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Current Efforts to Develop Alternate "TB 700-2" Test Protocols for the Hazard Classification of  
Large Rocket Motors

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**ABSTRACT**

When the Department of Defense (DoD) revised Technical Bulletin (TB) 700-2, NAVSEAINST 8020.8B, TO 11A-1-47, DLAR 8220.12 hazard classification guidelines in January 1998 [1], it significantly changed the procedures used to determine the explosive classification of rocket motors, to be shipped or placed in DoD storage facilities. The revised test protocols outlined in this document, (hereafter referred to as TB 700-2) are far more conservative and costly to implement than the previous ones. These changes could have a profound impact on the solid rocket community and in particular those involved with the research and development and manufacture of large ( $\geq 304.8$ -millimeter ( $\geq 12$ -inch)) diameter solid rocket motors (SRMs). The ramifications may include higher development costs and limitations on performance improvements. This paper outlines current efforts of the solid rocket community to develop acceptable alternate test protocols for large rocket motors that could fulfill the intent of TB 700-2 and be considered by the Department of Defense Explosive Safety Board (DDESB) for incorporation into a future revision to TB 700-2.

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\* New employer after retiring from ATK

## INTRODUCTION

Since the solid rocket community first became aware of the changes in the revised TB 700-2, members have voiced their opinions about three major areas of concern. The first involves the full-scale test article requirement of United Nations (UN) Test Series 6, which addresses storage and transportation hazards for Class 1 Hazard Divisions. The second area of concern also involves UN Test Series 6, particularly the fragment throw restrictions. The third area of concern is with the zero card requirement of the current alternate (shock sensitivity) tests in the protocol.

Workshops sponsored by the Joint Army-Navy-NASA-Air Force (JANNAF) Interagency Propulsion Committee served as a forum for technical discussions to develop acceptable alternate test protocols for large rocket motors. Technical discussions by members of two JANNAF subcommittees: Propulsion Systems Hazards Subcommittee (PSHS) and Propellant Development & Characterization Subcommittee (PDCS), focused on developing alternate hazard classification protocols in three areas with the following characteristics:

- Shock sensitivity and critical diameter tests indicative of credible storage and transportation threats.
- A subscale fast cookoff protocol that could be correlated with the full-scale fast cookoff tests required under UN Test Series 6.
- Development of an alternate test protocol to assess the effects of damaged propellants and DDT potential.

This paper outlines current JANNAF community efforts to develop acceptable alternate subscale hazard classification protocols for large rocket motors that could fulfill the intent of TB 700-2 and be considered by the DDESB for incorporation into a future revision to TB 700-2.

## BACKGROUND

### UN Test Series 6

UN Test Series 6 is mandatory for Hazard Divisions 1.1, 1.2, 1.3 and 1.4, and is the series that discriminates between these divisions. This test protocol consists of three tests: the single package test, the stack test and the external fire test to test for shock sensitivity, internal ignition and external heating. The single package test and the stack test (each done in triplicate) require twelve articles. The external fire test is conducted once with a minimum of three articles. This test series utilizes full size articles and according to the TB 700-2 guidelines, fifteen full-scale rocket motors could be required. With 2.3-meter (~90-inch) diameter motors costing about \$5 million each, a single rocket motor hazard classification could cost ~\$75 million for materials and additional costs for the physical testing. This is prohibitively expensive for large motor development programs and potentially dangerous because of the difficulty of preventing the motor from becoming propulsive and leaving the test facility.

In addition to the concerns listed above, there is an additional concern regarding the fragment throw restrictions. The attempt by the DDESB to make TB 700-2 agree with UN regulations has seemingly resulted in fragment throw restrictions to less than 50.29 meters (165 feet). The expulsion of rocket motor environmental seals during a cookoff trial can exceed this limit. Under the latest version of TB 700-2 this will result in a hazard classification of 1.2. Hazard Class 1.2 also contains large artillery shells that present lethal,  $4\pi$  distribution, and metal fragment hazards out to 381 meters (1250 feet). No Class 1.3 rocket motor under case burst conditions would throw more than a few fragments half that distance. Relief from the 50.29-meter fragment throw limit will be necessary to make subscale motor fire testing a practical means for large rocket motor explosive hazard classification.

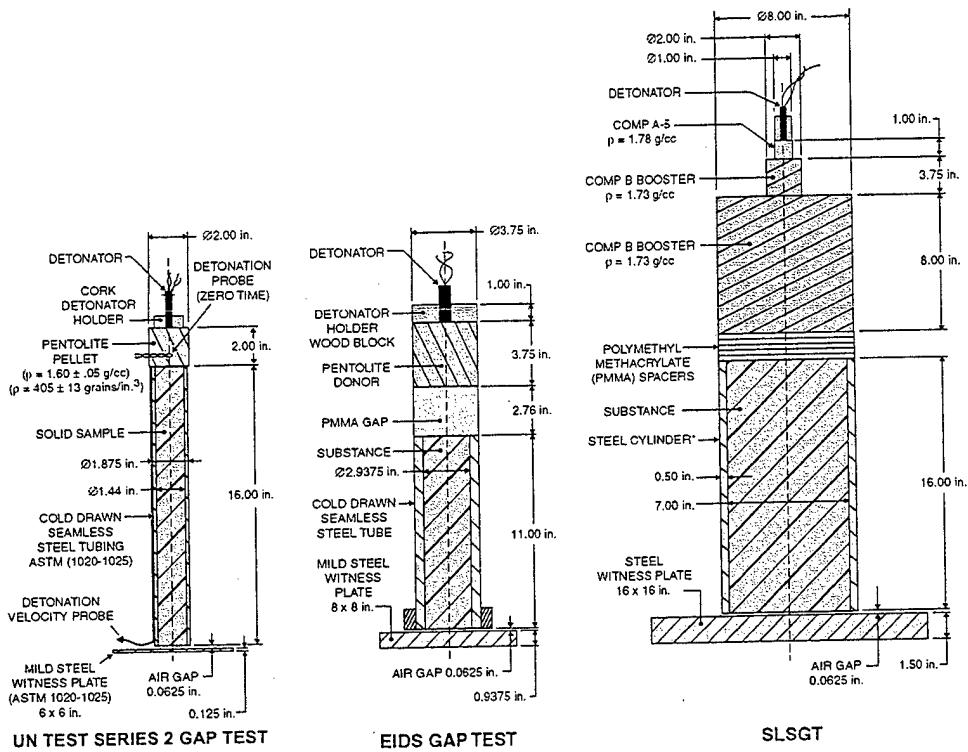
#### Alternate Tests to UN Test Series 6

The authors of TB 700-2 were aware that testing large solid rocket motors per the UN Series 6 protocol is impractical. A series of alternate tests was therefore designed for application specifically to solid rocket propellants and motors. For Hazard Division 1.3, TB 700-2 states: "Solid propellant rocket motors for which it is impractical to conduct the hazard classification tests given in Chapter 5 present special concerns. The following guidance for alternate testing is provided: The shock sensitivity of the propellants shall be measured at the diameter at which the material maintains a stable detonation (if at all) up to the web thickness for the rocket propellant or eight inches (203.2 millimeters) Super Large-Scale Gap Test - SLSGT), whichever dimension is less." A series of tests are run with variable amounts of cellulose acetate or polymethyl-methacrylate (PMMA) "cards" (each 0.254 millimeters thick (0.010 inches)) placed between the donor charge and the acceptor to attenuate the shock. The final test requirement is a zero gap, where all of the shock is transmitted directly into the propellant. The configurations for the alternate gap tests: UN Series 2 gap test; Extremely Insensitive Detonating Substances (EIDS) Gap Test; Super Large-Scale Gap Test (SLSGT); are shown in Figure 1. An acceptable alternative to the UN Series 2 gap test is the Naval Ordnance Lab (NOL) card gap test used for Interim Hazard Classification (IHC). The configuration for the NOL card gap test, also known as the Large-Scale Gap Test (LSGT), is shown in Figure 2.

The majority of members from the JANNAF Safety and Hazard Classification Panel feel the zero card requirement for all the alternate shock sensitivity tests are too extreme to represent actual transportation and storage threat concerns. With no buffer of cards to attenuate the  $>280$  kbar ( $>4$  Mpsi) of shock [2] into the 177.80-millimeter (7-inch) ID area sample, the stimulus imparted to the propellant is orders of magnitude higher than the worst-case scenarios of  $\sim 9$  kbar ( $>0.130$  Mpsi) maximum [3]. Most of the panel members favor the 70 kbar ( $>1$  Mpsi) shock stimulus used in the 70-card NOL gap test. [4].

Overly severe shock sensitivity requirements have been used because of concerns for the response of full-scale rocket motors to accidental ignition from external fires (fast cookoff). It was felt that acceptable subscale analog test specimens that adequately model the response of full-scale articles to fast cookoff do

not exist. If full-scale articles are not to be tested in a fast cookoff scenario, an overly severe shock sensitivity test was warranted to better insure that the rocket motor would not detonate in a fire.



\*MAY BE MACHINED FROM WELDED CARBON STEEL TUBING (1026) DRAWN OVER MANDRES (DOM), SPEC: A513

Figure 1. Current Alternate Test Series Gap Test Configurations

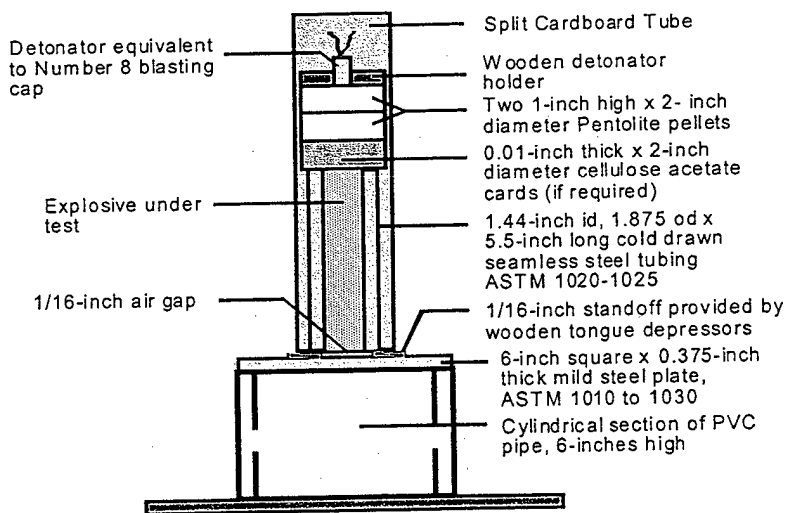


Figure 2. Naval Ordnance Lab (NOL) – Large-Scale Gap Test (LSGT) Configuration

## 00 JANNAF PSHS Workshop

At the JANNAF PSHS meeting in November 2000, a technical workshop was held on the subject of bonfire testing for rocket motor hazard classification and specifically, the development/validation of subscale test articles. This workshop addressed one of the concerns the solid rocket community has with the TB 700-2 test protocols, i.e., the UN Test Series 6, which requires full-scale articles testing for the tendency of an article to explode when heated by an external fire to destruction. At this workshop, Dr. Josephine Covino from DDESB stated that she has been asked by her superiors to head an effort to rewrite TB 700-2 into a more "user-friendly" document. She then asked if any of the workshop attendees would be willing to participate in a workshop to help rewrite TB 700-2 and specifically clarify the language of TB 700-2 to more clearly define the terms used in hazard classification criteria for large solid rocket motors. The rest of the workshop was spent discussing how to support Dr. Covino's request. The consensus was that a "Hazard Classification of Large Solid Rocket Motors" workshop sponsored by the JANNAF PSHS and PDCS should be conducted to develop an outline for alternate (to UN Test Series 6) subscale hazard classification test protocols for large solid rocket motors.

## 01 DDESB Joint Hazard Classifiers Meeting

On 21 Mar 2001, JANNAF community members from AFRL, Aerojet, ARC, ATK, CSD, NAWC and Thiokol met with DDESB and the Joint Hazard Classifiers (JHC) to discuss and finalize plans for the Hazard Classification of Large Solid Rocket Motors Workshop. In addition, the JANNAF group presented a strawman proposal for an alternate test protocol to DDESB and the JHC. The proposed alternate test protocol shown below would act as a starting point for the workshop efforts to develop alternate test protocols.

- **Proposed Mandatory**
  - UN Test Series 6 protocol with subscale FCO test
- **Proposed Option 1**
  - 70 kbar SLSGT with less confinement
  - Conical critical diameter test
  - Use Risk Based Assessment
- **Proposed Option 2**
  - 5 kbar SLSGT with less confinement
  - Conical critical diameter test
  - Critical Impact Velocity testing
  - Use Risk Based Assessment

The first test protocol was proposed as the mandatory protocol to determine if a Class 1 (Explosive) article is a candidate for Hazard Division (HD) 1.3. To establish which hazard division would be assigned to the HD 1.3 candidate, two test protocols were proposed. The first protocol titled "Option 1" starts with a

modified version of the SLSGT attenuated down to 70 kbar. If the article does not explode, it is assigned a HD 1.3 classification. If it does explode, the article can either receive a HD 1.1 classification or undergo critical diameter and shock initiation pressure testing. If the shock initiation pressure can be determined by analogy, Risk Based Assessment (RBA) is used to determine if the article receives a 1.3 or 1.1 designation. If analogy is not possible, a series of SLSGT's are conducted with varying attenuation gaps to determine the critical gap for shock initiation pressure. Again, RBA is used to determine if the article is classified HD 1.3 or 1.1.

The second protocol titled "Option 2" starts with a modified version of the SLSGT attenuated down to 5 kbar (>72,000 psi). If the article does not explode it undergoes shotgun friability testing to assess if the article has the potential for a Deflagration-to-Detonation Transition (DDT). If the article does explode, it can either receive a 1.1 designation or undergo the critical diameter and shock initiation pressure testing outlined in Option 1.

#### **Hazard Classification of Large Solid Rocket Motors Workshop**

The JANNAF PSHS, PDCS and DDESB sponsored the Hazard Classification For Large Solid Rocket Motors Workshop (June 4-8 2001) to address possible changes to the alternate test protocol for hazard classifying large rocket motors using the results from subscale shock sensitivity and external fire tests. It also outlined programs for the development of subscale analogs, and their validation through modeling and full-scale article tests.

The goals of the workshop were to develop subscale test protocols to thoroughly characterize large rocket motors in a manner that would:

- Give the DDESB/Tri-Service Hazard Classifiers the data to ensure the motors classified as HD 1.3 will not detonate in real life storage and transportation scenarios including accidental ignition and mechanical shock.
- Give the solid rocket community hazard classification test protocols that are not cost prohibitive and are indicative of credible storage and transportation threat scenarios.

The objectives of the workshop were to:

- Clarify the language of TB 700-2 to more clearly define the terms used in hazard classification criteria for large solid rocket motors.
- Establish test protocols and present proposals to characterize shock sensitivity for families of propellants.
- Establish test protocols and present proposals to determine the propensity of propellant in a full-scale motor to detonate in a DDT, Shock-to-Detonation Transition (SDT) or Unknown Detonation Transition (XDT), a.k.a. Delayed Detonation Transition scenario.
- Establish test protocols and present proposals to determine the relationship, if any, between propellant critical diameter and the bonfire response.

- Establish methods to assess and integrate the threats/hazards that a solid rocket motor might face during its lifetime (due to storage and transportation) into a hazard classification protocol.

The output of the workshop was a document containing a summary of the workshop discussions and recommendations for subscale alternate test protocols in the following three areas:

- Shock sensitivity and critical diameter
- Fast cookoff/bonfire testing
- Effects of damaged propellants and DDT potential

The document also outlined proposed research programs for the development of subscale test protocols in the three above mentioned areas.

The affiliations of the workshop participants are listed below.

#### **Workshop Participants Affiliations:**

1. DoD Propulsion Laboratory Representatives
  - a. Air Force Research Laboratory (AFRL)
  - b. Naval Air Warfare Center (NAWC)
  - c. Naval Surface Warfare Center (NSWC)
  - d. U.S. Army Aviation and Missile Command (AMCOM)
  - e. U.S. Army Space & Missile Defense Command (SMDC)
2. Navy Strategic Systems Program Office (SSPO)
3. NASA HQ Safety & Risk Management
4. DOE National Labs
  - a. Lawrence Livermore National Laboratory (LLNL)
  - b. Sandia National Laboratories (SNL)
5. DDESB
6. Joint Hazard Classifiers (JHC)
  - a. Air Force
  - b. Navy
  - c. Army
7. Systems Safety Representatives
  - a. Navy
  - b. Army
8. Industry Representatives
  - a. Aerojet
  - b. Alliant Techsystems (ATK)
  - c. Atlantic Research Corp. (ARC)
  - d. Lockheed Martin Missile & Space (LMMS)
  - e. Pratt & Whitney Chemical Systems Division (CSD)
  - f. Thiokol Propulsion

9. Chemical Propulsion Information Agency (CPIA)

10. Applied Propulsion Technology (APT)

**Workshop Agenda:**

The agenda for the workshop is shown in the block diagram below.

<b>Monday, 4 June</b>	<b>Tuesday, 5 June</b>	<b>Wed, 6 June</b>	<b>Thursday, 7 June</b>	<b>Friday, 8 June</b>
0900 - 1200 Plenary Session <ul style="list-style-type: none"><li>• Introduction</li><li>• Hazard Classification Overview</li><li>• System Safety Overview</li><li>• SHC Panel Recommendations</li><li>• SMDC Hazard Classification Perspective</li><li>• Draft Hazard Class Protocol Overview</li><li>• IHPRPT Overview</li></ul>	0830 - 1700 Technical Discussions on Shock Sensitivity and Critical Diameter  Moderator K. Graham, ARC	0830 - 1700 Technical Discussions on Reaction to Thermal Stimuli/Subscale Fast Cookoff/Bonfire Testing  Moderator A. Atwood, NAWC	0830 - 1700 Technical Discussions on Effects of Damaged Propellants and DDT Potential  Moderator G. Butcher, ATK	0830 - 1200 Conclusions, Summary, and Wrap up
1330 - 1700 Round Table Exercise				

**Day 1 Plenary Session and Definition of Issues:**

The workshop began with an overview of hazard classification presented by the Joint Hazard Classifiers. Eric Olson (Air Force) served as the spokesman for the JHC. He stated in regards to the strawman test protocols proposed by members of the JANNAF community at the February DDESB/JHC meeting, the JHC recognize Risk Based Assessment (RBA) or Threat Hazard Assessment (THA) for Insensitive Munitions (IM) testing and determining Quantity Distance (Q-D) for facilities but not for hazard classification. He went on to say that for hazard classification, the test protocols must be deterministic in nature rather than mechanistic. In regards to the optional test protocols in the strawman proposal, the JHC offered the following proposed alternatives to the current shock sensitivity tests listed in TB 700-2. One full-scale Fast Cookoff (FCO) test and one of the following options:

- Option 0
  - 0 card Super Large-Scale Gap Test (SLSGT) w/ L/D = 4
  - Velocity pins
  - Conical booster
  - Witness plate

- Option 1
  - Wedge test to determine critical diameter
  - 70 kbar gap test at 110%  $D_C$  in motor-like confinement; w/  $L/D = 4$
  - Velocity pins
  - Conical Booster
  - Witness plate
- Option 2
  - 70 kbar gap test at motor diameter & motor confinement; w/  $L/D = 4$
  - Velocity pins
  - Conical booster
  - Witness plate

When asked how large a sample diameter would be required for critical diameter testing, the JHC response was that propellants with a critical diameter greater than 0.3 meters (12 inches) would not require further testing.

Army and Navy system safety personnel gave the next presentations listing their key concerns and what data they need to establish MCE.

Bill Thomas from Applied Propulsion Technology gave a presentation on the Safety and Hazard Classification (SHC) Panel recommendations first presented at the DDESB 29<sup>th</sup> U.S. DoD Explosives Safety Seminar in New Orleans, LA (18-20 July). The panel recommended attenuating the shock stimulus down to 70kbar for the three shock sensitivity tests in the alternate test protocol.

Ms. Pat Vittitow from U.S. Army Space Missile Defense Command gave a presentation on the hazard classification protocols the Army used to classify the rocket motors utilized in the National Missile Defense (NMD), Patriot Advanced Capability (PAC-3) and Theater High Altitude Area Defense (THAAD) missile systems.

Following Ms. Vittitow, the strawman proposal for the alternate test protocol previously mentioned was presented to the group.

The final presentation of the day was an AFRL overview of the Integrated High Payoff Rocket Propulsion Technology (IHRPT) program. The IHRPT program is a joint government and industry effort that seeks to significantly increase the performance and reduce the cost of rocket propulsion (while maintaining a HD 1.3 designation).

The remainder of the first day was devoted to a pencil and paper round-table facilitated exercise, which defined and prioritized the major issues in the areas of shock initiation, thermal stimuli, and damaged energetic materials. Each participant was tasked to select three important topic areas relative to the three subjects (total of 9), which might be encountered during a transportation and storage accident. After people

jotted down their key topics, each person indicated their first choice. If that choice was already mentioned by someone else that was noted. Then each person indicated their second choice, and then the third choices were listed. A weighting factor of 3 was assigned to the topics listed as number one, followed by 2 for those topics listed as someone's second choice and a 1 rating assigned to the topics listed as third choices. The responses were collected and tallied. Those items were ranked in the order of highest scores. This then became the prioritized agenda for the following days.

## **Day 2 Technical Discussions on Shock Sensitivity and Critical Diameter:**

The second day began with discussions of the shock initiation issues (in priority order) from the previous day's round-table exercise. Ken Graham (ARC) served as the moderator of the session and wrote the following summary of the session. Thom Boggs (NAWC) served as the workshop recorder.

### **Introduction**

The only shock sensitivity test required by the current TB 700-2 for UN Test Series 6, is the detonator cap initiation on the first test run of the single package test. Many parties have expressed concern that this test is insufficient for discriminating between Hazard Division 1.1 and 1.3 articles. It is for this reason that the JANNAF Safety and Hazard Classification Panel developed the generic critical diameter and card gap test protocol for large rocket motor classification back in 1992. The original JANNAF intent was to use critical diameter as a means for determining which shock sensitivity test to perform and to actually measure the shock pressure required for propagation (as measured by varying the gap).

As stated previously, the majority of the community members feel the current alternate shock sensitivity tests at zero cards don't reflect credible storage and transportation threats. Therefore, it was suggested by the SHC panel members that the Alternate Test Series protocol listed in Chapter 6 of TB 700-2 should be modified to allow a shock input of 70 kbar for each of the three gap tests, to serve as the dividing line between assignment of HD 1.1 and HD 1.3 for solid propellants. A "Shock Sensitivity and Critical Diameter" session at the joint JANNAF/DDESB Workshop on Hazards Classification of Large Rocket Motors held on 5 June 2001 addressed the areas of shock sensitivity and critical diameter relative to transportation and storage of large rocket motors. In addition, the need for establishing a database for modern intermediate energy propellants was identified, which may in turn be used to characterize the full-scale motor response to a fire or mechanical shock threat, which might occur during transportation and storage.

### **Polling Results**

The results of the polling process for the mechanical shock issues are summarized in Table 1.

**Table 1. Important Subjects Relative to Shock Sensitivity and Critical Diameter**

Topic Area	Rating
Testing	
Subscale testing	38
Credibility	28
Critical Diameter/Shock Initiation	21
Lethality	9
IM	3
Mechanisms/Modeling	12
Database	8

The areas related to testing received the highest ratings with the issues of subscale testing and credibility being of highest concern. The areas of critical diameter/shock initiation and lethality were second in importance, followed by IM issues. The need for modeling to accompany the testing and the establishment of a database were also identified.

### Credibility

It was concluded that while shock and impact testing should simulate accident scenarios, the hazard classifiers don't recognize threat hazard assessment for hazard classification. Therefore, standard tests must be developed. This raises the question of: what tests mimic credible events?

Dr. Phil Miller (NAWC) presented DYNA2D hydrocode calculations performed by Ross Heimdahl on several accident scenarios and presented his findings to the group. The highest shock input of 9 kbar (>0.130 Mpsi) came from a 96 kilometers/hour (60 mph) truck crash into a pointed steel barrier. He concluded that propellants won't SDT at these pressures but could react due to shear at 1-2 kbar (>14,500-29,000 psi) causing ignition and possibly DDT.

The consensus of the group is that the maximum credible event in storage, handling and transport is less than 10 kbar (>145,000 psi) and that for the SLSGT, even a 70 kbar shock input over 7 inches in ½-inch steel confinement is an overkill test.

The question was asked if terrorism is a valid threat. Dr. Covino (DDESB) said that the Defense Threat Reduction Agency (DTRA) uses a 70 kbar shock input for a satchel charge placed on a motor. Dr. Ward stated that DDESB considers terrorist threats in Threat Hazard Assessment (THA) for IM testing but not for hazard classification.

### Subscale Testing

It was the conclusion of the workshop that any subscale shock sensitivity test protocol developed must maintain the fidelity of large-scale test articles. Therefore, the protocol needs to either mimic the full-scale credible event or be conservative and not tied to realistic events.

As mentioned in the credibility section, any subscale tests proposed must be standardized in terms of test conditions, procedures, instrumentation, data analysis and interpretation.

The consensus of the group is that there is too large a difference between subscale and large-scale for the formulators. The majority of the group felt the SLSGT is too large for formulation development. Most of the group thought that "Option 1" of the alternate tests proposed by the JHC offered a workable solution for the formulators and for the JHC in that it is a subscale test that prevents "gaming" critical diameter testing. Others felt this test was not conservative enough and needed a minimum diameter of 76.2 millimeters (3 inches). It was suggested that the EIDS test diameter of approximately 73.02 millimeters (2.8 inches) might be a reasonable minimum diameter to test at. Since the EIDS test is 2.88 inch diameter in a thick wall steel tube, it is analogous to over 4 inch unconfined diameter.

Many group members thought that overpressure measurements should be used to distinguish between a 1.2 "explosive reaction" versus a pressure burst. The JHC stated it is useful, but not required because it may not provide a conclusive hazard classification decision.

In regards to "Option 0" of the alternate tests proposed by the JHC, the group agreed that an L/D of 4, a minimum of 14 velocity pins and a conical booster were good changes for the SLSGT. However, it was felt there needed to be a specification for location of the velocity pins (SMDC recommends 25.4 millimeters (1inch) from top; 25.4 millimeters in depth; 25.4 millimeters apart). For the conical booster, it should fit over the full case diameter and the L/D does not need to be >2. In addition, the group recommended using a cast-cure explosive (like PBXN-109 or PBXN-110). Also, use the same witness plate for the current SLSGT.

### Critical Diameter & Shock Initiation

The workshop participants agreed that the areas of critical diameter and shock initiation are two of the most hotly debated topics in hazard classification and prompted several debates in subjects such as:

- Beyond what diameter should critical diameter be disregarded?
- How to measure and standardize a test for critical diameter?
- What is the relationship of shock initiation pressure to critical diameter?
- Is there too much emphasis on critical diameter?

Regarding the first subject area, the majority of the session participants agreed with the JHC assessment that a propellant with a critical diameter >0.3 meters (12 inches) does not pose a threat due to the unlikelihood of a planar shock wave of that diameter being transmitted into the propellant grain.

For the remaining subject areas, Ken Graham answered many of the questions when he presented some formulation issues from his National Defense Industrial Association (NDIA) paper [5]. He stated there is no direct, functional relationship between critical diameter and shock sensitivity of many propellants. Both critical diameter and shock sensitivity are a function of formulation variables such as binder type, solids type, total solids, percentage of ingredients, ingredient particle size and burn rate. In addition, detonation velocity is a very strong function of the sample diameter near the critical diameter. Below the critical diameter, shock initiation pressure is not a factor, only at or above critical diameter is there a minimum initiation pressure that can cause a detonation.

Graham went on to say that the Project SOPHY data on critical diameter as a function of nitramine content does not apply to the modern increased energy propellants such as those being developed for IHRPT. The SOPHY data used polybutadiene-acrylic acid-acrylonitrile (PBAN) propellants with 30  $\mu\text{m}$  RDX (cyclotrimethylenetrinitramine). The current IHRPT propellants utilize hydroxy-terminated polybutadiene (HTPB) binders and approximately 2  $\mu\text{m}$  RDX, significantly reducing the shock sensitivity. Mr. Graham suggested that a thorough test program to resolve some of the issues associated with hazard classification of large motors should test for burn rate at high pressures, shotgun/relative quickness, and critical diameter versus shock sensitivity relationships for a variety of propellant formulation families.

The consensus of the group is that there is a definite need for a program to conduct critical diameter and shock initiation testing on families of modern energetic propellants such as the ones developed under IHRPT. In addition, the results of this effort should be placed in a database and combined with correlation equations to aide the community in hazard classification for future propellants and rocket motors.

### Lethality

Most of the lethality issues that came up during the discussions were really applicable for the Fast Cookoff/Bonfire Testing session. The consensus of the group is that the current protocol ignores the differences between detonating warheads and case-bursting rocket motors. The group supported blast measurements to distinguish an "explosive reaction" from a pressure burst.

### IM

There has been increased effort in the hazard classification community to try and "harmonize" IM testing with hazard classification testing to save assets and reduce costs. There has also been talk of standardizing protocols between IM testing, hazard classification testing and the testing in the North Atlantic Treaty Organization (NATO) Standardization Agreements (STANAGS). While this makes sense for systems

designed for combat conditions, subjecting large booster motors designed for space launch systems to IM requirements would adversely impact the users with no added value.

### Mechanisms/Modeling

The consensus of the workshop participants was that models are useful but require rigorous characterization data. There are two categories, ideal and non-ideal explosives. Ideal explosives can be modeled accurately however, for non-ideal explosives modeling requires more development. The more energetic the propellant, the more they behave like explosives and may be modeled more readily. This should be the case with the IHRPT propellants.

### Database

All of the participants agreed that establishing a database on families of modern propellants is a must to give critical diameter and shock sensitivity of propellants as a function of formulation variables. This is especially important for the newer, higher energy propellants such as those developed under the IHRPT program.

Ms. Pat Vittitow (SMDC) offered to make the velocity pin database they established for 24 SLSGTs and 6 critical diameter tests 0.3 to 1.5 meters (12 to 60 inches) available to the propulsion community and specifically to CPIA.

### Conclusions

It was the conclusion of the mechanical shock portion of the workshop that Risk Based Assessment or Threat Hazard Assessment not be recommended for hazard classification and that subscale, standardized tests are needed. It was concluded that option 1 of the alternate tests proposed by the JHC offered a workable solution for the formulators and for the JHC but that a minimum diameter of at least 2.8 inches heavily confined, or over 4 inch unconfined, or moderately confined, should be required.

The consensus of the group is that there is a definite need for a program to conduct critical diameter and shock initiation testing on families of modern energetic propellants such as the ones developed under IHRPT. In addition, the results of this effort should be placed in a database and combined with correlation equations to aide the community in hazard classification for future propellants and rocket motors.

### **Day 3 Technical Discussions on Subscale Fast Cookoff/Bonfire Testing:**

The third day began with discussions of the thermal stimuli issues (in priority order) from the first day's round-table exercise. Alice Atwood (NAWC) served as the moderator of the session and wrote the following summary of the session. Thom Boggs served as the recorder.

## Introduction

U. S. hazards classifiers and DDESB have recognized that the current UN series 6(c) bonfire test is not practical for solid rocket motors of diameter greater than 0.3 meters (12-inches). The test is expensive for motor development programs because it could require a minimum of three full-scale test articles. There is also a procedural difficulty in prevention of the motor from becoming propulsive and leaving the test facility. It was suggested that a reasonable subscale test be developed that can be substituted for the current UN series 6 (c). A "Subscale Fast Cookoff/Bonfire Testing" session at the joint JANNAF/DDESB Workshop on Hazards Classification of Large Rocket Motors held on 6 June 2001 addressed the area of thermal hazards relative to transportation and storage of large rocket motors. The need for improved thermal tests at the subscale level was identified, which may in turn be used to characterize the full-scale motor response to a fire threat, which might occur during transportation and storage.

## Polling Results

The results of the polling process for the thermal issues are summarized in Table 2.

**Table 2. Important Subjects Relative to the Thermal Threat**

Topic Area	Rating
Testing	
Scaling /Subscale issues	68
Stimulus/Threat	24
Fragments, firebrands	11
Confinement	4
Modeling	17
Database	14

The areas related to testing received the highest ratings with the issues of scaling and subscale testing being of highest concern. The description of the fire stimulus or threat was second in importance, followed by fragmentation concerns and confinement issues. The need for modeling to accompany the testing and the establishment of a database were also identified. The scaling issues were further divided into the areas of fire stimulus, boundary conditions, and the test item.

## Scaling Issues

It was concluded that due to the transient nature of a fire, it does not readily scale. The size of the fire should be sufficiently large to engulf the item and the height monitored. The type of fire is also important. The two most common types of experimental fires, fuel and propane, differ widely in their radiative and convective behavior. The opacity of a sooty fuel fire and the irradiance should be evaluated. The contribution of turbulence, generated by either the wind or self-generated must be considered. The effect

of variations in the fuel to air ratio should be measured as should temperature as a function of distance and time.

Scaling of the boundary conditions is not as important as knowing the initial conditions very well. If the boundary conditions can be described in one experiment, then they can be varied parametrically using the available models. As a minimum, heat flux and temperature variations should be measured around the test item and at the interfaces between the motor case and the insulation/liner and between the insulation/liner and the propellant.

With regards to a generic test item, the response of different propellant families should be understood and well defined. The response of a traditional 1.3 propellant and a high performance 1.3 should be clearly contrasted with a known 1.1 propellant or explosive. It was noted that larger items tend to react with a higher level of violence than smaller items; however, we do not fully understand how to scale the size of a test fixture.

The physical/chemical/mechanical properties of the motor case, liner, and propellant should be measured as a function of initial temperature in order to analytically describe the test item subjected to a thermal stimulus. Kinetic parameters for the energetic material should be determined from thermochemical data such as One Dimensional Time to eXplosion (ODTX). If a generic subscale test is to be useful to hazards classification, the experimental and analytical protocol must clearly delineate not only the time to reaction but also give some measure of reaction violence by means of the fragment size, mass and velocity, blast and thermal response of the item to fire.

### Threat/Stimulus

It was the conclusion of the workshop that response of an ordnance item to mechanical shock stimuli is not strongly affected by temperature. The lack of thermal knowledge should not be the basis for artificially high shock requirements in classification, as the two responses tend to be mutually exclusive. The change in shock sensitivity, which may result in an item as a result of thermal damage, is a separate issue.

There is a need to define a credible thermal event relative to transportation and storage; however, hazards classification does not consider the threat hazard assessment. Hazards classification uses "defined" tests, which are designed to simulate the response of an item in a transportation and storage accident scenario. The workshop participants posed the question to the hazards classifiers and DDESB to describe the accident scenario that the current bonfire test procedure simulates.

### Confinement

Workshop participants agreed that the quasi-static burst pressure of a rocket motor case was not sufficient to describe the failure mechanisms associated with the fast cookoff response. The effect of elevated temperature on motor case failure should be evaluated. Large solid rocket motors tend to be manufactured

with motor cases consisting of composite materials. It was noted that the fiber wound epoxy filled systems are complex and their behavior is orthotropic, and there is a minimum thickness that can be laid up. How the motor case material behavior changes as the polymeric components soften, melt and gasify should be measured.

The role of the insulator and/or liner of the composite cased rocket motor are of equal or even greater importance since it may provide significant confinement during a thermal event. The gasification of the liner, followed by a debond region between the liner and motor case in which reactive gases may accumulate has been identified as a critical feature in the fast cookoff response [6].

### Fragments and Firebrands

The 1.2 hazards classification is based on the fragments that are generated as a result of an "explosive reaction." In order to avoid the 1.2 classification, the experimentalist must demonstrate that no explosive reaction occurred during the test. In other words, the tests must include the appropriate instrumentation such as blast gages, thermal flux measurements and video coverage. The mass of the fragments as well as the distance they travel must be recorded. It was also stated that the 20-Joule criterion for fragments is very conservative, for example, 20 Joule = 4.4 ft-lb and a "lethal" fragment is defined as 58 ft-lb. The 20-Joule criterion is an international standard. The 1.2 classification, as it is currently defined, may be too broad, encompassing items from 155-mm (6.10-in) shells to large solid rocket motors.

### Modeling

The current cookoff models being developed have focused on the hazard known as slow cookoff. For the development of a subscale bonfire test, the focus needs to be on the fast cookoff hazard. R. Schmitt of Sandia National Laboratory made a presentation to the workshop participants outlining some of the progress and data requirements for the modeling of the cookoff hazard.

Both engineering and detailed models based on first principles should be utilized in the development of subscale testing. In cases where the need for data predicting the time to reaction is adequate, a robust engineering model will be sufficient and cost effective. More detailed models will be required to evaluate reaction violence and the contribution of such geometric complexities as fins and storage containers. The models and experiments must be iterative and highly coupled in order to succeed. The implementation of a generic subscale test also becomes a model validation exercise.

### Database

Les Bowman (NAWC) presented a review of the current fast cookoff data for solid rocket motors contained in the Navy IM database. The results for solid rocket motors tested in fast cookoff Jet Propellant (JP) type fuel fire revealed many which burn or deflagrate, two which exploded, and none that detonated. There were not bonfire data readily available for large rocket motors in the Navy database. However, the

National Insensitive Munitions Information System (NIMIS II) database, which is available on the web, was a suggested source for fast cookoff fuel fire information. The data from all services needs to be incorporated into a master database related to fast cookoff and bonfire test results.

The kinds of data that should be included in a fast cookoff database are temperature measurements from the skin of the rocket motor, time to reaction and fragmentation data. In addition, their weight and travel distance should be included. The details of the test set up and environmental conditions under which the test was performed should also be included, as the cookoff hazard is a strongly coupled relationship between the energetic and its environment. Every effort should be made to maximize the quality of instrumentation used to record the data. In addition, North Atlantic Treaty Organization (NATO) and NATO Insensitive Munitions Information Center (NIMIC) recommendations should be followed.

### **Conclusions for Subscale Cookoff/Bonfire Testing**

It was the conclusion of the workshop that a generic subscale/modeling approach for bonfire testing could not be recommended at this time due to the lack of sufficient technological maturity in the area of fast cookoff. It was concluded, however, that a generic test/modeling approach would be very useful as an engineering tool to comparatively evaluate propellant, motor case and liner combinations with respect to the thermal threat. Due to the complexity of the fast cookoff hazard, a subscale test procedure will only be successful if it can be coupled with fully validated modeling techniques. It is recommended that a fast cookoff technology project be implemented in order to obtain the critical data required to design a subscale test, validate the models that will be required for extrapolation from the subscale to full-scale response and to populate a database that can be used for both comparison and design purposes.

### **Day 4 Technical Discussions on Effects of Damaged Propellants and DDT Potential:**

The fourth day began with discussions of the damage effects and DDT potential issues (in priority order) from the first day's round-table exercise. Garn Butcher (ATK) served as the moderator of the session and wrote the following summary of the session. Thom Boggs served as the recorder.

#### **Introduction**

One area of TB 700-2 that was found deficient is the possible increase in sensitivity of solid propellant in a damaged state, and the consequential increase in reaction violence from such propellant. Current testing does not address this situation. An "Effects of Damaged Propellants and DDT Potential" session at the joint JANNAF/DDESB Workshop on Hazards Classification of Large Rocket Motors held on 7 June 2001 addressed three areas of concern: shock, thermal and damage.

This report summarizes the discussion held on the topic of damage effects characterization as pertaining to the current requirements in the TB 700-2. The need for improved and/or new tests at the subscale level was

identified which may in turn be used to characterize the full-scale motor response to an incident resulting in significant damage to a propellant during transportation and storage.

### Polling Results

The results of the polling process for the damaged propellant issues are summarized in Table 3.

**Table 3. Important Subjects Relative to the Damaged Propellants and DDT Potential Threat**

Topic Area	Rating
Relevance of damage to hazards classification	22
Critical bed configuration for testing	12
How do we assess damage effects	11
Definition of a credible event	10
How do you create damage for testing	8
Database Generation	8
How to tie shock and fire together	7
Effects of damage on Critical Diameter and initiation pressure	7
Critical parameters to be measured in subscale test	6

Discussions were held on each of the above topics, and a few others that surfaced during the day. The order of discussion followed the round-table priorities. Results of the discussions were recorded as presented and then reviewed and summarized. The final summary is different than the listed round-table priorities as a result of the directions the discussions took during the workshop session. Information presented during the workshop brought to light several other questions expressed by the group which became topics of significant interest. The summary as presented follows the level of interest and flow of supporting data as presented during the workshop.

### Definitions and Background

The first order of business in the workshop was to provide everyone with definitions of some critical terms as pertaining to hazards classification. All forms of damage are not pertinent, thus the following was provided:

*Damage* = stress, shear, tensile impact or thermal energy applied to propellant that causes disruption of initial as-cast condition, such as tears, crumbling, internal dewetting, foaming, fracturing, etc.

- Damage must be relatively immediate and a consequence of the incident
- Damage must create a condition that contributes to the reaction consequences of the incident
- Damage that remains in an unreacted article, influencing handling of energetics after the incident is not considered in this application.

*DDT* = Deflagration-to-Detonation Transition. *DDT* involves initiation of energetic material that builds from combustion to a detonation.

*CIV* = Test velocity required to damage a solid propellant slug, 18 millimeters (0.71 inch) in diameter weighing approximately 8-9 grams (0.27-0.317 ounces) sufficiently that it will produce a pressurization rate of 172 kbar/sec (2.5 Mpsi/sec) in a 90-cubic centimeter (5.5-cubic inch) closed combustion bomb. *CIV* has its origins in and is only applicable at this time to XLDB and NEPE propellants of hazards class 1, division 1.

Applicable types of damage were defined as:

- *Dewetting* = separation of binder materials from solids within the propellant matrix with no obvious external tearing or cracking. Dewetting normally occurs around the largest solid particles in the propellant and may initiate at strain levels as low as 5%.
- *Tearing* = formation of cracks and tears in the propellant matrix on a macro scale, resulting in moderate to large fissures in the propellant grain.
- *Foaming/bubble degradation* = result of heating the propellant to the point of internal off gassing or deterioration of the binder resulting in porosity of the propellant.

#### Conclusions for Damaged Propellant

The following paragraphs highlight the conclusions of the various topics discussed during the damage session of the workshop.

Damage as a part of the Hazards Classification is currently a part of the Class 1.6 requirements but is not part of the Class 1.1, 1.2 or 1.3 requirements. No tests specifically address damage enhancement to the potential reaction violence of a propellant. The consensus of the workshop participants was that under the above definitions, damage should be considered in assigning a hazards classification. Further, both class 1.1 and 1.3 propellants should be included.

Data were presented by SMDC highlighting the fact that propellant can be significantly damaged by loading resulting from typical shipping or transportation accidents. This level of loading is considerably below the SDT threshold of the propellants, but may have a significant effect on the resultant sensitivity. Impacts of around 100 m/sec (328 ft/sec) can produce several kbar stress in propellants. Although this is well below the SDT or XDT thresholds of Class 1.1 propellants, it is well above the stress necessary to cause damage by shear, tensile or spall in most propellants. Some propellants will spall at stress levels as low as 0.2 kbar (2,900 psi).

NAWC data showed that a propellant may experience a 50% increase in sensitivity with as little as 1% void volume increase resulting from mild strain or moderate shock loading.

It was concluded that damage required to get a violent reaction depends on many factors, but as a general observation:

- Typical HTPB/Al/AP propellants will generally not XDT or SDT but could have severe reactions with moderate damage.
- Typical Class 1.1 propellants may require more damage to create a violent reaction but will more likely result in a detonation event.
- New families are as yet uncharacterized. Much needs to be learned about advanced formulations with new binder systems.
- Low tensile strength – high modulus propellant formulations may be more susceptible to damage effects than propellant with more ductile physical properties.

Discussions were held relative to the interactions between stimulus and sample configuration. The conclusions were that geometry, sample size, bore configuration, damaged area and volume and the type of damage were all of critical importance to the full scale motor. These items need discussion on how they relate to scale up of information from small scale testing.

Relevancy of the current SLSGT test to assess damage effects was discussed. It was concluded that the SLSGT or other smaller gap tests would not effectively account for the effects of damage. The gap test results in a compressive loading and leaves out consideration of shear and tensile damage, fractured propellant response to combustion in a confined space and explosive burn propagation.

Relevancy of the CIV shotgun test established threshold of 172 kbar/sec (2.5 Mpsi/sec) was debated. The conclusion is that the value of 172 kbar/sec is relevant only to the family of propellants for which it was established. To be accepted, new criteria must be established by experimental means to define acceptable level(s) of CIV for other propellant families.

#### **Summary and Recommendations, Damaged Propellants**

The workshop group concluded that:

- Assignment of a Hazards Division Classification should include some assessment of the effects of damage on the response of propellant.
- A study should be launched to evaluate and recommend a test or tests, preferably subscale in size, that will provide data pertinent to assure that a hazards classification assignment will adequately describe the expected response from a propellant damaged in a transportation or storage incident.
- The study should provide specific recommended criteria that must be met to qualify for a given classification.

Recommendations regarding tests, and critical test parameters:

- Shotgun with closed bomb combustion and computer evaluation to determine critical factors of:
  - Dp/dt
  - Burn rate
  - Area of burn
- Burn to violent Reaction test with the following critical parameters defined:
  - Gap
  - Reaction
  - Blast effect
  - Overpressure
- French Friability test
- Spigot Test – penetration with crush/impingement component
- Susan Test
- Other (TBD)

Recommendations regarding test configuration parameters needing characterization are:

- Bed Configuration:
  - Granulation
  - Porosity
  - Dimensions
- Stimulus to initiate test:
  - Igniter strength – soft as in hot wire versus hard as with a bag igniter
  - Mechanical compaction
- Confinement:
  - Steel pipe
  - Plastic pipe
  - Simulation of motor confinement
  - Dimensions relative to motor

Final recommendations included the need to better define the relation between damage and critical diameter and the relation between damage and initiation pressure.

All participants agreed that there is a need to establish an accessible database on criteria recommended by the study group assigned to develop tests and testing criteria.

In summary, the workshop identified a deficiency in the current UN Test Series 6 and alternate testing for large rocket motors with regards to including effects of damage in the assignment of hazards classification to solid rocket motors. Supporting data were presented showing that damage effects on sensitivity and potential reaction violence are real and should be considered in the overall hazards classification.

Discussions were held with respect to the need for defining acceptable test and evaluation criteria. Recommendations were made relative to the type of test needed, the parameters for the test configuration and the critical properties that need to be measured in order to define effects of damage relative to classification.

#### **Day 5 Conclusions, Summary and Wrap-Up:**

On the last day, the conclusions and summaries of the three sessions were presented.

### **CONCLUSIONS**

The UN Test Series 6 used to address storage and transportation hazards for Class 1 Hazard Divisions utilize tests for internal ignition, external heating and shock sensitivity. This test series requires full size articles and is cost prohibitive and impractical for large rocket motors. The current alternate tests in the protocol are too extreme to represent actual transportation and storage threat concerns, imparting a shock stimulus to the propellant orders of magnitude higher than the worst-case scenarios.

To meet the needs of the solid rocket community and DDESB/Joint Hazard Classifiers, the JANNAF PSHS and PDCS sponsored a workshop with DDESB to bring together representatives from organizations affected by TB 700-2 and from experts in the field of solid rocket propulsion, system safety and modeling to address possible changes to the alternate test protocol for hazard classifying large rocket motors.

Potential subscale alternate tests have been identified and proposed by members of the solid rocket community in the following three areas:

- Shock sensitivity and critical diameter
- Fast cookoff/bonfire testing
- Effects of damaged propellants and DDT potential.

To further assess the three areas mentioned above, research efforts will be required for characterizing families of high-energy propellants. This will give the DDESB/Joint Hazard Classifiers the data to ensure the motors will not detonate in real life storage and transportation scenarios including accidental ignition and mechanical shock.

Future workshops will report the ongoing and planned research efforts being conducted by the government labs and industry in the areas of shock sensitivity and critical diameter characterization; the effects of damaged propellants and DDT potential and the design and correlation of subscale analog fast cookoff test articles with full-scale articles.

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