches
– Case Bar Cutter
– External Thermite Case Penetrator
– Internal Thermite Case Penetrator
– Explosive Case Separator
– Multihazard Threat Mitigation System
Meeting title – Location - Date
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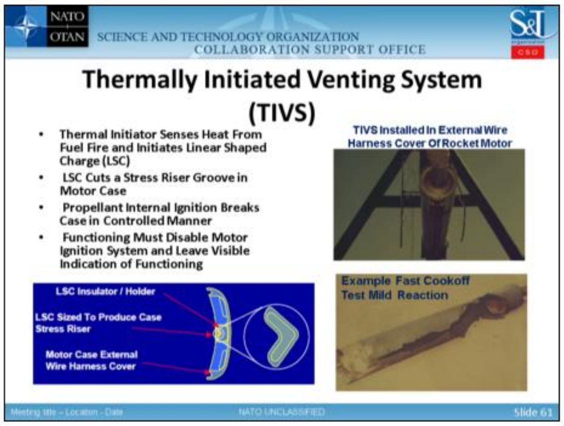
NATO
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COLLABORATION SUPPORT OFFICE
Thermally Initiated Venting System (TIVS)
• Thermal Initiator Senses Heat From Fuel Fire and Initiates Linear Shaped Charge (LSC)
• LSC Cuts a Stress Riser Groove in Motor Case
• Propellant Internal Ignition Breaks Case in Controlled Manner
• Functioning Must Disable Motor Ignition System and Leave Visible Indication of Functioning
TIVS Installed In External Wire Harness Cover Of Rocket Motor
LSC Insulator / Holder
LSC Sized To Produce Case Stress Riser
Motor Case External Wire Harness Cover
Example Fast Cookoff Test Mild Reaction
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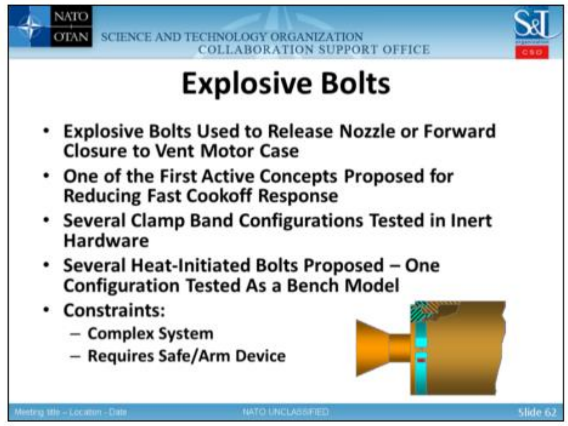
NATO
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COLLABORATION SUPPORT OFFICE
Explosive Bolts
• Explosive Bolts Used to Release Nozzle or Forward Closure to Vent Motor Case
• One of the First Active Concepts Proposed for Reducing Fast Cookoff Response
• Several Clamp Band Configurations Tested in Inert Hardware
• Several Heat-Initiated Bolts Proposed – One Configuration Tested As a Bench Model
• Constraints:
– Complex System
– Requires Safe/Arm Device
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COLLABORATION SUPPORT OFFICE
Piezoelectric Impact Sensor
• Sense Bullet and Fragment Impact As Elastic Stress Waves Within Steel Case Structure to Function LSC to Vent Case
– Piezoelectric Shock Transducer Responds to Fracture of the Case and Supplies a Signal to Solid State Switch
– Switch Supplies Power From High Energy Density Battery to Electric Initiator and Functions the LSC
• Prototype System Demonstrated on 8-Inch Steel-Cased Rocket Motor by Subjecting the Unit to a 20 mm Bullet Impact Test - Response Was Mild Burn
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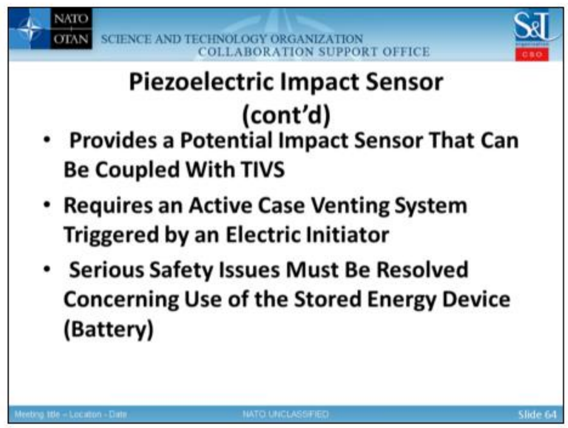
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COLLABORATION SUPPORT OFFICE
Piezoelectric Impact Sensor (cont'd)
• Provides a Potential Impact Sensor That Can Be Coupled With TIVS
• Requires an Active Case Venting System Triggered by an Electric Initiator
• Serious Safety Issues Must Be Resolved Concerning Use of the Stored Energy Device (Battery)
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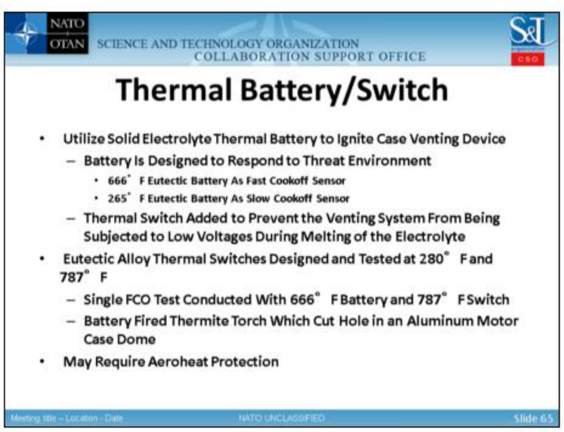
NATO
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SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Thermal Battery/Switch
• Utilize Solid Electrolyte Thermal Battery to Ignite Case Venting Device
– Battery Is Designed to Respond to Threat Environment
• 666° F Eutectic Battery As Fast Cookoff Sensor
• 265° F Eutectic Battery As Slow Cookoff Sensor
– Thermal Switch Added to Prevent the Venting System From Being Subjected to Low Voltages During Melting of the Electrolyte
• Eutectic Alloy Thermal Switches Designed and Tested at 280° F and 787° F
– Single FCO Test Conducted With 666° F Battery and 787° F Switch
– Battery Fired Thermite Torch Which Cut Hole in an Aluminum Motor Case Dome
• May Require Aeroheat Protection
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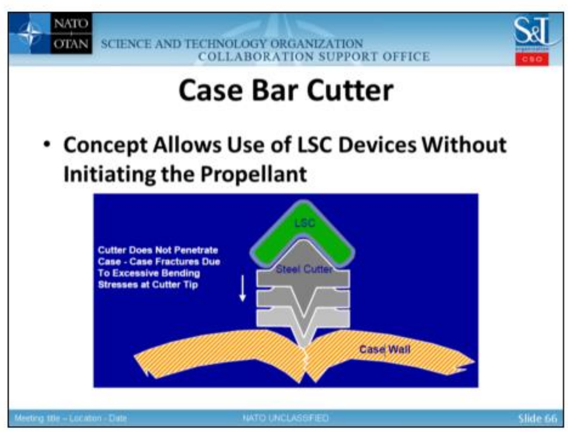
NATO
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SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Case Bar Cutter
• Concept Allows Use of LSC Devices Without Initiating the Propellant
LSC
Cutter Does Not Penetrate Case - Case Fractures Due To Excessive Bending Stresses at Cutter Tip
Steel Cutter
Case Wall
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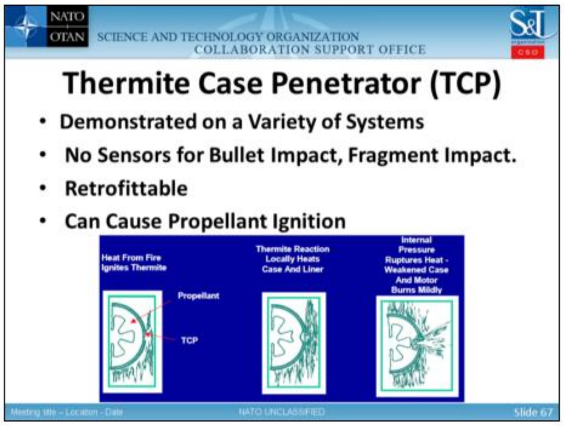
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Thermite Case Penetrator (TCP)
• Demonstrated on a Variety of Systems
• No Sensors for Bullet Impact, Fragment Impact.
• Retrofittable
• Can Cause Propellant Ignition
Heat From Fire Ignites Thermite
Propellant
TCP
Thermite Reaction Locally Heats Case And Liner
Internal Pressure Ruptures Heat - Weakened Case And Motor Burns Mildly
Meeting title – Location - Date
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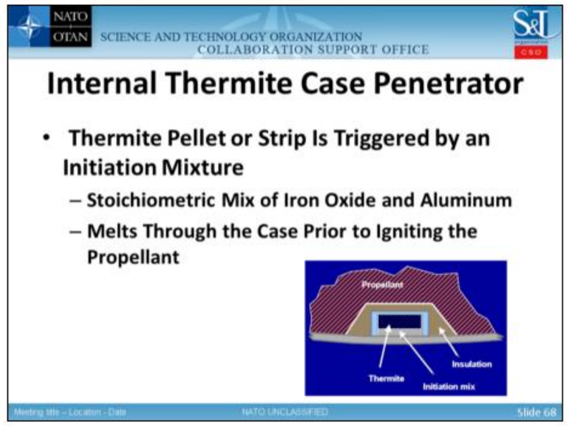
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Internal Thermite Case Penetrator
• Thermite Pellet or Strip Is Triggered by an Initiation Mixture
– Stoichiometric Mix of Iron Oxide and Aluminum
– Melts Through the Case Prior to Igniting the Propellant
Propellant
Insulation
Thermite
Initiation mix
Meeting title – Location - Date
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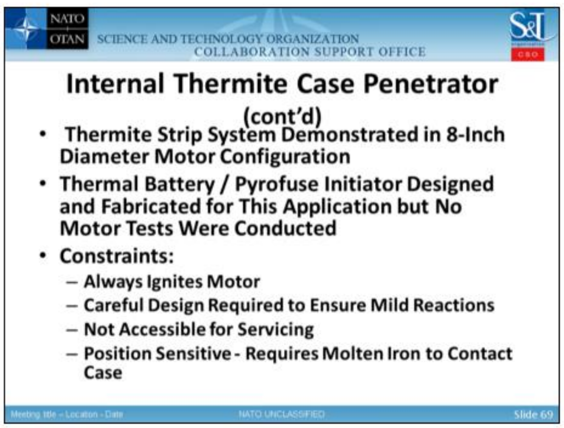
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Internal Thermite Case Penetrator (cont'd)
• Thermite Strip System Demonstrated in 8-Inch Diameter Motor Configuration
• Thermal Battery / Pyrofuse Initiator Designed and Fabricated for This Application but No Motor Tests Were Conducted
• Constraints:
– Always Ignites Motor
– Careful Design Required to Ensure Mild Reactions
– Not Accessible for Servicing
– Position Sensitive - Requires Molten Iron to Contact Case
Meeting title – Location - Date
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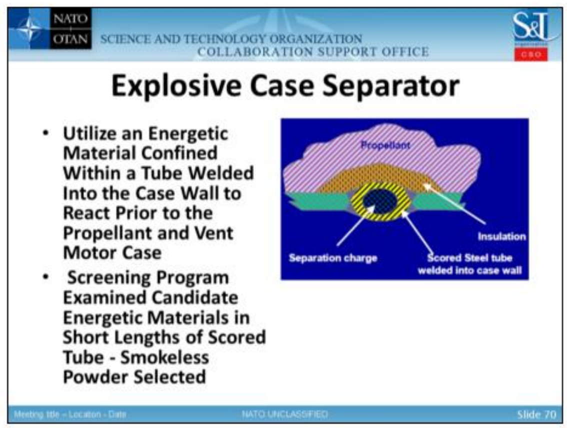
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Explosive Case Separator
• Utilize an Energetic Material Confined Within a Tube Welded Into the Case Wall to React Prior to the Propellant and Vent Motor Case
• Screening Program Examined Candidate Energetic Materials in Short Lengths of Scored Tube - Smokeless Powder Selected
Propellant
Insulation
Separation charge
Scored Steel tube welded into case wall
Meeting title – Location - Date
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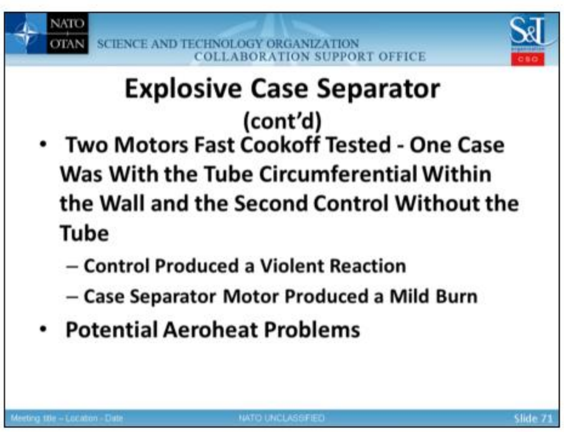
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Explosive Case Separator (cont'd)
• Two Motors Fast Cookoff Tested - One Case Was With the Tube Circumferential Within the Wall and the Second Control Without the Tube
– Control Produced a Violent Reaction
– Case Separator Motor Produced a Mild Burn
• Potential Aeroheat Problems
Meeting title – Location - Date
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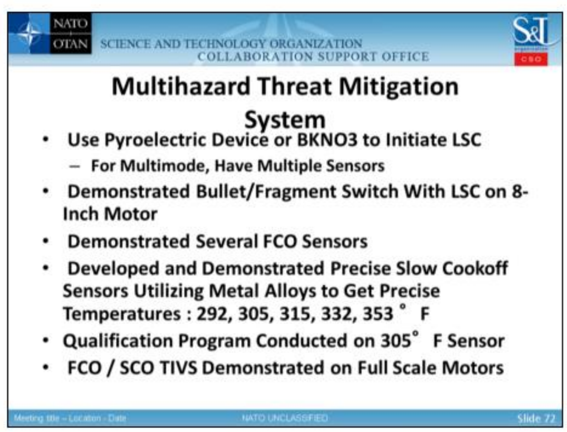
NATO OTAN SCIENCE AND TECHNOLOGY ORGANIZATION COLLABORATION SUPPORT OFFICE
Multihazard Threat Mitigation System
• Use Pyroelectric Device or BKNO3 to Initiate LSC
– For Multimode, Have Multiple Sensors
• Demonstrated Bullet/Fragment Switch With LSC on 8-Inch Motor
• Demonstrated Several FCO Sensors
• Developed and Demonstrated Precise Slow Cookoff Sensors Utilizing Metal Alloys to Get Precise Temperatures : 292, 305, 315, 332, 353 ° F
• Qualification Program Conducted on 305° F Sensor
• FCO / SCO TIVS Demonstrated on Full Scale Motors
Meeting title – Location - Date
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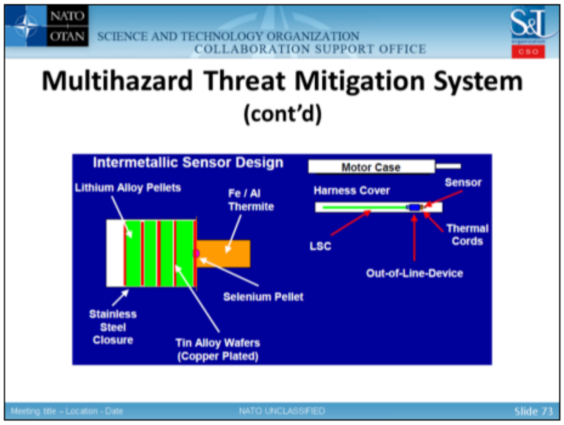
SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Multihazard Threat Mitigation System
(cont'd)
Intermetallic Sensor Design
Lithium Alloy Pellets
Fe / Al Thermite
Selenium Pellet
Stainless Steel Closure
Tin Alloy Wafers (Copper Plated)
Motor Case
Harness Cover
Sensor
Thermal Cords
LSC
Out-of-Line-Device
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SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Multihazard Threat Mitigation System
(cont'd)
• Benefits:
– Dramatic Reduction in FCO & SCO Violence
– Alloy Sensors: Small, Inexpensive and Reliable
– Can Be Incorporated Into a Variety of Mitigation Systems
– Precise Trigger Temperature Regardless of Prior Thermal History
• Constraints:
– Existing LSC / TIVS Ignite Main Fill
– Complexity for Air Launched Due to Cold
– Process for Manufacturing Intermetallic Sensors Needs Work
Meeting title – Location - Date
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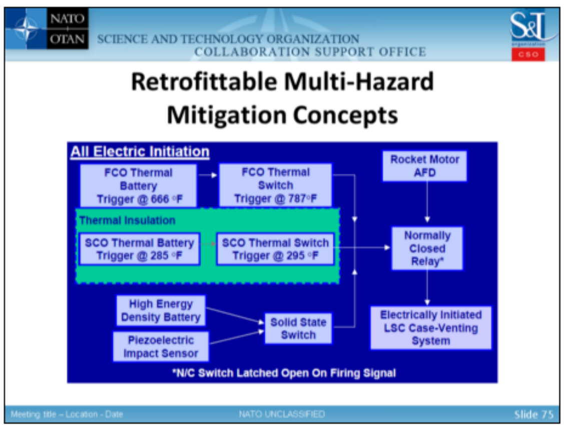
SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Retrofittable Multi-Hazard
Mitigation Concepts
All Electric Initiation
FCO Thermal Battery Trigger @ 666 °F
FCO Thermal Switch Trigger @ 787°F
Thermal Insulation
SCO Thermal Battery Trigger @ 285 °F
SCO Thermal Switch Trigger @ 295 °F
High Energy Density Battery
Piezoelectric Impact Sensor
Solid State Switch
Rocket Motor AFD
Normally Closed Relay*
Electrically Initiated LSC Case-Venting System
*N/C Switch Latched Open On Firing Signal
Meeting title – Location - Date
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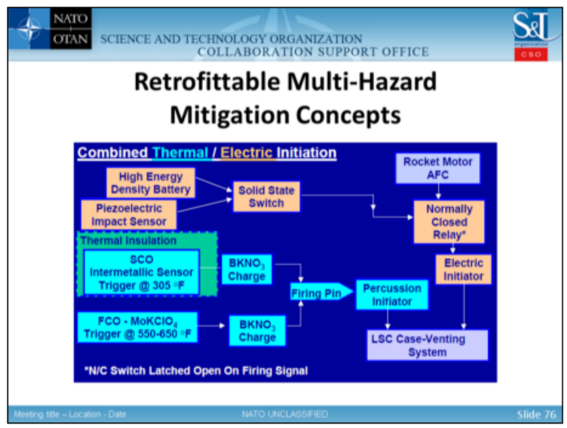
SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Retrofittable Multi-Hazard
Mitigation Concepts
Combined Thermal / Electric Initiation
High Energy Density Battery
Piezoelectric Impact Sensor
Solid State Switch
Rocket Motor AFC
Normally Closed Relay*
Thermal Insulation
SCO Intermetallic Sensor Trigger @ 305 °F
BKNO3 Charge
Firing Pin
Percussion Initiator
Electric Initiator
FCO - MoKClO4 Trigger @ 550-650 °F
BKNO3 Charge
LSC Case-Venting System
*N/C Switch Latched Open On Firing Signal
Meeting title – Location - Date
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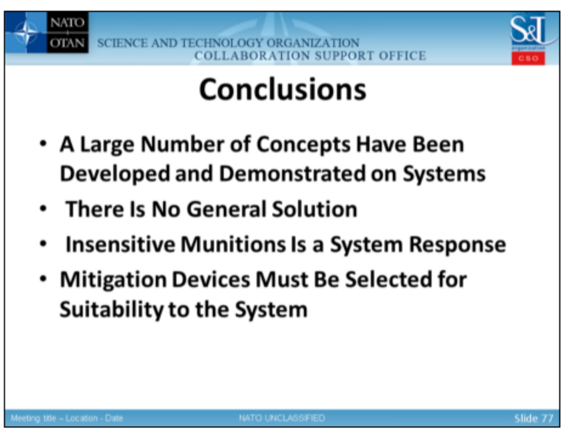
SCIENCE AND TECHNOLOGY ORGANIZATION
COLLABORATION SUPPORT OFFICE
Conclusions
• A Large Number of Concepts Have Been Developed and Demonstrated on Systems
• There Is No General Solution
• Insensitive Munitions Is a System Response
• Mitigation Devices Must Be Selected for Suitability to the System
Meeting title – Location - Date
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