# Rationalization of IM Test Requirements: The 6°F SCO Test

Dr. Kerry A. Clark
NOSSA IM and HC Office
3817 Strauss Ave, Bldg. D-323
Indian Head, MD 20640
301-744-4102, kerry.a.clark@navy.mil

**Abstract**:

In 2006, the US Joint Requirements Oversight Council (JROC) recommended a standardized, single set of Insensitive Munitions (IM) test and passing criteria based upon procedure 1 of appropriate NATO IM STANAGs for use to assess IM compliance. In early 2010, the endorsement/codification of the US DoD acquisition requirement to use these standard IM tests and passing criteria was finalized by the Office of the Undersecretary of Defense (OUSD). The issue or concern to be addressed in this paper is the slow cook-off (SCO) test (STANAG 4382) which is designed to simulate fire in an adjacent magazine, storage depot or vehicle and its relationship to system safety design approaches. The SCO test for IM compliance requires a 6°F/hr heating rate of an ordnance item until reaction occurs; a burning reaction is passing criteria. Recently, some programs have begun to design their ordnance items with thermal based engineering mitigation solutions or implements/devices to pass the SCO test with the sole objective or goal of the ordnance system being IM compliant. The Naval Ordnance Safety and Security Activity (NOSSA) has concerns that this approach to IM compliancy may be neglecting an overarching factor of System Safety. This paper will discuss SCO testing, mitigation applications, System Safety related to SCO and the US Navy's Way Forward to evaluate, analyze and address and evaluate system safety concerns.

**Introduction**:

"Cook-off" is the term used for the event that occurs when a device loaded with an explosive material is heated beyond a critical point and the explosive detonates or explodes violently.

Naval crews live and work amongst explosive ordnance. It is therefore crucial that a proper understanding of how an energetic material behaves when exposed to unplanned stimuli such as mechanical impact or heat be gained. Of particular importance here is the reaction of ordnance to heat. The application of heat to an energetic material results in (heat releasing) thermal decomposition reactions which occur within these materials. Eventually the material reaches a temperature where the thermal decomposition becomes self-sustaining and thermal run-away occurs. This generally starts a deflagration process which builds to a violent reaction such as explosion or detonation.

The application of heat to an energetic material for sufficient time for reaction to occur is generally known as "cook-off". For obvious reasons, knowledge of the cook-off time to reaction is important for those responsible for fighting fires near or within shipboard magazines.

**Background**:

This background is an excerpt taken from Reference [1]. From the historical vantage, the USS FORRESTAL(CVA-59) is the most well known cook-off event. This accident happened as planes were being readied for launch on a mission over North Vietnam. The ship was part of a task force operating in "Yankee Station" in the Gulf of Tonkin off of North Vietnam. A 5-inch Zuni rocket loaded in the pod under the wing of an F-4 aircraft was accidentally fired. The warhead crossed the flight deck, struck an A-4 aircraft puncturing the fuel tank, and igniting a fire. Two A-4 aircrafts each loaded with two 500 pound MK-82 bombs and SHRIKE missiles, one A-4 loaded with two MK-82 and two AN117A1 750 pound bombs, and seven A-4's each loaded with two ANM65A1 1,000 pound bombs were engulfed in the fire.

Though serious in itself, the initial fire was not catastrophic. However, only ninety seconds after the fire started a 750-pound M-117 bomb loaded with Composition B detonated killing or seriously wounding most of the fire fighters. The detonation ruptured the flight deck spilling fuel into the hangar deck below. As the fire progressed, more detonations followed.

Major explosions continued for about five and a half minutes after the start of the fire. One 500-pound bomb, one 750-pound bomb, seven 1000-pound bombs, and several missile and rocket warheads were exposed to the heat from the fire and exploded with varying degrees of violence. It took about 10 hours to extinguish all of the fires on the ship. This disaster resulted in 134 deaths, 161 injured, 21 aircraft destroyed, and 39 aircraft damaged.

After this tragic incident, representatives from the Naval Ordnance Systems Command (NAVORD) and the Naval Air Systems Command (NAVAIR) were summoned to a meeting in the office of Rear Admiral Outlaw in the Pentagon. Rear Admiral Outlaw's meeting reviewed the details of the accident and discussed what could be done to minimize damage and casualties resulting from this kind of incident. A few days after this meeting, the Navy established a panel under retired Admiral Russell to investigate the accident. The Panel recommended ways to improve fire-fighting capabilities aboard the aircraft carriers and to increase safety during carrier flight operations.

The Navy had no data on the time a munition could endure a fuel fire without reacting or on the violence of the explosive reaction that could be expected when it occurred. In the following weeks, the Navy established a Flag level Fire Fighting Steering Committee. Also, NAVAIR initiated an Aircraft and Ordnance Safety Program to investigate ways to extinguish flight deck fires and methods to delay munition cook-off reactions.

The NAVAIR Ordnance Safety Program [2] concentrated its efforts on 1) tests to measure the cook-off time and reaction violence of air-launched weapons, 2) research programs to acquire and test insulation materials and, 3) the development of methods for applying internal and external insulation to warheads to protect the explosive from the heat. Insulation, ablative materials and intumescent paints developed by NASA for the space program and other materials available on the commercial market were evaluated. Eventually, with the combination of internal and external insulation applied, cook-off times of 5 to 10 minutes were achieved for MK-82 (500 lb) bombs. However, the improved time delay for cook-off did not diminish the violence of the explosive reactions when they occurred.

**SCO Testing Standards**:

Portions of this section are taken from Reference [3]. In 2003, MIL-STD-2105C (DoD 2003) superseded MIL-STD-2105B by referencing the individual NATO STANAGs for the assessment of munition safety and insensitive munitions (IM) characteristics of non-nuclear munitions, the pass/fail criteria in STANAG 4439 (NATO 2006), and AOP-39 for guidance on the development, assessment and testing of IM. Efforts were undertaken during Calendar Year 2000 in NATO AC/310 and AC/258 (later to merge into AC/326) to harmonize Insensitive Munitions and Hazard Classification large-scale testing. This work has resulted in a more cost effective test and analysis program for program managers and technology development programs, although there is still room for improvement. With the approval of AOP-39 Edition 2 (NATO 2006) in 2006, STANAG 4439 and AOP-39 [4] became the controlling documents for assessment and testing of IM [5].

The SCO test is designed to assess the violence of reaction and time to reaction, if any, of munitions when subjected to a gradually increasing thermal environment. The SCO test was initially required by

WR-50, in which the test item was subjected to controlled heating at a rate of 6°F/hr air temperature rise per hour until destruction of the explosive load occurs. The passing criteria for the SCO test was the same as for the FCO test, i.e., burning, deflagration, or detonation of the warhead explosive load must not occur at a temperature (measured at the explosive to metal interface) less than 300°F. The first evidence of criteria for a Hazard Division 1.5 explosive occurred in 1981 when the DoD Joint Technical Coordinating Group Working Party for Explosives (WPE) developed the criteria for the Insensitive Explosives Hazard Classification Division 1.5, which recommended a WR-50-type test, and if no reaction was observed, the sample was to be raised to the point of reaction (JTCG 1981). These criteria were adopted by the Department of Defense Explosive Safety Board (DDESB) and published in TB 700-2.

The origin of the 6°F/hr heating rate requirement is not known but some involved in this field since the mid 1950s speculate that it had to do with hot gun problems in WW II and a desire to acquire a baseline of data on the most violent type of reaction that could occur when an munition loaded with a specific explosive material is exposed to thermal energy. Many scientists in the explosive materials community considered the 6°F/hr heating rate a “near worst-case” scenario that provided a real-world baseline on slow-heating-caused thermal reactions. Fontenot [6] in his study of heating rates for the SCO test was not certain where the 6°F/hr heating rate originated, and thought that it may be an attempt to approximate laboratory-type isothermal heating conditions without the expense of consuming many test items. He also theorized that this heating rate was calculated from World War II events where ships exploded after sustaining below-deck fires for up to two days. Lundstrom [7], in a paper presented at the 1993 NATO IM Information Center (NIMIC) Workshop on cook-off, noted that a workshop on SCO was held at the Naval Air Weapons Center (NAWC) in 1987 after project managers questioned the basis of the 6°F/hr (3.3°C/hr) heating rate and how could it be justified. The 3.3°C/hr heating rate requirement was also questioned at the cook-off Workshop at Naval Air Warfare Center (NAWC) in 1996 [8] for a munitions acceptance test, but might be credible for a scientific test. There were no changes to the 6°F/hr or 3.3°C/hr heating rate requirement throughout the different versions of the specifications.

In DOD-STD-2105 (Navy), there were no specific pass/fail criteria; the Weapon System Explosives Safety Review Board (WSESRB) would make a final recommendation for a weapon’s service use based on results of the hazard analyses and test program. For MIL-STD-2105A and subsequent controlling standards, the passing criterion was that there be no reaction more severe than burning (Type V) at a heating rate of 6°F/hr. The SCO requirements in MIL-STD-2105C provided harmonization with the Hazard Classification Slow Heating Test of TB 700-2 and the UN Orange Book for weapons that strived for classifications of Hazard Division 1.2.3 or Hazard Division 1.6.

**SCO Heating Rate Discussion**:

Much work has been done in measuring cook-off time to reaction and the violence of response. Slow heating rates apply to all situations where heat can be applied by means other than the direct exposure to a fuel fire. This involves a very large number of heating rates each applicable to its own scenario. The standard heating rate of 6°F/hr listed in MIL-STD-2105C is very low and can result in reaction times measured in days. Some researchers wish to use an intermediate heating rate of 40°F/hr - 60°F/hr in an effort to define a more realistic heating rate.

With the advent of Insensitive Munitions in the mid 1980’s, several offices and activities have studied SCO and attempted to determine the most appropriate heating rate. The US Navy conducted two studies, Fontenot and Jacobson in 1988 [6] and Gokee in 1996 [9]. Subsequently, the US Army studied the issue in 2000. One of the objectives of the SCO test was to evaluate the reaction of weapons to a slow thermal soaking. Combined with fast cook-off (FCO), this allowed evaluation of the ability of weapons to withstand thermal environments at opposite ends of the heating rate spectrum.

Both of the US Navy reports recognized that steam leaks can achieve an average 6°F/hr heating rate. Fontenot and Jacobson also recommended several different heating rates to achieve full thermal soaking based on the size of the weapon. Those heating rates were 53°F/hr, 31°F/hr, and 13°F/hr for 500 lb, 1000 lb and 2000 lb class weapons respectively. The scenario for these rates was below deck fires in adjacent compartments to magazines and the rates were calculated from what it took to achieve thermal soak. For the 2.75 inch rocket scenarios analyzed by Gokee, 40°F/hr was selected to represent below deck fires. Other scenarios such as stuck brakes on rail cars and smoldering debris piles have been postulated as SCO sources but were ruled out as less credible than the below decks fires. The US Army had chosen to use 50°F/hr based on their belief that this is the lower bound estimate of what may happen in a real event. Dr. Frey [10] noted that "Fires come in an infinite variety and I don't think that any analysis will ever lead us to a single appropriate slow heating rate." With the implementation of the codified and harmonized IM and HC standards (OSD 2010, [11]), the Joint Services are held to SCO testing at 6°F/hr.

**Designing Munitions to Mitigate SCO**:

**NOSSA has a concern that programs are attempting to design their munition systems to pass the 6°F/hr SCO test, a push point solution, not addressing the effect to overarching System Safety.**

It is very difficult from a practical and affordable standpoint to generate the data describing ordnance response with respect to the shipboard fire threat for every ordnance item loaded. Ship commanders require accurate answers to a number of fire-related questions: (1) How long do their sailors have to fight a fire? (2) What are the most vulnerable munitions in a shipboard fire? (3) Can the munitions be loaded in the magazine in such a manner as to reduce their vulnerability? (4) What are the consequences of a cook-off reaction? These questions should be considered in the design of more sophisticated fire protection systems and IM compliant munition systems that incorporate part or all of the cook-off model concepts and mitigation.

About 20 years ago, the Naval Air Systems Command (NAVAIR) issued design guidelines on the development of an Active Mitigation Device (AMD) that could be used to mitigate the expected reaction of a munition exposed to fast cook-off or one of the other environments characterized by the Insensitive Munitions criteria. The driver for these guidelines at the time was the Thermally Initiated Venting System (TIVS) that had been developed to help mitigate the reaction of an AMRAAM missile (AIM-120) to the fast cook-off environment. An AMD functioned during the fire event, set off an external linear shaped charge along the rocket motor, altered the structural strength of the motor material, and significantly reduced the severity of the reaction of the motor to the fast cook-off event.

The NAVAIR guidelines were an attempt to formalize some design observations should other programs attempt to develop an AMD to help mitigate one of the IM environments. Some of the guidelines were dated and sometimes duplicative, so the following design guidelines are an initial attempt to streamline the original guidelines into a form and format that could be used by any program that wishes to develop an AMD. The current trend is for Passive Mitigation Devices (PMDs), for which these same guidelines apply. This includes items like melt plugs that vent warhead or rocket motor reactions or other non-explosive devices that allow burning of high explosive loads rather than more destructive higher order reactions. These updated guidelines are designed to ensure the System Safety within a munition system. Concurrence is required with the Navy Weapon System Explosive Safety Review Board (WSESRB) for AMD or PMD use.

For the purpose of the following **DRAFT** guidelines, **of which only a small excerpt is presented**, the definition of Insensitive Munition threat environments are the following threat environments: Fast Cook-off, Slow Cook-off, Bullet Impact, Fragment Impact, Sympathetic Reaction and Shaped Charge

Jet. These tests are described in more detail in the latest editions of MIL-STD-2105 and STANAGs 4240, 4382, 4241, 4496, 4396 and 4526.

1. Active Mitigation Devices (AMDs) or Passive Mitigation Devices (PMDs) are required to respond to a specific Insensitive Munitions (IM)-threat environment (usually fast and/or slow cook-off), and to remain safe when exposed to both normal and abnormal environments at all other times.

2. AMD designs must comply with appropriate military specifications and standards to prevent inadvertent initiation of an energetic reaction in a rocket motor or warhead.

3. Programs must be able to demonstrate that there is a tangible benefit to having an AMD or PMD, and this benefit must relate to a reduction of the hazard.

4. Reaction temperatures of AMDs should be as high as the particular energetic material will allow without creating undesirable reactions (absolute temperature, not a rate-based temperature). The AMD must remain safe at all normal and abnormal thermal environments below this specific reaction temperature.

5. AMDs or PMDs must be designed to survive the same logistic cycle as the munition to which it is mounted. The devices must be tested as part of the actual munition, and must not react at an undesired thermal or mechanical environment.

6. Safety hazard analyses must consider the possibility of inadvertent activation of the AMD on a weapon loaded on a launch platform, and the safety risks to the platform, personnel, and adjacent weapons.

7. Recommendations for fire-fighting must be developed and coordinated with Safety authorities.

**Conclusion**:

It is a goal of any IM program to implement incremental improvements over time with the ultimate achievement of any munition to become fully IM compliant. In 2006, the US Joint Requirements Oversight Council (JROC) recommended a standardized, single set of Insensitive Munitions (IM) test and passing criteria based upon procedure 1 of appropriate NATO IM STANAGs for use to assess IM compliance. In early 2010, the endorsement/codification of the US DoD acquisition requirement to use these standard IM tests and passing criteria was finalized by the Office of the Undersecretary of Defense (OUSD). The issue or concern addressed in this paper was the slow cook-off test (STANAG 4382) which is designed to simulate fire in an adjacent magazine, storage depot or vehicle and its relationship to system safety design approaches. The SCO test for IM compliance requires a 6°F/hr heating rate of an ordnance item until reaction occurs; a burning reaction is passing criteria.

It has become evident that the SCO 6°F/hr heating rate is a characterization test; a test with use to identify a possible worst case scenario during a slow cook-off event. Literature discussions of the heating rate issue have focused on a heating range of somewhere between 40°F/hr and 60°F/hr, a true representation of the credible shipboard slow cook-off event.

When analyzing the SCO scenario from a shipboard System Safety perspective, using the data from a 6°F/hr SCO characterization test only, does not account for the munition reaction from the most credible thermal threat (below deck fires in adjacent compartments to magazines). The US Navy is recognizing this shortfall within the IM sanctioned SCO test protocol as providing an incomplete answer with respect to the overarching System Safety.

US Navy Recommendations:

- SCO hearing rates of 40°F/hr - 60° F/hr could be used to represent below deck fires. However, given that an objective in development of IM test programs is to harmonize with HC requirements, 6°F/hr is the recommended heating rate that should be maintained for any IM and Hazard Classification program. The 6°F/hr should be maintained for the IM SCO characterization test.

- There is a need for program Threat Hazard Assessments (THAs) that address the most hazardous SCO threats for test environments using the most credible SCO temperature as well as flexibility to test to safety concerns as well as standard requirements. This approach ensures System Safety has been implemented within a munition system. The OSD definition of a THA is shown below.

Requirement for THA remains per OSD [11]:

"In addition to standardized IM testing, each munitions program should continue to evaluate their cradle-to-grave lifecycle and develop a Threat Hazard Assessment (THA) to identify hazards and risks from threats more severe than those addressed by standardized testing, which DoD Component acquisition organizations should incorporate into the existing risk identification, mitigation, and acceptance process. Engineering testing of such other extreme conditions is encouraged, as appropriate, for assessing incremental improvements in performance such as vulnerability and survivability. The THA may also provide information relevant during Joint Capabilities Integration Development System (JCIDS) activities addressing proposed unique variations from the established standardized IM protocols."

- The US Navy recommends not designing a munition system to push a point solution. In other words, do not design to only pass the 6°F/hr IM SCO characterization test; design to address the appropriate and credible below deck fire threats as well as a possible worst case scenario. There is potential that a SCO test at 40°F/hr - 60° F/hr will produce a more adverse System Safety scenario. The US Navy will address both the IM testing as well as the System Safety aspect when brought before the WSESRB. The WSESRB may require evidence, through an additional SCO test at 40°F/hr - 60° F/hr or by an engineering analysis, that the munition system will meet the expectation of System Safety requirements.

- The US Navy recommends Joint Service discussions with Subject Matter Experts to address appropriate testing protocols. If there is sufficient interest, the US Navy will voluntarily take the lead to coordinate.

**References**:

[1] Ray Beauregard, "History of the US Navy's IM Program", 24 January 2005.

[2] The NAVAIR Ordnance Safety Program became known as the NAVAIR Insensitive Munition Technology Transition Program (IMTTP) shortly after the CNO IM policy was issued. This program compliments the IMAD program in that it seeks to apply the IM technology to air-launched weapons. I leave it to those more familiar with the IMTTP to document its history.

[3] Tomasello, K., Sharp, M., Adams, J. and Rich Bowen. "Origin of Test Requirements and Passing Criteria for the Qualification and Final (Type) Qualification of Explosives". DDESB Seminar, 2010.

[4] In 2010, STANAG 4439 Edition 3 (NATO 2010) superseded STANAG 4439 Edition 2, and AOP-39 Edition 3 (NATO 2010) superseded AOP-39 Edition 2.

[5] MIL-STD-2105C remains in effect and references STANAG 4439 and AOP-39.

[6] Fontenot, J. and Jacobson, M., 1988. Analysis of Heating Rates for Insensitive Munitions Slow Cook-off Test. NAWC China Lake.

[7] FitzGerald-Smith, Kernen and Stokes III, 1993, quoted Lundstom from a paper presented at the 1993 NIMIC Workshop on cook-off.

[8] Stokes, Sanderson and Kernen, 1997, quoted discussions at at the cook-off Workshop at NAWC in 1996.

[9] Gokee, Heather, 1996. 2.75 Rocket System Slow Cook-off Test. NSWC Indian Head.

[10] Frey, R, 2000. Appropriate Slow Cookoff Heating Rates. Army Research Laboratory (ARL).

[11] OUSD Memo Feb 01 2010

[12] Draft NAVAIR/NAVSEA Insensitive Munitions Active Mitigation Device Design Guidelines, July 2010, NOSSA.

**Biography**:

Dr. Kerry Clark is the Technical Authority of the Navy's Insensitive Munitions (IM) and Hazard Classification (HC) programs to include explosives and propulsives, qualification and type qualification programs and interim and final hazard classifications. She manages the Navy's IM Advanced Development (IMAD) program and leads and participates in Joint Services and international groups to guide IM and HC policy from a US Navy perspective. Dr. Clark is a supporting member of the OSD IM IPT, JSIMPT, JHC panel and collaborates with NATO and allied nations DEAs/IEAs and NATO Action Committee 326 Subgroups.