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# DEPARTMENT OF DEFENSE HANDBOOK

# CRITERIA FOR EXPLOSIVE SYSTEMS AND DEVICES USED ON SPACE VEHICLES

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# FORWARD

This handbook should be used as a guide for certifying applications of explosive systems and devices on space vehicle systems. This information may also be used for guidance during preparation of acquisition contracts and program specific documents. This handbook or any portion thereof, cannot be cited as a contractual requirement. If it is, the contractor does not have to comply. The handbook has been approved by the SMC/SDFP, Department of the Air Force and is available for use by all Departments and Agencies of the Department of Defense.

This handbook combines elements of Air Force specifications DOD-E-83578 and MIL-STD-1576 into common criteria for design, manufacture and performance verification of components and systems that contain or are operated by explosive materials. The criteria offered in this handbook have proven to be effective in Air Force space vehicle applications and are based on lessons learned. Criteria are standards, rules or tests by which an item an be judged. They are measures of value.

Primary objectives of this document are to provide methods for demonstrating assured functional and safe application of these items. It is intended to be as comprehensive as practical and to be periodically updated to incorporate technology advances and innovations.

Users of this handbook are encouraged to submit suggestions and pertinent data for its improvement to: (Please use the Standardization Document Improvement Proposal form (DD Form 1426) appearing at the end of the handbook for your submittal.)

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**“Those who can not remember the past are condemned to repeat it.”**
George Santayana, (1863-1952). Poet, novelist, Harvard professor of philosophy (1907-12).

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**1. SCOPE.** This handbook is a guide for certifying applications of explosive systems and devices on space vehicle systems.

**1.1 Purpose**. This handbook provides criteria for design, manufacture and performance certification of explosive systems and explosive devices commonly used on space vehicles and space systems. Explosive systems include components and assemblies that provide stimuli for initiation and propagation of explosive trains used to activate explosive devices. Explosive trains and devices are components or assemblies containing or operated by explosive materials. The latter are, by design, "one-shot" components that cannot be tested completely before use. Performance confidence of "one-shot" components can only be obtained by destructive tests of like samples from common production lots. This handbook describes criteria to certify safe and reliable performance of explosive systems and their "one-shot" components. The information contained in this handbook is intended to be universal sets of tools for explosive system manufacturers and users use during all phases of development and certification. This information can also be used for guidance during preparation of acquisition contracts and program specific documents, and may be used for explosive system applications unrelated to space vehicles.

**1.2 Application**. The criteria outlined in this handbook are a composite of those verified by previous use in space vehicle applications. Described are essential design characteristics, suggested manufacturing controls, and methods for certifying performance, acceptance, qualification and useful life. These criteria, defined as standards, rules, tests or measures of value by which an item can be judged, are applicable to explosive systems commonly used on space vehicle systems. Explosive systems are used for controlled rapid release of directed energy for, launch pad release, propulsion ignition and disablement, stage and payload separation, appendage and antenna release, and other functions. Explosive devices include all elements of explosive trains within the explosive system. These include, but are not limited to, explosive initiators, safe arm devices, explosive energy transfers, destruct charges, explosive actuated devices, and others. The criteria offered here are generic in nature therefore users are encouraged to consider tailoring criteria to best-fit individual applications.

## 2. APPLICABLE DOCUMENTS.

2.1 General The documents listed below are not necessarily all of the documents referenced herein, but are the ones that are needed in order to fully understand the information provided by this handbook.

**2.1.1 Industry Standards.**

| | |
|---|---|
| ANSI/ASME Y14.5M | Dimensioning and Tolerancing |
| ASTM E94-93 | Standard Guide for Radiographic Testing |
| ASTM E748-95 | Standard Practices for Thermal Neutron Radiography of Materials |

**2.1.2 Federal Regulations.**

| | |
|---|---|
| CFR 49 | Code of Federal Regulations - Transportation |
| ESMCR 127-1 | Eastern Range Safety Regulation |
| WSMCR 127-1 | Western Range Safety Regulation |

2.1.3 Military Handbooks

| | |
|---|---|
| MIL-HDBK-340A | Vol. 1 Test Requirements for Launch, Upper Stage and Space Vehicles – Baseline |
| MIL-HDBK-340A | Vol. 2 Test Requirements for Launch, Upper Stage and Space Vehicles – Application Guidelines |
| MIL-HDBK-343 | Design, Construction and Testing Requirements for One-Of-A-Kind Space Equipment |

**3. DEFINITIONS.** The following definitions of terms and acronyms are offered as an aide to handbook users. Although some of the items listed may not be referenced in the body of this handbook they represent a consolidation of those commonly used in the space vehicle industry. The list is as comprehensive as practical but may not include every term or acronym related to the field. There is no universal list as it is common practice to create new terms and acronyms as individual need dictates.

**Acceptor.** An explosive element that receives a detonating impulse from a previously exploded element, called a donor, and serves to propagate the detonation. An acceptor is also known as a receptor.

**All-Fire Rating.** The lowest level of energy which results in initiation of a first element within a specific reliability and confidence level as determined by test and analysis.

**Application.** Refers to the end item use of an explosive system, e.g., the space vehicle separation system, deployable mechanism, etc.

**Batch.** A specific quantity of explosive material prepared as a unit during manufacturing, chemical mixing or other processes.

**Booster Charge.** An explosive charge downstream of the first element of an explosive train that is used to cause ignition or detonation of a main explosive charge or to increase the energy output to the end item.

**Bridgewire.** A resistance wire incorporated into the first element that converts electrical energy into heat to cause ignition of the explosive charge.

**Bruceton Test.** A statistical test and analysis method for estimating first element ignition parameters. These include estimates of mean ignition stimulus levels, standard deviations, all-fire and no-fire ratings. Developed in the 1940's and applied to explosive devices in the 1950's its methodologies are described in numerous statistical texts and manuals including NAVORD 2101, Statistical Methods Appropriate for Evaluation of Fuze Explosive Train Safety and Reliability.

**Cartridge.** Another term that may be used to describe an EED or LID.

**Cartridge Actuated Device (CAD).** An explosive actuated device.

**Certification.** A process in which an explosive system, subsystem or device is subjected to validate acceptability for use in an end item application. This certification process may require use of inspections, tests and analysis methodologies.

**Charge.** A quantity of explosive loaded in an explosive device

**Confined Detonating Cord (CDC).** A linear explosive transfer assembly where the explosive material is confined in a metallic sheath and various types of over wrap materials intended to limit radial expulsion of detonation products but promote linear propagation of detonation waves. Fittings at both ends of the assembly may be threaded, or otherwise configured for ease of installation in the application, and are configured to accept a detonation input and deliver a detonation output. Linear detonation wave velocities in typical CDC configurations are greater than 20K feet per second.

**Cook-off Temperature.** The lowest temperature at which an exothermic reaction of an explosive material occurs, i.e., detonation or deflagration.

**Crossover.** A explosive connection or link between redundant explosive trains.

**Deflagration.** Deflagration is very rapid combustion. Although classed as an explosion, deflagration generally implies the burning of a substance with self-contained oxygen so that the reaction zone advances into the un-reacted material at less than the speed of sound. Deflagration is a surface phenomenon in which the heat produced is sufficient to allow it to proceed and accelerate without the aid of an external heat source. Confinement while in the deflagration process increases pressures, reaction rates and temperatures and may result in transition to detonation, i.e., an explosive.

**Destruct Charge.** An explosive assembly used to sever or penetrate through elements of a space vehicle to cause structural break-up or to disable propulsive systems.

**Detonation, High Order.** A chemical reaction propagating with such rapidity that the rate of advance into the reaction zone of the un-reacted material exceeds the velocity of sound in the un-reacted material. This explosion generates extremely high temperatures and pressures that form shock waves that violently act on the surrounding environment. Detonation is not a surface phenomenon. The rate of advance of the reaction zone is termed detonation rate or detonation velocity. When this rate of advance attains such a value that it will continue without diminution through the un-reacted material, it is termed the stable detonation velocity.

**Detonation, Low Order.** A chemical reaction where the reaction rate is lower than the stable detonation velocity and higher than the reaction rate of a deflagration. An explosive charge that detonates low order is usually incapable of initiating a high order detonation in a succeeding secondary explosive charge.

**Deflagration to Detonation Transition (DDT).** A physical process that occurs with some secondary explosives in specific confinement, porosity and particle size conditions where the initial ignition event generates a deflagration wave front in the material that rapidly transitions to detonation.

**Detonator.** A first element whose output is a high order detonation. Detonators are generally used to effect detonation transfers within explosive trains.

**Donor.** An explosive charge that transmits a detonation output into succeeding explosive elements, the acceptor or receptor, of an explosive train.

**Dud.** An explosive charge or component that fails to fire or function upon receipt of the prescribed initiating stimulus.

**Electro Explosive Device (EED).** The first element of an explosive train. It is activated by electrical energy, joule heating, applied to an internal bridgewire that transfers energy to a primary explosive charge pressed over it. An EED may include other explosive charges downstream of the primary charge. Detonators, squibs, hot bridgewire devices, and cartridges when electrically actuated are EEDs.

**Exploding Bridge Wire Device (EBW).** An EED that is designed to function using input energy levels far greater the common EED. There are two types of EBW devices; those with a gap in the electrical input conductive path and those without. Designs having a gap can use bridgewire configurations similar to EED designs. Those without gaps use low resistivity bridgewire materials. Typical input all-fire levels are greater than 1000 volts. EBW devices do not use primary explosive materials. Common explosive materials used in EBW devices include PETN, RDX and HMX pressed directly over the bridgewire.

**Exploding Foil Initiator (EFI).** An EED that requires high voltage inputs for actuation. These do not use primary explosive materials. Ignition occurs by application of high voltage to an internal membrane element that is then energized and rapidly propelled into a secondary explosive causing DDT.

**Explosion.** A sudden release of chemical energy by exothermic decomposition. The event is an inherently non-linear process that is not fully understood. It is initiated when a chemical compound is subjected to a stimulus such as heat, impact, friction, shock, or other phenomenon, causing rapid changes in its state. Deflagration and detonation events are explosions.

**Explosive.** A generic term for materials that explode and includes deflagrating materials and detonating materials.

**Explosive Actuated Device.** A component or assembly that performs work in an end item application after being actuated by explosive energy delivered from an interfacing explosive system. Explosive actuated devices may or may not contain explosive materials. Pin pullers, bolt cutters, separation nuts, frangible bolts, explosively formed projectiles are examples of explosive actuated devices.

**Explosive Bolt.** An explosive bolt is a structural member that will be fractured at a predetermined point by controlled ignition of a contained or inserted explosive charge.

**Explosive Ordnance.** A term used in DOD-E-83578 and Mil-Std-1576 defined as any component or assembly containing, or operated by an explosive material.

**Explosive Trains.** An assemblage of explosive elements that react and interact in a series of events delivering explosive energy input to explosive actuated devices in the end item application.

**Explosive Transfer Assembly (ETA).** An explosive transfer assembly is an explosive train consisting of an assembly of linear charges used to transfer a detonation from an initiator to an end function. The purpose of the ETA is to allow the initiator to be located away from the end function for accessibility. An example is a solid motor igniter, located inside a spacecraft, connected to the initiator, located on the exterior of the spacecraft, by an ETA.

**Explosive Transfer System (ETS).** An assemblage of ETA components, inert connecting elements and other components, i.e., time delays, that transfers explosive energy to another ET element or to an explosive actuated device.

**Explosively Formed Projectile (EFP).** An explosive device that when activated causes detonation products to act on an integral concave metallic liner that is projected at high velocity toward a predetermined target. The concave liner is reshaped during this process into a slug of metal simulating a finned projectile that can be used to penetrate space vehicle structures.

**Flexible Confined Detonating Cord (FCDC).** CDC whose over wrap material allows for flexure of the core for ease in handling and installation. Radial expulsion of detonation products may not be totally contained in this type of design.

**Flexible Linear Shaped Charge (FLSC).** A linear column of explosive material in a soft metal sheath, over wrapped with material that allows flexibility that when placed on a substrate and ignited causes severance or penetration. MDF can be configured to be a FLSC.

**Flight Termination System (FTS).** An explosive system that when actuated causes losses of integrity of space vehicle structural elements or propulsion systems. An FTS is used in applications requiring compliance with Eastern and Western Range Safety Regulations 127-1.

**Hot Bridge Wire Device (HBW).** Another name for a electro explosive device.

**High Explosive (HE).** Secondary explosives are also known as high explosives.

**HMX.** A secondary explosive chemically known as cyclo tetra methylene tetra nitramine, and is also known as either Her or His Majesties Explosive. HMX is by-product from the manufacture of RDX and can exhibit DDT characteristics.

**HNS.** A secondary explosive which is chemically known as hexa nitro stilbene.

**High Voltage Initiator (HVI).** Another name for a EBW device.

**Ignition System.** The initial element of an explosive system that provides power, command and control of electrical, optical or mechanical input stimuli to the first element of an explosive train.

**Inadvertent Separation Destruct System (ISDS).** An explosive system that ignites explosive charges when an un-planned separation of a specific portion of a space vehicle occurs. An ISDS may be required for compliance with Eastern and Western Range Safety Regulation 127-1.

**Initiator.** An initiator is the first element in an explosive train. Upon receipt of the proper mechanical or electrical impulse it produces a deflagration or detonation action. The deflagration or detonation action is transmitted to other elements in the train. An initiator may be a shock actuated percussion primer, electrically actuated EED or optically initiated LID.

**Laser Initiated Device (LID).** A first element containing secondary explosives that are ignited by energy produced from collimating coherent light excited in the infrared region of the electromagnetic spectrum. This energy density is optically transmitted by way of silicone fibers from crystalline rod or semiconductor diode lasers onto secondary explosives altered to enhance thermal absorption properties. The incident energy density is absorbed into the explosive allowing it to undergo DDT. The output energy of a LID can be configured to be equivalent to an EED.

**Laser Initiated Ordnance System (LIOS).** An explosive system whose ignition system and explosive train are configured to use lased light energy sources to actuate a LID.

**Lead.** A lead is an explosive charge contained in a can or in pellet form used within a device to transfer a detonation from one point to another downstream of the first element.

**Linear Explosive Assembly (LEA).** Another name for a ETA.

**Linear Shaped Charge (LSC).** A linear explosive charge in a metal sheath whose cross section is formed into a chevron shape. The chevron shape results in concentrated directionality of a jet of molten sheath material expelled perpendicular to the linear propagation of detonation waves. Properly positioned the LSC can be used to sever or penetrate a substrate. Optimum jet performance is obtained using dense yet ductile sheath materials like lead or nearly pure copper or aluminum.

**Motor Case Cutter (MCC).** A LSC specifically designed to penetrate a solid rocket motor case.

**Mild Detonating Fuse (MDF).** A linear explosive transfer assembly where the explosive material in confined in a metallic sheath and various types of over wrap materials intended to limit radial expulsion of detonation products but promote linear propagation of detonation waves. Linear detonation wave velocities in typical MDF configurations are greater than 20K feet per second. An MDF can be configured to sever or penetrate a substrate when placed in contact with it.

**No-Fire Rating.** The highest level of input energy to a first element at which initiation will not occur within a specific reliability and confidence level as determined by test and analysis.

**NSI (NASA Standard Initiator).** An unique EED designed and used by the NASA for various applications.

**Ordnance Transfer Assembly (OTA).** Another name for a ETA.

**PETN.** A secondary explosive chemically known as penta erythritol tetra nitrate. PETN can exhibit DDT characteristics.

**Percussion.** Percussion is a method of initiating a explosive reaction by an intentional sudden pinching or crushing of the explosive material, as between a blunt firing pin and an anvil.

**Primary Explosive.** A primary explosive is an explosive material that is extremely sensitive to heat or shock as the initiating mechanism, such as azides and styphnates. Primary explosives are normally used in first elements.

**Production Lot.** A group of components or assemblies of a single type and size, fabricated at one place in a continuous manufacturing process using the same tooling and material batches.

**Pyrotechnics.** Pyrotechnics are mixtures of fuels and oxidizers that may include organic binders and color intensifiers. Pyrotechnic compositions produce considerable amounts of heat and gases.

**Receptor.** Receptor is another name for an acceptor charge.

**Rigid Explosive Transfer Assembly (RETA).** A linear explosive transfer assembly encased in metallic tubing to prevent expulsion of radial detonation products onto the application.

**RDX.** A high or secondary explosive chemically known as cyclo tri methylene tri nitramine, AKA Research and Development Explosive.

**Safe Arm Device.** A mechanical or electromechanical device that provides a means to remotely safe or arm an explosive train by means of a structural barrier in the train downstream of the first element.

**Secondary Explosive.** An explosive material that is relatively insensitive to heat or impact and must be initiated by a suitable primary explosive or another secondary explosive.

**Sensitivity.** Sensitivity is the characteristic of an explosive or charge which expresses its susceptibility to initiation by externally applied energy such as heat, mechanical shock, or other stimuli.

**Service Life.** The service life is that period of time extending from the date of manufacture of a component containing age sensitive materials to a date when it is considered no longer acceptable for use in the end item application.

**Shaped Charges.** A severing or penetrating explosive actuated device whose physical shape is used to focus explosive energy in a desired direction. Shape charges include EFP and LSC designs.

**Shielded Mild Detonating Cord (SMDC).** Same basic design as CDC except over wrap materials are designed to resist detonation by lateral high velocity impacts.

**Shock to Detonation Transition (SDT).** A process occurring when a shock wave impacting a secondary explosive is not strong enough to initiate detonation directly but does cause a chemical decomposition that accelerates until it becomes a self supporting detonation wave within the material.

**Squib.** A squib is a general term that is used for any one of many small explosive devices that are loaded with deflagration explosive material so that the output is primarily gas and heat. Squibs may be initiators for gas generators and igniters or may be cartridges for cartridge actuated devices. Electrically actuated squibs are EEDs.

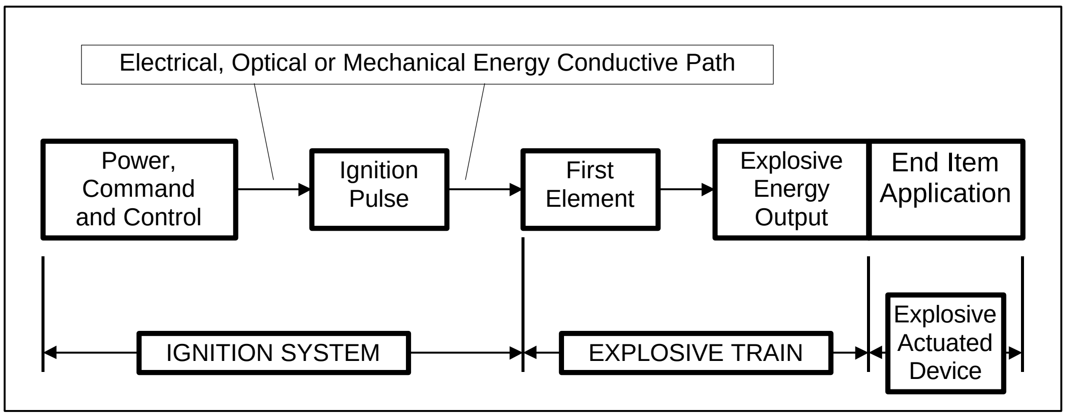
**Thin Layer Explosive (TLX).** A light weight ETA having a deflagration transfer velocity of approximately 6K feet per second. The design uses particles of explosive vacuum deposited onto inner walls of a non-metallic thin

walled tube. The tubing is over wrapped with a metallic braided material for protection. End configurations are designed to be similar to those used for all other types of ETA but are unique. Detonation inputs transition to deflagration and continue in that state until a transition to detonation is configured at the opposite end.

**Through Bulkhead Initiator (TBI).** A through bulkhead initiator is a high order detonation transfer element which propagates the detonation through an integral metal bulkhead by transmitting shock waves from the donor side to the acceptor side. The through bulkhead initiator is generally used where complete sealing is needed between explosive elements after firing.

## 4. PERFORMANCE CRITERIA.

**4.1 Explosive Systems**. Each explosive system is comprised of three major elements, an ignition system, an explosive train (ET) and an explosive actuated device. The ignition system receives commands from the using application to generate an ignition pulse that, when applied to the first element of the ET, initiates a chain of events resulting in an explosive energy output for the explosive actuated device in the end item application. The ignition pulse or stimuli is in the form of electrical, lased light or mechanical energy. The compatibility of interfaces between ignition stimuli and first elements of the ET, between ET explosive energy output and the explosive actuated device, and between the explosive actuated device and the end item application are primary concerns that require system performance margin demonstrations. The ability of the explosive system to survive electrical energy environments, such as, electrostatic discharge, electromagnetic radiation, radio frequency interference, without degraded performance or unplanned ignition is also a concern needing validation. The following paragraphs describe specific performance criteria for all systems and components within the explosive system. The relationship of the ignition system, ET and explosive actuated device is shown below.




**4.1.1 Ignition Systems**. Ignition systems are powered, controlled and commanded by inputs from the application. The inputs are converted into electrical, optical or mechanical energy stimuli that are applied to the first element of the ET. The limits of these ignition stimuli should be controlled and inhibited, to the extent practical. Controls insure reliable ignition. Inhibits prevent inadvertent or premature ignition.

**4.1.1.1 Low Energy Electrical Ignition**. Most space vehicles use low energy electrical ignition systems that are either constant current and capacitor discharge designs. They input finite electric energy pulses to the first element in the ET, the electro-explosive device, or EED. The amplitude and duration of this pulse should be configured to be greater than the all-fire threshold of the EED to assure reliable performance. The duration of the pulse is controlled by the EED ignition threshold limits. This threshold can be expressed as:

$$P(t) = I^2 r t$$

Where P(t) is the ignition energy threshold of the EED in watt-seconds or joules; I is the input current to the EED; r is EED resistance and t is the duration of the applied current.

A constant current ignition system should provide current amplitudes at least 20% greater than the all-fire rating specified by the EED. The duration of the applied current should be at least twice the duration value specified by the EED design. These criteria should be verified by tests during development, acceptance and qualification of the ignition system design.
For capacitor discharge systems the P(t) energy threshold limit of the EED can be expressed as one half the product of the ignition circuit capacitance (C) and the square of the voltage of the ignition system, or:

$$P(t) = 1/2\ CV^2$$

In this case voltage dominates the input to the EED, while capacitance determines the rate of the input. This type of system should be designed to provide voltage output amplitudes at least 20% greater than EED all-fire ratings using capacitance values that are equal to or greater than those specified by the EED design. These criteria should be verified by tests during development, acceptance and qualification of the ignition system design.

Both systems should validate that maximum energy inputs to the EED do not exceed design limits specified by the EED. Both should also validate an ability to provide the outputs specified when subjected to dynamic and thermal environments anticipated before or during use in the application.

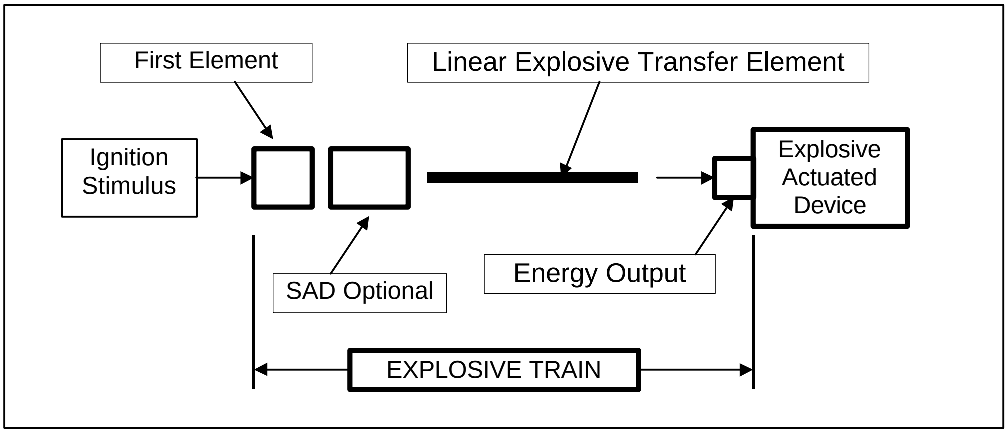
Electrical circuit designs used for power, command and control of the ignition system should be fail-safe and have validated an ability to prevent premature EED activation. The circuitry should preclude narrow band, high amplitude energy pulses near EED ignition thresholds, during all switching operations. Measurements during switching operations should be made as part of system validation. If continuity checks of the conductive path between the ignition system and EED are performed the amplitude of the electric current used should be limited to a value that is no greater than 10 percent of the rated no-fire threshold energy of the EED.

**4.1.1.2 High Energy Electrical Ignition**. This type of ignition system uses capacitor discharge electrical circuits to provide stimuli to exploding bridgewire (EBW) devices, high voltage initiators (HVI) and exploding foil initiators (EFI). These devices are EEDs that generally require input energies greater than 500 VDC for ignition. High voltage ignition system designs should provide voltage inputs to the EED that are at least 20% greater than EED all-fire ratings using capacitance values equal to or greater than those specified by the EED. These criteria should be verified by tests during development, acceptance and qualification of the ignition system design. The system should have validated an ability to provide the outputs specified when subjected to dynamic and thermal environments anticipated before or during use in the application. Electrical circuitry designs used for power, command and control should be fail-safe and have validated their ability to prevent premature EED activation. Validation that maximum energy inputs do not exceed EED design limits should also be done.

**4.1.1.3 Optical Ignition Systems**. Optical ignition systems deliver lased light energy density inputs to first elements of explosive trains configured to use laser initiated devices (LIDs). This energy is transferred to the LID by way of electrically non-conductive optical fiber paths. To assure reliable performance this type of ignition system should provide energy density inputs to the LID that are at least 20% greater than the all-fire rating of the LID design used. These criteria should be verified by tests during development, acceptance and qualification of the ignition system design. It should be validated that these energy density inputs are not affected by dynamic and thermal environments anticipated before or during use in the application. Electrical circuit designs used for power, command and control of optical ignition systems should be fail-safe and have validated their ability to prevent premature laser activation. If continuity checks of optical fiber paths between the ignition system and the LID are performed the magnitude of the optical energy used should be less than 10 percent of the no-fire energy density rating of the LID used.

**4.1.1.4 Mechanical Ignition Systems**. Mechanical ignition systems use release of potential energy as a means to cause ignition of explosive materials. Typical space vehicle applications include destruct systems where initiation is required after of an unplanned event, such as inadvertent separation. A common device used is known as a lanyard pull initiator (LPI). The LPI has a mechanical firing pin that is kinetically driven by release of stored potential energy and impacts the first element of an explosive train causing its ignition. Power, command and control of these types of ignition systems are mechanical. Performance margins for them should be validated by tests. The tests should demonstrate that minimum kinetic energy of the LPI is at least 20% greater than its rated all-fire level in terms of limits of potential energy and firing pin translation distances used. These tests should also validate ignition system performance before and during exposure to dynamic and thermal environments anticipated in the application. To prevent unplanned ignitions, mechanical inhibits within the LPI or in its application are required.

**4.1.2 Explosive Trains (ET).** The application of explosive materials to perform work requires that they be configured so that outputs are controlled and properly directed. To do this, a series of events is required. This alignment of events is called an explosive train (ET). The first element in any ET is its most sensitive component and is initiated by an ignition stimulus, as described in paragraph 4.1.1. Each explosive element of the ET following the first element is initiated by its predecessor in a chain reaction until the final output produces the work desired. This end item work can be applied to a variety of mechanical devices and other functions within a space vehicle. Inhibits can be applied to the ET between the first and second elements to prevent unplanned explosive energy propagation between them. These inhibits are referred to as safe arm devices (SAD). They provide a remotely controlled mechanical barrier between the elements. The figure below outlines an explosive train.




**4.1.2.1 First Elements**. First elements of an ET provide an explosive impulse for initiation of other explosive events. They are intentionally activated by the ignition stimuli. These include low voltage electro-explosive devices (EEDs), high voltage exploding bridgewire (EBW) devices and high voltage initiators (HVIs), laser initiated devices (LIDs) and mechanically actuated lanyard pull initiators (LPIs). The output of these first elements is used to initiate either the next element in an ET or to provide input energy for activation of a explosive actuated device.

**4.1.2.1.1 Low Voltage EED**. Low voltage EED designs are items that use input energies less than 200 mill joules for ignition. EED output is generated when external electrical energy is applied to a resistive element within the EED that interfaces with explosive materials that are also interior to it. This electrical energy is conveyed through conductors integral with the EED. The resistive element is known as a bridgewire. The explosive material adjacent to the bridgewire is called a primary charge. When properly energized the bridgewire transfers thermal energy to the primary charge causing a deflagration of the explosive material that then rapidly transitions to detonation. Energy from this deflagration to detonation transition (DDT) can then be applied to either the next element in the ET or to other explosive materials within the EED. Criteria for performance margin, acceptance and qualification certification of EED designs is given in paragraph 4.10.

The output of the EED should be configured to be compatible with the next element of the ET. Compatibility and performance margins of EED outputs and interfacing elements downstream should be validated. Appendix A discusses methods for measuring EED outputs and for verifying compatibility and performance margins. EED performance should also not be degraded by exposure to dynamic and thermal environments anticipated before or during use in the end item application.

An optimum EED design utilizes a single bridgewire for each primary charge. The physical proximity of the bridgewire to primary charge interface is an important EED design consideration. Efficient energy transfer between the two is dependent upon their direct contact.

If other explosive materials such as booster charges are required they should form a part of the EED assembly, or be an inseparable assembly thereof. Electrically conductive explosive charges within the EED should be isolated from the EED case.

Tests and analysis should determine the current or power level at which an EED design will reliably function. This should yield an input energy level, known as the all-fire rating, at which, as a minimum, 99.9 percent of the units from each design will function with a confidence of 95 percent. Suggested tests and analysis methods to validate these criteria are discussed in Appendix B.

It should be verified by test and analysis that each EED design will not function when the bridgewire is subjected to either a current of 1.0 ampere or a power of 1.0 watt, applied for 5.0 minutes. The function probability when subjected to this no-fire energy should be less than 0.001 with a confidence of 95 percent. Following exposure to this no-fire energy EED performance should not be degraded. Suggested tests and analysis methods to validate these criteria are discussed in Appendix B.

EED designs should not function or deteriorate in performance as a result of being subjected to external energies in the form of electrostatic discharges, electromagnetic radiation or radio frequency interference that do not exceed accepted limits of the EED or the application. Suggested test methods to validate designs subjected to these environments are discussed in Appendix C. EED design features used to inhibit these environments should be configured to be an integral part of the EED assembly. Features that depend on gaps in electrical conductors should be environmentally sealed within the EED assembly.

All electrically conductive paths of the EED should be isolated from the EED outer case. The insulation resistance between these conductors and the EED case should be greater than 2.0 Meg ohms when a 250 VDC potential is applied for 1.0-minute minimum.

The EED bridgewire element may be configured to be a semiconductor or a high resistivity wire segment. It should be capable of withstanding repeated measurements of its resistance values throughout its service life without degrading functional performance or safety.

**4.1.2.1.2 High Voltage Initiators**. These include EBW and HVI EED designs that require more than 500 VDC for ignition. They use high-energy electrical systems for ignition as described in paragraph 4.1.1.2. Criteria for performance margin, acceptance and qualification certification of these designs is given in paragraph 4.10. For simplicity the acronym EED may be used in place of EBW or HVI in the following discussions.

Output of these designs is generated in the same manner as described for a low voltage EED in paragraph 4.1.2.1.1. Differences between these and low voltage EED designs can include the use of a physical gap in the electrically conductive path to the bridgewire and use of a low resistivity bridgewire material.

Like low voltage EED designs, the output of these designs should be configured to be compatible with the next element of the ET. Compatibility and performance margins of EED outputs and interfacing elements downstream should be validated. Appendix A discusses methods for measuring EED outputs and for verifying compatibility and performance margins. EED performance should also not be degraded by exposure to dynamic and thermal environments anticipated before or during use in the end item application.

An optimum high voltage EED design utilizes a single bridgewire for each primary charge. If explosive materials other than the primary charge are required they should be integral part of the EED assembly, or be an inseparable assembly thereof.

Tests and analysis should determine the energy level at which an EED design will reliably function. This should yield an input energy level, known as the all-fire rating, at which, as a minimum, 99.9 percent of the units from each design will function with a confidence of 95 percent. Suggested tests and analysis methods to validate these criteria are discussed in Appendix B.

Tests should be conducted to show that each EED produced will not function when subjected to a 500 VDC input from a 1.0 micro farad capacitor, applied for 1.0 minute, minimum, across input electrical conductors of the EED. Tests should also demonstrate that each EED will not function when subjected to 250 VAC applied across input electrical conductors for 5.0 minutes minimum.

EED designs should not function or deteriorate in performance as a result of being subjected to external energies in the form of electrostatic discharges, electromagnetic radiation or radio frequency interference that do not exceed accepted design limits of the EED or the application. Suggested test methods to validate EED designs subjected to these environments are discussed in Appendix C. EED design features used to inhibit these environments should be configured to be an integral part of the EED assembly. Features that depend on gaps in electrical conductors should be environmentally sealed within the EED assembly.

All electrically conductive paths of the EED should be isolated from the EED outer case. The insulation resistance between these conductors and the EED case should be greater than 20.0 Meg ohms when a 500 VDC potential is applied for 2.0 minutes minimum.

The EED bridgewire element may be configured to be a semiconductor or a low resistivity wire segment. For EED designs without discontinuities or gaps in their electrically conductive paths the bridgewire should be capable of withstanding repeated measurements of its resistance values throughout its service life without degrading functional performance or safety. For EED designs with gaps, the condition of the bridgewire may be evaluated by first determining acceptable limits of resonant frequency measurements of the EED electrical circuit design and then performing measurements on each EED produced.

For EED designs having interrupts or gaps in their electrically conductive paths measurements of the amount of energy required to arc across the gap should be made as a means of the verifying acceptability. The acceptable limits of this slow rise rate breakdown voltage test are unique to each EED design and should be determined during development.

**4.1.2.1.3 Laser Initiated Device (LID)**. A laser initiated device is a non-electrically initiated first element that is ignited by energy produced by collimating coherent light excited in the infrared region of the electromagnetic spectrum. This energy density is optically transmitted by way of silicone fibers from crystalline rod or semiconductor diode lasers onto explosives within the LID. Output energy of a LID can be configured to be equivalent to an EED. LID designs can use secondary explosive materials altered to enhance thermal absorption properties in place of primaries normally used in EED designs. In LID designs, incident energy density is absorbed into the secondary explosive allowing it to undergo a deflagration to detonation transition. Use of secondary explosives and the lack of an electrically conductive path to them can be attractive safety attributes since concerns related to external environments like ESD, RF and EMI are reduced. LID design standardization is not yet equivalent to EED standardization. Criteria for certification of performance margins, acceptance and qualification are given in paragraph 4.10.

**4.1.2.1.4 Percussion Initiators**. These designs use mechanical energy impulse to cause shock to detonation transition (SDT) of primary explosive materials. They should be designed with all-fire rated energies that do not exceed 50 percent of the minimum supplied operating energy. No-fire rated energy should prevent ignition when subjected to energy of 50 percent of the all-fire rated energy. Percussion initiators have limited application in space vehicle systems mainly due to the need for mechanical inhibits during handling and installation. Criteria for certification of performance margins, acceptance and qualification are given in paragraph 4.10.

**4.1.2.2 First Element Outputs.** First element outputs should configured to be compatible with needs of the interfacing ET or explosive actuated device. They can be designed to be a detonation impulse or a hot particulate gaseous output by selective use of various explosive materials downstream of the primary charge. Consistency in the amount of energy produced for a given design is critical. Production lot manufacturing and process controls need to assure that the output of each first element produced will be within acceptable limits. Since measurement of these outputs in the application are not practical, results of output performance tests during design development and qualification should be used to certify acceptability. Appendix A describes methods that can be used to measure first element outputs and assess compatibility with interfacing ET or explosive actuated device components.

**4.1.2.3 Other Explosive Elements.** Some ET designs may require additional explosive elements downstream of the first element to enable transfer of energy to the next element in the train or to the explosive actuated device. These are typically referred to as booster charges. They can be configured to be an integral part of the first element assemblage. Integral designs can be certified for use in the application using first element tests of paragraph 4.10. Booster charge designs that are not integral with the first element should use tests for explosive energy transfer elements in paragraph 4.10. Compatibility with the ET for integral or non-integral booster charges should be demonstrated by tests of Appendix A.

**4.1.2.4 Safe-Arm Devices.** A safe arm device (SAD) is an electro-mechanical assembly used to prevent ET energy propagation if premature or unplanned initiation of an ET first element occurs. It is used in ET applications having first element designs susceptible to ignition from external energy environments, i.e., EMI, RF or ESD, if incident energy densities exceed accepted thresholds. These include ET applications where Eastern and Western Range Safety Regulation 127-1 compliance is required. This regulation states that a SAD is required in applications where unplanned expenditure of ET output energy, or its chain of events, may cause injury or death to people or damage to property.

**4.1.2.4.1 SAD Certification Requirements.** SAD designs should be certified acceptable for use after successful completion of all tests and analysis of paragraph 4.10. Other tests not defined in paragraph 4.10 but deemed necessary for performance validation of unique or novel SAD configurations should be included in certification requirements.

**4.1.2.4.1.1 SAD Explosive Components.** All explosive components within a SAD should have been certified acceptable as defined in paragraph 4.10 prior to installation. Preferred SAD designs are those that allow for ready installation and removal of all explosive components without adversely affecting environmental seal features of the assembly.

**4.1.2.4.2 SAD Barrier Design.** The SAD design should include a physical barrier that when positioned between the output of the first element and inputs to other downstream ET elements inhibits explosive energy transfer. The ET is termed “safe” when the SAD barrier is positioned between these elements so that explosive energy transfer is inhibited. It is termed “armed” when the barrier is positioned to allow explosive energy transfer. The barrier should be designed to be manually or remotely driven to the “safe” position. This disarming operation should be accomplished without passing through the “armed” position. The SAD design should prevent manual positioning of the barrier to the “armed” position. The SAD barrier design should provide a mechanical means to allow it to remain in “armed” or “safe” positions during all environmental conditions predicted by the application.

**4.1.2.4.3 SAD Barrier Performance.** Test and analysis should be used to demonstrate that the SAD barrier will reliably inhibit explosive energy transfer between ET first and downstream elements. The demonstration should also evaluate limits of all possible barrier misalignments relative to “save” and “armed” positions to establish performance margin limits for both inhibit reliability and energy transfer reliability.

**4.1.2.4.3.1 SAD Barrier Position Indicators.** The SAD design should provide remote and visible means to indicate the position of the barrier. Visual indicators should be located within the SAD, although visible from the exterior. The visible indicator should be readily discernable at least 15 degrees from a line-of-sight normal of the center of the indicator. It should also be readable at a distance of 5 feet away from the SAD. The visible indicators should be highlighted using internationally recognized colors, red for “armed” and green for “safe.” The “safe” status indicator can be visible when the SAD barrier is within safe operation performance margin limits as determined by test and analysis of paragraph 4.1.2.4.3. The “armed” indicator should be visible when the SAD barrier position is within the region determined by paragraph 4.1.2.4.3 tests and analysis to allow explosive energy transfer to the ET. The SAD user should be responsible for assuring that the indicators are visible when the SAD is installed in the application. Remote indicators should also assure that “safe” and “armed” status is within the performance margin limits determined by paragraph 4.1.2.4.3 tests and analysis and use the same criteria established for positioning of visual indicators.

**4.1.2.4.4 SAD Safing Pin.** A SAD should include a fail-safe mechanical device that inhibits remote or manual arming of the SAD during application processing. This item is referred to as a safing pin. The safing pin should be manually removed from the SAD to allow “arming.” Removal of the safing pin should not cause the SAD barrier to transition to the “armed” position. The SAD design should prevent safing pin removal when electrical circuits are commanded to position the SAD barrier to “armed.” When installed the safing pin should prevent the SAD barrier from being positioned to "armed" as established by tests and analysis of paragraph 4.1.2.4.3. A feature

such as a remove-before-flight streamer should attached to the safing pin to identify it as an item that needs to be removed before final use in the application. It is the responsibility of the SAD user to assure ready access in the application for safing pin removal and installation.

**4.1.2.4.4.1 <u>SAD Safing Pin Design</u>.** When the SAD is in the "safe" mode the safing pin should be retained within it by design features that can survive environmental conditions predicted by the application. These design features should apply resistance during safing pin removal and installation but not more than 40 pounds tension or 40 inch-pounds torque. The safing pin and interfacing SAD mechanism should be designed to withstand 100 pounds of tension or 100 inch-pounds of torque without failure.

**4.1.2.4.5 <u>SAD Cycle Life</u>.** The SAD should have a demonstrated cyclic life of 1000 "safe" to "armed" transitions, or five (5) times the number of transitions predicted during its lifetime, whichever is greater, without failure or degraded performance. The SAD barrier should be capable of being manually positioned to "safe" during any phase of this cyclic life. This requirement should be demonstrated during qualification tests. Post test disassembly and inspection should be used to confirm design adequacy.

**4.1.2.4.6 <u>SAD Electrical Design</u>.** Electrical control, monitor and EED circuitry should be environmentally sealed within the SAD. Independent and isolated circuits and connectors are required for ET first element command and monitoring and for barrier command and monitoring. The SAD should provide an enclosure for these circuits that shields them from external energy fields such as RF, EMI and ESD, to the extent practical.

**4.1.2.4.7 <u>SAD Stall Survivability</u>.** The SAD design should be capable of meeting all performance requirements after application of maximum operational voltages for five (5) minutes with safing pin installed. The SAD design should also prevent degradation or premature ignition of any explosive component within the SAD if maximum operation voltages are applied to control circuits for one (1) hour with the safing pin installed. SAD designs ability to survive these environments should be demonstrated by test as noted in paragraph 4.10.

**4.1.2.4.8 <u>SAD Switching Networks</u>.** Switching network designs using mechanical contacts for make or break circuits should assure by test that they will not inadvertently open or close during dynamic environments predicted during use in the application. During transition from SAD barrier "safe" to "armed" positions each switching network contact should completely disconnect prior to connecting to next circuit.

**4.1.2.4.9 <u>SAD Power Circuit Safety</u>.** When the SAD barrier is in the "safe" position, as established by the tests and analysis of paragraph 4.1.2.4.3, the switching network should assure that power paths to all ET first elements are disconnected. Also, in the "safe" position as established by paragraph 4.1.2.4.3 the paths to ET first elements should be shorted through appropriate resistance to SAD ground. If this ground path remains connected when the SAD barrier is in the "armed" position the ground path resistance value should be at least 10K ohms.

**4.1.2.4.10 <u>SAD Simulator Resistors</u>.** A SAD may use resistors installed across first element ignition circuits to allow for resistance or continuity measurements without applying energy to them. The application of operational voltages to these resistors for twenty (20) seconds minimum should not degrade subsequent SAD performance. The application of these voltages for a duration greater than twenty (20) seconds should not be cause for premature ignition of any explosive component within the SAD.

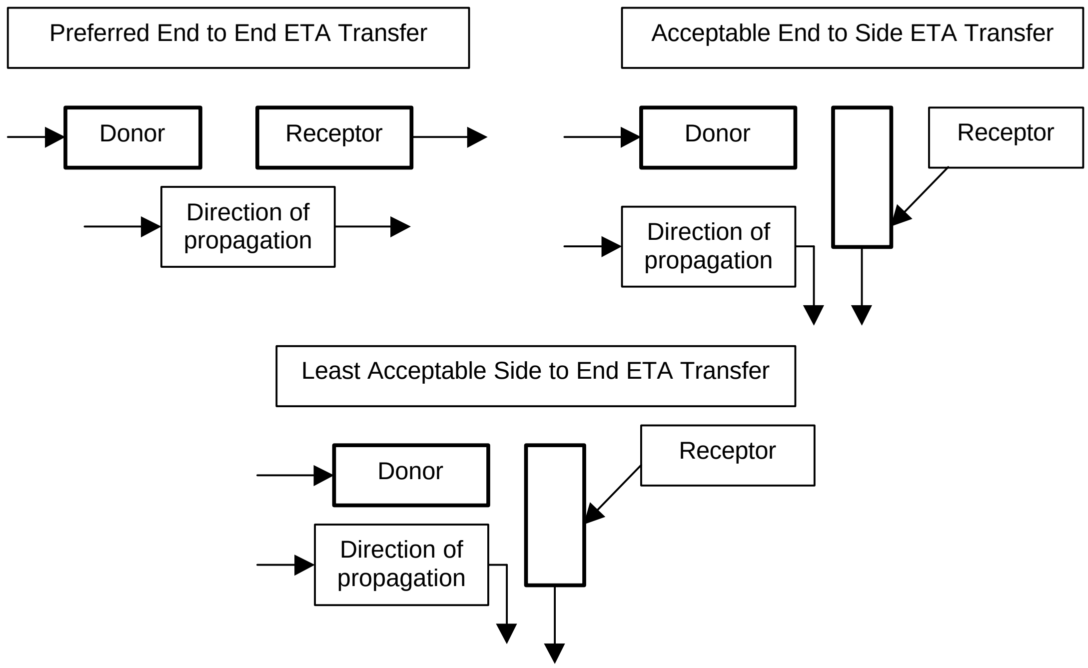
**4.1.2.5 <u>Linear Explosive Transmission</u>**. An ET may require additional elements downstream of the first element or SAD to effect transmission of the explosive energy signal to the explosive actuated device. This can be accomplished by use of explosive elements with a constrained column of explosive material that, when properly ignited, allows linear transmission of detonation or deflagration waves along its axis to the end item. These elements have fittings at each end to allow connection of them in the ET. The end fittings have explosive charges that accept inputs from the first element or SAD and either continue to propagate as detonations in the column or transition to deflagration. To allow for transfer to the next element a linear deflagration should transition to a detonation at the opposite end. Interconnect of these is done using inert fittings of various configurations.

The assemblage of these elements is known as a explosive transfer assembly (ETA). This may also be referred to as a explosive transfer system (ETS) or as a linear explosive assembly (LEA). The ETA, ETS or LEA may also include explosive time delay elements to control sequencing of events as dictated by specific requirements of an end item application.

Typical linear explosive elements used in an ETA have a variety of names and configurations. These include: Confined detonating cord (CDC); Mild detonating fuse (MDF); Shielded mild detonating cord (SMDC); Flexible confined detonating cord (FCDC); Rigid explosive transfer assembly (RETA); Flexible explosive transfer assembly (FETA); Thin layer explosive (TLX); and others. Some of these are trade names or variations thereof. All accept detonation inputs and deliver detonation outputs. Only the TLX type transitions from detonation to deflagration and then back to detonation as its output.

There are no limitations of the length of an ETA. Explosive signal transmission speeds for a detonating ETA is approximately 20K feet per second. For a deflagration ETA speeds are approximately 6K feet per second. Although all elements except MDF are designed with the intent of containing radial products of detonation waves travelling along its length some expulsion of contaminates can be expected. Radial combustion product expulsion is a random event of varying degrees. Only ETA designs having rigid metallic tubing installed over the explosive column with a demonstrated ability to contain combustion products should be used in applications having contamination restrictions.

Preferred alignment of ETA elements to assure reliable explosive energy transfer is the end to end configuration as shown as follows. An acceptance transfer configuration is end to side and a least acceptable is side to end. Side to side transfers are not recommended.



**4.1.2.6 Inert ETA Elements.** To facilitate interconnection and preferred alignment of ETA elements unique inert fittings to accommodate each configuration should be used. Manufacturing and process controls during fabrication of these are required to assure their physical integrity. Materials used in construction of these should be consistent with the needs of the application. For applications where fragmentation of the fittings is not acceptable tests and analysis should show that structural integrity during and after the explosive transfer event is maintained. Inert fittings should be designed to correctly position and align the ETA end fittings to assure reliable explosive energy transfer to the next element in the ET. Verification of acceptability of inert element designs can be attained by use of them during performance margin demonstrations discussed in paragraph 4.4.3.

**4.1.2.7 Time Delays.** In specific applications a sequencing of ETA events may be required. To accomplish this columns of linear explosive or pyrotechnics having slow burn rates or transfer speeds are used. Duration of the delay is determined by column length and by the chemistry of the material used. The time delay design should be capable of accepting a detonation input then transition to deflagration then back to detonation. A key parameter in explosive time delay design is heat dissipation of the burning material. Inadequate compensation for the dissipation of heat generated

in designs where the deflagration column is coiled onto a spool may be cause for ignition of adjacent coils or altered burn rates of the explosive material, or both. Performance certification of time delays should use the same methods used for energy transfer elements qualification and destructive acceptance, Methods 2C and 4C, except that tests should be done with samples at predicted operating temperatures of the end item application in lieu of default temperatures. This is meant to assure that time delay duration is within required limits in the thermal environment in which it will be used. Age surveillance demonstrations for time delays should be conducted in accordance with Method 5A.

**4.2 Explosive Actuated Devices.** Explosive actuated devices are the final major element of an explosive system. They are components or assemblies that use ET output energy to initiate and perform work in the end item application. They may or may not contain explosive materials. The following are descriptions of types of explosive actuated devices commonly used in space vehicle systems. Performance margin verification methods for explosive actuated devices are discussed in paragraph 4.4. Methods for certification of their use in the end item application are given in paragraph 4.10. Other tests not defined in 4.4 and 4.10 but deemed necessary for performance verification of unique or novel configurations should be included in the series of demonstrations.

**4.2.1 Mechanical Devices.** These are moving mechanical assemblies that use ET input energies to perform work. The ET input energy device is generally installed into the mechanical device during installation in the end item application. The installed ET energy source is used to translate pistons within these devices. These translations can be used to cause release of mechanical forces like tension, compression or lateral shear applied on the device by the end item application. They can also be used to cut or sever bolts, rods, braided cords, wires, optical fibers or like items used in the end item application. Or they can be used to open or close valves used in gaseous or liquid systems in the application. Translating piston devices include separating nuts, pin pullers, pin pushers, cable cutters, bolt cutters, cord cutters, reefing line cutters, bellows actuators, valves and others.

Performance demonstrations of paragraph 4.4.5 and Appendix C should be used to assure that these devices are capable of performing their intended functions with a definable margin within limits of input energy variations. These demonstrations should be followed by certification demonstrations of paragraph 4.10 where Method 2D describes qualification, Method 3A non-destructive acceptance and Method 4D destructive acceptance.

For devices used to release mechanical forces these performance demonstrations and certifications should include worse case external mechanical loads and loading configurations of the end item application. For devices used to cut or sever the demonstrations and certifications should use worse case physical and material configurations of the bolts, rods, braided cords, wires, optical fibers or like items used in the end item application. Demonstrations and certifications of valve performance should include gaseous or liquid mediums identical to those used in the end item application, to the extent practical, at pressures used in the application. Test fixtures used in these demonstrations should be configured to simulate the physical size, material and dynamic properties and stiffness of the end item application, to the extent practical. Where practical, post test radiographic inspection, disassembly and dissection should be used to assist evaluation of device performance.

**4.2.2 Through Bulkhead Initiator (TBI).** These are explosive actuated devices having explosive donor and receptor charges installed as permanent elements of them. Upon receipt of ET input the TBI donor charge ignites and transfers shock waves through an adjacent structural bulkhead with sufficient intensity to cause high order ignition of a receptor charge on the opposite side of the bulkhead. The structural integrity of the bulkhead should remain viable during and after this explosive energy transfer. The bulkhead is intended to provide a structural barrier to prevent loss of pressure of downstream elements of the end item application. TBI outputs can be configured to fit needs of any application by varying the design of the booster downstream of the receptor charge.

Performance demonstrations of paragraph 4.4.4 should be used to assure that TBI designs are capable of performing their intended functions with a definable margin. These demonstrations should be followed by certification demonstrations of paragraph 4.10 where Method 2C describes qualification, Method 3C non-destructive acceptance and Method 4C destructive acceptance. Test fixtures used in these demonstrations should be configured to simulate physical conditions of the end item application, to the extent practical. Post test evaluation of device performance should include radiographic inspection and structural bulkhead integrity inspections. Where practical metallurgic inspections of cross sectioned bulkheads should also be conducted. Age surveillance testing for these should be in accordance with Method 5A.

**4.2.3 Severing and Penetrating Devices.** These are explosive actuated devices designed to use explosive energy to sever or penetrate substrates in the end item application. They use ET inputs and continue as a detonation process that is converted into either a focused high velocity jet of molten material onto an object to be severed, or a high velocity metallic projectile directed onto objects to be penetrated. Severing devices can be used in a controlled manner to allow separation of segments or to effect access through substrates of the end item application. Both severing and penetrating devices can be used to defeat structural integrity of elements of the end item application. Severing devices are referred to as linear shaped charges (LSC) or shaped charges. A penetrating device is an explosively formed projectile (EFP) or shaped charge.

Performance demonstrations of paragraph 4.4.6 should be used to assure that LSC and EFP designs are capable of performing their intended functions with definable margins. These demonstrations should be followed by certification demonstrations of paragraph 4.10 where

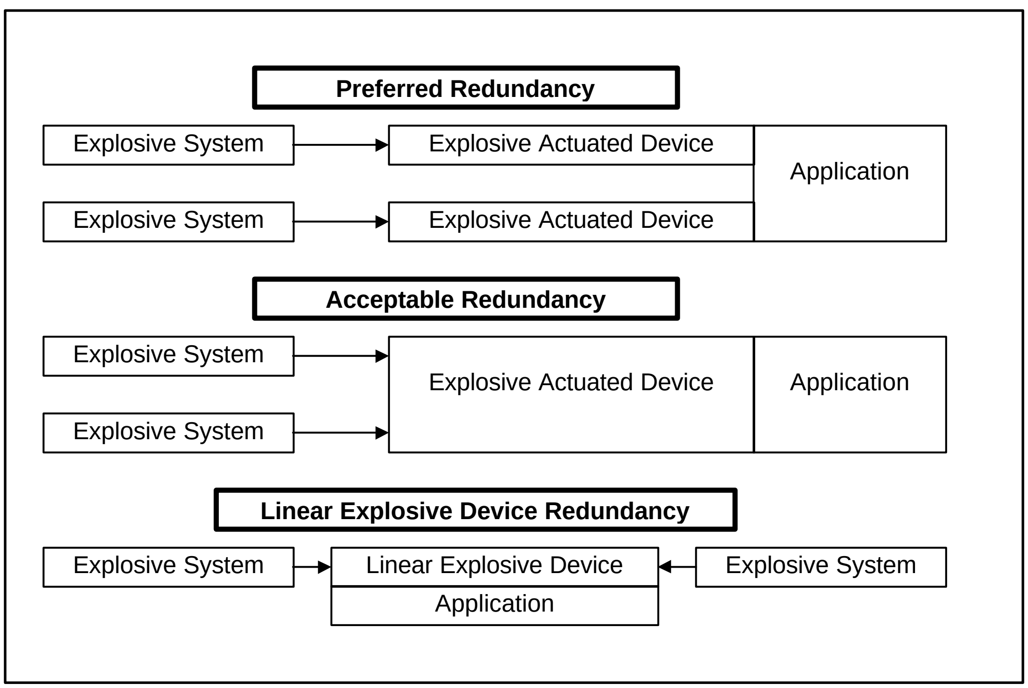
Method 2C describes qualification, Method 3C non-destructive acceptance and Method 4C destructive acceptance. Test fixtures and samples of substrates or structures used in these demonstrations should be configured to simulate the physical size, material properties and relative stiffness of the

materials to be severed or penetrated in the end item application, to the extent practical. Age surveillance demonstrations for these devices are outlined in Method 5B.

**4.2.4 Fragmenting Devices.** These are explosive actuated devices that use ET inputs to continue the detonation process and impart an explosive shock impulse in a controlled manner to effect fragmentation of structural elements in end item applications. These devices include explosive nuts and bolts, expanding tube frangible links and other similar devices. They are commonly used in separation and deployment systems in the end item application.

Performance demonstrations of paragraph 4.4 7 should be used to assure that fragmenting device designs are capable of performing their intended functions with definable margins. These demonstrations should be followed by certification demonstrations of paragraph 4.10 where Method 2C describes qualification, Method 3C non-destructive acceptance and Method 4C destructive acceptance. Test fixtures and samples of frangible elements and structures used in these demonstrations should be configured to simulate physical size, material, dynamic and relative stiffness properties of the items to be fragmented in the end item application, to the extent practical. Age surveillance demonstrations for elements of these devices that contain explosive materials should be conducted in accordance with Method 5B.

**4.3 Redundancy.** Dual explosive systems for each event within an application are preferred, where practical. Acceptable redundancy can be achieved using dual inputs to a single explosively actuated device. For linear explosive devices acceptable redundancy can be achieved by providing ET inputs to both ends of the device. The figure below describes these redundancy configurations.



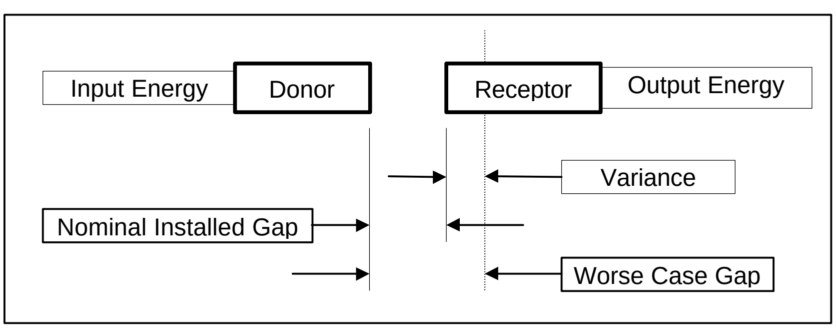

**4.4 Performance Margins.** Demonstrations and/or analysis of each system or component should be conducted to verify performance within limits of specified envelopes. These demonstrations and/or analysis should identify the amount of performance margin between specified envelopes and specific performance characteristics.

**4.4.1 <u>Ignition System Margins</u>.** Demonstrations should quantify the amount of positive margin between ignition system worse case output energy and ignition threshold limits of interfacing ET first elements. Threshold limits of first elements should be determined during tests and analysis described in Appendix B. A positive performance margin between these of 1.25 should be a goal. Measurement of ignition system output circuits during power, command or control switching should verify that the magnitude and duration of any output occurring during these operations be less than 20% of minimum ignition energy threshold of the ET first element as determined by tests and analysis of Appendix B.

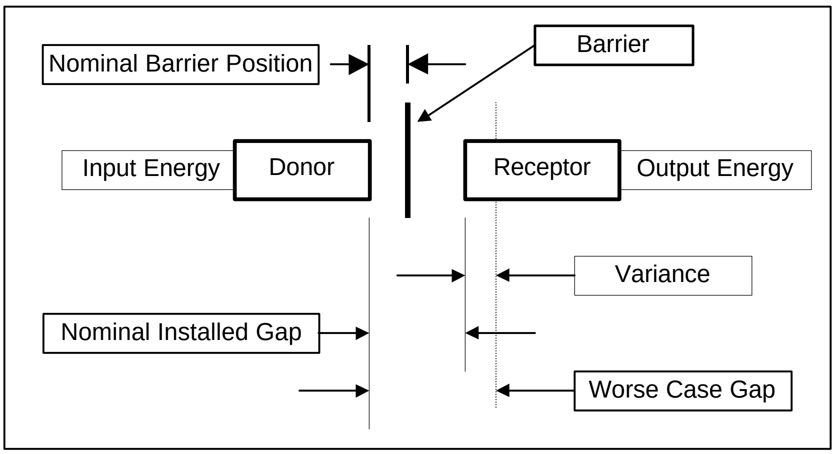
**4.4.2 <u>First Element Margins</u>.** Input energy performance margins for first elements are to be determined by tests and analysis of Appendix B. These tests provide an estimate of the all-fire and no-fire limits of the first element. The number of test samples required for Appendix B tests is dependent on the type of test selected. First element output energy performance margins should be established by tests and analysis described in Appendix A. These tests require a minimum of ten (10) first element test samples for determining minimum output energy limits and ten (10) for determining maximum output energy limits. Test samples used in these tests should be configured to be identical to those planned for use in the application. Appendix A tests and analysis should be used to verify that a positive margin of at least 1.20 exists between first element minimum output energy and minimum input energy requirements of the interfacing ET. The Appendix A tests should also verify that a margin of no less than 1.20 exists between the maximum first element energy output and the upper bound limit of acceptable input energy of the interfacing ET.

**4.4.3 <u>Explosive Energy Transfer Margins</u>.** Performance margins for explosive energy transfer of all elements of an ET should be determined by tests and analysis described in Appendix C using the criteria defined in the following paragraphs.

**4.4.3.1 <u>End-To-End Transfer Margin</u>.** Energy transfer performance margins tests should be conducted on all elements of an ET where transfer across a discontinuity, or gap, in the ET is required. The elements used in these tests should be configured identical to like elements planned to be used in the end item application. Test set-up should simulate the actual end item configuration to the extent practical. Knowledge of the nominal installed gap between donor and receptor ET elements in the application, and its worse case variance is required. Axial eccentricity or angular misalignment between donor and receptor should also be considered, to the extent practical. To demonstrate performance margin successful energy transfer should occur when the distance between the donor and the receptor is at least equal to the worse case gap plus a value equal to three (3) times its variance. Transfer margin demonstrations should also be performed at the lesser of the nominal gap minus three times the variance, or zero. A minimum of five (5) successful energy transfer tests of each configuration are required.




**4.4.3.2 <u>Transfer Through Barrier Margin</u>.** ET configurations requiring a barrier between the donor and receptor charges should conduct performance margin demonstrations in the same manner as described in paragraph 4.4.3.1 except should include the barrier. Barriers are metallic structures that do not maintain structural integrity during or after explosive energy transfer. The barrier should be nominally positioned as specified by its design relative to either the donor or the receptor. The barrier configuration used in these tests should be identical to that used in the end item application.




**4.4.4 <u>Transfer Through Bulkhead Margins</u>.** Performance margins for explosive energy transfer across bulkheads should be demonstrated by tests. Bulkheads are metallic structures that should maintain structural integrity during and after explosive energy transfer. To demonstrate margin, six (6) tests using nominal application inputs to nominal TBI donor charges should ignite nominal TBI receptor charges by shock transmission through a bulkhead that is 1.20 times the maximum specified thickness used in the end item application. Receptor charge ignition demonstrates successful performance with margin. To demonstrate structural integrity of the bulkhead, six (6) tests using nominal application inputs to nominal TBI donor charge inputs should ignite nominal TBI receptor charges through a bulkhead that is 0.80 times the minimum specified thickness used in the end item application. These tests should demonstrate structural integrity of the bulkhead during and after ignition of the receptor charge. Integrity can be validated by application of hydrostatic pressures equivalent to 1.5 times the maximum predicted operating pressure of the end item application. Metallurgic inspections of cross sections of bulkheads should also be conducted. In both test series, three (3) of the test should conducted at the maximum predicted operated temperature of the application and three (3) at the minimum predicted operating temperature.

**4.4.5 <u>Explosively Actuated Device Margins</u>.** Performance margins for explosive actuated devices should be determined by test and analysis. The tests should be conducted using worse case minimum and maximum ET output energies as inputs to the devices. For minimum performance margin demonstrations the ET input energy to the device should be configured to be less than 0.80 times the worse case ET minimum energy. For maximum performance margin demonstrations the ET input energy to the device should be at least 1.20 times the worse case ET maximum energy. Devices used in these demonstrations should be configured to be identical to those planned for use in the end item application. Test fixtures used should be configured to simulate the application including mechanical, dynamic and structural stiffness, to the extent practical. Interfaces between the device and the application that induce loads, frictions or other conditions on the device should also be simulated, to the extent practical. To validate performance margins at least six (6) devices should be tested using minimum ET input energies and six (6) using maximum ET input energies. In each case three (3) of the tests should be performed at maximum predicted operating temperature of the application and three (3) at the minimum predicted operating temperature of the application. All tests should be successful. Appendix C describes test methods that can be used for assessing ET output energies and conducting these performance margin tests.

**4.4.6 Severing and Penetrating Device Margins.** Performance margins for explosive actuated devices used for severing or penetrating should be determined by tests and analysis. For applications requiring severance or penetration of a single layer homogeneous material substrate performance margins should be demonstrated using nominal charges, positioned at maximum standoff, directed at a substrate with a thickness 1.5 times the maximum thickness to be used in the end item application. For applications requiring severance or penetration of multi-plied composite substrates performance margins should be demonstrated using nominal charges, positioned at maximum standoff, directed at a substrate with a thickness 2.0 times the maximum thickness to be used in the end item application. A minimum of six (6) successful severance or penetration tests of each configuration are required. Substrate materials should be identical to those to be used in the end item application. Test fixtures should simulate the end item application, including all materials in contact with it, to the extent practical.

**4.4.7 Fragmenting Device Margins.** Performance margins for explosive actuated devices used for fragmenting of structural elements should be determined by tests and analysis. A minimum of six (6) tests should be conducted using energy outputs no greater than 0.80 times the minimum output values to be used in the end item application. A minimum of six (6) tests should also be conducted using explosive energy outputs that are at least 1.2 times greater than maximum output values used in the end item application. Success is to be based on the amount of fragmentation desired. In all tests the fragmenting structure and associated elements should simulate the end item application, to the extent practical.

**4.5 Manufacturing and Quality Controls**. Explosive components and systems should be manufactured in accordance with established processes and criteria that can be verifiable by established quality control methods. Development testing should validate use of any innovative manufacturing technique before subjecting manufactured items to tests of this handbook. Selection of parts, materials and processes should be controlled, inspected and documented. Quality of all manufactured items should be assessed and results documented.

**4.5.1 Production Lot Controls**. All items within an explosive system should be grouped together in individual production lots, to the extent practical. All items used in components that contain or are operated by explosive materials that can not be tested completely before use should be from grouped individual production lots. A production lot is a group of assemblies or components of a single type and size, fabricated at one place in continuous manufacturing processes using the same tooling and material batches. These controls assure items destructively tested during qualification and acceptance are representative of items that cannot be fully tested before use in the application.

**4.5.1.1 Explosive Materials.** Explosive materials used in commercial or military applications are acceptable for use in the ET as long as performance and safety characteristics for them have been validated. These validations should have been conducted by recognized facilities. Supporting documentation for them should be readily available. Proprietary or other unique compositions that may result in superior performance, increased reliability, or improved safety may be used if components and systems containing them pass performance tests defined in this handbook. The use of sensitive primary explosives should be minimized.

**4.5.1.1.1 Temperature Limits.** Decomposition, cook-off, and melting temperatures of all explosives should be at least 30 degrees C higher than the maximum predicted environmental temperature to which the material will be exposed during storage, handling, installation, transportation, launch, or on orbit. Temperature limits should be determined by test. Where practical these tests should be conducted with the explosive materials or compositions installed in the end item configuration or simulations thereof.

**4.5.1.1.2 Sealing Requirements.** End item components or assemblages should use environmental sealing techniques that prevent external elements or contaminates from interacting with explosive materials installed in them. Where practical, sealing should be accomplished by fusion of metallic and/or non-metallic materials. Use of non-fused crimp type joints or application of organic materials to effect a seal should be avoided. Seal effectiveness should be verifiable before and after exposure to thermal and dynamic environments described in destructive qualification and acceptance tests of this handbook. Seal effectiveness design goals should use leak rate criteria that are less than $5 \times 10^{-6}$ standard cubic centimeters per second of helium at a differential pressure of one atmosphere. Method 103 defines tests to validate seal designs.

**4.5.1.2 Inert Materials.** Inert materials used for construction of components containing or operated by explosives should be selected to fit the needs of the application. Materials selected should survive thermal and dynamic environments and demonstrate performance as described by tests in this handbook.

**4.6 Identification and Marking.** Explosive systems and components should have markings permanently attached to them, or appropriately marked on them, that include identifying part numbers, nomenclatures and manufacturer identifiers. Items that contain explosive materials or other items requiring control of useful life should also include unique production lot identifiers, unique serial number for each item manufactured and either the date of manufacture or the date of useful life expiration. If it is not practical to apply these markings on the item the identifications should be included with the item in their packaging.

**4.6.1 Explosive Component Data.** A data sheet defining the amount of explosive material by weight in each component, a description of the chemical composition of the explosive material, its date of manufacture, manufacturer and production lot identifier should accompany the items. The data sheets should have identifiers that relate them to specific part numbers, production lot numbers and serial numbers of the explosive components.

**4.6.1.1 Explosive Component Classification.** The explosive component manufacturer is responsible for obtaining documentation that defines appropriate federal, state and local agency transportation and handling classification for each configuration produced. The manufacturer should include this documentation and any supporting information with the explosive component data package.

**4.6.2 Age Sensitive Material Data.** A data sheet describing any age sensitive material used in an explosive system or component should accompany the elements within which it is used. The data sheet should also identify age surveillance verification methods that should be used.

**4.7 Environment Survivability.** Explosive systems and components should be designed to survive and perform intended functions during and after exposure to dynamic, thermal, humidity, pressure or other environments that are predicted to be encountered in use in the end item application. Performance and survivability can be demonstrated with exposures to these environments during qualification and destructive acceptance tests described in paragraph 4.10. It is the responsibility of the user of the explosive system or component to determine the types of environments to be experienced in each application; predict the magnitudes, limits and ranges of these environments; and assure that they are included in appropriate tests of paragraph 4.10. MIL-HDBK-340 can be used for guidance in assessments and predictions of these environments.

**4.8 Safety.** Explosive systems and components should be designed to minimize accident risk to personnel, equipment and facilities. Handling and installation procedures should be formally documented and clearly identify operations where warnings and cautions are necessary to deter accidents. Safety requirements and procedures should comply with of all appropriate federal, state and local regulations. It is the responsibility of both user and manufacturer of explosive systems and components to ascertain which regulations should be adhered to. The ability of explosive systems and first elements to survive electrical energy fields without premature ignition or degraded performance should certified by tests, inspections and analysis.

**4.8.1 Electrical Energy Field Survivability.** Tests and analysis should be performed to assess explosive system and first element survivability when subjected to electrical energy environments that may occur during storage, handling or application. These environments include electro static discharge (ESD), electro magnetic interference (EMI) and radio frequency interference (RFI). Affects of ESD environments on an explosive system and the ability to prevent premature ignition of first elements within in it should be evaluated. ESD tests of each first element design should be performed. Evaluations of electro magnetic compatibility (EMC) of all power generating elements within the explosive systems should be made. Test and analysis estimates of RFI survivability limits of first element designs should be performed. The following discusses tests, evaluations and analysis criteria for these environments. Appendix D provides discussions and methods for certifying explosive system and first element survivability.

**4.8.1.1 Explosive System ESD Survivability.** Explosive systems and components should be designed to survive external applications of an ESD environment. Protective features should be included within the explosive system to prevent premature ignition of first elements or deactivation of safety inhibits within it. All ESD sensitive components should be shielded or otherwise protected from exposure to the environment. Analysis should confirm that there are no sneak circuits or unplanned capacitance discharges that could cause these premature events. Certification of effectiveness of these features should be based on inspection and analysis, as appropriate.

**4.8.1.2..First Element ESD Survivability.** Each first element used in the explosive system that is potentially susceptible to premature ignition or degraded performance by an ESD energy field should be tested to verify survivability. Those of primary concern are EED designs. Each EED produced should be capable of withstanding a 25 K volt pulse from a 500 pico farad capacitor applied between shorted pins and case, or a 25 K volt pulse from a 500 pico farad through a 5 K ohm resistor applied between EED pins. Appendix D describes certification methods for ESD testing.

**4.8.1.3 Explosive System EMC Evaluations.** The explosive system power, command and control electrical circuitry should be designed to limit generation of electro magnetic fields onto sensitive components within it to a level that is at least 20 dB below the maximum no-fire rating of the first element used in it. These circuits should also be designed to limit power produced at any inhibit within it to a level at least 6 dB below the minimum activation power of any inhibit. Appendix D discusses methods for evaluating these criteria.

**4.8.1.4 RF Environment Survivability.** All explosive system and first element designs should be capable of surviving exposures to externally applied RFI fields anticipated in the end item application without premature ignition or degraded performance. Methods for evaluation and certifying survivability are discussed in Appendix D.

**4.9 Service Life.** Explosive systems and components should be designed to have useful lives commensurate with service life requirements dictated by the end item application. All explosive systems and components containing age sensitive materials should be identified as noted in paragraph 4.6.2 and an age surveillance program for them should be established. The age surveillance program should define inspection intervals, useful life verification methods and refurbishment methods, if applicable.

**4.9.1 Storage, Transportation and Handling.** Where practical, temperatures during storage, transportation and handling should be controlled to be within 0 to 40 degrees C and humidity between 20 to 80 percent. Dynamic environments should be no greater than 6 dB above maximum predicted levels of the end item application. The affects of adverse storage, transportation and handling environments that exceed these limits should be accounted for in surveillance test programs of age sensitive components.

**4.9.2 Age Surveillance of Explosive Components.** Of primary interest are explosive components that individually contain less than thirty (30) grams of explosive materials that are environmentally sealed assemblages of multiple elements. First elements and booster charges are components that are in this category although there can be others. The premise is that the assemblage may be adversely affected by interactions of materials and processes within them causing output energy to be altered. Although the specific component design may have satisfied all material compatibility tests and analysis, subtle production lot to lot manufacturing and processing variations may have adverse affects on a particular lot of the design. Potential adverse affects can only be determined by inspections of samples from each production lot. These inspections are destructive therefore they cannot be performed on items to be used in the end item application. The solution is to perform a periodic age surveillance test of samples from each production lot. Surveillance tests can then be used as tools to detect potential anomalous conditions before other items from the lot are used in the end item application. Two types of tests are discussed below and are outlined in Method 5A. Also discussed are surveillance tests for components that individually contain more than thirty (30) grams of explosive material. Tests for these are outlined in Method 5B.

**4.9.2.1 Near Real Time Age Surveillance.** Optimum surveillance tests are those performed as near to end item application need as possible. Practical conduct would have them performed within a timeframe allowing recovery should an anomaly occur. Suggested test timing is within one year of the intended use in the end item. Method 5A defines the sequence of tests suggested to evaluate useful life using five (5) test samples. The tests can be repeated at time intervals determined to best fit end item application needs. There is no limit to the number of tests performed on any specific production lot of components. These near real time tests can also be combined with accelerated age tests of 4.9.2.2 to best fit end item application needs.

**4.9.2.2 Accelerated Age Surveillance.** These tests are met to augment those of paragraph 4.9.2.1 and provide a method to estimate aging processes by simulation of its affects. The simulation assumes adverse reactions due to manufacturing and process variations noted in paragraph 4.9.2 can be accelerated by introduction of an elevated temperature storage environment for a specific period of time. As shown in Method 5A, ten (10) test samples are subjected to various tests including storage at 160 degrees F for a period of 672 hours. The estimated useful life equivalence of this environment is three (3) years. The relation of this estimate and the duration of the elevated temperature storage environment are assumed to be linear. Using this assumption other useful life increments can be estimated by increasing or

decreasing the duration of the temperature storage test. As with near real time tests there is no limit to the number of accelerated age surveillance tests that can be performed on a specific production lot of components.

**4.9.2.3 Surveillance of Other Explosive Components.** Age surveillance of components individually containing more than thirty (30) grams of explosive material should be performed per Method 5B. This test requires functioning of only one sample selected from the production lot. It is suggested that this test be performed within three (3) years of intended use of items from the production lot. There is no limit to the number of times that this test can be performed on a specific production lot of explosive components.

**4.10 Certification**. Explosive systems should be certified acceptable before use on a space vehicle. Certification can be accomplished by performing tests, inspections, measurements and analysis to verify performance criteria and margins as described in the following.

**4.10.1 Explosive System Certification.** An explosive system is considered certified for use on a space vehicle if the following conditions are met:

a. Compatibility of external inputs to ignition systems should have been verified by inspection, measurement or analysis.

b. Compatibility of the explosive train output with explosive actuated device needs and end item application interfaces should have been verified by inspection, measurement and analysis.

c. All elements within the explosive system should have been certified as qualified and acceptable for use in the explosive system by inspection, test and/or analysis.

d. The user should have assured that the explosive system was qualified to survive all environmental conditions predicted during the end item application.

e. Tests and analysis should have confirmed electro static discharge, electromagnetic radiation or radio frequency interference survivability for levels that exceed accepted limits of the application.

**4.10.2 Ignition System Certification.** All elements of an ignition system are considered certified for use in an explosive system if the following conditions are met:

a. Compatibility of input energy to the ET should have been verified acceptable by inspection, measurement and analysis.

b. Power, command and control circuits should have been verified fail-safe and to preclude premature activation by inspection and analysis.

**4.10.3 Explosive Train Certification**. All elements of an explosive train are considered certified for use in an explosive system if the following conditions are met:

a. Each component or assembly should comply with manufacturing and quality control criteria for parts, materials and processes and be grouped into common production lots.

b. Components or assemblies should have passed tests, inspections, measurements and analysis verifying that performance margins of their designs are within acceptable limits.

c. Destructive test samples of component or assembly designs should have passed tests demonstrating qualification.

d. All components or assemblies to be used in the application should have passed individual non-destructive acceptance tests.

e. All components or assemblies should be from production lots that have passed destructive acceptance tests of samples from the lots.

f. All elements should have been transported and stored within environmental limits of the application.

g. Production lot service life limits should be verified by age surveillance tests, inspections and analysis, and be within operational limits of the application.

**4.10.4 Explosive Actuated Device Certification.** Explosive actuated devices are considered certified for use in an explosive system if the following conditions are met:

a. Each explosive actuated device should comply with manufacturing and quality control criteria for parts, materials and processes and be grouped into common production lots.

b. Explosive actuated device designs should have passed tests, inspections, measurements and analysis verifying that performance margins of their designs are within acceptable limits.

c. Destructive test samples of explosive actuated device designs should have passed tests demonstrating qualification.

d. All explosive actuated devices to be used in the application should have passed individual non-destructive acceptance tests.

e. All explosive actuated devices should be from production lots that have passed destructive acceptance tests of samples from the lots.

f. All explosive actuated devices should have been transported and stored within environmental limits of the application.

g. Production lot service life limits for designs containing age sensitive materials should be verified by age surveillance tests, inspections and analysis, and be within operational limits of the application.

**4.1O.5** **Certification Methods**. The following Tables and Methods describe certification criteria methodologies.

**Table I - Explosive System Certification**

| Certification Criteria | Certification Method |
|---|---|
| Application input compatibility | Inspection, measurement & analysis |
| System output compatibility | Inspection, measurement & analysis |
| System elements certification | Inspection & analysis |
| Application environment survivability | Inspection, test & analysis by user |
| External energy survivability | Appendix D |

**Table II - Ignition System Certification**

| Certification Criteria | Certification Method |
|---|---|
| ET input energy compatibility | Inspection, measurement & paragraph 4.4.1 |
| Fail-safe operation | Inspection & analysis |

**Table III - Explosive Train Certification**

| Certification Criteria | Certification Method |
|---|---|
| Parts, materials & process controls | Inspection |
| Performance margin limit verifications | Methods 1A, 1B or 1C |
| Qualification tests | Methods 2A, 2B or 2C |
| Non-destructive acceptance tests | Methods 3A, 3B or 3C |
| Destructive acceptance tests | Methods 4A, 4B or 4C |
| Transportation & storage controls | Inspection |
| Service life verifications | Method 5A or 5B |

**Table IV - Explosive Actuated Device Certification**

| Certification Criteria | Certification Method |
|---|---|
| Parts, materials & process controls | Inspection |
| Performance margin limit verifications | Methods 1D, 1E or 1F |
| Qualification tests | Methods 2C or 2D |
| Non-destructive acceptance tests | Methods 3C |
| Destructive acceptance tests | Methods 4C or 4D |
| Transportation & storage controls | Inspection |
| Service life verifications | Method 5B |

**Method 1A - First Element Performance Margin Evaluation**

| Margin Criteria | Evaluation Method | Quantity |
|---|---|---|
| Minimum energy output limit | Paragraph 4.4.2 & Appendix A | 10 min |
| Maximum energy output limit | Paragraph 4.4.2 & Appendix A | 10 min |
| All-fire energy limit | Paragraph 4.4.1, 4.4.2 & Appendix B | <50 |
| No-fire energy limit | Paragraph 4.4.1, 4.4.2 & Appendix B | <50 |
| External electrical energy survivability | Paragraph 4.8.1 & Appendix D | <250 |

**Method 1B – Explosive Energy Transfer Performance Margin Evaluation**

| Margin Criteria | Evaluation Method | Quantity |
|---|---|---|
| Minimum gap transfer limit | Paragraph 4.4.3.1 & Appendix C | 5 min |
| Maximum gap transfer limit | Paragraph 4.4.3.1 & Appendix C | 5 min |
| Minimum barrier limit | Paragraph 4.4.3.2 & Appendix C | 5 min |
| Maximum barrier limit | Paragraph 4.4.3.2 & Appendix C | 5 min |

**Method 1C -Explosive Energy Transfer Through Bulkhead Performance Margin Evaluation**

| Margin Criteria | Evaluation Method | Quantity |
|---|---|---|
| Minimum energy input limit | Paragraph 4.4.4 & Appendix C | 6 min |
| Maximum energy input limit | Paragraph 4.4.4 & Appendix C | 6 min |

**Method 1D - Explosive Actuated Device Performance Margin Evaluation**

| Margin Criteria | Evaluation Method | Quantity |
|---|---|---|
| Minimum energy input limit | Paragraph 4.4.5 & Appendix C | 6 min |
| Maximum energy input limit | Paragraph 4.4.5 & Appendix C | 6 min |

**Method 1E - Severing and Penetrating Device Performance Margin Evaluation**

| Margin Criteria | Evaluation Method | Quantity |
|---|---|---|
| Severance/Penetration limit | Paragraph 4.4.6 & Appendix C | 6 min |

**Method 1F - Fragmenting Device Performance Margin Evaluation**

| Margin Criteria | Evaluation Method | Quantity |
|---|---|---|
| Minimum energy input limit | Paragraph 4.4.7 & Appendix C | 6 min |
| Maximum energy input limit | Paragraph 4.4.7 & Appendix C | 6 min |

### Method 2A - Qualification Tests for First Elements

| Qualification Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3A | 126 min |
| High temperature limit test | Method 406 | 5 |
| Qualification level cyclic temperature test | Method 401 | 5 5 105 |
| Qualification level dynamic shock test | Method 402 | 5 5 105 |
| Qualification level random vibration test | Method 403 | 105 |
| 2-meter Drop test | Method 404 | 6 |
| Elect resistance, resonant frequency or optical continuity health measurement | Method 201, 202 or 203 | 6 5 5 105 |
| Environmental seal effectiveness test | Method 103 | 6 5 5 105 |
| X-ray inspection | Method 104 | 6 5 5 105 |
| Neutron ray inspection (Optional) | Method 105 | 6 5 5 105 |
| No-Fire verification | Appendix B | 6 5 5 105 |
| Ambient temperature function at specified All-Fire energy | Appendix A | 6 5 5 |
| Function – See Method 2A-1 | Appendix A | 105 |

### Method 2A-1 – Qualification Functional Tests of First Elements

| TEST CONDITIONS | Rated All-Fire input energy | Predicted application input energy | Max rated input energy or 2x All-Fire |
|---|---|---|---|
| Ambient temp | 15 | 15 | 5 |
| Greater of Max predicted temp or +71 degree C | 15 | 15 | 5 |
| Lesser of Min predicted temp or –57 degree C | 15 | 15 | 5 |

### Method 2B - Qualification Tests for Safe and Arm Devices

| Qualification Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3B | 8 min |
| Qualification level cyclic temperature test | Method 401 | 6 1 1 |
| Qualification level dynamic shock test | Method 402 | 6 1 1 |
| Qualification level random vibration endurance | Method 403 | 6 1 1 |
| Insulation resistance test | Method 204 | 6 1 1 |
| Cyclic electro-mechanical function test | Method 206 | 6 1 1 |
| Environmental seal effectiveness test | Method 103 | 6 1 1 |
| Function 2 units at predicted temperature in application | Appendix C | 2 |
| Function 2 units at maximum qualification temperature | Appendix C | 2 |
| Function 2 units at minimum qualification temperature | Appendix C | 2 |
| Electro-mechanical cycle life | Method 408 | 1 |
| Disassembly and inspection | Method 409 | 1 |
| Electro-mechanical stall test | Method 410 | 1 |
| 6 meter drop test | Method 405 | 1 |

**Method 2C - Qualification Tests for Explosive Energy Transfer, LSC, EFP, TBI, and Fragmenting Components or Assemblies**

| Qualification Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3C | 6 min |
| Qualification level cyclic temperature test | Method 401 | 6 |
| Qualification level dynamic shock test | Method 402 | 6 |
| Qualification level random vibration test | Method 403 | 6 |
| Function 2 units at predicted temperature in application | Appendix C | 2 |
| Function 2 units at maximum qualification temperature | Appendix C | 2 |
| Function 2 units at minimum qualification temperature | Appendix C | 2 |

**Method 2D - Qualification Tests for Explosive Actuated Devices**

| Qualification Criteria | Test Description | Quantity |
|---|---|---|
| Non destructive acceptance | Method 3C | 27 min |
| Qualification level cyclic temperature test | Method 401 | 6 21 |
| Qualification level dynamic shock test | Method 402 | 21 |
| Qualification level random vibration test | Method 403 | 21 |
| Function 9 units at predicted temperature in application | Appendix C | 2 7 |
| Function 9 units at maximum qualification temperature | Appendix C | 2 7 |
| Function 9 units at minimum qualification temperature | Appendix C | 2 7 |

**Method 3A - Non Destructive Acceptance Tests for First Elements**

| Acceptance Criteria | Test Description | Quantity |
|---|---|---|
| Visual inspection | Method 101 | All |
| Dimensional inspection | Method 102 | All |
| Electrical resistance, resonant frequency or optical continuity health measurement | Method 201, 202 or 203 | All |
| Electrical spark gap breakdown test 1.) | Method 205 | All |
| Electrical insulation resistance measurement | Method 204 | All |
| Environmental seal effectiveness test | Method 103 | All |
| Electrostatic discharge test | Appendix D | All |
| X-ray inspection | Method 104 | All |
| Neutron ray inspection | Method 105 | All |

1.) Applicable only to EED designs with gaps in conductive circuits.

**Method 3B - Non Destructive Acceptance Tests for Safe and Devices**

| Acceptance Criteria | Test Description | Quantity |
|---|---|---|
| Visual inspection | Method 101 | All |
| Dimensional inspection | Method 102 | All |
| Electrical resistance measurement | Method 201 | All |
| Electrical insulation resistance measurement | Method 204 | All |
| Acceptance level cyclic temperature test | Method 301 | All |
| Acceptance level random vibration test | Method 302 | All |
| Cyclic electro-mechanical function tests | Method 206 | All |
| Environmental seal effectiveness test | Method 103 | All |

**Method 3C - Non Destructive Acceptance Tests for Explosive Energy Transfer Elements and Explosive Actuated Devices**

| Acceptance Criteria | Test Description | Quantity |
|---|---|---|
| Visual inspection | Method 101 | All |
| Dimensional inspection | Method 102 | All |
| X-ray inspection | Method 104 | All |
| N-ray inspection | Method 105 | All |

**Method 4A - Destructive Acceptance Tests for First Elements**

| Acceptance Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3A | All |
| Qualification level cyclic temperature test | Method 401 | 1) |
| Qualification level dynamic shock test | Method 402 | 1) |
| Qualification level random vibration test | Method 403 | 1) |
| X-ray inspection | Method 104 | 1) |
| N-ray inspection (optional) | Method 105 | 1) |
| Electrical resistance, resonant frequency or optical continuity health measurement | Method 201, 202 or 203 | 1) |
| Environmental seal effectiveness test | Method 103 | 1) |
| No-fire verification | Appendix B | 1) |
| Function – See Method 4A-1 | Appendix A | 1) |

1) Quantity should be 30 units or 10% of production lot, which ever is greater.

**Method 4A-1 – Acceptance Functional Tests for First Elements**

| TEST CONDITIONS | Rated All-Fire input energy | Predicted application input energy |
|---|---|---|
| Ambient temp | 1/6 of 1) | 1/6 of 1) |
| Greater of Max predicted temp or +71 degree C | 1/6 of 1) | 1/6 of 1) |
| Lesser of Min predicted temp or –57 degree C | 1/6 of 1) | 1/6 of 1) |

**Method 4B - Destructive Acceptance Tests for Safe and Arm Devices**

| Acceptance Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3B | 1 |
| Electro-mechanical cycle life | Method 408 | 1 |
| Disassembly and inspection | Method 409 | 1 |

**Method 4C - Destructive Acceptance Tests for Explosive Energy Transfer, LSC, EFP, TBI and Fragmenting Components or Assemblies**

| Acceptance Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3C | 3 |
| Qualification level cyclic temperature test | Method 401 | 3 |
| Qualification level dynamic shock test | Method 402 | 3 |
| Qualification level random vibration test | Method 403 | 3 |
| X-ray inspection | Method 104 | 3 |
| N-ray inspection (Optional) | Method 105 | 3 |
| Function test<br>- Ambient temperature<br>- Greater of Max predicted or +71 degree C<br>- Lesser of Min predicted or –57 degree C | Appendix C | <br>1<br>1<br>1 |

**Method 4D - Destructive Acceptance Tests for Explosive Actuated Devices**

| Acceptance Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3C | 9 |
| Qualification level cyclic temperature test | Method 401 | 9 |
| Qualification level dynamic shock test | Method 402 | 9 |
| Qualification level random vibration test | Method 403 | 9 |
| X-ray inspection | Method 104 | 9 |
| N-ray inspection (Optional) | Method 105 | 9 |
| Function test<br>- Ambient temperature<br>- Greater of Max predicted or +71 degree C<br>- Lesser of Min predicted or -57 degree C | Appendix C | <br>3<br>3<br>3 |

**Method 5A - Age Surveillance Tests for Components Containing <30 Grams of Explosive Materials**

| Surveillance Criteria | Test Description | Quantity | |
|---|---|---|---|
| Non-destructive acceptance | Method 3A | 5 | 10 |
| Qualification level cyclic temperature test | Method 401 | 5 | 10 |
| Qualification level dynamic shock test | Method 402 | 5 | 10 |
| Qualification level random vibration test | Method 403 | 5 | 10 |
| X-ray inspection | Method 104 | 5 | 10 |
| N-ray inspection (optional) | Method 105 | 5 | 10 |
| Electrical resistance, resonant frequency or optical continuity health measurement – If applicable | Method 201, 202 or 203 | 5 | 10 |
| Environmental seal effectiveness test | Method 103 | 5 | 10 |
| No-fire verification – If applicable | Appendix B | 5 | 10 |
| Elevated temperature storage simulation test | Method 407 | | 10 |
| Function test<br>- Ambient temperature<br>- Greater of Max predicted or +71 degree C<br>- Lesser of Min predicted or -57 degree C | Appendix A | <br>5 | <br>4<br>3<br>3 |

**Method 5B - Age Surveillance Tests for Components Containing >30 Grams of Explosive Materials**

| Surveillance Criteria | Test Description | Quantity |
|---|---|---|
| Non-destructive acceptance | Method 3C | 1 |
| Function test<br>- Ambient temperature | Appendix C | <br>1 |

## TEST DESCRIPTION SERIES 100 - NON-DESTRUCTIVE INSPECTIONS AND TESTS

### Method 101 – Visual Inspection of Explosive System Components and Assemblies

1. **Purpose.** Verify that explosive system components or assemblies comply with product specification physical descriptions and that supporting documentation is available and complete.

2. **Applicable Documents.** Product specifications with descriptions of components and assemblies to be inspected. Explosive component data packages.

3. **Procedure.** Visually inspect components or assemblies and compare with product specification descriptions. Review supporting documentation for completeness.

4. **Accept/Reject Criteria.** Accept all items that comply with product specifications and have complete document packages. Reject all items that do not comply. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This failure rate should be considered a potential cause for rejection of the entire lot.

### Method 102 – Dimensional Inspection of Explosive System Components and Assemblies

1. **Purpose.** Verify that the physical dimensions of explosive system components or assemblies comply with product specification descriptions.

2. **Applicable Documents.** Product specification descriptions of dimensioned features to be inspected. Industry standard ANSI/ASTM Y14.5M, Dimensioning and Tolerancing.

3. **Procedure.** Using product specification dimensional descriptions physically measure dimensioned features on each item and compare to requirements.

4. **Accept/Reject Criteria.** Accept all items that comply with product specifications. Reject all items that do not comply. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

### Method 103 – Environmental Seal Effectiveness Verification for Explosive System Components and Assemblies

1. **Purpose.** Verify that environmental seal features of explosive system components or assemblies are effective and are within accepted limits. Sealed feature leak rate should be less than $5x10^{-6}$ standard cubic centimeters per second of helium at a differential pressure of one atmosphere, or equivalent.

2. **Applicable Documents.** Product specifications of the components or assemblies to be inspected and tested with detail descriptions of seal features, if practical. Detailed descriptions of test and measurement equipment used in these tests.

3. **Procedure.** Individual or groups of components or assemblies should be subjected to the following series of operations.

**3.1 Visual Inspection.** Every component or assembly should be visually inspected to assess the quality of the seal feature. The intent of this inspection is to determine if there are apparent interrupts, cracks, voids or other imperfections in the sealed feature that could allow leakage at rates far greater than the value being measured, that is, a gross leak rate. Items suspected to have gross leak rate imperfections should be rejected. Imperfections should be identified and a record made of their location. Magnification may be required to perform this inspection.

**3.2 Leak Test.** Components or assemblies should be collectively or individually placed into a chamber capable of being evacuated of ambient air. The pressure in the chamber should be reduced to a vacuum of 25 millimeters of mercury or less for a minimum of five (5) minutes. The chamber should then be pressurized to at least three (3) atmospheres of helium for two(2) hours minimum. The chamber pressure should then be reduced to one atmosphere and maintained there until each component or assembly has been transferred to other chamber or chambers that are connected to a mass spectrometer leak detector apparatus. The mass spectrometer apparatus should then be used to detect the release of higher pressure helium from the interior of the component or assembly. The number of components or assemblies within the chamber should be limited to allow no more than ten (10) minutes of elapsed time from chamber opening to time of last component or assembly leak rate check. Gases other than helium may be used for this test with leak rate values appropriately converted for equivalence to helium rates.

**4. Accept/Reject Criteria.** Accept all items having leak rates less than $5x10^{-6}$ cubic centimeters per second. Reject all items with greater leak rates. These rejects and those rejected during visual inspections can be reworked and re-tested, if practical. Documentation of rework should be included with appropriate data packages that accompany components or assemblies. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

## Method 104 – Radiographic Inspection Methods (X-Ray) for Explosive System Components and Assemblies

**1. Purpose.** Verify that metallic based elements of explosive system components and assemblies are properly aligned, assembled or positioned and that no apparent defects are present, as compared with product specification descriptions.

**2. Applicable Documents.** Drawings, figures and sketches from product specifications or other sources that provide detailed descriptions of the items to be inspected and specific areas of interest within them. Industry standard ASTM E94-93, Radiographic Testing.

**3. Procedure.** Individual or groups of components or assemblies should be subjected to the following operations.

**3.1 Positioning.** Components or assemblies should be positioned to minimize parallax effects. Multiple orthogonal views should be considered based on degree of inspection desired or on the complexity of items.

**3.2 Image Quality.** Intensity, brightness and contrast should be adjusted to best define features to be inspected. Multiple radiographs having varying degrees of clarity may be required.

**3.3 Identification.** Each radiograph should include all appropriate part, production lot and serial numbers describing the items inspected as a permanent part of the film.

**4. Accept/Reject Criteria.** Accept all items that comply with detailed descriptions. Reject all items that do not. Rejects that can be reworked should be recycled through the appropriate non-destructive test series, if practical. Documentation of rework should be included with appropriate data packages that accompany components or assemblies. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

## Method 105 – Radiographic Inspection Methods (N-Ray) for Explosive System Components and Assemblies

**1. Purpose.** Verify that non-metallic based elements of explosive system components and assemblies are properly aligned, assembled or positioned and that no apparent defects are present, as compared with product specification descriptions.

**2. Applicable Documents.** Drawings, figures and sketches from product specifications or other sources that provide detailed descriptions of the items to be inspected and specific areas of interest within them. Industry standard ASTM E748-95, Standard Practices for Thermal Neutron Radiography of Materials.

**3. Procedure.** Individual or groups of components or assemblies should be subjected to the following operations.

**3.1 Positioning.** Components or assemblies should be positioned to minimize parallax effects. Multiple orthogonal views should be considered based on degree of inspection desired or on the complexity of items.

**3.2 Image Quality.** Intensity, brightness and contrast should be adjusted to best define features to be inspected. Multiple radiographs having varying degrees of clarity may be required.

**3.3 Identification.** Each radiograph should include all appropriate part, production lot and serial numbers describing the items inspected as a permanent part of the film.

**4. Accept/Reject Criteria.** Accept all items that comply with detailed descriptions. Reject all items that do not. Rejects that can be reworked should be recycled through the appropriate non-destructive test series, if practical. Documentation of rework should be included with appropriate data packages that accompany components or assemblies. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

## TEST DESCRIPTION SERIES 200 – ELECTRICAL AND OPTICAL NON-DESTRUCTIVE INSPECTIONS AND TESTS

### Method 201 – Electro-Explosive Device Bridgewire Resistance Measurements

**1. Purpose.** Verify that resistance measurements of bridgewire elements of each electro-explosive device (EED) are within product specification limits.

**2. Applicable Documents.** Product specifications describing limits of bridgewire resistance values. Detailed descriptions of test equipment used.

**3. Procedure.** Resistance of each EED bridgewire should be measured using a remote electrical test circuit. The test circuit design should be verified before use to have an electrical current limit of 10 milli amperes measured at the bridgewire. The open circuit voltage of the test circuit should not exceed one volt. Test circuit should be verified to have measurement accuracy within 2% of the true value. Duration of application of current to the bridgewire during this measurement should not exceed sixty (60) seconds. There should be a five (5) minute delay between repetitive measurements of any one bridgewire.

**4. Accept/Reject Criteria.** Accept all EED measurements that are within product specification limits. Reject all that do not. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

### Method 202 – Electro-Explosive Device Electrical Circuit Resonant Frequency Measurements

**1. Purpose.** Verify that measured resonant frequencies of each electro-explosive device (EED) design having gaps in conductive paths are within product specification limits. Resonant frequency measurement is used to verify the health of the EED conductor and bridgewire circuit via a gap in the circuit.

**2. Applicable Documents.** Product specifications describing limits of resonant frequency values. Detailed descriptions of test equipment used.

**3. Procedure.** Resonant frequency of each EED should be measured using a remote test circuit. The test circuit design should be verified before use to have an electrical current limit of 500 microamperes to the EED conductors. Test circuit should be verified to have measurement accuracy within 2 MHz of the true value. Resonant frequency measurements should be repeated at least five (5) times for each EED and the mean of these values used for comparison with product specification limits.

**4. Accept/Reject Criteria.** Accept all EED measurements that are within product specification limits. Reject all that do not. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

## Method 203 – Laser Initiated Device Optical Time Domain Reflectometer (OTDR) Measurements

**1. Purpose.** Verify that the time of reflected light wave transmission for each laser initiated device (LID) design is within product specification limits. Reflected light wave measurement is used to verify the health and continuity of fiber optic conductors within a LID.

**2. Applicable Documents.** Product specifications describing limits of reflected light wave values. Detailed descriptions of test equipment used.

**3. Procedure.** Reflected light wave speed of each EED should be measured using a remote test circuit. A test circuit known as an optical time domain reflectometer (OTDR) should be used. The OTDR design should be verified to limit energy density input to LID explosive material interfaces to less than 10% of the minimum no-fire energy density rating of LID. OTDR measurements should be repeated at least five (5) times for each LID and the mean of these values used for comparison with product specification limits.

**4. Accept/Reject Criteria.** Accept all LID measurements that are within product specification limits. Reject all that do not. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

## Method 204 – Electro-Explosive Device Insulation Resistance Measurements

**1. Purpose.** Verify resistance between insulation and electrically conductive paths of low and high voltage electro-explosive device (EED) designs to be within product specification limits.

**2. Applicable Documents.** Product specifications describing insulation features and limits of insulation resistance values. Detailed descriptions of test equipment used.

**3. Procedure.** Resistance of each EED insulation feature should be measured using a remote electrical test circuit such as a meg-ohm bridge meter or a unique insulation resistance test set. Measurement error of these should be less than 10%. The test method and equipment should be designed to prevent erroneous measures of current leakage, to the extent practical. The measurements should be made between mutually insulated points of the EED, and between these points and ground, immediately after a 1-minute application of voltage between the points. The applied voltage should be no less than 500 volts direct current for high voltage EED designs and no less than 250 volts direct current for low voltage EED designs. The measured insulation resistance should be greater than 2 meg-ohms. Other voltage and insulation values may be used as dictated by EED design specifications.

**4. Accept/Reject Criteria.** Accept all EED measurements that are within product specification limits. Reject all that do not. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

### Method 205 – EED Spark Gap Breakdown Voltage Test Measurements

**1. Purpose.** Verify that the magnitude of the voltage needed to arc across a spark gap in the conductive circuit of each electro-explosive device (EED) is within product specification limits. Spark gap breakdown voltage measurement is used to verify health of the EED circuit.

**2. Applicable Documents.** Product specifications describing limits of spark gap breakdown voltage values. Detailed descriptions of test equipment used.

**3. Procedure.** Spark gap breakdown voltage of each EED should be measured using a remote test circuit. The test circuit design should be configured to input voltage to the EED conductors that is slowly ramped upward until arcing occurs. The test set-up should be capable of capturing the voltage level at which arcing occurs within a measurement accuracy within 10% of true value. Measurements should be repeated at least five (5) times and the mean of these values used for comparison with product specification limits.

**4. Accept/Reject Criteria.** Accept all EED measurements that are within product specification limits. Reject all that do not. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

### Method 206 – Safe Arm Device Cyclic Electro-Mechanical Function Measurements

**1. Purpose.** Verify that safe arm device (SAD) cyclic and safing pin functions, and electrical resistance repeatability are within product specification limits. These tests and inspections can be used throughout SAD service life as means to check electro-mechanical function. These have been referred to as bench tests.

**2. Applicable Documents.** Product specifications or other documents with detailed descriptions of SAD mechanical, electrical and electro-mechanical design, functional parameters and performance limits.

**3. Procedure.** The following operations and inspections should be performed on each SAD using a remote test sets that can supply nominal input voltage, measure safe to arm to safe cycle times, measure insulation and bridgewire resistance of all SAD circuits and electronically verify safe and arm positions. Bridgewire and insulation resistance measurements should comply with Methods 201 and 204, respectively. The total number of cyclic functions performed during these operations should be recorded and added to the cumulative total listed in supporting data packages that should accompany each SAD.

a.) Remove safing pin from SAD. Record resistive force required for removal. Compare force resistance with product specification limits.

b.) Remotely position SAD to arm mode using nominal input electrical voltages. Measure and record cycle time from safe to arm positions. Compare measured time with product specification limits. Visually and electronically verify that arm indictors are correctly positioned.

c.) Measure and record insulation and bridgewire resistance of all circuits. Compare with the product specification limits.

d.) Remotely position SAD to safe mode using nominal input electrical voltages. Measure and record cycle time from arm to safe positions. Compare measured time with product specification limits. Visually and electronically verify that safe indictors are correctly positioned.

e.) Measure and record insulation resistance of all circuits. Compare with product specification limits.

f.) Cycle SAD from safe to arm to safe modes twenty-five (25) times using nominal input voltages. Measure and record cycle time from safe to arm and from arm to safe and compare with product specification limits. Visually and electronically verify that safe or arm indictors are correctly positioned.

g.) Measure and record insulation resistance of all circuits. Compare with product specification limits.

h.) Remotely position SAD to arm mode using nominal input electrical voltages. Measure and record cycle time from safe to arm positions. Compare measured time with product specification limits. Visually and electronically verify that arm indictors are correctly positioned.

i.) Measure and record insulation and bridgewire resistance of all circuits. Compare with product specification limits.

j.) Manually position the SAD to the safe mode using the safing pin. Visually and electronically verify that arm indictors are correctly positioned.

**4. Accept/Reject Criteria.** Accept all measurements that are within product specification limits. Reject all that do not. Rejection rates that exceed 10% of the total number of items in a production lot should generate further investigations into cause, effect and corrective action. This rejection rate should be considered a potential cause for rejection of the entire lot.

## TEST DESCRIPTION SERIES 300 – NON-DESTRUCTIVE ACCEPTANCE ENVIRONMENTAL TEST EXPOSURES AND INSPECTIONS FOR SAFE ARM DEVICES

### Method 301 - SAD Acceptance Level Thermal Cycle Tests

**1. Purpose.** Provide test method to expose each SAD to acceptance level thermal cycle environments.

**2. Applicable Documents.** Product specifications of SAD designs to be tested. MIL-HDBK-340, Vol. 1 & 2, Test Requirements for Launch, Upper Stage and Space Vehicles, and MIL-HDBK-343, Design, Construction & Testing Requirements for One-Of-A-Kind Space Equipment.

**3. Procedure.** Subject each SAD to eight (8) complete cycles of temperature exposures as part of Method 3B Non-Destructive Acceptance Test sequence. When installed in a suitable test chamber each SAD should be exposed to a temperature cycle as follows. Starting from an ambient temperature condition, elevate the chamber temperature at a rate at least one degree C per minute to the maximum predicted operating temperature, as determined by the end item application, or 61 degrees C, which ever is greater. Then dwell at this temperature for a minimum of one hour. Following this dwell period reduce the temperature at a rate of at least one degree C until the minimum predicted operating temperature, as determined by the end item application, or –24 degrees C, which ever is less, is reached. Then dwell at this temperature for one hour. Following this dwell elevate the chamber temperature at a rate of at least one degree C per minute until the original ambient temperature condition is reached. Repeat the above cycle seven (7) more times.

**4. Accept/Reject Criteria.** Verification of performance following this test will be conducted during Method 206 Cyclic Electro-Mechanical Function Tests performed during Method 3B Non-Destructive Acceptance sequence. Accept or reject assessments will be made at that time.

### Method 302 – SAD Acceptance Level Random Vibration Tests

**1. Purpose.** Provide test method to expose each SAD to acceptance level random vibration environments.

**2. Applicable Documents.** Product specifications of SAD designs to be tested. MIL-HDBK-340, Vol. 1 & 2, Test Requirements for Launch, Upper Stage and Space Vehicles, and MIL-HDBK-343, Design, Construction & Testing Requirements for One-Of-A-Kind Space Equipment.

**3. Procedure.** Subject each SAD to a random vibration environment that is equivalent to the maximum predicted envelope of the end item application but not less than the minimum frequency versus power spectral density envelope described in the table below. The minimum overall test level should be 6.1 grms. The environment should be applied to three orthogonal axes of the SAD for one minute at each axis minimum. Fixtures used during these tests should dynamically simulate the end item application, to the extent practical.

| Frequency, Hz | Power Spectral Density, Minimum |
|---|---|
| 20 | 0.0053 g*2/Hz |
| 20-150 | 3 dB/Octave slope |
| 150-600 | 0.04 g*2/Hz |
| 600-2000 | - 6 dB/Octave slope |
| 2000 | 0.0036 g*2/Hz |

**4. Accept/Reject Criteria.** Verification of performance following this test will be conducted during Method 206 Cyclic Electro-Mechanical Function Tests performed as part of the Method 3B Non-Destructive Acceptance sequence. Accept or reject assessments will be made then.

## TEST DESCRIPTON SERIES 400 – DESTRUCTIVE ACCEPTANCE AND QUALIFICATION INSPECTIONS AND TESTS

### Method 401 – Qualification Level Thermal Cycle Tests

**1. Purpose.** Expose explosive system components and assemblies to a qualification level cyclic thermal environment as part of qualification, destructive acceptance and age surveillance performance certifications.

**2. Applicable Documents.** Product specifications of components or assemblies tested. Applicable portions of MIL-HDBK-340, Vol. 1 & 2, Test Requirements for Launch, Upper Stage and Space Vehicles, and MIL-HDBK-343, Design, Construction & Testing Requirements for One-Of-A-Kind Space Equipment. Detailed descriptions of test and measurement equipment used.

**3. Procedure.** All components or assemblies except those from production lots installed in a SAD during SAD qualification or destructive acceptance should be subjected to eight (8) complete cycles of temperature exposures as described below. Components or assemblies from production lots installed in a SAD should be subjected to twenty-four (24) complete cycles of temperature exposures. In a suitable test chamber each component or assembly should be exposed to a temperature cycle as defined in the following. Starting from an ambient temperature condition, elevate the chamber temperature at a rate of at least three (3) degrees C per minute to the maximum predicted operating temperature plus 10 degrees C, as determined by the end item application, or 71 degrees C, which ever is greater. Then dwell at this temperature for a minimum of two (2) hours. Following this dwell period reduce the temperature at a rate of at least three (3) degrees C until the minimum predicted operating temperature minus 10 degrees C, as determined by the end item application, or -57 degrees C, which ever is less, is reached. Then dwell at this temperature for two (2) hours. Following this dwell elevate the chamber temperature at a rate of at least three (3) degrees C per minute until the original ambient temperature condition is reached. Continue the cyclic process from this point until the proper quantity is completed.

**4. Accept/Reject Criteria.** Verification of performance following this test will be conducted during the qualification, destructive acceptance or age surveillance tests defined in Methods 2A, 2B, 2C, 2D, 4A, 4C, 4D or 5A. Accept or reject assessments will be made at that time.

### Method 402 – Qualification Level Dynamic Shock Tests

**1. Purpose.** Expose explosive system components and assemblies to a qualification level dynamic shock environment as part of qualification, destructive acceptance and age surveillance performance certifications.

**2. Applicable Documents.** Product specifications of components or assemblies tested. Applicable portions of MIL-HDBK-340, Vol. 1 & 2, Test Requirements for Launch, Upper Stage and Space Vehicles, and MIL-HDBK-343, Design, Construction & Testing Requirements for One-Of-A-Kind Space Equipment. Detailed descriptions of test and measurement equipment used.

**3. Procedure.** Subject each component or assembly to a dynamic shock spectrum and transient that is at least 6 dB greater than the maximum predicted environment expected in the end item application. The components or assemblies should be mounted on fixtures that dynamically simulate the end item application, to the extent practical. The environment should be applied to each of three orthogonal axes of the item tested.

**4. Accept/Reject Criteria.** Verification of performance following this test will be conducted during the qualification, destructive acceptance or age surveillance tests defined in Methods 2A, 2B, 2C, 2D, 4A, 4C, 4D or 5A. Accept or reject assessments will be made at that time.

## Method 403 –Qualification Level Random Vibration Tests

**1. Purpose.** Expose explosive system components and assemblies to a qualification level random vibration environment as part of qualification, destructive and age surveillance performance certifications.

**2. Applicable Documents.** Product specifications of components or assemblies to be tested. Applicable portions of MIL-HDBK-340, Vol. 1 & 2, Test Requirements for Launch, Upper Stage and Space Vehicles, and MIL-HDBK-343, Design, Construction & Testing Requirements for One-Of-A-Kind Space Equipment. Detailed descriptions of test and measurement equipment used.

**3. Procedure.** Subject each component or assembly to a random vibration environment that is equivalent to the maximum predicted envelope of the end item application plus 4.5 dB but not less than the minimum frequency versus power spectral density envelope described in the table below. The minimum overall test level should be 12.2 grms. The environment should be applied to three orthogonal axes of the SAD for three (3) minutes at each axes minimum. Fixtures used during these tests should dynamically simulate the end item application, to the extent practical.

| Frequency, Hz | Power Spectral Density, Minimum |
|---|---|
| 20 | 0.021 g*2/Hz |
| 20-150 | 3 dB/Octave slope |
| 150-600 | 0.16 g*2/Hz |
| 600-2000 | - 6 dB/Octave slope |
| 2000 | 0.014 g*2/Hz |

**4. Accept/Reject Criteria.** Verification of performance following this test will be conducted during the qualification, destructive acceptance or age surveillance tests defined in Methods 2A, 2B, 2C, 2D, 4A, 4C, 4D or 5A. Accept or reject assessments will be made at that time.

## Method 404 – Qualification 2-Meter Drop Test

**1. Purpose.** Expose explosive system first elements to a qualification level 2-meter drop test as part of qualification performance certification.

**2. Applicable Documents.** Product specifications of first elements tested. Detailed descriptions of test and measurement equipment used.

**3. Procedure.** Drop each of six (6) first elements onto a steel plate from a height of 2-meters, twice. One drop should result in impact on the output end of the first element the other on the input end, or as near to those ends as practical.

**4. Accept/Reject Criteria.** Verification of performance following this test will be conducted during the qualification tests defined in Method 2A. Accept or reject assessments should be made at that time.

**Method 405 – Qualification 6-Meter Drop Test**

**1. Purpose.** Expose safe arm device (SAD) designs to a qualification level 6-meter drop test as part of qualification performance certification.

**2. Applicable Documents.** Product specifications of SAD designs tested.

**3. Procedure.** Drop one SAD with safing pin installed onto a steel plate from a height of 6-meters. Post test verify that the SAD explosive components have not functioned. Also verify that the SAD remains in the safe mode.

**4. Accept/Reject Criteria.** Accept other SAD units from this production lot if post test verifications are positive. Reject other SAD units if post test verifications are negative.

**Method 406 – High Temperature Limit Test**

**1. Purpose.** Expose first element designs to a high temperature limit test as part of qualification performance certification.

**2. Applicable Documents.** Product specifications of first element designs tested. Detailed descriptions of test and measurement equipment used.

**3. Procedure.** Place five (5) first elements into a thermal chamber preheated to a temperature of 34 degree C above the maximum predicted temperature of the end item application but not less than 71.1 degrees C for one hour. The first elements should not auto-ignite or decompose as a result of this exposure. Decomposition, or the lack thereof, should be verified by dissection of the first elements and examination of the constituents within them.

**4. Accept/Reject Criteria.** Accept all first elements of this design if post temperature exposure examinations are positive. Reject all first elements of this design if post temperature exposure examinations are negative.

**Method 407 – Elevated Temperature Storage Simulation Test**

**1. Purpose.** Expose explosive system components and assemblies to an elevated temperature storage simulation test as part of accelerated age surveillance test program.

**2. Applicable Documents.** Product specifications of components and assemblies tested. Detailed descriptions of test and measurement equipment used.

**3. Procedure.** Place ten (10) components or assemblies selected from a production lot to be exposed to accelerated age surveillance tests into a thermal chamber preheated to of 71.1 degrees C. Maintain at this temperature for 672 hours then remove and cool to ambient temperature. Continue test sequence described in Method 5A, Age Surveillance Tests for Components Containing <30 Grams of Explosive Materials.

**4. Accept/Reject Criteria.** Accept or reject determinations will be made during subsequent performance measurement tests of Method 5A.

## Method 408 – Safe Arm Device Cycle Life Test

**1. <u>Purpose</u>.** Verify that each safe arm device (SAD) design can survive 1000 safe to arm to safe cycles without malfunction, failure or degraded performance.

**2. <u>Applicable Documents</u>.** Product specifications of SAD designs tested. Detailed descriptions of test and measurement equipment used.

**3. <u>Procedure</u>.** Conduit cycle life test in the same manner as described in Method 206, SAD Cyclic Electro-Mechanical Function Measurements, expect change the number of safe to arm to safe cycles in procedure 3.6 to 998.

**4. <u>Accept/Reject Criteria</u>.** Accept all SAD designs that can be cycled 1000 times from safe to arm to safe without malfunction, failure or degraded performance. Reject those designs that can not survive this test.

## Method 409 – Safe Arm Device Post Cycle Life Disassembly Inspection

**1. <u>Purpose</u>.** Disassemble and inspect internal elements of each safe and arm device (SAD) design subjected to a Method 408 SAD Cycle Life Test. Assess the integrity of all sliding or rotating components, surfaces and interfaces.

**2. <u>Applicable Documents</u>.** Product specifications and sufficient detailed design descriptions of each SAD design to facilitate inspection.

**3. <u>Procedure</u>.** Disassemble SAD and record the condition of all sliding or rotating components, surfaces and interfaces.

**4. <u>Accept/Reject Criteria</u>.** Accept all SAD designs that have survived Method 408 Cycle Life Tests without malfunction, failure or degraded performance. Reject those can not survive this test.

## Method 410 – Safe Arm Device Electro-Mechanical Stall Test

**1. <u>Purpose</u>.** Verify that each safe arm device (SAD) design can survive the application of maximum arming voltage for five (5) minutes minimum with safing pin installed without malfunction, failure or degraded performance.

**2. <u>Applicable Documents</u>.** Product specifications of SAD designs tested. Detailed descriptions of test and measurement equipment used.

**3. <u>Procedure</u>.** With safing pin installed apply maximum arming voltage to the SAD arm circuit for a minimum of five (5) minutes. Maximum arming voltage values should be determined from end item application input limits. Post test performance should be determined by conducting a cycle test of the SAD. Use Method 206, SAD Cyclic Electro-Mechanical Function Measurements, procedures 3.1, 3.2, 3.3 and 3.10.

**4.** **Accept/Reject Criteria.** Accept all SAD designs that can be cycled from safe to arm to safe without malfunction, failure or degraded performance. Reject all SAD designs that can not survive this test.

# APPENDIX A

## First Element Output Measurement and ET Interface Compatibility Validation Methods

**1. Scope.** This Appendix provides methods to measure first element outputs and assess their compatibility with ET interfaces. Methods described apply to deflagration or detonation first element outputs. Parameters measured are explosive energies in the form of pressure versus time, force displacement, impulse, or particulate velocity. First element to ET interface compatibility methods include consideration of environmental conditions, physical barriers or other features between the first element and the ET used in the end item application.

**2. Applicable Documents.** Product specifications of each first element or ET interface component to be evaluated. Drawings or sketches defining first element and ET interfaces, physical positioning, barriers or other features. Detailed descriptions of data acquisition measurement methods and instrumentation components used in the tests.

**3. First Element Output Measurement.** First element output measurements are made during test firings of samples of each production lot built. These test firings are conducted using controlled measurement devices that may or may not be directly related to end item application configurations. The measurements are compared to criteria established for each first element design during development and qualification. The criteria are generated from the aggregate of output data gathered during development and qualification. The aggregate data forms an envelop of probable output limits of the first element and are used for evaluating output performance during Method 4A destructive acceptance tests and Method 5A age surveillance tests for all production lots. The criteria are explosive energies expressed in terms of pressure versus time, force displacement, impulse, or particulate velocity as discussed in the following.

**3.1 Pressure vs. Time Measurements.** First element deflagration output is generally expressed as pressure versus time histories. These time histories are taken from test firings of first elements into controlled volumes that are instrumented with transducers intended to measure pressure. The transducers attempt to capture waveforms that rise and decay during the violent release of chemical energy in the ensuing exothermic decomposition process. The data processed from this event should be used as tools to assess and certify the utility of the first element design with respect to energy needs of ET interfaces. This data should also be used to certify the repeatability during destructive acceptance and age surveillance tests of all production lots of the first element design.

**3.1.1 Instrumentation and Fixtures.** Transducer response characteristics, and those of the data acquisition and processing elements, are historically assumed to be capable of gathering all data. Due to the violent nature of the event the presentation of the data is typically filtered to a degree that a relatively smooth waveform is displayed. Care should be exercised in the amount of filtration used to ensure that events of import are not lost. Fixtures that first elements are fired into are generally fixed volumes machined from high strength steels. The term “closed bomb” has been used to describe them. Transducers are installed in the closed bombs with their sensing surfaces exposed to the interior of the volume. The principle axes of the transducers should be perpendicular to the principle axis of the first element output waveforms. Where practical, sensing elements should be positioned flush or slightly sub-flush with respect to the interior bore of the closed bomb to minimize transducer response damping. Placing the transducer sensor face farther away may also result in data with slower pressure rise rates than would otherwise be indicated. Two transducers are commonly used in each closed bomb as an attempt to provide redundancy in data gathering. Some key parameters that should be controlled during these tests are listed below:

a.) Instrumentation, transducers, data acquisition and processing equipment designs should be documented and controlled. The same design should be used for all tests of a given first element design so that data gathered in one test series can be compared with any other test or test series of the same design, i.e., the same types of equipment should be used in all tests.

b.) The amount of filtration used in data processing should be limited to a degree that all events of importance are not lost. Where practical an effort should be made to evaluate different filter configurations, then optimize the data acquisition and processing design to best display the data of interest.

c.) Controlled volume fixtures, i.e., closed bombs used in one test series of a first element design should be identical to those used in any other test series of the design. The design of these fixtures should be documented and controlled.

d.) Controlled volume fixtures should simulate the initial free volume of the ET interface, where practical. Use of other configurations is acceptable as long as common industry standard volumes are used, i.e., 2.5, 5.0 or 10.0 cubic centimeters.

**3.1.2 <u>Data Interpretation and Application</u>.** Key elements of the data retrieved are time from application of first element ignition stimulus to first indication of an explosive event, pressure rise rates, peak pressures, and sustained or decaying pressures for a specific time period. For EED first elements time from application of fire energy to time of bridgewire burnout is also data that should be retrieved. There is no direct correlation of these data with the interfacing ET component, although they could be used for first order approximations in initial component design phases. The aggregate of data from various firings of a first element design, such as development and qualification tests, should be grouped and analyzed to establish limits of variance of all of the specific data elements of interest. This variance analysis should define upper and lower limits of first indication times, bridgewire burnout times, rise rates, peak pressures and the sustained or decaying pressures for a specific time period. This variance limit analysis should be used as a tool to measure performance of all production lots of a given first element design during their destructive acceptance and age surveillance certifications. The optimum measurement tool for this certification process is a pressure time history for a specific period of time, otherwise known as a pressure time integral. The duration of the integral should be selected to best fit the needs of the specific end item application.

**3.2 <u>Force/Displacement Output Measurements</u>.** Deflagration first elements can be test fired into mechanisms designed to measure downstream output energy in terms of force and displacement. In these tests the first element output is applied as a forcing function onto a translating piston. Transducers than measure force and displacement time histories as the piston is first accelerated then decelerated longitudinally within the mechanism. The mechanism design should be capable of being repeatedly refurbished without compromising consistency of measurement and integrity of the data attained.

**3.2.1 <u>Data Interpretation and Application</u>.** Interpretation of the data retrieved should include considerations of repeatability of the measurement mechanism. The effects of static and dynamic conditions on performance of the mechanism should be addressed. It may be possible to use the data from these tests to aid the design process of interfacing ET components. This assumes that the design of the mechanism simulates the design parameters of import to the component. For certification purposes the aggregate of data from various firings in the mechanism, such as development and qualification tests, should be grouped and analyzed to establish limits of variance of the measurements. This variance analysis should define upper and lower limits of force and displacement time histories. This variance limit analysis should be used as a tool to measure performance of all production lots of a given first element design during their destructive acceptance and age surveillance certifications.

**3.3 Impulse or Particulate Velocity Measurements.** Performance of first elements having detonation outputs should be made using either measure of dent depth, perforation or measures of velocity of particulate components expelled from them. The following describe these types of measurements.

**3.3.1 Dent Depth Measurements.** A measurable dent depth results when detonation output first elements are fired onto metallic witness plates. The first element output end is placed in contact with a metallic witness plate and then fired. The resulting dent is measured. To ensure consistency in data obtained the witness plate physical shape and thickness should be controlled and documented. Material properties should be verified and documented for all tests. The dent depth measurement technique should be documented.

**3.3.1.1 Data Interpretation and Application.** A relation of dent depth to performance compatibility with interfacing ET components is not defined by this measurement. These data should therefore only be used to certify performance of other production lots of a specific design. The aggregate of data from various firings onto metallic witness plates, such as development and qualification tests, should be grouped and analyzed to establish limits of variance of the measurements. This variance analysis should define upper and lower limits of dent depths. This variance limit analysis should be used as a tool to measure performance of all production lots of a given first element design during their destructive acceptance and age surveillance certifications.

**3.3.2 Particulate Velocity Measurements.** Measures of Doppler phase shafts of light wave reflections off of particulate components expelled from the end of the first element when it is fired can be used as performance measurement criteria. A device known as a velocity interferometer system for any reflector (VISAR), a tool used to measure rapid movements of translating piston devices or projectiles, can also be used in these measurements. This is best used for detonation output first elements having defined fragmentation components.

**3.3.2.1 Data Interpretation and Application.** Relation of particulate velocity measurements to needs of interfacing ET components should established for each application, where practical. The data can then be used for both certifications of other production lots of a specific first element design but also as a performance parameter to aid interface component design. The aggregate of velocity data from various firings, such as development and qualification tests, should be grouped and analyzed to establish limits of variance of the measurements. This variance analysis should define upper and lower limits of dent depths. This variance limit analysis should be used as a tool to measure performance of all production lots of a given first element design during their destructive acceptance and age surveillance certifications.

**4. First Element/ET Compatibility.** Compatibility between first element outputs and ET interfaces should be certified by tests. These tests are also intended to demonstrate performance margins between the two. Empirically, the optimum test would have first element outputs configured at envelop extremes that are then applied to interfacing ET components also configured to be at performance envelop extremes. A series of tests could then be used to show the affect of first element minimum or maximum output energies on maximum or minimum input needs of the ET. This assumes that the energy outputs and inputs can be adjusted to suit each test. This is not always practical. In those interfaces where outputs can not be adjusted a defined margin between the two extremes should be included. This margin can be used to compensate for uncertainties in demonstrating compatibility. The following are discussions of the types of compatibility certifications that can be performed.

**4.1 First Elements vs. ET Components**. The intent is to demonstrate that the interfaces between the first element and the ET component immediately downstream of it are compatible and have a defined performance margin. To do this test firings of these interfaces should be performed using first elements having outputs configured to be above and below envelop limits by at least 20%. The output of these altered first elements should be verified by paragraph 3.1, 3.2, 3.3.1 or 3.3.2 tests of samples of the altered designs. The first element to ET component test set-up should be identical to the end item application to the extent practical. It should align the altered first element to a nominally configured ET component in the same physical position and include any other features such as barriers between them. Ten (10) tests using first elements with outputs at least 20% below the minimum variance determined in paragraph 3.1, 3.2, 3.3.1 or 3.3.2 should conducted. Ten (10) tests using first elements with outputs at lest 20% greater than the maximum variance determined in paragraph 3.1, 3.2, 3.3.1 or 3.3.2 should also be conducted. All tests should success; i.e. the downstream component should be capable of performing its intended function.

# APPENDIX B

## All-Fire/No-Fire Test and Analysis Methods

**1.** **Scope.** This Appendix offers test and analysis methods for estimating first element functional all-fire and non-functional no-fire input energy ratings. These are applicable to electrical, optical and mechanical first elements. Reliability and safety issues necessitate use of methodologies that can assure consistency in derivation of these estimates. Accepted test and analysis methods for estimating these parameters include the Bruceton method, and other advanced methods such as Langlie and Neyer D-Optimal, all of which are described here. The Bruceton method was developed in the 1950's and has proven its value. Advanced methods described here have been evaluated through experience in use and may provide improved knowledge of estimates of key parameters while reducing costs to obtain them.

**2.** **Applicable Documents.** Product specifications of first elements tested. Detailed descriptions of data acquisition measurement methods and instrumentation components used in tests and, the following technical reports and publications.

**Technical Reports**

NAVORD Report 2101 - Statistical Methods Appropriate for Evaluation of Fuze Explosive Train Safety and Reliability, U.S. Naval Ordnance Laboratory, White Oak, MD, (1953).

Report MLM-3736 - An Analysis of Sensitivity Tests, EG&G Mound Applied Technologies, (1992).

Report U-1792 - A Reliability Test Method for One-Shot Items, Langlie, H. J. (1965), Technical, Aeronautical Division of Ford Motor Company.

**Publications**

Journal of the American Statistical Association - A Method for Obtaining and Analyzing Sensitivity Data, Dixon, J. D., and Mood, A. M. (1948), Vol. 43, 109-126

Technometrics - A D-Optimality Based Sensitivity Test, February 1994, Volume 36, Number 1, pages 61-70, Neyer, B. T. (1994)

**3.** **Test and Analysis Methods.** The following describes test and analysis techniques most commonly used for estimating and evaluating first element all-fire and no-fire input energy ratings. Although test and analysis are independent functions, each unique test method is historically associated with a unique analysis technique. These methods and techniques are commonly referred to as sensitivity tests and analysis.

**3.1** **Objectives.** Objectives of sensitivity test and analysis methodologies used should be assurance that estimates derived are as accurate and precise as possible. The parameter to be estimated is the mean stimulus level at which some fraction of the samples of a specific first element design will always ignite, in the case of an all-fire test, or not ignite, in the case of a no-fire test. There are no methodologies capable of exact determinations of this parameter without testing each first element produced. There are no non-destructive methods available to obtain the data needed. The tests described here are usually considered to destructive in nature and therefore, the test articles should not be re-used in the end item. The analysis portion of the method uses estimates of mean stimulus and standard deviations of distributions of data around the mean to compute an estimated all-fire or no-fire rating. These estimated ratings are computed at a specific reliability and confidence and are applicable to only the specific first element design tested.

**3.2 Limitations.** All methods used are small sample based. Therefore err in the estimates may occur. Care must be exercised when choosing test stimulus levels during the tests. If empirical data on the specific design is not available to assist selection of test levels before start of the test then additional samples should be allocated to perform pre-test evaluations. All of the methods used here assume the distribution of the threshold stimulus levels is normal. It is simple to generalize this assumption and require that some function, such as a logarithm of the threshold levels are normally distributed.

**3.3 Reliability and Confidence Levels.** Reliability and confidence level values conventionally used in sensitivity tests and analysis are 0.999 and 95 %, respectively. This is literally interpreted to mean that 95% of the time 1 in 1000 first elements will fail to function at the estimated all-fire or no-fire rating. Therefore, the user should assure that the ignition stimulus delivered to the first element in the end item application not be limited to the all-fire rating, as noted in ISO 14304-1, paragraph 4.4.1. Users of these computed values should be made aware that adding margin to estimated all-fire and no-fire values is standard practice. As noted in paragraph 4.4.1 of ISO 14304-1 an ignition system should use input stimulus 1.25 times greater than the estimated all-fire threshold of the interfacing first element. For example, when using an EED having an all-fire estimate of 3.25 amperes, the ignition system should be designed to have a minimum input of 4.06 amperes. Explosive system reliability assessments should therefore use the minimum stimulus values that the ignition system delivers to the first element to assess realistic system level reliability.

**3.4 Test Conduct.** Tests should be performed in an ambient temperature environment unless conditions anticipated in the end item application dictate a need to do otherwise. Heat sinks used should simulate thermal properties of the end item application, to the extent practical. Once started the test should continue uninterrupted until completed. Analysis can be performed at any time during or after completion of the test portion of the task. For EED and LID first elements all-fire tests should use an ignition stimulus pulse duration equivalent to that used in the end item application but should be no greater that 30 milliseconds. No-fire tests are not required for mechanical first elements.

**3.4.1 Bruceton Test.** At least forty-five (45) first elements should be allocated for each test. The first sample is pulsed at a defined stimulus level and duration. If that sample fires the next test sample is pulsed at a stimulus level and duration that is reduced by a defined increment, or step, lower than the first. If the first sample had not fired the next sample would have been pulsed with a stimulus increased by the same defined increment. The test continues in this process until at least forty (40) samples are expended. Each sample is pulsed only once during these tests.

The total number of incremental steps of fire and no fire data points should be greater than three (3) but not more than six (6). Tests where the numbers of increment steps are outside this range these should be considered invalid. To prevent this, care should be exercised in selecting the magnitude of the initial stimulus used and in the amount of the defined increment, or step between succeeding pulses before starting the test. Experience with similar first element designs and/or pre-test firings can be used to estimate these values. Five (5) samples of the allocated group can be used in initial searches for reasonable starting points and increments. If determined to be valid data these five may be combined with the total sample tested.

**3.4.2 Langlie Test.** The main goal in developing the Langlie method was to overcome the dependence of the efficiency of the Bruceton test on the choice of the step size. Analysis and experience had shown that the defined increment, or step size of the Bruceton test had to be correct to within a factor of two for reliable results.

The Langlie test has been shown to be less susceptible to variations in efficiency caused by inaccurate test design. The efficiency of the test is somewhat dependent on the choice of lower and upper stress limits. Most users specify limits that are extremely wide to avoid the situation where the limits are too close together, or do not contain the region of interest. The method is most efficient if the upper and lower limits are ± 4 standard deviations from the mean.
One problem with the test method, however, is that the method concentrates the test levels too close to the mean, resulting in inefficient determination of the standard deviation of the population.

To perform a Langlie test the experimenter must specify lower and upper stress limits. The first test is conducted at a level midway between these limits. The remaining levels can be found by obtaining the $(n+1)^{st}$ stress level, having completed $n$ trials, and work backward in the test sequence, starting at the $n^{th}$ trial, until a previous trial (call it the $p^{th}$ trial) is found such that there are as many successes as failures in the $p^{th}$ through $n^{th}$ trials. The $(n+1)^{st}$ stress level is then obtained by averaging the $n^{th}$ stress level with the $p^{th}$ stress level. If there exists no previous stress level satisfying the requirement stated above, then the $(n+1)^{st}$ stress level is obtained by averaging the $n^{th}$ stress level with the lower or upper stress limits of the test interval according to whether the $n^{th}$ result was a failure or success.

**Neyer D-Optimal Test.** This test was designed to extract the maximum amount of statistical information from the test sample. Unlike the other test methods, this method requires detailed computer calculations to determine the test levels. The Neyer D-Optimal test uses the results of all the previous tests to compute the next test level.

There are three parts to this test. The first part is designed to "close-in" on the region of interest, to within a few standard deviations of the mean, as quickly as possible. The second part of the test is designed to determine unique estimates of the parameters efficiently. The third part continuously refines the estimates once unique estimates have been established.

This test requires the user to specify three parameters, i.e., lower and upper limits, and an estimate of the standard deviation. The first two parameters are used only for the first few tests (usually two (2) tests) to obtain at least one fire and one fail to fair. The estimate of the standard deviation is used only until overlap of the data occurs. Thus, the efficiency of the test is essentially independent of the parameters used in the test design.

**3.5 Comparison of Test Methods.** There is no unambiguous method of ranking the test methods. A good test method should yield estimates of the parameters of the population that are accurate and precise. All of the test methods yield accurate parameters on average. Thus, the best way to characterize the tests is by their precision. The purpose of most sensitivity tests is to determine an all-fire or a no-fire level. These levels are usually defined as that level at which at least 0.999 of the first elements fire (all-fire) or at which no more than 0.001 of the first elements fail to fire (no-fire). With the assumption of normality, the all-fire and no-fire levels can be converted into a simple function of the mean, $\mu$, and the standard deviation, $\sigma$, of the population. The 0.999 all-fire level is $\mu+3.09\ \sigma$, and the no-fire level is $\mu-3.09\ \sigma$. Thus, precise determination of the all-fire or no-fire level requires precise determination of the mean, and especially the standard deviation.

There are several ways to compare the ability of the various test methods to precisely determine estimates of the standard deviation. One method would be to determine the variation of the estimates of the standard deviation as a function of sample size and test method. This variation depends not only on the test method, but also on the selection of the parameters of the population before beginning the test.

The efficiency of the Bruceton test is strongly dependent on the choice of step size. The efficiency of the Langlie test is somewhat dependent on the spacing between the upper and lower test levels. The Neyer D-Optimal test is essentially independent of the choice of parameters.

Figure 1 shows the variation of the estimates of the standard deviation as a function of the sample size for the three test methods under the assumption that the standard deviation is well known before start of testing. If the first elements are well characterized from previous tests, the standard deviation may be known to approximately a factor of two. The figure assumes that the parameters of the test were optimized for the population.

The figure also shows that variation of the estimate of the standard deviation has a strong dependence on the test method chosen. For example, a 20 shot Bruceton test yields a relative variance of 66%, while the Langlie test yields a variance of 28% and the Neyer D-Optimal yields a variance of 20%. The publication by Neyer (1994) noted in section 2. gives greater details of the analysis used to produce this graph.

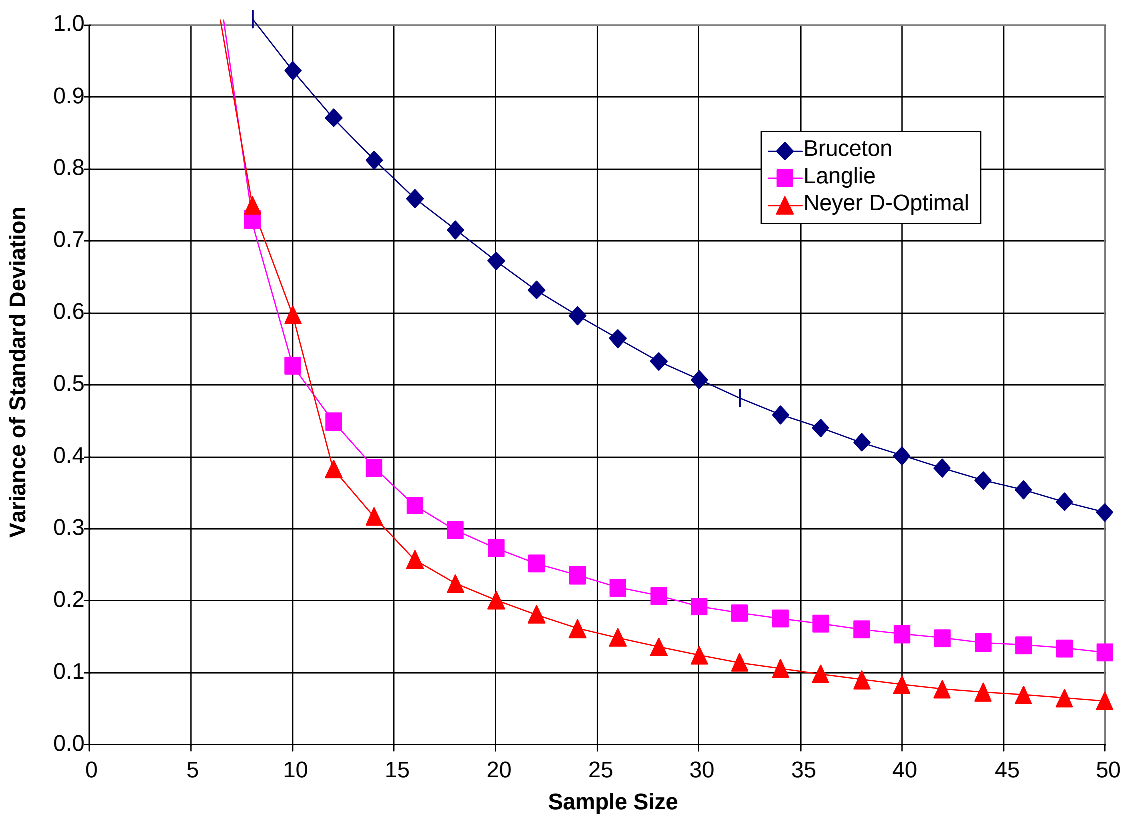



**Figure 1: Comparison of the Variation in Estimates of the Standard Deviation**

Another method of judging the utility of the various test methods is to determine the extreme values of the estimates of a parameter. The greatest concern in conducting and analyzing sensitivity tests is the tendency of the method to produce estimates of the parameters that are far removed from the true parameters.

Figure 2 shows the 5% and 95% values of the standard deviation as a function of sample size for the three test methods. Also shown in the figure are the corresponding curves for the F Test whose significance is described in the text below.

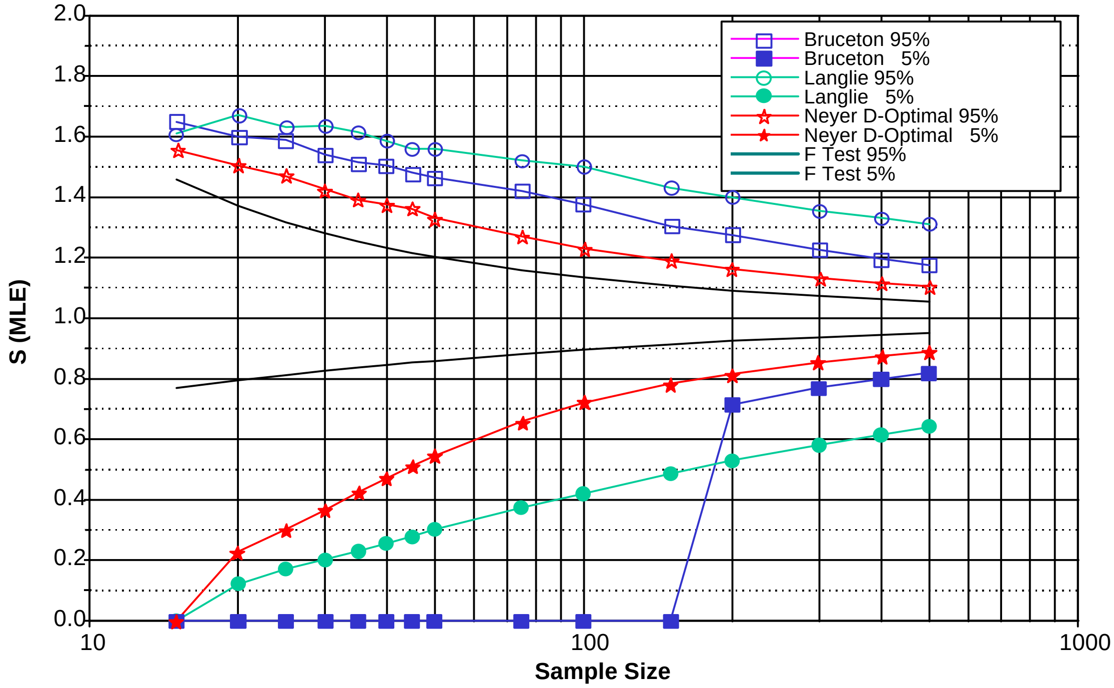



**Figure 2: 5% and 95%Estimates of the Relative Standard Deviation**

The figure illustrates several important points. First, it is extremely difficult to establish the value of the standard deviation to a degree of precision desired with a limited sample size. For example, in a Neyer D-Optimal test with a sample size of 150, 5% of the estimates of the standard deviation will be more that 20% lower than the true value, and 5% of the estimates will be more than 20% higher than the true values. For the same sample size for the Langlie test, 5% would be 50% lower, and 5% would be 45% higher. For the Bruceton test the corresponding results are 100% lower, and 30% higher.

For the typical sample size used in threshold tests, e.g., 20 - 50, it is impossible to estimate the standard deviation, and thus the all-fire and no-fire levels, with great certainty. Thus, in addition to the estimation of the parameters of the population, it is also imperative that the appropriate analysis be performed to estimate the confidence of the estimate of the parameters. Confidence estimation is discussed in the next section.

The F Test curves shown in Figure 2 indicate how much less information is available for sensitivity tests compared to standard statistical tests. The F Test is used in standard statistical testing to calculate the fraction of estimates of the standard deviation that are higher or lower than a given value. If it were possible to measure the exact threshold of individual first elements, then the estimates of the standard deviation would be governed by the F Test. Inspection of the curves shows that a sensitivity test requires a sample size many times greater than the sample size of a classical statistical test to achieve the same range of values for the standard deviation.
The final point illustrated by the figures is that the ability to determine reasonable estimates of the parameters is extremely dependent on the test method chosen to conduct the test. Both Figure 1 and Figure 2 illustrate the importance of choosing an efficient test method when conducting sensitivity tests.

**3.6 Analysis Methods.** More methods of analyzing the results of sensitivity tests have been proposed than have test methods. The method chosen to analyze the data of the test is at least as important as the test method. While many analysis methods can be used to analyze the results of any test method, other analysis methods are designed to analyze only one test design. All of the analysis methods do a good job of estimating the parameters of the population, i.e. the estimate of the mean, *M*, is close to the true mean, $\mu$, and the estimate of the standard deviation, *S*, is close to the true $\sigma$. However, the ability of the various methods to compute reliable confidence levels varies greatly.

The variance function method assumes that the variances of *M* and *S* can be estimated by simple functions of the sample size and the standard deviation. These functions are generally dependent on the initial conditions, sample size, and the test design, i.e., Bruceton, Langlie, Neyer D-Optimal. Some groups use the T test to compute confidence intervals for the mean and Chi Squared or F tests to compute confidence intervals for the mean. However, these generalized statistical methods should not be used. The assumptions that are used to construct the general statistical tests are violated in the case of sensitivity tests. Figure 2 shows the curves for both the F test as well as curves for the various sensitivity tests. The figures clearly show that the F test can not be used to analyze sensitivity tests.

The simulation method uses test results to determine the variance of the parameters after the test has been completed. This method can provide reliable estimates of the variances as long as the simulation is carried out with parameterization relevant to the population. If simulation is used to estimate the variation of the parameters, the parameters for the simulation must span a wide area around the estimates of the test data. The number of simulation runs must be sufficient (over 1000) to ensure that the results are statistically valid.

The Cramer-Rao method is used by some computer programs, such as ASENT discussed in section 3.6.3, and in the calculations of the variance in the Bruceton method.

Simulation discussed in some of the referenced papers shows that the variance of both *M* and *S* scales approximately with $\sigma^2$. Because $\sigma^2$ is not independently known, all of the previously mentioned techniques base their estimates on the maximum likelihood estimate of $\sigma$, which is *S*. If the successes and failures do not overlap, $S = 0$ and these methods fail to produce estimates for confidence regions for both *M* and *S*. The likelihood ratio method discussed in section 3.6.3 can produce reliable confidence interval estimates in all cases, including this degenerate case.

Almost all of the analysis methods used to date produce false confidence. That is, what is reported as a 95% confidence level is in actuality more like a 60% confidence level. Thus, there should be agreement between the first element user and the test facility as to which analysis method is used, and the method should be one that has been shown to produce realistic confidence levels.

Records of test data, computations and results should be retained as permanent parts the first element documentation package.

**3.6.1 Bruceton Analysis.** The Bruceton test was developed before the advent of electronic computers. It was designed so that simple paper and pencil calculations could be used to determine the mean, the standard deviation, as well as estimates of their variance. Today, more advanced analysis methods are available to analyze this data. The traditional Bruceton analysis method can still be used but only when the number of test levels are between 4 and 6, and the sample size is not less than 40. In all cases it is preferable to use advanced analysis methods, such as the ones described in the following two sections.

**3.6.2 Advanced Analysis.** Advanced methods include computer software known as ASENT which is in use at many test facilities. Although this analysis software is usually associated with the Langlie test method, it can analyze the results of tests conducted according to any test method. The analysis method computes the maximum likelihood estimates of the parameters. It computes estimates of the variance of the parameters by computing the curvature of the likelihood function. This analysis method gives the correct results asymptotically. It will not analyze the results of a test where the successes and failures do not overlap. It gives reliable results if the sample size is greater than 200.

**3.6.3 Likelihood Ratio.** The likelihood ratio method is used in software called MuSig, as described in Report MLM-3736 of section 2. This software is in use at many laboratories around the world. Although this is the analysis method usually associated with the Neyer D-Optimal method, it can analyze the results of tests conducted using any test method. The analysis method computes the maximum likelihood estimates of the parameters. It computes estimates of the variance of the parameters by using the likelihood ratio test. This analysis method gives the correct results asymptotically. It will analyze the results of any test, even if the successes and failures do not overlap. It gives reliable results if the sample size is greater than 20.

**3.7 Comparison of Analysis Methods.** The two most widely used general analysis methods can be compared in a number of ways. The most meaningful way to compare the methods is to determine what fraction of the time the true parameters are outside of the specified confidence region. A properly computed 95% confidence region, for example, should contain the true parameters approximately 95% of the time.

Figure 3 shows the fraction of parameters outside a given confidence region for both the asymptotic analysis used by ASENT and the likelihood ratio analysis used by MuSig. This figure is for a sample size of 30 for the Bruceton, Langlie, and Neyer D-Optimal tests. The solid line in the figure is what a perfect analysis method would produce. For the group of lines using boxes to denote plot points the upper line is the Langlie method, the next lower is the Neyer D-Optimal method and the next is the Bruceton. For the group using zeros the upper is Langlie, the next Neyer D-Optimal and the lower Bruceton.

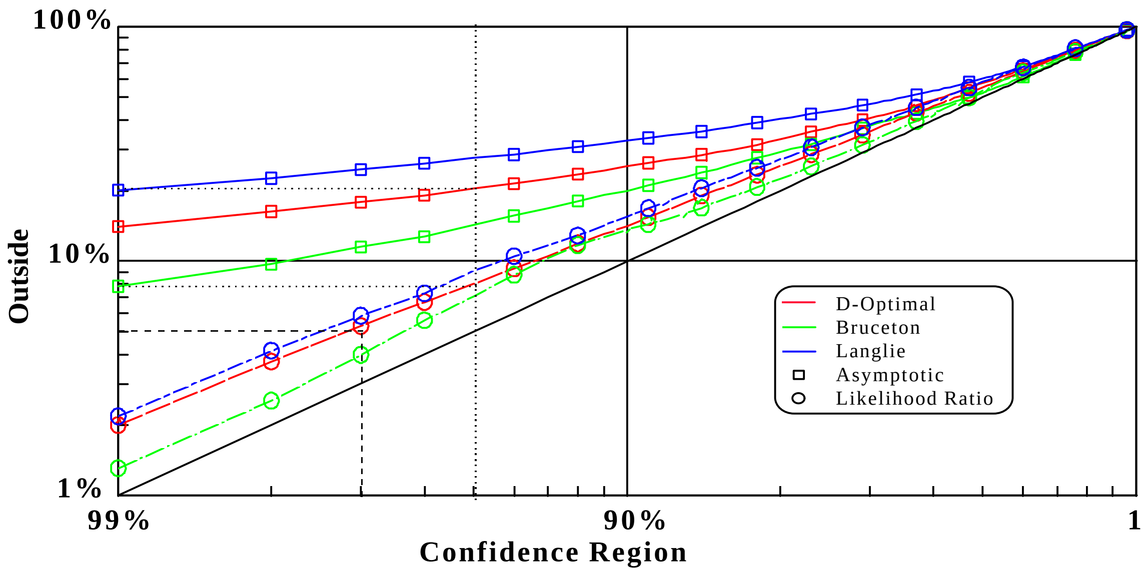


**Figure 3: Comparison of Confidence Likelihood Ratio versus ASENT**

The figure clearly shows that both of the analysis methods produce false confidence. For example, for a nominal 95% confidence region, the likelihood ratio test has the parameters outside of the confidence region approximately 8% of the time. While this is more than the 5% expected for a true 95% confidence region it is close to the requested confidence. Note that it would be prudent for the user of this information could specify a slightly more restrictive confidence (such as 97%) to achieve the required 95% confidence region.

The asymptotic 95% confidence region however, has the parameters outside of the confidence region approximately 20% of the time. To achieve a true 95% confidence region using this analysis method would require the computation of a confidence region greater than 99%.

First elements that are considered qualified when analyzed according to one analysis method could be unqualified when analyzed according to a more exact analysis method such as the likelihood ratio test. Thus, the end item user should either specify the analysis method or be consulted by the test facility as to options available. If a true 95% confidence region is required, then only analysis methods capable of producing a realistic confidence region should be used.

# APPENDIX C

## Explosive Energy Transfer and Explosive Actuated Device Performance Evaluation Methods

**1. Scope.** This Appendix in conjunction with applicable portions of MIL-HDBK-83578 paragraph 4.4 provides methods for assessing performance of explosive energy transfer components and explosive actuated devices. These methods should be used during appropriate tests and evaluations of MIL-HDBK-83578 for qualification, acceptance and age surveillance certification. Energy transfer methods assess component input and output limits at ET installation extremes for each configuration. Explosive actuated device methods assess worse case ET input energy versus needs.

**2. Applicable Documents.** Product specifications of components tested. Detailed drawings and sketches defining interfaces, physical positioning, barriers or other features related to components tested. Detailed descriptions of any data acquisition measurement methods and instrumentation components used in component tests.

**3. Performance Evaluation.** The ability of explosive train (ET) component designs and explosive actuated device designs to perform intended functions can only be evaluated in destructive tests of samples from their production lots. These tests should demonstrate performance at the extremes of input energies with definable margins, when necessary. Where appropriate the tests should also demonstrate that output performance is within limits compatible with interface needs. The methods described in the following are intended for use during MIL-HDBK-83578 performance margin evaluations of Methods 1B, 1C, 1D, 1E and 1F; qualification tests of Methods 2B, 2C and 2D; destructive acceptance tests of Methods 4B and 4C and age surveillance test of Method 5B. These are also used for performance margin demonstrations to satisfy criteria denoted in portions of paragraph 4.4 of MIL-HDBK-83578.

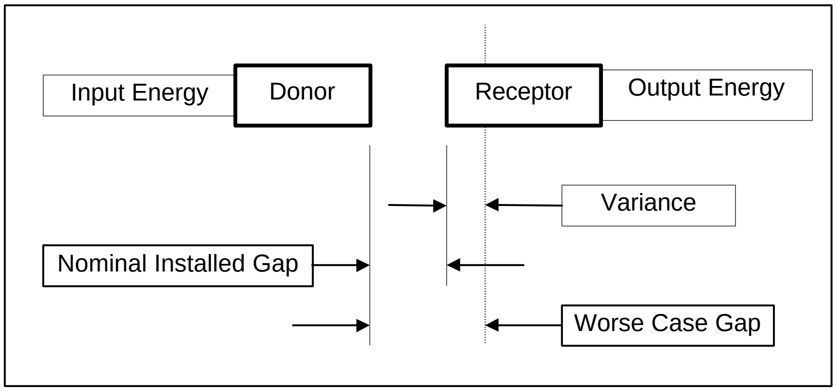
**3.1 Explosive Energy Transfer Performance.** These methods should be used to demonstrate that explosive energy transfer during safe arm device qualification and during tests of other linear explosive transfer assemblies (ETA) of an ET are within acceptable limits.

**3.1.1 Safe Arm Device Methods.** For safe arm devices having first elements, and those that include other explosive elements, the function portions of Method 2B qualification tests should include interfacing downstream explosive train components configured identical to the end item application, to the extent practical. To perform qualification function tests an ignition stimulus at the rated all-fire level or greater should be applied to the first element of the safe arm device and result in high order detonation of all elements downstream. Conformation of high order detonation should be made by either measure of detonation velocity or output impulse of the downstream components. For safe arm devices having redundant first elements, Method 2B qualification tests should apply the all-fire stimulus to a first element designated as primary first, then apply the all-fire stimulus to the first element designated as redundant no less than thirty (30) seconds later. Successful high order detonation of all elements is required for qualification certification of the safe arm device design. Failure to transfer or failure to demonstrate redundancy should cause rejection of the design. Performance margins of explosive energy transfers between the safe arm device first element, other explosive elements, and the downstream interface of the explosive train should be certified by tests as described in paragraph 3.1.2 below. These latter tests should be performed prior to qualification.

**3.1.2 Linear ETA Component Methods.** Qualification and destructive acceptance function tests of Methods 2C and 4C for ETA components should be conducted using input stimuli configured to be physically and explosively identical to the end item application interface, to the extent practical. Measures of detonation or deflagration velocity and downstream impulse should be made during these tests. Other measurements or inspections of any end item application unique parameters, such as containment of products of combustion, or others, should be included. Qualification or acceptance certification is granted when the ETA components perform as intended and all measurements and inspections of interest are found to be acceptable.

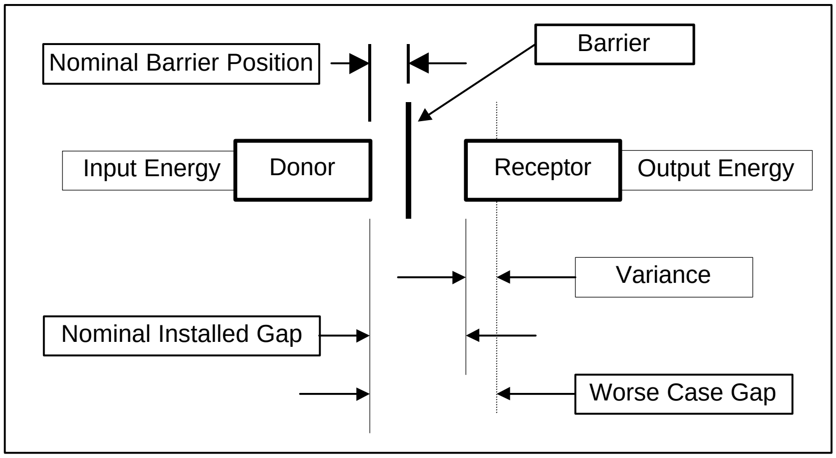
**3.1.3 Linear ETA Installation Methods.** End item applications using multiple ETA elements, related inert elements and other explosive components in a common installation should be certified by destructive test firings, where practical. The tested installation should simulate physical interfaces, routing and any other unique features. Affects of thermal and dynamic environments anticipated in the applications should be included, if appropriate. Test firings should be used to confirm that intended functions are properly completed. Measures and inspections of propagation velocities, sequencing, timing, output impulse, and any other unique parameter should be made, as appropriate. Qualification or acceptance certification is granted when the ETA installation performs as intended and all measurements and inspections of interest are found to be acceptable.

**3.1.4 End-To-End Transfer Margin Methods.** Energy transfer performance margins tests should be conducted on all elements of an ET, including safe arm devices, where transfer across a discontinuity, or gap is required. The elements used in these tests should be identical to those planned for use in the end item application. Test set-up must simulate the actual end item configuration to the extent practical. Knowledge of the nominal installed gap between donor and receptor ET elements in the application, and worse case variance is required. Axial eccentricity or angular misalignment between donor and receptor should also be considered, to the extent practical. To demonstrate performance margin successful energy transfer should occur when the distance between the donor and the receptor is at least equal to the worse case gap plus a value equal to three (3) times its variance. Transfer margin demonstrations must also be performed at the lesser of the nominal gap minus three times the variance, or zero. A minimum of five (5) successful energy transfer tests with minimum gaps and five (5) at worse case conditions are required to certify that transfer margins exist. The figure below describes gap dimensional relationships.




**3.1.5 Transfer Through Barrier Margin Methods.** Any ET assembly or safe arm device design requiring use of a barrier between the donor and receptor charges should conduct performance margin demonstrations in the same manner as described in paragraph

3.1.4 except should include the barrier. Barriers are metallic structures that do not maintain structural integrity during or after explosive energy transfer. The barrier should be physically positioned relative to donor and receptor to simulate nominal placement used in the application. The physical configuration and material properties of barrier used in these tests should be identical to those used in the end item application. Barrier positioning during these tests is described in the figure below.




**3.2 Explosive Actuated Device Performance.** These methods should be used to demonstrate that explosive energy inputs from the explosive train are within acceptable limits of the interfacing explosive actuated device and, where appropriate, that outputs are within acceptable limits.

**3.2.1 Mechanical Device Methods.** Qualification and destructive acceptance function tests of Methods 2D and 4D for explosive actuated mechanical devices should be conducted using input energies configured to be identical to those to be used in the end item application, to the extent practical. Test conduct should assure that the device tested is positioned, attached or otherwise installed onto fixtures in a manner that simulates the application. The fixtures should be have structural, thermal and dynamic properties that simulate the end item application, to the extent practical. Interfaces between the device and the application that induce loads, frictions or other conditions on the device must also be simulated, to the extent practical. Measurements and inspections made during and after the test should include, but not be limited to function times, displacements, reaction forces, velocities, shock responses, stress fields, contamination and any other parameter unique to the application. Qualification or acceptance certification is granted when the device performs its intended function and all measurements and inspections of parameters of interest are found to be acceptable.

**3.2.2 Mechanical Device Margin Methods.** Performance margin demonstrations of explosive actuated mechanical devices should be conducted using worse case minimum and maximum ET output energies as inputs to the devices. For minimum performance margin demonstrations the ET input energy to the device should be configured to be less than 0.80 times the worse case ET minimum energy. For maximum performance margin demonstrations the ET input energy to the device should be at least 1.20 times the worse case ET maximum energy. Devices used in these demonstrations must be configured to be identical to those planned for use in the end item application. Test fixtures used should be configured to simulate the application including structural, thermal and dynamic properties, to the extent practical. Interfaces between the device and the application that induce loads, frictions or other conditions on the device must also be simulated, to the extent practical. To certify performance with margin at least six (6) devices should be tested using minimum ET input energies and six

(6) using maximum ET input energies. In each case three (3) of the tests should be performed at maximum predicted operating temperature of the application and three (3) at the minimum predicted operating temperature of the application. Measurements and inspections made during and after these tests should include, but not be limited to function times, displacements, reaction forces, velocities, shock responses, stress fields, contamination and any other parameter unique to the application. Performance margin certification is granted when the device performs its intended function and all measurements and inspections of parameters of interest are found to be acceptable.

**3.2.2.1 Mechanical Device Performance Limits**. Where practical tests should be performed to determine performance threshold limits of explosive actuated mechanical device designs in terms of energy. These tests should use devices identical to designs to be used in the end item application. They should be installed into fixtures allowing application of known amounts of dynamic energy. Test objectives are to impart a dynamic load onto the mechanical in increments so as to establish the threshold at which the device performs intended functions. Measurements and inspections made during and after these tests should include, but not be limited to function times, displacements, reaction forces, velocities, shock responses, stress fields and any other parameter unique to the application. Data gathered should be used to develop limits of ET inputs required to effect mechanical device function. These limits should be used to configure ET inputs for paragraph 3.2.2 margin tests, where practical.

**3.2.3 Through Bulkhead Initiator (TBI) Methods.** Qualification and destructive acceptance function tests of Methods 2C and 4C for TBI designs should be conducted using input energies configured to be identical to those to be used in the end item application, to the extent practical. Test conduct should assure that the TBI tested is positioned, attached or otherwise installed onto fixtures in a manner that simulates the application. The fixtures should be designed to have structural, thermal and dynamic properties that simulate the end item application, to the extent practical. Measurements and inspections made during and after the test should include, but not be limited to function times, shock responses, contamination and any other parameter unique to the application. TBI output measurement should be made using Appendix A methods. Metallurgic inspections of cross sectioned of bulkheads should also be conducted. Qualification or acceptance certification is granted when the TBI performs its intended function and all measurements and inspections of parameters of interest are found to be acceptable.

**3.2.4 TBI Margin Methods.** Performance margin for TBI designs should be demonstrated by test. Bulkheads are metallic structures that should maintain structural integrity during and after explosive energy transfer. To demonstrate margin, six (6) tests using nominal application inputs to nominal TBI donor charges, that are both identical to the end item application, should ignite nominal TBI receptor charges by shock transmission through a bulkhead that is 1.20 times the maximum specified TBI thickness. Receptor charge ignition demonstrates successful performance with margin. To demonstrate bulkhead structural integrity six (6) tests using nominal application inputs to nominal donor charge inputs should ignite nominal TBI receptor charges through a bulkhead that is 0.80 times the minimum specified TBI thickness. These tests should demonstrate structural integrity of the bulkhead during and after ignition of the receptor charge. Integrity can be validated by post-test use of hydrostatic pressures equivalent to 1.5 times the maximum predicted operating pressure of the end item application. Metallurgic inspections of cross sections of bulkheads should also be conducted. In both test series, three (3) should be conducted at the maximum predicted operated temperature of the application and three (3) at minimum predicted operating temperature. Measurements and inspections made during and after the test should include, but not be limited to function times, shock responses, contamination and any other parameter unique to the application. TBI output measurement should be made using Appendix A methods. Performance margin certification is granted when the TBI performs its intended function and all measurements and inspections of parameters of interest are found to be acceptable.

**3.2.5 Severing and Penetrating Device Methods.** Qualification and destructive acceptance function tests of Methods 2C and 4C for severing and penetrating devices should be conducted using input energies configured to be identical to those to be used in the end item application, to the extent practical. Severing and penetrating devices include linear shaped charges (LSC) and explosively formed projectiles (EFP). Test conduct should assure that the LSC or EFP tested is positioned, attached or otherwise installed onto fixtures in a manner that simulates the application. For LSC tests, the test sample should of a length that best simulates the installation, to the extent practical. Test fixtures used to support LSC and EFP during these tests should simulate structural, thermal and dynamic properties of the end item application, to the extent practical. Target substrates should simulate the application material properties and be nominally positioned in the same manner as the end item application, to the extent practical. Measurements and inspections made during and after the test should include, but not be limited to function times, shock responses and any other parameter unique to the application. Qualification or acceptance certification is granted when LSC or EFP severance or penetration complies with product specification requirements and all measurements and inspections of parameters of interest are found to be acceptable.

**3.2.6 LSC and EPF Margin Methods.** Performance margins for explosive for severing or penetrating should be determined by tests using nominally configured LSC or EFP test samples. For applications requiring severance or penetration of a single layer homogeneous material substrate performance margins should be demonstrated using nominal charges, positioned at maximum standoff, directed at a substrate with a thickness 1.5 times the maximum thickness to be used in the end item application. For applications requiring severance or penetration of multi-plied composite substrates performance margins should be demonstrated using nominal charges, positioned at maximum standoff, directed at a substrate with a thickness 2.0 times the maximum thickness to be used in the end item application. For LSC tests, the test sample and the substrate should of a length that best simulates the application, to the extent practical. Six (6) successful severance or penetration tests of each configuration are required for performance margin certification, as a minimum. Substrate materials used in these tests must be identical to those to be used in the end item application. Test fixtures must simulate the end item application, including all materials in contact with it, to the extent practical. Measurements and inspections before, during and after the tests should include LSC or EFP to substrate standoff distances, function times, penetration or severance depths and any other parameter unique to the application.

**3.2.7 Fragmenting Device Methods.** Qualification and destructive acceptance function tests of Methods 2C and 4C for fragmenting devices should be conducted using input energies configured to be identical to those to be used in the end item application, to the extent practical. Fragmenting devices use ET inputs to continue a detonation process that imparts an explosive shock impulse in a controlled manner causing fragmentation of structural elements in end item applications. These include explosive nuts and bolts, expanding tube frangible links and other similar devices. Qualification and destructive acceptance tests should be conducted with fragmenting devices installed in fixtures configured to simulate physical sizes, materials, dynamic and relative stiffness properties of the items to be fragmented in the end item application, to the extent practical. Test conduct should assure that the fragmenting device tested is positioned, attached or otherwise installed onto fixtures in a manner that simulates the application. Measurements and inspections made during and after testing should include, but not be limited to function times, shock responses, metallurgic inspections or any other parameter unique to the application. Qualification or acceptance certification is granted when fragmenting devices demonstrate their ability to comply with product specification requirements and when all measurements and inspections of parameters of interest are found to be acceptable.

**3.2.8 <u>Fragmenting Device Margin Methods</u>.** Performance margins for explosive actuated devices used for fragmenting of structural elements should be determined by tests. A minimum of six (6) tests should be conducted using energy outputs in the device that are no greater than 0.80 times the minimum output values to be used in the end item application. A minimum of six (6) tests should also be conducted using explosive energy outputs within the device that are at least 1.2 times greater than maximum output values used in the end item application. In all tests the fragmenting structure and associated elements must simulate the end item application, to the extent practical. Certification of performance margins is to be based on successful fragmentation to the degree desired. The degree of fragmentation should be based on product specification and application requirements.

# APPENDIX D

# Test and Analysis Methods for Electrical Energy Field Exposure Survivability

**1. Scope**. This Appendix provides test and analysis methods for assessing survivability of explosive systems and first elements to electrical energy environments that may occur during storage, handling or application. These environments include electro static discharge (ESD), electro magnetic interference (EMI) and radio frequency interference (RFI). Affects of ESD environments on an explosive system and the ability to prevent premature ignition of first elements within in it are discussed. ESD tests to assess survivability of each first element design are presented. Methods for evaluating electro magnetic compatibility (EMC) of elements within the explosive systems are offered. RFI test and analysis methods are provided to estimate survivability limits of first element designs.

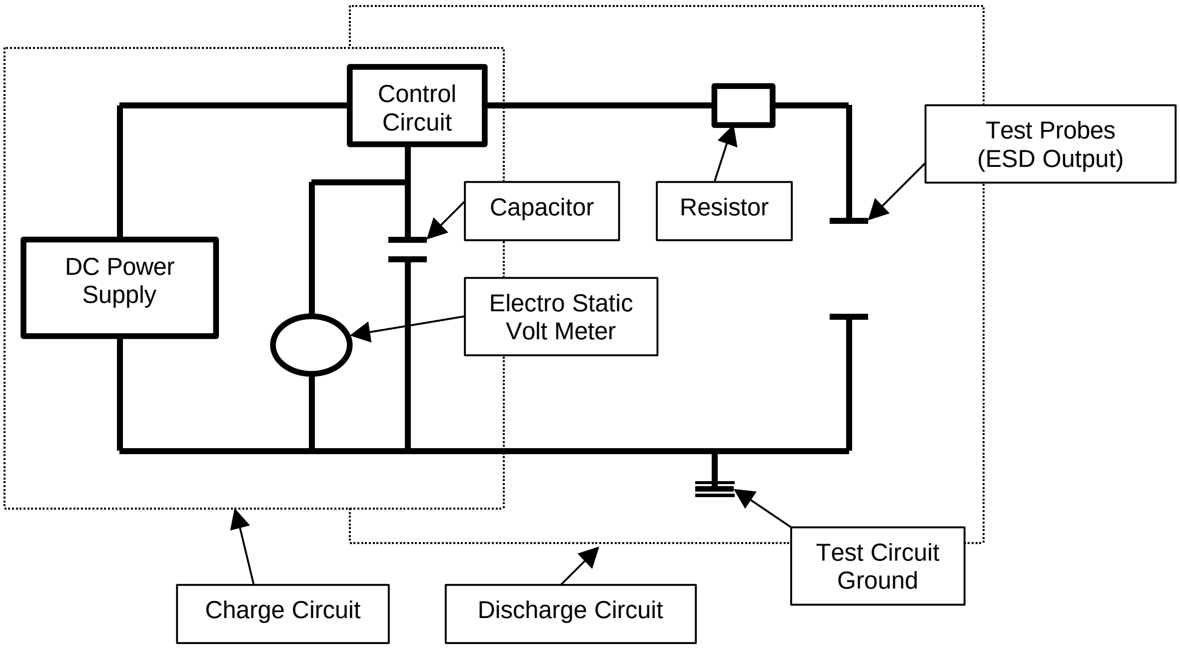
**2. Applicable Documents.** Product specifications of tested designs. Detailed descriptions of test environment generating equipment, electrical circuits, data measurement methods and instrumentation used in all tests.

**3. External Energy Survivability Assessment Methods.** The following are discussions on inspection, test and analysis methods for assessing survivability of explosive systems and first elements when exposed to external environments such as ESD, EMI and RFI.

**3.1 Explosive System ESD Survivability.** Explosive systems and components should be designed to survive external applications of an ESD environment. Protective features should be included within the explosive system to prevent premature ignition of first elements or deactivation of safety inhibits within it. Analysis should confirm that there are no sneak circuits or unplanned capacitance discharges that could cause these premature events. Certification of effectiveness of these features should be based on inspection and analysis, as appropriate.

**3.2 First Element ESD Survivability.** All first elements used in the explosive system that have a potential to be affected by an ESD environment should have their survivability certified by test. Tests that apply this environment should be performed on each first element in this category. First element qualification tests outlined in MIL-HDBK-83578 Method 2A should be used to confirm that performance is not degraded after exposure to an ESD environment. During appropriate phases of manufacture of first elements an exposure to an ESD environment should be performed. Ignition during this phase is not considered a failure unless ignition rates exceed 10% of the production lot. Ignition rates greater than this should generate investigations into cause and corrective action. A limit to the number of ESD tests that can be performed on a first element design should be determined during its design development and should be referenced in product specifications. This number should be greater than twenty (20). An ignition during first element non-destructive acceptance tests of MIL-HDBK-83578 Method 3A should be cause for rejection of the entire production lot.

**3.2.1 ESD Test Conduct.** A test circuit designed to deliver a repeatable simulation of an accepted representation of a human borne ESD environment is required for first element ESD testing. The accepted environment can be delivered from a test circuit similar to the one shown below that has an output of 25 K volts delivered from a 500-pico farad capacitor. With a 5K resistor in series with the circuit, output energy delivered to a first element having an assumed one-ohm load is approximated as 0.03 milli joules. Without the 5K ohm resistor the energy delivered is approximately 156 milli joules. As a design goal, the test circuit output should be within 20% of the desired 25 K volt peak. The control circuit should attempt to assure that initial voltage rise to 80% of peak occurs in less than 100 nanoseconds. The output waveform limits of the test circuit should be characterized and documented. Prior to start of tests and periodically during a test series output waveforms of the test circuit should be verified to be within acceptable limits. Each first element should be tested in two modes. In the first mode, test circuit output probes should be connected to the first elements electrical conductors, shorted together, and the outer its metallic case. In the second mode the probes should be connected to the conductors, negative to negative, positive to positive. The 5K ohm should be installed in the test circuit for tests in the second mode only. Accept and reject criteria are as stated in paragraph 3.2.




**3.3 <u>Explosive System EMC Evaluations</u>.** It should be shown by test and analysis that any electro magnetic field generated by the explosive system power, command and control electrical circuitry that can be radiated or conducted onto first elements within it are at least 20 dB below the maximum no-fire rating of the first element used. It should also be shown that any radiated or conducted electro magnetic fields onto any inhibit in the power, command and control circuitry is at least 6 dB below the minimum inhibit activation power. Radiated and conducted electro magnetic environment can produce a peak alternating current power at the first element or inhibit. If this occurs the level measured should be compared to the maximum direct current no-fire power level of the first element or inhibit activation power threshold. Certification of compliance to these can be accomplished by test. Using a suitable measurement device installed at the ignition system output firing circuit, cycle the explosive system through all possible commands. Measure and record any direct current response at the ignition system output circuit. The measurement device should be designed to simulate the electrical characteristics of the first element and should be capable of detecting energy pulses that are as short as one millisecond. The measuring device sensitivity levels should be far less than the no fire level of the first element or activation threshold of any circuit inhibit so that a 20 dB margin can be demonstrated without irradiating the explosive system at damaging levels. The above test can be performed in the end item application.

**3.4 <u>Worse Case Electro-Magnetic Hazard Analysis</u>.** If the explosive system is unable to comply with paragraph 3.3, or if a first element is used within it that is considered abnormally susceptible to premature ignition in an electro magnetic field, a worse case analysis should be performed. This analysis should consider all cycles of explosive system power, command and control circuitry, during all phases of operation including storage, handling, checkout and end item application. This worse case analysis should demonstrate that the electro magnetic environment acting directly on ignition circuitry produces an RFI level less than the maximum RFI no fire level of the first element.

**3.4.1 Worse Case Analysis Conduct.** Explosive system configurations in which premature ignition due to coupling of EMI environments could result in a hazard to personnel or facilities should be analyzed. These configurations include but are not limited to, hand-held operations, pre-assembled operations, checkout operations, and final installation operations. The assumed incident EMI environment used in the analysis should be 2 watts per square meter from 1 megahertz to 50 megahertz, and 100 watts per square meter form 50 megahertz to 32 gigahertz. Although calculations of coupling through shielding and aperture penetration may be presented in simple derivative forms they should be capable of withstanding rigorous review and comparison to known computation methods and tools such as hazard computation monographs. The computations should use aperture parameters that allow evaluation of power radiated on the circuitry that results in a simple multiplication of the assumed EMI environment and aperture, as a function of frequency. The result of this computation is the worse case power incident on the first element as a function of frequency. This value should be compared to the RFI no-fire level of the first element, as determined in tested to be described in paragraph 3.5.2, for each configuration. The result of this comparison should be presented as a dB safety parameter as a function of frequency as shown below. If the value of $dB_s$ is less than zero the explosive system is to be considered hazardous and should be redesigned.

$$dB_s = 10 \log_{10} P_{NF}/P_{FE}$$

Where $P_{NF}$ is the no-fire power level determined in paragraph 3.5.2 and $P_{FE}$ is the calculated worse case power delivered to the first element.

**3.5 First Element RFI Survival Limit Estimates.** The following tests should be performed on each first element design susceptible to premature ignition of degraded performance when exposed to a RFI environment. These tests should be conducted prior to completion of qualification of the first element design as noted in MIL-HDBK-83578 paragraph 4.10.

**3.5.1 RF Impedance Tests.** Test objectives are to measure first element impedance, i.e., resistance and reactance at specific frequencies. The values determined in these tests may be used in worse case electro-magnetic hazard analyses of paragraph 3.4.1. Ten (10) first element samples identical to the design to be used in the end item application are required for these measurements. At the completion of the measurements the ten samples may be used in RF sensitivity or dudding tests of paragraph 3.5.2 and 3.5.3. The impedance of each test sample should be measured for each potential ignition mode of the first element design. For EED designs these modes are conductor to conductor, and between conductors shorted together and the outer metallic case. For multiple bridgewire EED designs bridge to bridge modes should also be measured. Measurements in each mode should be made at ten (10) frequencies between 1 and 1200 megahertz. The individual test frequencies selected should be spaced in approximate equal logarithmic increments. The measurement device should limit input energy to the first element to be no more than one (1) milli-watt. Fixtures used to support the first element during these tests should be constructed so that the measurement is focused to a point close to the junction between the first elements outer case and insertion point of its conductors. These fixtures should simulate thermal properties of the end item application, to the extent practical. Measured impedance values should be recorded and made available for use in worse case analysis of paragraph 3.4.1.

**3.5.2 RF Sensitivity Tests and Analysis.** These tests are used to measure the radio frequency sensitivity of first element designs and provide a no-fire level for use in hazard analyses. A minimum of 230 single bridgewire EED samples (370 for multiple bridgewire designs) of a common design from a common production lot, are required for these tests. The tests and analysis methods are described in the following.

**3.5.2.1 Basic RF Sensitivity Probing Tests.** These tests subject EED samples to RF power over a range of frequencies applied in continuous or pulsed modulations. At each frequency ten (10) samples are exposed for five (5) minutes in the conductor to conductor mode and ten (10) samples for five (5) minutes in the conductors shorted together to case mode. For multiple bridgewire EED designs ten (10) EED samples should be added to the total. These should be tested at each frequency for five (5) minutes in the bridgewire to bridgewire mode. Up to five (5) EED samples that survive the conductor to conductor mode can be reused and be part of the ten required for conductors shorted together to case mode. For an optimum test this would yield a total test sample size of fifteen (15) for single bridgewire EED designs and twenty-five (25) for multiple bridgewire EED designs at each frequency. Frequencies used in these tests should be within a range from 1 megahertz to 32 gigahertz. At least ten (10) frequency levels within this range should be selected for these tests. The selected frequencies should include those of interest in the end item application. If there are no specific frequencies of interest the following default frequencies should be used.

| Default Test Frequencies and Modulations | |
|---|---|
| Frequency, Megahertz | Modulation |
| 1.5 | CW |
| 27.0 | CW |
| 154.0 | CW |
| 250.0 | CW |
| 900.0 | CW |
| 2700.0 | P |
| 5400.0 | P |
| 8900.0 | P |
| 16000.0 | P |
| 33000.0 | P |

Where CW is a continuous wave, and P is a one-(1) microsecond pulse at a 1 K Hertz rate.

At each frequency and in each mode the RF power dissipated in the EED should be varied from one unit to the next in order to determine the approximate range of power levels that will fire the EED. The first, or starting RF power level may be equivalent to the product of the square of the EED direct current resistance and the mean direct current as determined in all-fire tests of MIL-HDBK-83578 Appendix B. Fixtures used for EED mounting during these tests should be configured to allow measurements to be focused to a point close to the junction between the first elements outer case and insertion point of its conductors. These fixtures should simulate thermal properties of the end item application, to the extent practical. Test equipment should be designed to minimize and to account for any power loss during measurements including loses in the impedance matching elements. During the tests if two (2) or less EED samples ignite a low risk of ignition in these environments is apparent and any further analysis of hazards can use the direct current sensitivity in lieu of RF radiation values. If three (3) to seven (7) EED samples ignite during these tests the risk associated with using direct current in any further hazard analysis is considered to be approximately 11%. If eight (8) or more ignite the EED design should be considered to be more sensitive to RF than to direct current. These data are used in the following analysis.

**3.5.2.2 Statistical RF Tests.** Data from paragraph 3.5.2.1 should be used to determine the most sensitive frequency and modulation stimulus of the EED design in each mode tested. This most sensitive stimulus should be used as the starting point for a five-(5) minute RF power exposure Bruceton type of statistical test. At least forty (40) EED samples should be allocated for this test in each firing mode. Test conduct should be similar to methods defined in Appendix B.

**3.5.3 <u>RF Dudding Evaluation</u>.** This evaluation can be used to determine if a RF environment will degrade or otherwise dud an EED design within an estimated confidence. This evaluation should not to be performed if the EED design will not be exposed to RF levels greater than the RF no-fire level determined in tests of paragraph 3.5.2. The evaluation compares differences between five-minute and one-millisecond pulse duration direct current no-fire data relative to RF test data. Objectives are to determine which environment is most severe and provide an estimate of confidence of the comparison. Three groups of a specific EED design are used in these comparisons. The original group test data was derived during five-minute no-fire rating tests described in Appendix B of MIL-HDBK-83578. The control group is a new test series requiring forty (40) samples no-fire tested in accordance with MIL-HDBK-83578 Appendix B except the direct current pulse duration should be one-millisecond. The third is a post exposure group subjected to a RF environment as described in paragraph 3.5.2.2. To determine if the RF environment has altered the direct current no-fire characteristics of the EED design separately compute the following.

$$T_c = | X_C - X_E | \{N_C S_C{}^2 + N_E S_E{}^2\}^{-0.5} (\{N_E N_C (N_E + N_C - 2\} / N_C + N_E)^{0.5} \text{ and,}$$

$$T_o = | X_O - X_E | \{N_O S_O{}^2 + N_E S_E{}^2\}^{-0.5} (\{N_E N_C (N_E + N_O - 2\} / N_O + N_E)^{0.5}$$

If $N_C = N_E = N$ or, $N_O = N_E = N$ then,

$$T_c = | X_C - X_E | \{S_C{}^2 + S_E{}^2\}^{-0.5} (N - 1)^{0.5} \text{ and,}$$

$$T_o = | X_O - X_E | \{S_O{}^2 + S_E{}^2\}^{-0.5} (N - 1)^{0.5}$$

Where:

a. $T_c$ is a thermal density parameter in amperes of control and post exposure groups.

b. $T_o$ is a thermal density parameter in amperes of original and post exposure groups.

c. $X_C$ is the $\log_{10}$ of the mean current at which 50% of the samples fired during control group tests of the EED design.
d. $X_O$ is the $\log_{10}$ of the mean current at which 50% of the samples fired during original group tests of the EED design.
e. $X_E$ is the $\log_{10}$ of the mean current at which 50% of the samples fired during post exposure group tests of the EED design.
f. $N_C$ is ½ the number of samples used in control group tests rounded to the nearest integer.
g. $N_O$ is ½ the number of samples used in original group tests rounded to the nearest integer.
h. $N_E$ is ½ the number of samples used in post exposure group tests rounded to the nearest integer.
i. $S_C$ is the standard deviation of distribution of control group data.

j. $S_O$ is the standard deviation of distribution of original group data.

k. $S_E$ is the standard deviation of distribution of post exposure group data.

Then using a two-sided probability distribution at P(t) equal to 0.05, compare computed thermal density parameters to the value corresponding to the frequency (f) computed by $f = N_C + N_E - 2$, or $f = N_O + N_E - 2$. If the P(t) value is greater or equal to the computed thermal density value then it can be assumed with 95% confidence that a similar RF environment will not adversely affect EED performance in the end item application.

## CONCLUDING MATERIAL

REVIEW ACTIVITIES:

Air Force: 10, 11, 17

PREPARING ACTIVITY:

Air Force: PA-19
Project 1820-9901

# STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.

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3. The preparing activity must provide a reply within 30 days from receipt of the form.

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| **I RECOMMEND A CHANGE:** | **1. DOCUMENT NUMBER**<br>MIL-HDBK-83578 | **2. DOCUMENT DATE (YYMMDD)**<br>990101 |
|---|---|---|

**3. DOCUMENT TITLE CRITERIA FOR EXPLOSIVE SYSTEMS AND DEVICES USED ON SPACE VEHICLES**

**4. NATURE OF CHANGE** *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

**5. REASON FOR RECOMMENDATION**

**6. SUBMITTER**

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|---|---|---|
| a. NAME *(Last, First, Middle Initial)* | b. ORGANIZATION | |
| c. ADDRESS *(Include Zip Code)* | d. TELEPHONE (Include Area Code)<br>(1) Commercial<br>(2) AUTOVON<br>*(if applicable)* | **7.DATE SUBMITTED**<br>(YYMMDD) |

**8. PREPARING ACTIVITY**

| | |
|---|---|
| a. NAME SPACE & MISSILE SYSTEM CENTER<br>ATTN: MR. DAVID E. DAVIS | b. TELEPHONE *Include Area Code)*<br>(1) Commercial (310) 362-2406<br>(2) AUTOVON 833-2406 |
| c. ADDRESS *(Include Zip Code)*<br>SMC/AXMP<br>160 SKYNET STREET, SUITE 2315<br>EL SEGUNDO, CA 90245-4683 | **IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT:**<br>DEFENSE QUALITY AND STANDARDIZATION OFFICE<br>5203 Leesburg Pike, Suite 1403, Falls Church, VA 22401-3466<br>Telephone (703) 756-2340 AUTOVON 289-2340 |