

**METRIC**

**MIL-STD-3029**

**23 July 2009**

**DEPARTMENT OF DEFENSE  
TEST METHOD STANDARD  
HOT GUN COOK-OFF HAZARDS ASSESSMENT,  
TEST AND ANALYSIS**



## MIL-STD-3029

## FOREWORD

1. This standard is approved for use by the Department of the Navy and is available for use by all Departments and Agencies of the Department of Defense.

2. This standard provides a practical, comprehensive, consistent, and LEAN-efficient process to define the hot gun hazards associated with a cook-off of propellants or explosives in ammunition left in a hot gun barrel as a result of a misfire, hangfire, or even in some instances a ceasefire. Insensitive munitions tests do not provide the information needed to evaluate hot gun cook-off hazards (see MIL-STD-2105 for additional tests). The hot gun hazards determined by executing this process should be used as a rationale for developing hot gun misfire procedures used by a gun crew in the event of a hangfire or misfire. Hot gun procedures are also required for a ceasefire situation in guns that chamber a round prior to an intent-to-shoot.

3. A hot gun cook-off is a serious, thermally-induced reaction (for example, detonation, deflagration, burning, and out-gassing) of an explosive in a projectile or propellant in a propelling charge resulting from significant heating from the gun barrel. In the past, prolonged gun firings have ended in a hangfire or misfire where either or both the propelling charge or projectile remained in a very hot gun barrel for a prolonged period of time and a cook-off has occurred. Such a detonation or deflagration can result in serious injury to, or even death, of a gun's crew and/or serious damage to a weapon or weapon platform. Examples of actual cook-offs aboard U.S. Navy ships include:

a. On September 25, 1965, near the end of a 24-hour shore-bombardment by USS TURNER JOY off the coast of Vietnam, a 5-inch round misfired. The projectile in the hot gun barrel cooked off; three sailors were killed and three more were wounded.

b. While the USS BOSTON was conducting a gunfire support mission off the coast of Vietnam on July 9, 1969, the left gun in mount number 53 had a round cook-off in the gun barrel. The explosion from the round caused part of the barrel to hit the ship's superstructure and exit through the top of the bridge. One officer on the bridge and ten sailors from the gun crew were injured. A cook-off of the round or a fuze activation was assumed.

c. In 1972, aboard the USS BENJAMIN STODERT, a misfired-round was jettisoned from gun mount number 52 after a 4-minute waiting period. The propelling charge ignited just prior to entering the water.

d. While conducting reliability tests of a 5-inch/54-caliber MK 45 gun mount aboard the USS NORTON SOUND in 1972, 567 rounds were fired in 4 hours prior to a misfire occurring. The propelling charge in the hot gun barrel cooked off in 2 minutes and 45 seconds.

e. In 1977, a hangfire was experienced aboard the USS MANLEY. Subsequently, two crewmen were injured after a second attempt to fire the propelling charge. Facts indicate that the breech block was not completely closed and the gun mount was seriously damaged.

4. This document contains a description of the process (tests and analyses) that is used to define the hazards associated with ammunition (projectile and propelling charge) being left in a hot gun barrel as the result of an inadvertent hangfire or misfire. Knowledge of these hazards is the starting point for developing hot gun misfire procedures to be used by a gun crew to safely attempt to clear ammunition from a hot gun barrel and prevent the ammunition from cooking off. Hot gun hazards are a function of the firing scenario conducted immediately prior to a hangfire/misfire (types and number of rounds fired, rates of fire, lengths of pauses in the firing), as well as the type of gun, and the type of ammunition left in a hot gun barrel.

5. Four types of tests are normally conducted to generate data that will be used to determine how: (1) the gun barrel heats up during firing, (2) the heat flows from the hot barrel back into the projectile, (3) the heat flows into the propelling charge subsequent to a misfire, and (4) the explosive or propellant reacts (e.g., detonates or deflagrates) once it is heated.

6. The data from these tests are used to calibrate finite element method (FEM) thermal models of the gun barrel, projectile (warhead and rocket motor if appropriate), and propelling charge. These FEM thermal models are used to evaluate the cook-off hazards that exist for realistic and reasonable (but not all possible) firing scenarios.

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7. This process should apply to each different combination of ammunition and gun, because the cook-off hazards are dependent upon the designs of both. Different variants of the same type of gun can heat up differently when firing the same ammunition. Different ammunition can heat up differently in the same hot gun if the two types of ammunition have different designs, including the type of explosive and propellant used, the projectile design (such as wall thickness), the presence or absence of liners, or the cartridge case design (material).

8. Fortunately, documented lessons learned from one gun and ammunition combination can frequently be used to help evaluate other similar combinations, e.g., the same explosive used in another gun. Accordingly program managers and munitions developers should tailor the process in this standard to take advantage of documented lessons learned in other ammunition and gun programs.

9. Gun and ammunition program managers are responsible for planning and executing hot gun cook-off hazards assessment programs. The cook-off assessment includes a test plan (that is dove-tailed with the insensitive munitions and system safety evaluation plans) based on realistic firing scenarios. Program managers should establish safety design goals for the assessment plan and have these goals approved by the service review organization within the applicable department. Program managers should generate test and analysis reports (documenting a rationale for the final hot gun misfire procedures) for submission to their service review organization.

10. The service review organization should review the hot gun cook-off assessment plan as well as the test and analysis reports. It should examine the results of the hot gun cook-off hazards assessment program to ensure that hot gun cook-off safety as well as insensitive munitions and system safety requirements are met. The service review organization should produce a final recommendation for or against service use of each gun/ammunition combination and whether the hot gun misfire procedures are adequate. For joint programs, all affected service review organizations should conduct this review and examination and develop a final recommendation.

11. Documentation of a hot gun cook-off assessment should be kept in a library for use by future gun and ammunition programs. Such a collection should minimize unnecessary and redundant testing and analyses in the future, allowing the potential use of previously conducted testing and analyses as leverage in current efforts.

12. Comments, suggestions, or questions on this document should be addressed to: Commander, Naval Sea Systems Command, ATTN: SEA 05M2, 1333 Isaac Hull Avenue, SE, Stop 5160, Washington Navy Yard DC 20376-5160 or emailed to [CommandStandards@navy.mil](mailto:CommandStandards@navy.mil), with the subject line "Document Comment". Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at <http://assist.daps.dla.mil>

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## 1. SCOPE

1.1 Scope. This standard provides or references test and analysis procedures for the assessment of hot gun cook-off hazards for all non-nuclear gun munitions. These procedures compliment the insensitive munitions (IM) evaluation procedures in MIL-STD-2105, as well as the appropriate system safety requirements specified in MIL-STD-882.

1.2 Purpose. The purpose is to provide a framework for the development of a test and analysis program for non-nuclear gun munitions. These tests and analyses are to assist in the characterization of gun munitions to yield a documented record of the hot gun hazards for each gun/ammunition combination. This document provides the rationale for hot gun misfire procedures for gun crews that must deal with a misfire/hangfire (or even a ceasefire if the ammunition is loaded into a gun chamber prior to an intent to fire) involving live ammunition in a gun barrel/chamber. These procedures address a comprehensive range of firing scenarios that could be expected prior to a misfire/hangfire/ceasefire, not just the worst case scenario. This document also provides the service review organization information with which to make a decision.

1.3 Application. This standard applies to all-up non-nuclear gun propelling charges and projectiles (e.g., which may contain fuzes, booster charges, warheads, and rocket motors). It is not possible to test all hot gun conditions; however, a comprehensive range of realistic firing scenarios should be evaluated through a minimum of testing and an analytical extrapolation of data from those tests.

## 2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4, or 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3, 4, or 5 of this standard, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

## INTERNATIONAL STANDARDIZATION AGREEMENTS

- |             |   |   |
|-------------|---|---|
| AOP-15      | - | Guidance on the Assessment of the Safety and Suitability for Service of Non-Nuclear Munitions for NATO Armed Forces |
| AOP-39      | - | Guidance on the Development, Assessment and Testing of Insensitive Munitions (IM)                                   |
| STANAG 4439 | - | Policy for Introduction, Assessment and Testing for Insensitive Munitions (MURAT)                                   |

## DEPARTMENT OF DEFENSE STANDARDS

- |              |   |   |
|--------------|---|---|
| MIL-STD-810  | - | Environmental Engineering Considerations and Laboratory Tests |
| MIL-STD-882  | - | System Safety   |
| MIL-STD-2105 | - | Hazard Assessment Tests for Non-Nuclear Munitions             |

(Copies of these documents are available online at <http://assist.daps.dla.mil/quicksearch/> or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

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2.2.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

## NAVAL SEA SYSTEMS COMMAND (NAVSEA) PUBLICATIONS

SW300-BC-SAF-010 - Safety Manual for Clearing Live Ammunition from Guns

(Copies of this document are available from the Naval Logistics Library, 5450 Carlisle Pike, Mechanicsburg, PA 17055 or online at <http://nll.ahf.nmci.navy.mil>.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

## ASME INTERNATIONAL

ASME Y14.3M - Drawings, Multiview and Sectional View (DoD adopted)

(Copies of this document are available from ASME International, 22 Law Drive, PO Box 2900, Fairfield, NJ 07007-2900 or online at [www.asme.org](http://www.asme.org).)

## ASTM INTERNATIONAL

ASTM E698 - Standard Test Method for Arrhenius Kinetic Constants for Thermally Unstable Materials

ASTM E1231 - Standard Practice for Calculation of Hazard Potential Figures-of-Merit for Thermally Unstable Materials

ASTM E2070 - Standard Test Method for Kinetic Parameters by Differential Scanning Calorimetry Using Isothermal Methods

(Copies of these documents are available from ASTM International, 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, PA 19428-2959 or online at [www.astm.org](http://www.astm.org).)

2.4 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence unless otherwise noted. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

## 3. DEFINITIONS

3.1 All-up-round (AUR). An AUR consists of the completely assembled unit of ammunition including both the projectile and propelling charge (fixed ammunition) or in the case of semi-fixed ammunition the complete projectile (body, energetic material, and fuze) or the complete propelling charge (cartridge case, propellant, primer, and ancillary components).

3.2 Ambient temperature. The ambient temperature refers to the air temperature outside of the gun weapon system.

3.3 Bare round or configuration. A bare round is a munition with no external protection (for example, a shipping container).

3.4 Cartridge case. A cartridge case is a metallic- or composite-component of the ammunition designed to contain the gun propellant and provide an attachment for the primer.

3.5 Ceasefire. A ceasefire is an intentional stoppage of gun firing. In some guns this corresponds to a round being fully chambered in the gun barrel and in others a round will not be chambered.

3.6 Cold gun. A gun whose barrel and chamber temperatures have not been raised to a point where the energetic material in a projectile or propelling charge (left in the gun barrel) could cook off.

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3.7 Cook-off. A cook-off is an exothermic decomposition of the energetic material in ammunition that could result in serious injuries to a gun's crew or significant damage to a weapon and weapon platform. In the event of a hot gun misfire, the gun barrel is the source of ammunition heating.

3.8 Data acquisition system (DAS). A DAS is an instrumentation device that provides signal conditioning of electronic data and storage for that data.

3.9 Energetic material. An energetic material is a chemically active ammunition component such as a propellant, explosive, or illuminating element.

3.10 Exothermic decomposition. An exothermic decomposition is a thermally-induced release of energy in the form of out-gassing, deflagration, and/or detonation.

3.11 Explosive. An explosive is a solid or liquid energetic substance (or mixture of substances) that is in itself capable, by chemical reaction, of producing gas at such temperature, pressure, and speed as to cause damage to the surroundings. Included are pyrotechnic substances, even when they do not evolve gases. The term explosive is used to describe various energetic materials known as explosives and propellants, along with igniter primer, initiation, and pyrotechnic (including illuminant, smoke delay, decoy, flare, and incendiary) compositions.

3.12 Explosive device. An explosive device contains explosive material(s) and is configured to provide quantities of gas, heat, or light by a rapid chemical reaction initiated by an energy source usually electrical or mechanical in nature.

3.13 Exudation. An exudation is a discharge or seepage of material. The material may be a component of a chemical payload, a component of an explosive/propellant payload, or a reaction product due to the heating of components.

3.14 Fixed ammunition. Fixed ammunition consists of a projectile and cartridge case where the projectile is crimped mechanically in the cartridge case mouth and is rammed into a gun as a single entity.

3.15 Hangfire. A hangfire is a delay beyond the normal ignition time in the functioning of an ammunition component after the initiating action is taken.

3.16 Hazardous fragment. A hazardous fragment is a piece of a reacting weapon having an impact energy of 79 Newton-meters (58 foot-pounds) or greater (see 6.9).

3.17 Hot gun. A hot gun is a gun whose barrel and/or chamber temperatures have been raised to a point where the energetic material in the projectile or propelling charge (left in the gun barrel) could cook off.

3.18 Hot gun misfire procedures. Hot gun misfire procedures are prepared by the relevant service agency prior to a gun/ammunition combination being approved for service use. These procedures are based on hot gun testing and analysis of the full range of firing histories that a gun is capable of executing. Hot gun procedures address all realistically possible hot gun conditions that could occur in the fleet, not just the worst case. These procedures also address instructions appropriate for gun/ammunition combinations where a ceasefire can result in a round being rammed in a hot gun chamber without an immediate intent to fire that round.

3.19 Insensitive munitions (IM). Insensitive munitions are those which reliably fulfill (specified) performance, readiness, and operational requirements on demand, but which minimize the probability of inadvertent initiation and the severity of subsequent collateral damage to the weapon platforms, logistic systems, and personnel when subjected to unplanned stimuli.

3.20 Kinetic thermal properties. The kinetic thermal properties of the explosive include the activation energy, frequency factor and the heat of reaction.

3.21 Magazine. A magazine (for purposes of this standard) refers to a weapon system's compartment(s) used to store gun ammunition in the hours prior to it being gun fired. The temperature of the magazine determines the initial temperature of ammunition when it experiences a misfire or hangfire and its subsequent reaction time and the violence of the reaction.

3.22 Misfire. A misfire is a failure of a round of ammunition to fire after an initiating action is taken.

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3.23 Munition. A munition is an assembled ordnance item that contains explosive material(s) and is configured to accomplish its intended mission.

3.24 Munition subsystem. A munition subsystem is an element of an explosive system that contains explosive material(s) and that, in itself, may constitute a system.

3.25 Primer. A primer is used to initiate a propelling charge.

3.26 Projectile. A projectile consists of the body, filler (sometimes explosive or illuminating compound)/burst charge, and fuze/plug.

3.27 Propelling charge. A propelling charge consists of the cartridge case, propellant, primer, and ancillary hardware (e.g., wad, spacer, or case closure plug).

3.28 Propulsion. Propulsion is a reaction whereby adequate force is produced to impart flight to a test item in its least restrained configuration.

3.29 Reaction types.

3.29.1 Type I (detonation reaction). A detonation is the most violent type of explosive event. A supersonic decomposition reaction propagates through the energetic material to produce an intense shock in the surrounding medium (such as air or water) and very rapid plastic deformation of metallic cases, followed by extensive fragmentation. All energetic material will be consumed. The effects will include large ground craters for munitions on or close to the ground, holing/plastic flow damage/fragmentation of adjacent metal plates, and blast overpressure damage to nearby structures.

3.29.2 Type II (partial detonation reaction). A partial detonation is the second most violent type of explosive event. Some of the energetic material reacts (contrasted to all of the explosive reacting as in a detonation). An intense shock is formed; some of the case is broken into small fragments, a ground crater can be produced, adjacent metal plates can be damaged as in a detonation, and there will be blast overpressure damage to nearby structures. A partial detonation can also produce large case fragments as in a violent pressure rupture (brittle fracture). The amount of damage, relative to a full detonation, depends on the portion of the material that detonates.

3.29.3 Type III (explosion reaction). An explosion is the third most violent type of rapid decomposition event. Ignition and rapid burning of the confined energetic material builds up high local pressures leading to violent pressure rupturing of the confining structure. Metal cases are fragmented (brittle fracture) into large pieces that are often thrown long distances. Unreacted and/or burning energetic material is also thrown about. Fire and smoke hazards will exist. Air shocks are produced that can cause damage to nearby structures. The blast and high velocity fragments can cause minor ground craters and damage (breakup, tearing, or gouging) to adjacent metal plates. Blast pressures are lower than for a detonation.

3.29.4 Type IV (deflagration reaction). A deflagration is the fourth most violent type of rapid decomposition event. Ignition and burning of the confined energetic material leads to a nonviolent pressure release as a result of a low strength case or venting through case closures (such as loading ports or fuze wells). The case might rupture but does not fragment, closure covers might be expelled, and unburned or burning energetic material might be thrown about and spread the fire. Propulsion might launch an unsecured test item, causing an additional hazard. No blast or significant fragmentation damage to the surrounds occurs, only heat and smoke damage from the burning energetic material.

3.29.5 Type V (burning reaction). Burning is the least violent type of rapid decomposition. The energetic material ignites and results in a non-propulsive burn. The case may open, melt, or weaken sufficiently to rupture nonviolently, or closure covers may be expelled allowing mild release of combustion gases. Debris stays mainly within the area of the fire. This debris is not expected to cause fatal wounds to personnel or to be a hazardous fragment.

3.30 Round. A round is ammunition that may be either fixed or semi-fixed. Fixed (one-piece) ammunition consists of a projectile and propelling charge that are joined at the cartridge case mouth. Semi-fixed (two-piece) ammunition consists of a projectile and propelling charge that are not connected together.

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3.31 Safe clearing time predictor (SCTP). An SCTP is an automated software resident in the gun control computer in the gun mount itself. The SCTP automatically receives data from the gun telling what type of ammunition is fired and when it is fired. The barrel temperatures at critical locations are continuously calculated by the SCTP, which monitors the thermal state of the barrel and automatically decides whether the next type of ammunition rammed could create a hot gun condition. In the case of a misfire or hangfire, the SCTP automatically determines whether the type of misfired ammunition would cook off in less than a predetermined amount of time and informs the gun crew whether it is safe to try to clear the gun. Finally if the gun has been abandoned because the misfired round could not be cleared, the SCTP determines and informs the gun crew of how long the gun must be abandoned before it is safe to return. All of the above decisions are based on the actual firing scenario preceding the misfire, not on the worst case.

3.32 Semi-fixed ammunition. Semi-fixed ammunition consists of two separate components, a projectile and propelling charge, that are rammed as two unattached components into the gun chamber.

3.33 Service review organization. The various service organizations responsible for the assessment of explosive safety (see 6.8).

3.34 Thermophysical properties. The thermophysical properties of the ammunition components include the density, thermal conductivity, and specific heat.

3.35 Threat hazard assessment (THA). The THA should include an evaluation of the realistic firing scenarios (types of ammunition fired, numbers of rounds fired, rates of fire, and cooling periods between bursts) that could precede a misfire or hangfire. The thermal state of the gun barrel is strongly dependent upon the conditioning provided by the firing that occurred prior to an inadvertent stoppage, resulting in ammunition being left in the barrel. The THA should also address the potential reactions (such as detonation or deflagration) of the ammunition being exposed to a hot gun barrel for a prolonged time. The THA should be updated as new types of ammunition (new explosives or significantly different designs) are introduced into a given type of gun.

3.36 Units of measurement and abbreviations. Units of measurement are expressed in metric or SI (Le System International d'Unites). The corresponding English equivalent follows in parentheses. Standard abbreviations used throughout this document are as follows:

Metric (SI)		English	
°C	degrees Celsius	°F	degrees Fahrenheit
cm	centimeters	in	inches
m	meters	ft	feet
m/s	meters per second	ft/s	feet per second
N-m	Newton-meter	lbf-ft	pound-force-foot
Kpa	kilopascal (gauge)	psig	pounds per square inch (gauge)
cal/gm	calories per gram	Btu/lb <sub>m</sub>	British thermal units per pound-mass
cal/mole	calories per mole	Btu/mole	British thermal units per mole
1/sec	per second	1/sec	per second
gm/cc	grams per cubic centimeter	lb <sub>m</sub> /ft <sup>3</sup>	pounds-mass per cubic foot
cal/sec-cm-°C	calories per second- centimeter- degrees Celsius	Btu/in-sec-°F	British thermal units per inch per second per degrees Fahrenheit
cal/gm-°C	calories per gram per degree Celsius	Btu/lb <sub>m</sub> -°F	British thermal units per pound-mass per degree Fahrenheit

3.37 Weapon system. A weapon system consists of the weapon components and equipment required for its operation and support as well as the munitions used in the weapon.

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## 4. GENERAL REQUIREMENTS

4.1 General. The hot gun hazard assessment shall identify the full range of hot gun hazards to ammunition necessary to create hot gun misfire procedures for each ammunition/gun combination. A hot gun hazard assessment test program shall include a test plan generated in conjunction with a THA and a comprehensive and realistic evaluation of an extensive range of firing histories that could precede an inadvertent hangfire/misfire (or even a ceasefire), as well as the relevant environmental conditions.

4.1.1 Test and analysis plan. The new ammunition or gun program shall develop a test and analysis plan and base it on a comprehensive evaluation of realistic firing histories that could reasonably be expected to precede an inadvertent gun stoppage with ammunition left in a hot gun barrel. The plan shall address the relevant environmental conditions that could exist. The plan shall include provisions for the conduct and sequence of testing and analyses illustrated on Figure 1. The plan shall also reference previous testing and analysis from the hot gun hazard assessments of similar ammunition or weapon systems that will be used in lieu of new testing and analysis. A review and concurrence is required by the appropriate service review organization(s) prior to conduct of the testing and analysis program. Finally, gun or ammunition programs shall coordinate the plan with that of the system safety program described in MIL-STD-882, AOP-15, and the insensitive munitions program described in MIL-STD-2105, STANAG 4439, and AOP-39.

4.1.2 Environmental profile. The new gun or ammunition program shall identify the in-service environmental temperatures (magazine storage, gun mount, and ambient temperatures) that would affect the cook-off of ammunition in a hot gun barrel/chamber. These temperatures shall be considered in the THA and sited in the test and analysis plan.

4.1.3 Threat hazard assessment (THA). The gun or ammunition program shall develop a THA that addresses the entire range of environments and firing scenarios that could precede a misfire, hangfire, or even a ceasefire. The hot gun hazards shall appear as a component of the overall gun or ammunition THA.

4.2 Test parameters. The gun or ammunition program shall determine the hot gun safety and sensitivity characteristics of the gun/ammunition combination for the entire realistic range of operational capabilities, not just the worst case. The test parameters shall reflect the entire range (not all) of barrel and chamber temperature histories (at the time of a hangfire, misfire, or ceasefire) that can be expected in service use.

4.2.1 Initial temperatures. All ammunition tested shall be conditioned to  $20 \pm 5$  °C ( $68 \pm 9$  °F) prior to testing.

4.2.2 Barrel temperatures. The simulated barrel temperatures tested shall reflect a reasonable range of barrel temperatures expected in service use. These temperatures may be based on actual measured temperatures or temperatures predicted using calibrated barrel thermal models.

4.2.3 Ammunition configurations. All ammunition configurations shall be considered for inclusion in testing, although not all need be tested. The program shall include ammunition configurations that result in the fastest and slowest cook-off times.

4.3 Hazard assessment test report. The gun or ammunition program shall prepare a hazard assessment test report that contains the detailed information specified herein (see 5) and is consistent with the test and analysis plan (see 4.1.1). The test report shall include the rationale for deviations from the test plan, test item configuration, and identification, test date, test results, and safety related conclusions that may be drawn from the test results. This report shall summarize test data and analysis results from other gun/ammunition hazard assessments that were substituted for tests and analyses for the current gun/ammunition combination. The results from this assessment shall be presented to the service agency creating the hot gun misfire procedures for the ammunition and gun. The test results shall be reported to the service review organization for consideration and approval prior to the introduction of the gun and its ammunition into service use.

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4.4 Test hardware. The items to be tested shall be either all-up production hardware or a representative of all-up production hardware. Instrumented ammunition shall be identical to in-service hardware, unless it is not possible to add instrumentation to explosively-loaded components. In that instance, an inert filler may be substituted for the explosive components in some (not all) of the test ammunition, as long as the filler reasonably simulates the thermal characteristics of the actual explosive. Actual gun barrels (or representative barrels with production-simulated chamber and rifling geometry) shall be used in these tests. Again the thermal properties of a simulated barrel should be reasonably similar to that of the actual barrel. When the test items differ from production hardware, the tested configuration shall be described in the test plan.

4.5 Test facilities. The test fixtures shall not interfere with the test stimulus being imposed on the test ammunition or influence the subsequent reaction of the ammunition. Unless otherwise specified in the test and analysis plan, tolerances of test conditions and instrumentation calibrations shall be in accordance with MIL-STD-810. An example of what the overall test facility could look like is presented on Figure 2. Central to this figure is a gun barrel section, a barrel stand, a tray to position the test ammunition (in preparation for remote ramming) aft of the barrel section, a blast shield and door, a rammer pole aft of the tray (viewed through the rammer port), a cylindrical blast shield around the barrel, as well as the electrical heaters, power cables and insulation on the outside of the barrel.

4.5.1 Test ammunition. Actual or realistic simulations in some (but not all) of the ammunition tests may be used in the hot gun hazard evaluation testing.

4.5.1.1 Live ammunition. The live test ammunition shall be either all-up production hardware or a representative of all-up production hardware and shall realistically interface with an actual hot gun barrel/chamber section. The ammunition sections containing the live explosive and/or propellant, the simulated sections of the ammunition, and the gun barrel configurations shall be described in detail in the test plan and shall be reviewed and approved by the service review organization prior to testing. The electronic or guidance sections of the ammunition not containing explosives may be simulated as long as the simulation realistically represents the thermal mass of those components and the heat transfer paths to the explosive in the round.

4.5.1.2 Instrumental ammunition. Some of the ammunition tested shall contain thermal instrumentation (thermocouples) in order to obtain the time-dependent temperature distribution in the round during hot gun hazard testing. These rounds should (if possible) be first instrumented and then loaded with the actual live explosive or propellant. If that is not feasible, the instrumented round may be loaded with an inert filler whose physical configuration is similar to the actual explosive or propellant (granulation), and whose thermal properties (density, specific heat, and thermal conductivity) are known and are similar to those of the actual explosive. Instrumented, inert ammunition "cook-off" tests will be used to complement cook-off time data measured in live ammunition; inert ammunition tests cannot be used to entirely replace live ammunition cook-off tests.

4.5.2 Test gun barrel. The test gun barrel shall be of adequate length to ensure the correct convective, radiative, and conduction heat transfer between the barrel/chamber and the ammunition. Furthermore, the test gun barrel shall accurately simulate the correct location where the specific piece of ammunition should be positioned in a hot gun situation. The temperature distribution in the barrel (with respect to axial distance) shall realistically simulate the actual distribution at the time of hangfire, misfire, or ceasefire.

4.5.3 Ancillary test hardware. The test ammunition shall be remotely rammed with sufficient force to place it in the barrel as would occur in an actual gun. Remote, automated controllers shall be used to power the electrical band heaters, which maintain the desired time- and spatial-dependent barrel temperatures during the ammunition cook-off tests. Blast protection shall be provided to protect the rammer, heater controllers, and instrumentation from damage due to fragments and blast overpressure.

4.6 Instrumentation requirements. Instrumentation for each test shall be selected from the following options.

4.6.1 Thermal instruction. Whenever possible, the ammunition shall be instrumented temperature sensors (thermocouples) to measure the temperature histories of the key components of the projectile and/or propelling charge. The barrel section shall also be instrumented with temperature sensors (thermocouples) in the vicinity of the test ammunition. Some of the barrel temperature sensors shall be used to provide feedback to the heater-controller units that create the desired time and spatial temperature distribution in the barrel test section. Other sensors shall be used to record the barrel temperature histories.

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4.6.2 Pressure instrumentation. Whenever possible and practical the test hardware shall be instrumented with pressure sensors (such as pressure gauges or copper crusher gauges) to document the interior ballistic cycle during the single- and multiple-round firing tests used to determine single-shot heating to the gun barrel for a particular gun/ammunition combination.

4.7 Photographic requirements. The photographic media to be used shall be selected from the following:

4.7.1 Still photography. Pre- and post-test still, digital, and color photographs (with a minimum image resolution of one mega-pixel) shall be taken of the projectile components and fragments, the test barrel and barrel stand, and the surrounding witness panels and blast shields.

4.7.2 Video coverage. Video coverage shall be recorded of the test event in order to define the time to cook-off and the violence of the reaction. A variety of camera angles/locations may be selected to adequately collect this information.

4.8 Analysis of hot gun hazards. Finite element method (FEM) thermal models of the ammunition and the gun barrel shall be developed and calibrated. These models shall be used to extrapolate the test data from the approved test and analysis plan (see 4.1.1) in order to evaluate the hot gun hazards for a particular gun/ammunition combination for the entire range of realistic firing scenarios (not every possible scenario).

4.9 Pre-test examination. Prior to each test, a visual inspection of the test items shall be performed to ensure that no unusual conditions exist that might invalidate the tests. Still photographic records shall be made of the test ammunition, gun barrel, ancillary test hardware, and test setup. All safety mechanisms and devices shall be set to a safe condition.

4.10 Post-test requirements. A complete description of the significant post-test remains of the test hardware shall be recorded, including: condition and location of the ammunition components and fragments, condition of the test barrel, and blast protection surrounding the test facility. Still photographic records shall be made of the remains of the test ammunition, gun barrel, and ancillary test hardware.

## 5. DETAILED REQUIREMENTS

5.1 Hot gun tests. A gun or ammunition program shall consider all of the following tests and analyses for inclusion in the overall hot gun hazard assessment program. The ammunition shall be tested and analyzed sequentially as shown on Figure 1.

5.1.1 Barrel heat input tests. Two types of tests shall be conducted to evaluate the single-shot total heat input to the gun barrel as a function of the axial distance from the breech face, or in some instances the bolt face, of the gun barrel over the entire length of the gun barrel from breech face to muzzle. The single-shot tests shall measure the heat input in the region where the combusting gases are in direct contact with the bore surface of the gun barrel. The multiple-round firing tests shall be employed to measure the heat input in a chamber region where a cartridge case resides; in this region the cartridge case provides a partial thermal shield to the bore surface.

5.1.1.1 Single-shot tests. Ten single-shot tests shall be performed in an instrumented gun barrel using the final propelling charge design and a simulated projectile consistent with the final design (i.e., correct total weight, seating distance, rotating band, and projectile volume/shape aft of the rotating band). This data shall be used to determine the single-shot heat input to the gun barrel from the muzzle back to either the breech face if the propellant is in a consumable case or to the cartridge case mouth if the cartridge case is not consumable. An instrumented, inert round identical to that used in cook-off tests (see 4.5.1.2) may be used to obtain barrel heating data (see 5.1.1.2.g), if it is not possible to instrument a barrel with temperature sensors.

a. Test procedures shall be developed in accordance with local requirements and approved by the appropriate range safety committee prior to testing. These procedures shall address each of the following requirements in 5.1.1.1.b. through 5.1.1.1.j.

b. The gun barrel shall be the actual length of the in-service barrel and shall be instrumented with near-bore surface, fast-response temperature sensors (thermocouples) located approximately 50 mils from the bottom of the rifling groove. These sensors shall be located at a minimum of four axial locations over the first 20 percent of the length of the gun barrel forward of the forcing cone. Additional near-bore surface temperature sensors shall be located at a minimum of four evenly spaced axial stations over the remaining length of the gun barrel. When

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possible, two diametrically opposed thermocouples will be located at each axial location.

c. The near-bore, within 50 mils from the bottom of the rifling groove, sensors shall measure the transient temperature at that depth and be capable of accurately responding to changes in temperature that occur in two milliseconds. An example of an instrumentation port in the test barrel that accommodates this type of instrument is shown on Figure 3. This design or even this type of temperature sensor is not mandated but displayed here only for convenience, if the program is interested.

d. The outputs from the temperature sensors shall be recorded at a minimum of 1,000 Hertz starting at least 2 seconds before each round is fired and continuing for a minimum of 5 seconds after the firing.

e. The measured temperature data shall be analyzed in order to determine the total heat input to the gun barrel at each of the eight axial locations. All of the available heat inputs at a given location from the 10 tests shall be averaged to produce an average single-shot total heat input. These total heat inputs shall be combined with those derived from the multiple-round firing tests (see 5.1.1.2) to fully describe the total heat input to the entire length of the barrel.

f. Chamber pressure should be measured, either the peak pressure or pressure-time history in order to establish that the interior ballistics were normal.

g. No still photography or video coverage is required for this type of test.

h. The results of these tests shall be documented in a test report including a description of the test hardware, temperature histories recorded, deviations from the published test procedure, and the single-shot heat inputs determined for each axial location in each of the tests.

5.1.1.2 Multiple-round tests. Two to 3 multiple-round firing tests, consisting of a minimum of 50 rounds each, shall be performed in an instrumented gun barrel, using the final propelling charge design and a projectile simulating the final design (i.e., correct total weight, seating distance, rotating band, and projectile volume/shape aft of the rotating band). The data from this test series shall be used for two purposes: (1) to determine the single-shot heat input to the chamber, via a non-consumable cartridge case, and (2) to obtain barrel temperature histories to be used later for calibrating a barrel heating model.

a. Test procedures shall be developed in accordance with local requirements and approved by the appropriate range safety committee prior to testing. These procedures shall address each of the following requirements in 5.1.1.2.b. through 5.1.1.2.k.

b. The gun barrel shall be the actual length of the in-service barrel and instrumented with robust, near-bore surface, slow-response temperature sensors located approximately 100 mils from the bottom of the rifling groove. These temperature sensors shall be located at a minimum of three axial locations between the breech face and the forcing cone. Additional near-bore surface temperature sensors shall be located at a minimum of four evenly spaced axial stations over the remaining length of the gun barrel. When possible, two diametrically opposed thermocouples will be located at each axial location.

c. The sensors approximately 100 mils from the bottom of the rifling groove shall measure the transient temperature at that depth and be capable of accurately responding to changes in temperature that occur in 2 seconds. An example of an instrumentation port in the test barrel that accommodates this type of instrument is shown on Figure 3. This design or even this type of temperature sensor is not mandated but displayed here only for convenience, if the program is interested.

d. The output from such an instrument shall be recorded at a minimum of 2 Hertz during the firing starting at least 1 minute prior to the test and continuing for at least 30 minutes after the last round fired.

e. The barrel temperature data shall be analyzed in order to determine the total heat input to the gun barrel at each of the three axial locations in the gun chamber. The heat inputs at each axial location adjacent to the cartridge case from the three tests shall be averaged to produce an average single-shot total heat input for each position. These total heat inputs shall be combined with those derived from the single-shot firing tests (see 5.1.1.1) to fully describe the total heat input to the entire barrel from breech face to muzzle.

f. The near-bore temperature histories from all of the instruments for all of the multiple-round firing tests shall also be used later to calibrate the FEM thermal model of the gun barrel.

g. An inert instrumented round containing temperature sensors shall be prepared and used in the multiple-round firing tests to record how misfired ammunition would respond to an actual hot gun barrel. The instrumented round shall be loaded into the gun's magazine and automatically rammed immediately after the last fired round in

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multiple-round firing tests. An example of an instrumented round is presented on Figure 4. Note the temperature sensors are located on the inside surface of a projectile body and the cartridge case at critical locations: In the vicinity of the fuze, under the bourrelet, on the rotating band, under the rotating band, on the projectile base, between the projectile and the cartridge case in the vicinity of where the two are joined (for fixed ammunition only), and at the front of the propellant bed in the cartridge case.

h. The instrumented inert round in 5.1.1.1.g shall contain an internal data acquisition system (DAS) such that no external instrumentation or power leads are required. This arrangement facilitates the automated and immediate ramming of the instrumented round without delay. An example of a previously fabricated round with a DAS that was incorporated in fixed ammunition is described on Figure 5. The DAS is located in the coolest portion of the cartridge case, the base, in an inert propellant bed. The temperature sensors in this round were hard-wired to the DAS which conditioned the sensor outputs and stored them during the test; after the test the stored data may be downloaded to a laptop in the field. In the event that it is not possible to instrument a gun barrel with temperature sensors, the preferred method to obtain data to calibrate the barrel thermal model an instrumented inert round may be used to obtain a minimal amount of temperature data for this purpose.

i. No still photography or video coverage is required for this type of test.

j. No chamber pressure data is required.

k. The results of these tests shall be documented in a test report including a description of the test hardware, temperature histories recorded, and deviations from the test procedure.

5.1.2 Hot gun cook-off tests. The purpose of these tests is to obtain both cook-off times and temperature-time histories of the ammunition rammed in a hot gun barrel to calibrate the FEM thermal models of the ammunition. Four simulated hot gun cook-off tests shall be performed for each ammunition component (i.e., propelling charge, warhead, rocket motor), one at each of four different barrel temperatures. The barrel temperatures shall be selected based on preliminary analyses to provide a wide range of cook-off times between a minimum of 5 minutes to approximately 2 hours.

5.1.2.1 Hot gun cook-off testing procedures. Test procedures shall be developed in accordance with local requirements and approved by the appropriate range safety committee prior to testing. These procedures shall address each of the following requirements in 5.1.2.2 through 5.1.2.7.

5.1.2.2 Simulated hot gun cook-off test fixture. A hot gun environment shall simulate the thermal environment of a hot gun barrel in service use. A gun barrel segment (see 4.5.2) shall be sectioned from a reasonably new full-length barrel of the same design, instrumented, and fitted with electric band heaters. One approach to simulating a hot gun barrel environment is as follows: the barrel segment is mounted in a stand in front of a ramming tray and a hydraulic rammer (see Figure 2). Central in this figure is the barrel segment, and around the barrel are remotely-controlled, electrically-powered band heaters covered with white thermal insulation. Black instrumentation leads are attached to barrel temperature sensors and are visible at the base of the stand. Behind the barrel section is a ramming tray where the ammunition is placed prior to being remotely rammed into the hot gun barrel. A port in the blast shield, to allow movement of the rammer, is covered by remotely dropping a blast door once the ammunition had been rammed. The barrel section is surrounded by a cylindrical blast shield to help contain the projectile and barrel fragments produced at cook-off. An example of barrel fragments that could be produced by a cook-off in a fixture like this is presented on Figure 6. Note that a new projectile is placed in the center of the collected debris to demonstrate the scale of the barrel fragments.

5.1.2.3 Barrel thermal instrumentation. The barrel temperature sensors shall measure the transient temperature 100 mils below the bottom of the rifling groove. An example of an instrumentation port in a test barrel that shall accommodate this type of temperature sensor is shown on Figure 3. This design or even this type of temperature sensor is not mandated but displayed here only for convenience, if the program is interested.

5.1.2.4 Ammunition for cook-off tests. It is preferable that the cook-off test ammunition contain temperature sensors in order to simultaneously record the time-dependent temperature distribution in the round and the cook-off time. Some of the ammunition tested shall contain thermal instrumentation in order to obtain the time-dependent temperature distribution in the round during hot gun hazard testing. These rounds should be first instrumented and then loaded with the actual live explosive or propellant. If that is not feasible, the instrumented round may be loaded with an inert filler whose physical configuration is similar to the actual explosive or propellant, and whose thermal properties (i.e., density, specific heat, and thermal conductivity) are known and are similar to those of the

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actual explosive. If this is not possible, four cook-off tests with non-instrumented live ammunition should be complimented with the same number of tests, conducted at the same barrel temperatures, using an inert instrumented round. It is recommended that the instrumented inert round tests be conducted first, because a barrel is not damaged in those tests. In any case a minimum of four live rounds shall be tested.

5.1.2.5 Ammunition thermal instrumentation. The ammunition used to evaluate the temperature-time histories during a cook-off test shall be instrumented in order to record how that ammunition heats up. The instrumentation shall be mechanically attached (i.e., welded or soldered) to the ammunition to ensure a good thermal contact with the components throughout the test. An example of the key locations in a projectile is shown on Figure 4.

5.1.2.6 Ancillary test hardware. A fixture is required to capture the projectile that is launched when the propelling charge (in a fixed round) cooks off first.

5.1.2.7 Video coverage. Four video cameras shall be used to record the entire ammunition cook-off test event on magnetic video tape. Normal speed video coverage with a framing rate of between 18 and 30 frames/second with a time stamp is adequate. One camera shall record an overall view of the entire test hardware (i.e., rammer, barrel, ammunition in ramming tray, witness panels, and blast shields). A second camera shall record the ramming of the ammunition into the breech end of the heated barrel section as well as the cook-off reaction from that perspective. A third camera shall record the cook-off reaction at the muzzle end of the barrel section. A fourth camera shall record a close up view of the front of the ammunition and muzzle end of the barrel section and the cook-off reaction from that perspective.

5.1.2.8 Still photography. Still photographs shall be used to record the condition of the test ammunition and test setup prior to and after the test.

5.1.2.9 Test documentation. The results of these tests shall be documented in a test report including a description and still photographs of the test hardware, temperature histories recorded, cook-off times, violence of reactions, fragments created, and deviations from the test procedure.

5.2 Analysis of hot gun hazards. Computational analyses shall be performed to evaluate the entire range of the realistic hot gun hazards that can be expected in service use. An analysis plan shall be prepared to outline the approach to be followed when analyzing the test data and evaluating the hot gun hazards.

5.2.1 Preparing for thermal analysis. The analysis of the above test data shall be accomplished using FEM models to predict how a gun barrel is heated when it is fired and then how a misfire, hangfire, or cease-fire round would heat up and respond when rammed in a hot barrel.

5.2.1.1 Creating thermal models. The FEM models shall be accurate representations of the actual hardware based on either existing geometric models or geometric models created from drawings in accordance with ASME Y14.3M. It is necessary to make a tradeoff between the fidelity of a thermal model and the practicality of using that model. Basically, the tradeoff is between using a coupled barrel and ammunition model versus an uncoupled approach.

a. The coupled barrel and ammunition approach is where the initial temperature fields of the barrel and ammunition are specified as a function of radius and axial position at the time of the misfire. The coupled barrel/ammunition model is the most realistic approach, because as the ammunition heats up the barrel loses the corresponding amount of heat. However, this approach may not be practical if the ammunition being studied has a complex geometry that leads to an excessively fine FEM grid. This complexity can result in an untenable amount of computer memory to describe a barrel FEM grid that is compatible with the projectile FEM grid and unacceptably long computational times.

b. Another approach is the uncoupled analytical ammunition/barrel model where the only information needed about the barrel is its bore surface temperature, specified as a function of axial position and time throughout the cook-off event. This bore surface temperature history becomes the boundary condition for the ammunition portion of the thermal model, which computes the heat up and possible cook-off of the explosive or propellant. In this approach, the post-misfire barrel temperature history during cool down after the last round fired is first derived from barrel thermal model, not considering any ammunition inside to act as a heat sink. This uncoupled approach is a more conservative approach because an empty barrel would remain hotter than one with ammunition in the chamber; however, the amount of conservatism is difficult to assess. The advantage of the uncoupled approach is

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that it requires less computer memory to describe the barrel and less execution time.

5.2.1.2 Thermophysical and kinetic properties. The thermophysical and kinetic properties of the actual components shall be used in the analysis of the hot gun hazards. The use of the properties of similar materials may be substituted when it is not possible to obtain samples of the actual materials for testing. These properties shall accurately describe all of the key components, such as metallic, composite, and explosive, of the ammunition. The kinetic properties (activation energy, frequency factor, and the heat of reaction) of the explosive components must be those for the actual explosive under consideration or for an explosive with a very similar composition. These kinetic properties shall be derived using either ASTM E698 or ASTM E2070. The thermophysical properties (e.g., density, specific heat, and thermal conductivity) shall be determined in accordance with ASTM E1231.

5.2.1.3 Calibrating thermal models. It is recommended that three sets of experimental data be used to calibrate a thermal model: One set to calibrate and two others to check the calibration.

a. Calibrating the barrel thermal model. Data from the multiple-round tests are used to calibrate the barrel thermal model to ensure that it can be used to accurately predict barrel heating by simply inputting the exact firing scenario characteristics (e.g., type of ammunition fired, numbers of rounds, rates of fire for each burst, and times between bursts). Calibration of the barrel thermal model is accomplished by analytically matching the measured barrel temperature histories from one test. Checking the calibration of the barrel thermal model is accomplished by demonstrating that it can predict two other measured barrel temperature histories by simply specifying their corresponding firing scenarios. As an objective, a calibrated model should reproduce temperatures within 15 percent of empirical data.

b. Calibrating the ammunition thermal models. The projectile and propelling charge thermal models are calibrated and checked to demonstrate they can be used to predict the ammunition heat up and cook-off times by simply specifying a barrel thermal environment. Calibration of the ammunition thermal model(s) shall be accomplished by analytically matching the measured data from one test consisting of: (1) temperature-time histories at key locations in the ammunition body and in the explosive or propellant, and (2) the time to cook-off. To check the accuracy of these models, data from two additional tests shall be compared to the model outputs, starting with the corresponding barrel thermal environment. As an objective, a calibrated model should reproduce temperatures within 15 percent of empirical data.

5.2.2 Parametrically evaluating hot gun cook-off hazards. The above calibrated models shall be used to study the entire range of realistic firing scenarios that can be expected in service use. These studies will produce nominal cook-off times and barrel temperatures that describe the average hazards that can be expected in service use. An example of the nominal results from one firing scenario using calibrated models of all three of the above components is presented on Figure 7. An example of the summary of an entire parametric study of another type of ammunition is given on Figure 8.

5.3 Hot gun hazard definitions. The primary purpose of the above testing and analysis is to define the hot gun hazards that can be expected within the entire range of firing scenarios associated with each gun/ammunition combination. The hot gun hazards are dependent upon (1) how the gun barrel heats up when firing that ammunition, and (2) how the ammunition heats up when it misfires and is exposed to a hot gun barrel. The hot gun hazards may be different for a particular type of ammunition in different guns and must be evaluated for each gun/ammunition combination. The Hazard Assessment Test Report (see 4.3) shall summarize test data and the subsequent analysis results from the current gun/ammunition evaluation as well as any complementing data from evaluations of the current gun and other ammunition as well as the current ammunition and other guns.

5.3.1 Hot gun criteria. There are four hot gun criteria that must be deduced from the preceding test data and analysis before the hot gun misfire procedures can be developed. All of the criteria shall include a margin of safety. Furthermore, each criterion could take on one of many forms (e.g., for example, number of rounds fired or barrel temperature adjacent to the energetic material).

5.3.1.1 Margin of safety. It is crucial that a reasonable and safe margin of safety be applied to the nominal cook-off times or nominal barrel temperature criteria derived from the above thermal analyses. The following hot gun criteria must reflect the addition of a margin of safety to take into account the variations that occur as a result of lot-to-lot and round-to-round variations in ammunition and guns.

5.3.1.2 Hot gun condition. The first criterion is used to identify the initial onset of a hot gun condition: The

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first time it is possible for any firing scenario to sufficiently heat a gun barrel to the point where a cook-off could occur in the event of a misfire.

5.3.1.3 Safe clearing time. The second criterion is used to determine when a gun crew has a minimum amount of time (e.g., 10 minutes) to safely attempt to clear a misfired round from a gun barrel. That specific time is gun dependent and is determined by the design of the gun and its capabilities.

5.3.1.4 Safe return time. The third criterion is used to determine when enough time has passed since a misfire that could not be cleared immediately, such that there is no longer a hazard of the ammunition in the gun barrel cooking off. It would then be safe for the gun crew to return to the gun and resume the process of clearing the misfired ammunition and firing the gun.

5.3.1.5 Violence of reaction. The fourth criterion is used to define the danger that the cook-off reaction poses to the ship and its personnel (e.g., include detonation, explosion, deflagration, and burning).

5.4 Hot gun misfire procedures. The above information shall be combined with the operational capabilities of a gun in order to develop safe procedures for a gun's crew to cope with a misfire, hangfire, or even a possible cease-fire with ammunition chambered in a hot gun. The process of using the knowledge of the hot gun hazards in order to develop hot gun misfire procedures is beyond the scope of this standard and will not be discussed here.

5.4.1 Simplest hot gun misfire procedures. There is a wide range of possibilities to implement the hot gun misfire procedures, depending on the funding available and the capability of the gun system controls. The simplest, least expensive, but most restrictive approach is a one-size-fits-all procedure which consists of:

- a. assuming, regardless of what type of rounds have been fired and at what rate, that the gun becomes a hot gun when a minimum number of rounds have been fired. This corresponds to the worst type of ammunition and rate of fire.
- b. assuming that the gun crew never has more than the minimum amount of time to attempt to clear the misfire from a hot gun. This corresponds to the worst type of ammunition and rate of fire.
- c. assuming that the gun crew must always abandon the gun and the uncleared ammunition for the maximum amount of time before return to safely attempt to clear the misfire. This corresponds to the worst type of ammunition and rate of fire.
- d. assuming the cook-off reaction will always be a detonation. This corresponds to the worst type of ammunition and rate of fire.

5.4.2 Sophisticated hot gun misfire procedures. An automated safe clearing time predictor is the most sophisticated form of misfire procedures. It is also the most expensive to implement; however, it is based on the same test data and analysis needed for the simplest form of misfire procedures. The additional cost arises in the implementation of the knowledge of the hot gun hazards. This procedure is formally referred to as a Safe Clearing Time Predictor (SCTP) that is automated software resident in the gun control computer in the gun mount itself. The SCTP automatically receives data from the gun telling what type of ammunition is fired and when it is fired. The barrel temperatures at critical locations are continuously calculated by the SCTP, which monitors the thermal state of the barrel and automatically decides whether the next type of ammunition rammed could create a hot gun condition. In the case of a misfire or hangfire, the SCTP automatically determines whether the type of misfired ammunition would cook off in less than a predetermined amount of time and informs the gun crew whether it is safe to try to clear the gun. Finally, if the gun has been abandoned because the misfired round could not be cleared, the SCTP determines and informs the gun crew how long the gun must be abandoned before it is safe to return. All of the above decisions are based on the actual firing scenario preceding the misfire, not on the worst case.

5.4.3 Paper backup hot gun misfire procedures. Regardless of the approach taken to implement the hot gun misfire procedures, there must always be a paper backup. An example of this paper backup in the U.S. Navy is SW300-BC-SAF-010. The paper backup must always be updated to include the latest information on any new ammunition or gun introduced into service use.

## 6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. The tests and subsequent analyses described herein or referenced are used to assess the hot

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gun hazards associated with non-nuclear gun ordnance. The ordnance covered by these tests and analyses are designed for military use only, hence this standard does not apply to commercial items.

6.2 Acquisition requirements. Acquisition documents should specify the following:

- a. Title, number, and date of the standard.

6.3 Associated Data Item Descriptions (DIDs). This standard has been assigned an Acquisition Management Systems Control (ASMC) number authorizing it as the source document for the following DIDs. When it is necessary to obtain the data, the applicable DIDs must be listed on the Contract Data Requirements List (DD Form 1423).

<u>DID Number</u>	<u>DID Title</u>
DI-NDTI-80603	Test Procedure
DI-SAFT-81124	Threat Hazard Assessment
DI-SAFT-81125	Hazard Assessment Test Report
DI-SAFT-81126	Photographic Requirements

The above DIDs were current as of the date of this standard. The ASSIST database should be researched at <http://assist.daps.dla.mil> to ensure that only current and approved DIDs are cited on the DD Form 1423.

6.4 Tailoring guidance for contractual application. To ensure proper application of this standard, invitations for bids, requests for proposals, and contractual statements of work should tailor the requirement in sections 4 and 5 of this standard to exclude any unnecessary requirements. Contractual documents must specify the following:

- a. Ambient ammunition temperature if other than as specified (see 4.2.1).
- b. When a pre-test examination is not required (see 4.9).
- c. The number of test items to be tested if other than as specified (see 5.1.1.1, 5.1.1.2, and 5.1.2).
- d. The number of sets of test data used to verify the thermal models if other than as specified (see 5.2.1.3).

6.5 Subject term (key word) listing.

Arrhenius-rate kinetics  
 Finite element method (FEM)  
 Insensitive munitions  
 Kinetic properties  
 Misfire procedures  
 Safe clearing time  
 Safe clearing time predictor (SCTP)  
 Safe time to return  
 Single-shot heat input  
 Thermal decomposition  
 Thermophysical properties

6.6 International standardization agreement implementation. This standard implements the International Standardization Agreements in 6.6.1.1 through 6.6.1.8. When changes to, revision, or cancellation of this standard are proposed, the preparing activity must coordinate the action with the U.S. National Point of Contact for the international standardization agreement, as identified in the ASSIST database at <http://assist.daps.dla.mil>.

6.6.1 General. There is not a comprehensive set of guidance for the evaluation of both projectile and propelling charge hot gun cook-off hazards in the international standardization agreements. A summary of the existing international approach to hot gun hazards evaluation is presented below.

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6.6.1.1 STANAG 4224. This STANAG states: “The tests below (e.g., cook-off in a hot gun) may be required in addition to the Standard tests above [...]. As an interim measure, national procedures should be used for the conduct of these tests until NATO procedures are agreed (upon) and published”.

6.6.1.2 STANAG 4382. This STANAG deals only with slow cook-off in an oven, a test that does not provide information helpful for the evaluation of hot gun cook-off hazards.

6.9.1.3 STANAG 4439. This STANAG addresses only fuel fire, slow heating, small arms attack, fragmenting munition attack, shaped charge attack, sympathetic reaction, and behind armor debris testing. This STANAG does not deal with hot gun cook-off.

6.6.1.4 STANAG 4516. This STANAG states: “The Hot Gun Cook-Off test is conducted to establish the conditions under which cook-off may occur [...] in accordance with national procedures”.

6.6.1.5 AOP-15. This Allied Ordnance Publication (AOP) deals only with temperature and humidity, solar radiation, precipitation, sand and dust, salt spray, fungus (mold), shock, shipboard shock, vibration, freefall, sympathetic reaction, electromagnetic radiation, electrostatic discharge, fuel fire (fast heating), nuclear hardening, icing, low temperature, thermal shock, slow heating (oven), bullet attack, contamination, electrical safety, and shock and acceleration testing. This AOP does not deal with hot gun cook-off.

6.6.1.6 AOP-39. This AOP deals only with fast heating (exposure to open fuel fires) and slow heating (in an oven) tests, neither of which support the evaluation of hot gun cook-off hazards.

6.6.1.7 ITOP 4-2-504(1). This International Test Operation Procedure (ITOP) describes hot gun cook-off testing for field artillery propelling charges that is not practical (cost prohibitive) for use by the U.S. Navy. This ITOP requires an extensive number of tests in which an instrumented gun barrel, housing and breech block must be destroyed in each test. Furthermore this ITOP does not address projectile cook-offs in a hot gun.

6.6.1.8 ITOP 4-2-504(4). This ITOP addresses projectile testing such as 12-meter drop, environmental, salt fog, radio-frequency hazard, hot dry storage, water immersion testing – but no hot gun cook-off testing.

6.7 Submission of test reports and results. Submit copies of test reports and results to the following address for storage in the National Insensitive Munitions Information System (NIMIS-11):

Navy/Marine Corps – (IM)

Commanding Officer  
Naval Ordnance Safety & Security Activity  
Attn: NOSSA, N6  
Indian Head, MD 20640-5555

6.8 Service review organizations. The following service contacts are responsible for the assessment of explosive safety and IM characteristics:

Army – (for explosives safety)

Director  
U.S. Army Technical Center for Explosives Safety  
Attn: SOSAC-EXT  
1 C Tree Road, Bldg 35  
McAlester, OK 74501-9053

Army – (for IM)

Commander  
U.S. Army TACOM  
Armament Research, Development and Engineering Center  
Attn: AMSTA-AR-ASL Army Insensitive Munitions Board  
Picatinny Arsenal, NJ 07806-5000

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Navy/Marine Corps – (for explosives safety)

Commanding Officer  
 Naval Ordnance Safety & Security Activity  
 Attn: NOSSA, N3  
 Indian Head, MD 20640-5151

Navy/Marine Corps – (IM)

Commanding Officer  
 Naval Ordnance Safety & Security Activity  
 Attn: NOSSA, N6  
 Indian Head, MD 20640-5151

Air Force – (for explosives safety)

AFSA/SEWV  
 9700 G Street  
 Kirtland AFB, NM 87117-5670

Air Force – (IM)

ASC/YOX  
 Eglin AFB, FL 32542-6808

6.9 Tests for hazard classification. The tests referenced herein have potential application for hazard classification and some specifics of testing may require approval by service review organizations and the DDESB prior to testing.

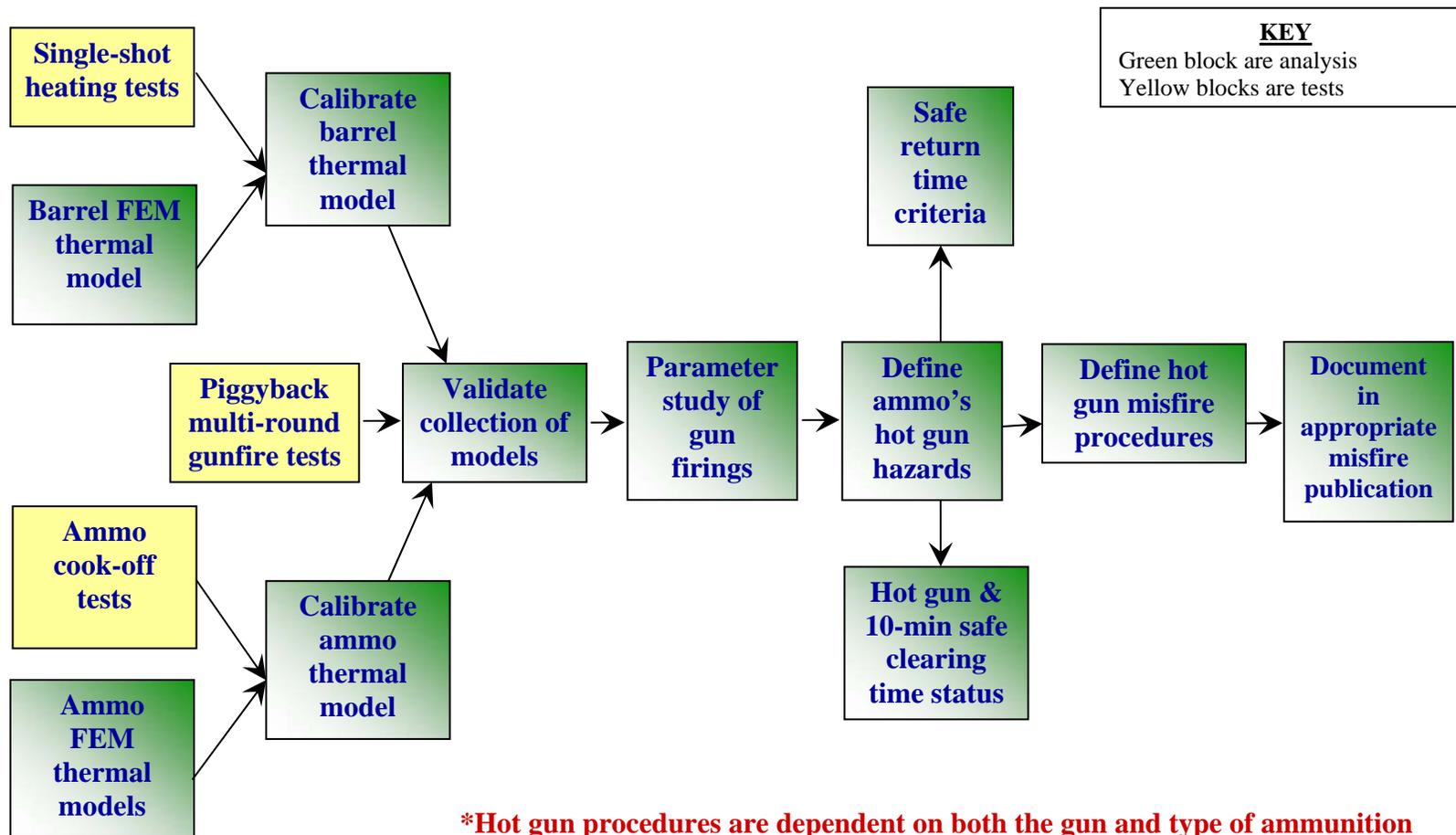
6.10 Hot gun misfire procedures. The primary purpose of the above testing and analysis is to define the hot gun hazards possible within the entire range of firing scenarios associated with each gun/ammunition combination. These hazards are dependent upon (1) how the gun barrel heats up when firing that ammunition and (2) how ammunition heats up and possibly cooks off when a misfired round is exposed to a hot gun barrel.

6.10.1 Hot gun criteria. There are four hot gun criteria that must be deduced from the preceding test data and analysis before the hot gun misfire procedures can be developed. These criteria are used to determine: (1) the first onset of a hot gun condition, (2) if a gun crew has a specific amount of time (for example, 10 minutes) to safely attempt to clear a misfired round from a gun barrel, (3) when the cook-off hazard has past, and (4) the severity of the cook-off (including detonation or deflagration) that could endanger the ship and/or its crew.

6.10.2 Simplest hot gun misfire procedures. There is a wide range of possibilities to implement the hot gun misfire procedures, depending on the funding available and the capability of the gun system computer. The least expensive is a one-size-fits-all approach that is the simplest to implement but is the most restrictive on operational capability.

6.10.3 Sophisticated hot gun misfire procedures. The most sophisticated form of misfire procedures is also the most expensive to implement; however, it is based on the same test data and analysis needed for the simplest form of misfire procedures. The implementation is via automated software, referred to as a safe clearing time predictor that is resident in the gun control computer. Even this approach represents a wide range of sophistication and complexity.

6.10.4 Paper backup hot gun misfire procedures. Regardless of the approach taken to implement the hot gun misfire procedures, there must always be a paper backup. An example of a paper backup, SW300-BC-SAF-010, is used by the U.S. Navy. The paper backup must always be updated to include the latest information on any new ammunition or gun introduced into service use.

FIGURE 1. Testing and analysis process to define hot gun misfire procedures.

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FIGURE 2. Gun simulator test fixture (projectile tests).

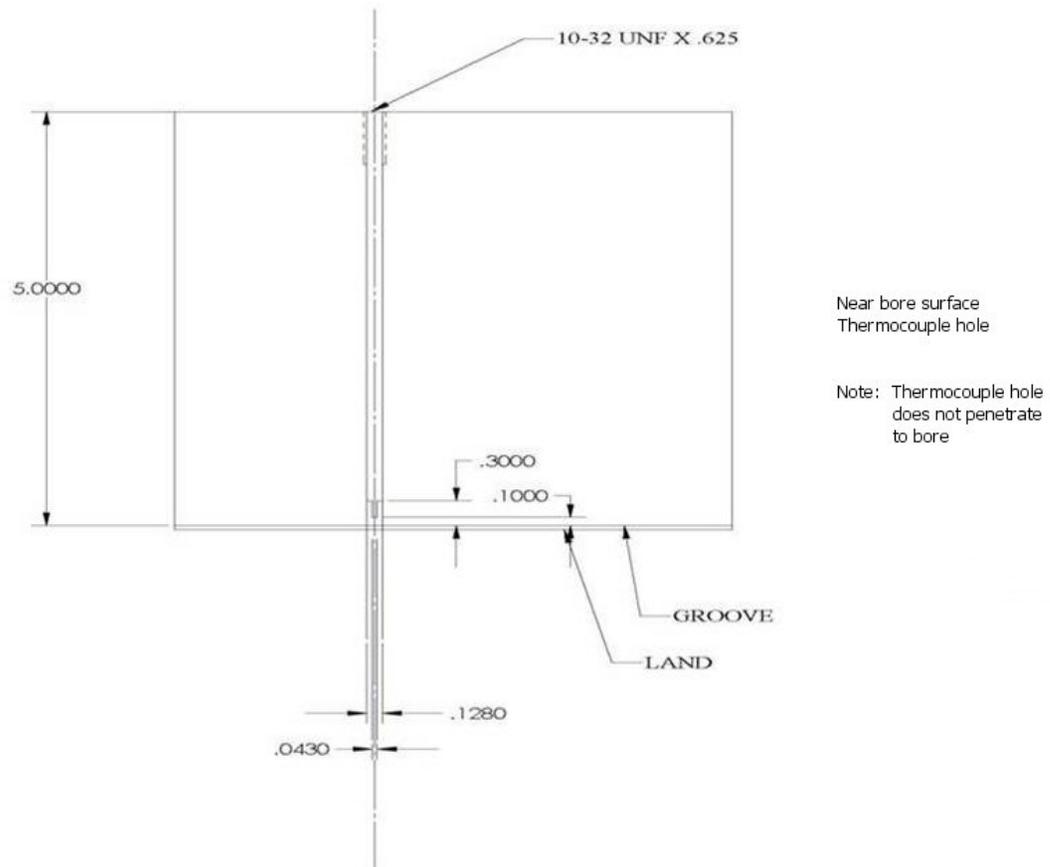


FIGURE 3. Instrumentation port for slow-response (100 mils) thermocouple.

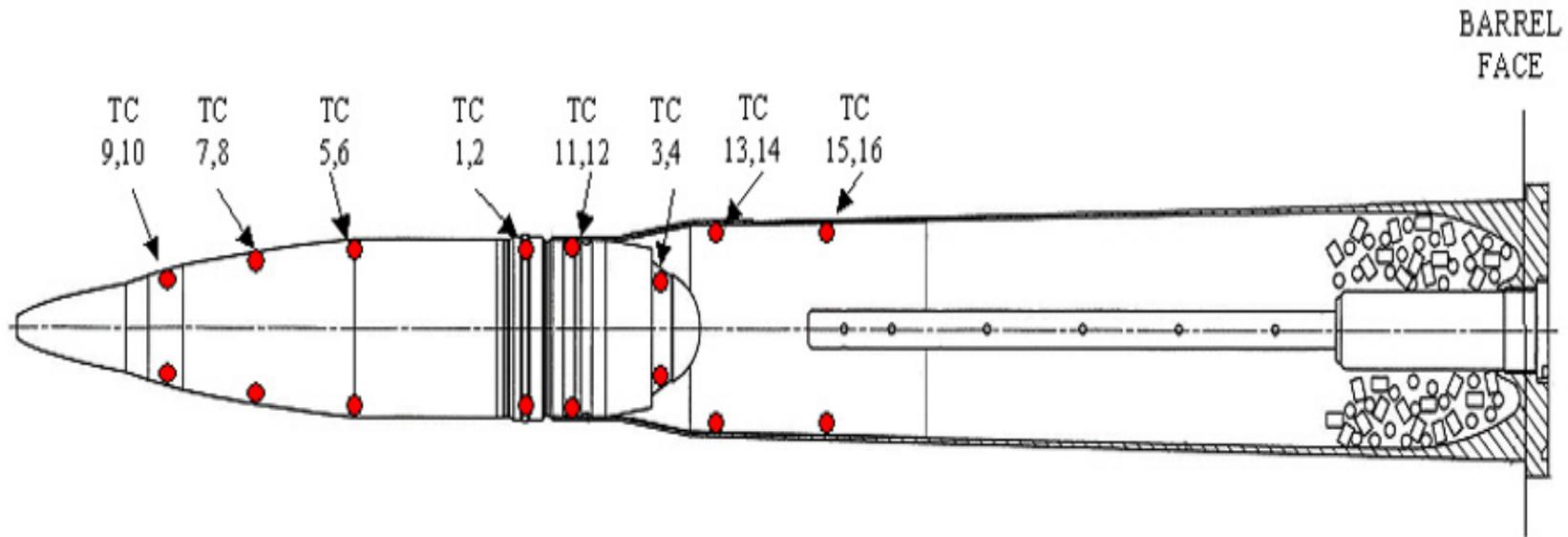


FIGURE 4. Example of instrumented inert ammunition.

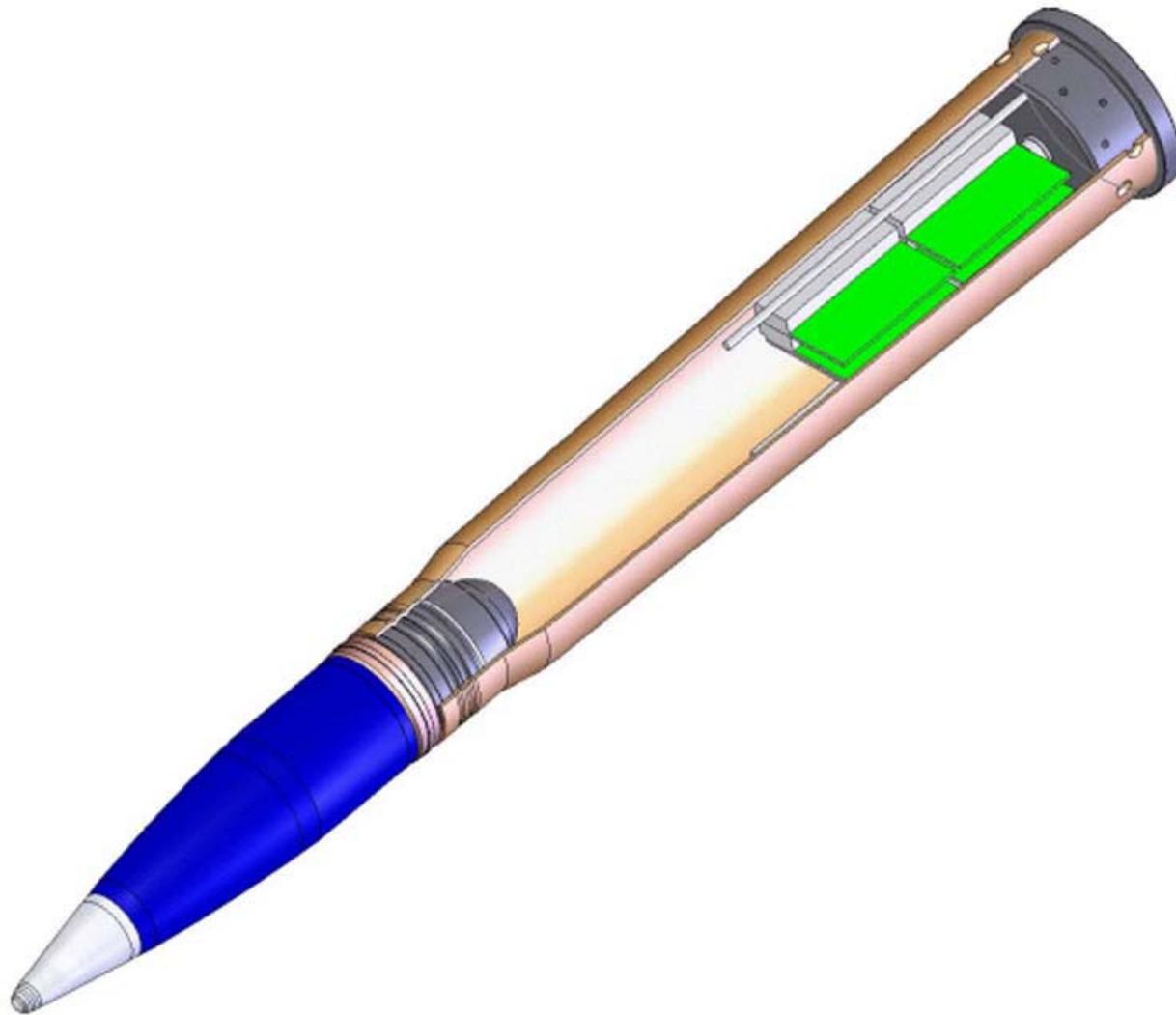


FIGURE 5. Example of instrumented inert ammunition with self contained DAS.



FIGURE 6. Example of barrel fragments produced by a projectile cook-off reaction.

TEMPERATURE CONTOUR PLOT  
FIRE 600 ROUNDS @ 115 RPM

COOK-OFF IN 2.6 MIN

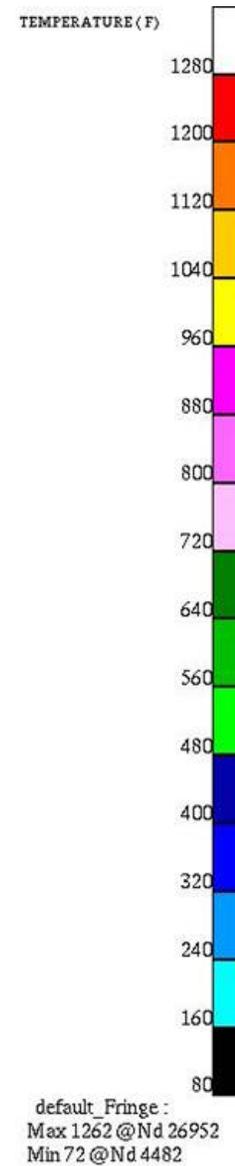
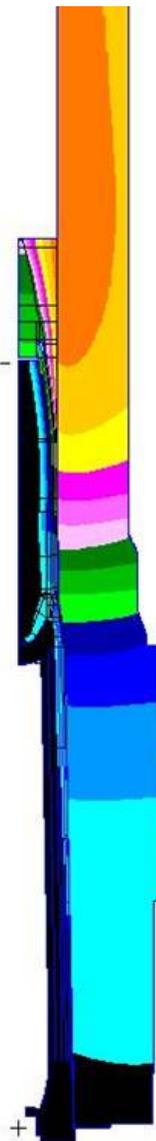
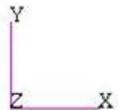


FIGURE 7. Coupled barrel, projectile, and propelling charge models.

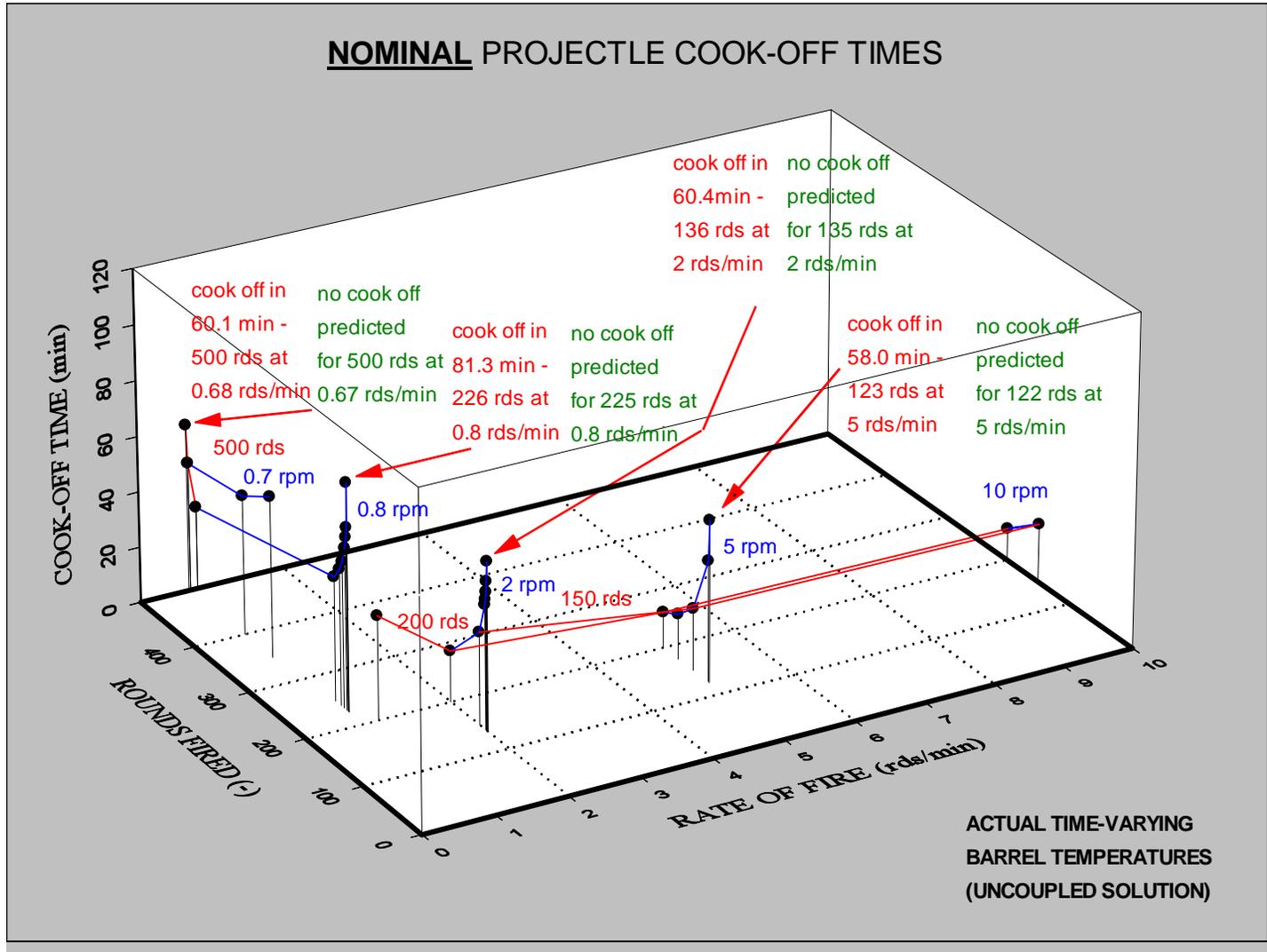


FIGURE 8. Example of a projectile hot gun cook-off hazard summary.

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Navy – SH  
(Project 1395-2008-002)

Review activities:

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Civil activity:

GSA – FAS

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