**MEASUREMENT
SYSTEM
INCH-POUND**

National Aeronautics and
Space Administration

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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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MSFC TECHNICAL STANDARDS

PYROTECHNIC SYSTEM SPECIFICATION

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DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline	Baseline	12/5/2011	Baseline Release; document authorized through MPMDS
Revision	A	10/22/2012	- Revision A Release; document authorized through MPDMS. - Added IPC J-STD-001E-2010 and ICP J-STD-001ES and removed NASA STD 8739.3 - Added NASA-STD-6012 and removed MIL-STD-889 and MSFC-SPEC-250 - Sec 1.0: added caveat to be able to use industry, government, and company specifications in lieu of this specification if approved by the responsible NASA technical authority - Sec 3.8: updated compatibility analysis exception - Sec 3.9.1.5 revised to title to Shielding and updated verbiage to align with MIL-STD-1576 - Sec 3.9.1.6: updated Radio Frequency (RF) power limit at the electroexplosive devices (EED) - Sec 3.9.2: updated specification for soldering of electrical connections for Safe and Arm Devices - Sec 4.3.2 revised to add caveat for performing the subsystem separation test only if results cannot be achieved at another level of testing - Sec 4.6: updated pyrotechnic component reviews to initial, pre-production and hardware acceptance - Appendix A- updated acronyms to add IPC
Revision	B	12/11/2014	- Revision B Release was authorized by the MSFC Technical Standards Document Control Board (DCB) through the Multiprogram Document Management System (MPDMS). - Sec 2.1: added AFMAN 91-201, DoD 6055.09-M, FED-STD-228, ICAO Doc 9284, (JSC) SEB26100001, (JSC) SKH26300066, (JSC) SLH26300001 MIL-DTL-38999, MIL-STD-1168, NASA-STD-8719.12, MSFC-STD-1800, MWI-3410.1, MWI-8715.10, and MPR-6000.1 - Sec 3.1: added reference to MSFC-STD-1800 - Sec 3.4: revised verbiage; no technical change - Sec 3.9.1: added reference to NSI-3 and associated drawing/specification documents - 3.9.1.1: clarified verification of current will be by using an EED simulator, delete duplication of requirements for RF energy and bent pins, quantify the definition of narrow band high amplitude energy pulses, and clarify during power on/off transients must meet the 16.5 dB margin for RF MNFS - Sec 3.9.1.4: deleted and combined requirements with sec 3.9.1.7.2; re-numbered subsequent sections - Sec 3.9.1.5: deleted and included requirements in sec 3.9.2.10; re-numbered subsequent sections - New sec 3.9.1.5: (Lightning) added 16.5 dB margin requirement - New sec 3.9.1.6: (Bonding) clarified verbiage issue stating the 16.5 dB margin is for the initiation system and not the EED - Sec 3.9.2: added new section for pyrotechnic electrical circuit requirements - Sec 3.9.3.2,e: added definition of partially armed S&A device - Sec 3.9.6: revised verbiage; no technical change - Sec 3.9.11: revised verbiage to state non-electrically initiated pyrotechnic components shall be designed to meet class “S” bonding requirement - Sec 3.11.3: added requirement for single heat lot for fracture critical pyrotechnic components - Sec 3.11.5.1: revised to impose MIL-STD-1168 - Sec 3.12: added new section for pyrotechnic systems handling, installation, and checkout requirements - Appendix A: updated acronyms to add RMS, Vac, Vdc, MPR, MWI, MNFC, MNFV, MNFP, MNFE, and MNFS - Appendix B: add definition for initiation system

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Revision	C	06/25/2018	- Revision C Release was authorized by the MSFC Technical Standards Document Control Board (DCB) through the Multi-Program Document Management System (MPDMS). - Sec 3.4: Removed exceptions for failure tolerance - Sec 3.7: Updated Sealing requirements - Sec 3.9.6: Updated to add pancake charge and apply requirement to non-FTS LSC - Sec 3.9.7.3: Added sub-sections 3.9.7.3.1 through 3.9.3.7.3 for new frangible joint requirements - Sec 3.9.8: Added sub-section 3.9.8.1 for Thrust Rail separation systems - Sec 3.11.5: Added MIL-STD-1168 to lot numbering requirement - Sec 4.3.2: Updated to specify full-scale testing required for new designs - Sec 4.4.1.3: Updated Leakage testing criteria to match updated Sec 3.7 - Appendix A: updated acronyms for FJA, KC, LEA, and XTA

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1.0 SCOPE

This specification covers requirements for pyrotechnic component and system design, development, qualification, acceptance, manufacture, shipping, storage, and service life for unmanned and manned space flight. When this specification is specified on contract documents, the contractor may submit an alternative, corporate, detailed specification that meets the intent of this specification. Industry, government, and company specifications may be used in lieu of this specification if approved by the responsible National Aeronautics and Space Administration (NASA) Technical Authority.

1.1 Purpose

This specification provides the criteria for design, manufacture, and performance of pyrotechnic components and pyrotechnic systems for use in unmanned and manned Space Vehicles, e.g. Space Launch System (SLS) Heavy Lift Vehicle (HLV). This specification is not intended for pyrotechnic components installed on launch vehicle payloads but is applicable for upper stage (including kick-stage) pyrotechnic components, payload/vehicle separation pyrotechnic components and payload fairing (shroud) separation pyrotechnic components.

1.2 Applicability

This specification is applicable to the launch vehicle pyrotechnic components, pyrotechnic-actuated components, and pyrotechnic systems. Pyrotechnic components include all elements in a pyrotechnic train within a pyrotechnic system. These components include, but are not limited to, initiators, detonators, safe and arm (S&A) devices, explosive transfer lines (ETL), shaped charges, frangible devices, cartridge actuated devices/propellant actuated devices (CAD/PAD), and mechanically actuated devices.

This document applies the following: all mandatory actions (i.e., requirements) are denoted by statements containing the term “shall.” The following terms also apply: “may” or “can” denote discretionary privilege or permission, “should” denotes a good practice and is recommended, but not required; “will” denotes expected outcome, and “are/is” denotes descriptive material.

2.0 DOCUMENTS

2.1 Applicable Documents

The following documents of the revision or date listed (or latest version if none is listed) form a part of this document to the extent specified herein. For documents not marked with a specified date or issue designation, the document in effect on the date of the contract shall apply.

2.2 Government Documents

49 CFR Parts 100-199	Code of Federal Regulations, Title 49 (Parts 100 through 199), Department of Transportation
AFMAN 24-204	Preparing Hazardous Materials for Military Air Shipments
AFMAN 91-201	Air Force Manual Explosives Safety Standards
AFSPCMAN 91-710	Range Safety User Requirements Manual
DoD 6055.09-M	Department of Defense (DoD) Manual DoD Ammunition and Explosives Safety Standards
FED-STD-228	Cable and Wire, Insulated; Methods of Testing
JSC 20431	NASA JSC Neutron Radiography Specification
JSC 65877	HNS Specification
(JSC) SEB26100001	NASA Standard Initiator
(JSC) SKB26100066	Design and Performance Specification for NASA Standard Initiator (NSI)-1
(JSC) SKD26100132	Performance Specification for NSTS Use of Percussion Primers
(JSC) SKH26300066	NASA Standard Initiator (NSI-3)
(JSC) SLH26300001	Design and Performance Specifications for the NSI-3
MIL-DTL-38999	Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification For
MIL-HDBK-454	General Guidelines for Electronic Equipment
MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-286	Propellants, Solid: Sampling Examination and Testing
MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-1168	Ammunition Lot Numbering and Ammunition Data Card
MIL-STD-1576	Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems
MIL-STD-2073-1	Standard Practice for Military Packaging
MPR-6000.1	Transportation
MS20003	Indicator, Humidity, Card, Three Spot, Impregnated Areas
MSFC-STD 246	Standard Design and Operational Criteria for Çontrolled Environmental Areas

MSFC-STD-1800	Electrostatic Discharge (ESD)Control for Propellant and Explosive Devices
MSFC-STD-3029	Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments
MSFC-STD-3598	Standard for Foreign Object Damage/Foreign Object Debris (DOD) Prevention
MWI 3410.1	Personnel Certification Program
MWI 8715.10	Explosives, Propellants, and Pyrotechnics Program
NASA/CR-2005-213424	Lubrication for Space Applications
NASA-STD-4003	Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment
NASA-STD-5009	Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components
NASA-STD-5019	Fracture Control Requirements for Spaceflight Hardware
NASA-STD-6012	Corrosion Protection for Space Flight Hardware
NASA-STD-6016	Standard Materials and Processes Requirements for Spacecraft
NASA-STD-8719.12	Safety Standard for Explosives, Propellants, and Pyrotechnics
NASA/TM-1999-209734	Lightning Protection Guidelines for Aerospace Vehicles
NASA/TM-86556	Lubrication Handbook for the Space Industry
NPR 8715.5	Range Flight Safety Program

2.3 Non-Government Documents

ANSI/ASQ Z1.4	Sampling Procedures and Tables for Inspection by Attributes
ANSI/NCSL Z540.3	Requirements for the Calibration of Measuring and Test Equipment
ASME Y14.100	Engineering Drawing Practices
ASTM E1003	Standard Test Method for Hydrostatic Leak Testing
ASTM E1742	Standard Practice for Radiographic Examination
ASTM E2033	Standard Practice for Computed Radiology (Photostimulable Luminescence Method)
ASTM E8	Standard Test Methods of Tension Testing of Metallic Materials

IATA DGR	International Air Transport Association Dangerous Goods Regulations Manual
ICAO Doc 9284	International Civil Aviation Organization (ICAO) Doc 9284 Technical Instructions for the Safe Transport of Dangerous Goods by Air
IPC J-STD-001E	Requirements for Soldered Electrical and Electronic Assemblies
IPC J-STD-001ES, December 2010	Joint Industry Standard, Space Applications Electronic Hardware Addendum to IPC J-STD-001E Requirements for Soldered Electrical and Electronic Assemblies
SAE AMS2759	Heat Treatment of Steel Parts, General Requirements
SAE AMS2770	Heat Treatment of Wrought Aluminum Alloy Parts
SAE AMS2771	Heat Treatment of Aluminum Alloy Castings
SAE AMS2772	Heat Treatment of Aluminum Alloy Raw Materials
SAE AMS-H-6875	Heat Treatment of Steel Raw Materials
SAE AS9100	Quality Management Systems - Requirements for Aviation, Space and Defense Organizations

3.0 REQUIREMENTS

3.1 Safety

Pyrotechnic systems and components shall be designed to minimize accident risk to personnel, equipment and facilities. The ability of explosive systems and first elements (electroexplosive devices (EEDs) and safe and arm devices with internal electroexplosives) to survive electrical energy fields without premature ignition or degraded performance shall be certified by tests, inspections and analyses. Control of electrostatic discharge (ESD) shall be in accordance with MFSC-STD-1800, Electrostatic Discharge (ESD) Control For Propellant and Explosive Devices. The ability of pyrotechnic components to survive the installation safety drop test (12.192 meter (m) (40-foot)) and the excessive thermal environment (autoignition) test (reference 3.10.6) shall be demonstrated by test. The pyrotechnic component shall not create a safety or disposal hazard as a result of the 12.192 m (40-foot) drop test.

3.2 Performance

The predicted performance requirements, including maximum and minimum limits for key performance parameters, for each pyrotechnic system and component within the system shall be established. All detonation interfaces (e.g. detonator-to-booster) and detonator transfer connections shall be designed and installed to ensure positive gap and angle-control. Joints and interfaces should be standardized to the greatest possible extent. Optimum spacing and margins for initiation and detonation transfer joints shall be determined and demonstrated by gap separation, angle offset, and centerline offset tests. Performance parameters shall be updated based upon demonstrated margin and qualification tests.

3.3 Environments

Pyrotechnic systems and components shall 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 during manufacturing, transportation, storage, and flight. Environment type, predicted magnitude, limits, and ranges, shall be established for each pyrotechnic system or component.

Each pyrotechnic system or component shall be certified to the environments the system or component would experience throughout its service life including handling and transportation. Predictions of magnitude, durations, and margins for natural and induced environments shall be determined. The combination thereof shall be documented by the procuring activity and approved by the appropriate NASA center. Unless it has been determined by the appropriate NASA center that the 1.829 m (6-foot), minimum, handling drop test is not applicable to the pyrotechnic component design, the 1.829 m (6-foot), minimum, handling drop test shall be included in the environmental test sequence and the results approved by the appropriate NASA center.

Pyrotechnic component performance shall be demonstrated after exposure to natural and induced environments, with the appropriate levels, margins, and durations assigned, including handling drop test as applicable, for qualification, acceptance, and service life extension.

3.4 Failure Tolerance

Pyrotechnic systems and components shall be designed to be single failure tolerant for ‘fails-to-operate’ failure modes.

3.5 Design Life

Pyrotechnic systems and components shall be designed to have a design life of 10 years, minimum. All pyrotechnic systems and components containing age-sensitive materials shall be identified, and a service life extension program for them shall be established. Design life shall be reassessed periodically to ensure that performance has not degraded with time. The design life of pyrotechnic components used in flight termination systems (FTS) shall be in accordance with AFSPCMAN 91-710, Range Safety Users Requirements Manual.

3.6 Range Safety

The pyrotechnic components used in the flight termination systems shall be designed to comply with tailored edition of AFSPCMAN 91-710 for each specific range user’s program and NPR

8715.5, Range Flight Safety Program. Where conflicts exist between requirements for components used in both FTS and mission critical applications the requirements of the program specific tailored edition of AFSPCMAN 91-710 and NPR 8715.5 requirements shall take precedence over the requirements specified herein. Examples include detonators, ETLs, booster charges, shaped charges, and safe and arm devices.

3.7 Sealing

Explosive, propellant, and pyrotechnic materials shall be sealed with an actual maximum leak rate not greater than 5 X 10^{-6} standard (std) centimeter $(cm)^3$ (std cc)/second (sec) of helium (reference 4.4.1.3). Where sealing is accomplished by non-metallic seals (e.g., metal end-caps bonded to linear shaped charge [LSC] and mild detonating fuse [MDF] with adhesive), end-to-end electrical conductivity shall be maintained to ensure that there is no buildup of electrical charge potential.

Environmental seals for pyrotechnic components or assemblies shall have a maximum actual leak rate of 1X 10^{-2} std cc/ sec of the gas medium used for the test (reference 4.4.1.3).

3.8 Electrical/Electromagnetic

Pyrotechnic systems shall be designed to operate without performance degradation or inadvertent firing when exposed to electrical energy environments such as electrostatic discharge, electromagnetic radiation, radio frequency interference, and lightning. An electromagnetic compatibility (EMC) analysis in accordance with MIL-STD-1576, Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems, shall be performed with the exception that the electromagnetic environment shall be at least 16.5 decibel (dB) below the pin-to-pin and pin-to-case Radio Frequency (RF) no-fire power level of the EED.

3.9 Pyrotechnic Design Requirements

Requirements for pyrotechnic systems or component designs not specifically addressed within this specification shall be approved by the appropriate NASA center.

3.9.1 Electroexplosive Devices (EEDs)

EEDs shall be approved by the appropriate NASA center and shall conform to the requirements herein. If the EED used is the NSI-1 (JSC/SEB26100001), NASA Standard Initiator, it shall conform to JSC/SKB26100066, Design and Performance Specifications for the NSI-1. If the EED used is the NSI-3 (JSC/SLH26300001), NASA Standard Initiator (NSI-3), it shall conform to JSC/SKH26300066, Design and Performance Specifications for the NSI-3. EEDs used in FTS shall comply with AFSPCMAN 91-710 and NPR 8715.5 requirements.

3.9.1.1 Initiation System

The initiation system shall be designed such that the minimum stimulus applied to each EED in the system at initiation is equal to or greater than 1.5 times the all-fire current or voltage level of the EED using EED simulator before the final connection to live EED. During system power on and power off checks and all switching operations the maximum voltage/current applied to the EED shall be verified to be limited to no more than 16.5 dB below the RF maximum no-fire stimulus (MNFS).

Electrical circuit designs used for power, command, and control of the initiation system shall be fail-safe against premature activation and have a validated ability to prevent premature EED activation. The circuitry shall preclude narrow band high-amplitude energy pulses, defined as having a magnitude of 1 volt or greater and a duration of 50 microseconds or greater, during all switching operations.

3.9.1.2 Bridgewire

For all EED designs without discontinuities or gaps in their electrically conductive paths, the conductive path shall be capable of withstanding repeated measurements of its resistance value throughout its service life without degrading functional performance or safety.

3.9.1.3 Shorting and RF Protection

The EED design shall include a provision for shorting all contacts to each other. Once the device is assembled, adequate protection from RF, Electrostatic Discharge (ESD), and handling damage shall be provided.

3.9.1.4 Radio Frequency Interference (RFI)

EEDs shall be designed to survive exposures to externally applied RFI fields predicted in the EED application without premature ignition or degraded performance. RF power at the EED shall be limited to 16.5 dB below the pin-to-pin and pin-to-case RF no-fire power level of the EED.

3.9.1.5 Lightning

EEDs shall be designed to preclude premature activation due to electrical energy fields generated within the pyrotechnic system from exposure to lightning strikes as defined in MIL-STD-464, Electromagnetic Environmental Effects Requirements for Systems, and NASA/TM-1999-209734, Lightning Protection Guidelines for Aerospace Vehicles. The EED shall be considered adequately designed if, in the specified environment, the stimuli do not exceed the following in any EED in the launch vehicle:

A 16.5 dB margin shall be verified as defined by:

0.15 maximum no-fire current (MNFC) or 0.15 maximum no-fire voltage (MNFV)
$(0.15)^2$ maximum no-fire power (MNFP) or $(0.15)^2$ maximum no-fire energy (MNFE)

3.9.1.6 Bonding

Electroexplosive subsystem shall be designed to meet class “R” electrical bonding (2.5 milliohms) per NASA-STD-4003, Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment.

3.9.1.7 Low Voltage EED

All electrically conductive paths of the EED shall be isolated from the EED outer case. The insulation resistance (IR) between these conductors and the EED case, at a potential of 500 volts, minimum, direct current (DC), shall be 2 megohm (MΩ) minimum. All EEDs, except for semiconductor bridge (SCB) or thin film bridge (TFB) devices, in a low-voltage capacitive firing system shall fire when subjected to currents between sure-fire and 22 amperes.

3.9.1.7.1 All-Fire/Sure-Fire

Tests and analysis shall determine the current, power, or energy level for which an EED design will reliably function. This should yield an input energy level, known as the statistical all-fire rating, at which, as a minimum, 99.9% of the units from an EED design will function with a confidence level of 95%.

3.9.1.7.2 No-Fire/Electrostatic Discharge (ESD)

Unless otherwise specified, electroexplosive devices (EED) shall be designed to withstand a constant direct current firing pulse of up to 1 ampere and 1 watt power (minimum) for a period of 5 minutes (minimum) duration without initiation or deterioration of performance (dudding). The DC no-fire shall be determined by Test Method 2203 of MIL-STD-1576 (Bruceton Test) or equivalent penalty test (e.g. Langlie, Neyer, etc.) at room temperature (25 degrees Celsius (C)). The EED should be held in a mounting device to minimize heat transfer away from the initiator. The test method shall indicate that the 0.1% firing level (with 95% confidence) is 1 ampere or more. EEDs shall not fire, dud, or deteriorate in performance as a result of being subjected to an electrostatic discharge of 25,000 volts from a 500 picofarad capacitor applied in the pin-to-case mode with no series resistor and in the pin-to-pin mode with a 5 kilohm resistor in series. EEDs using an external spark gap require appropriate NASA center approval.

3.9.1.8 Semiconductor Bridge Device (SCB)/Thin Film Bridge Device (TFB)

SCBs/TFBs shall meet the same requirements (sections 3.9.1.7.1 - 3.9.1.7.2, inclusive) as low-voltage, capacitor-fired, EEDs.

SCBs/TFBs may be integrated into addressable, or intelligent, initiation systems provided each individual SCB/TFB contains electronics that allow the device to be fired upon receipt of a properly encoded arming/firing signal, and reject improperly coded signals.

3.9.2 Pyrotechnic Electrical Circuits

3.9.2.1 Firing Circuits

A separate firing circuit shall be provided for each EED. Prior to the pyrotechnic system being configured for launch and where premature firing may result in a catastrophic event, the pyrotechnic system shall provide a condition such that no single failure or single operator error can cause a critical hazard and no combination of two failures or operator errors can cause a catastrophic hazard. The design of all pyrotechnic electrical circuits associated with pyrotechnic devices shall require approval from the responsible NASA center. Firing circuits shall include a means for limiting current surges that result from multiple instantaneous firings. Firing circuits shall also include protection for the power supplies to prevent power loss or voltage drops that might result from post-firing short circuits in the EED.

The pyrotechnic firing circuitry shall be shielded, filtered, grounded, or otherwise isolated to preclude energy sources (e.g. electromagnetic energy or stray lightning) from the Range and/or launch vehicle causing interference which would inhibit the functioning of the system or cause an undesired output of the system.

The firing circuitry shall not contain fuses or similar type protection devices. Current limiting resistors are permitted in firing circuits.

Electrical firing circuits shall be isolated from the initiating pyrotechnic case, electronic case and other conducting parts of the vehicle. If a circuit must be grounded, there shall be only one interconnection with other circuits (single point ground). This interconnection shall be at the power source only. Static bleed resistors of 10k-110k ohms are not considered to violate the single point ground. Other ground connections with equivalent isolation shall be handled on a case-by-case basis.

Ungrounded circuits, capable of building up static charge, shall be connected to structure by static bleed resistors of between 10k and 110k ohms.

Structural ground shall not be used as return for pyrotechnic circuitry.

Source circuits shall terminate in a connector with socket contacts.

Firing circuit design shall preclude sneak circuits and unintentional electrical paths due to ground loops, failure of solid state switches, etc.

Watchdog circuits which automatically shut down or disable firing circuitry when certain parameters are violated are disallowed.

Firing circuits that do not share a common fire command shall be electrically isolated from one another such that current in one firing circuit does not induce a current greater than 16.5dB below the no-fire current level in any other firing output circuit.

The housing or enclosure of electrical pyrotechnic circuit elements shall be bonded in accordance with class “R” bonding per NASA-STD-4003.

Firing output circuits shall be physically separated from all other types of circuits.

Fusible resistors (fusistors) shall be included only where necessary: to prevent high current surges during EED firing, to limit current, and to interrupt flow in the event of a post-firing short in the EED.

3.9.2.2 Arming Circuits

Control circuits shall include an arming circuit that is energized by a separate signal or action before the initiation of the firing signal. Pyrotechnic firing circuits shall be designed so circuits are not armed until necessary. Provisions shall be made to disarm pyrotechnic devices promptly when no longer needed.

3.9.2.3 Switches

Control circuit arm switches, firing switches, command receiver power switches (if used), and arm and disarm position control switches shall be capable of being locked or safed in the OFF (disarm) position and shall be located in a common area accessible to the crew.

3.9.2.4 Safing

Safing of firing circuits shall be accomplished by removal of the arm command.

3.9.2.5 Monitor Circuits

Each parameter measurement made by a monitor circuit must show the status of the parameter. Each monitor circuit must be independent of any firing circuit. A monitor, control, or checkout circuit must not share a connector with a firing circuit. A monitor circuit must not route through a safe-and-arm plug. Any monitor current in an EED system firing line shall be limited to 50 mA or one-tenth of the no-fire current of the EED whichever is less. Monitor circuits and test equipment that applied current to the bridgewire shall be designed to limit the open circuit output voltage to one volt. Resolution, accuracy, and data rates for each monitoring circuit must provide for detecting whether performance specifications are satisfied and detecting any out-of family conditions.

3.9.2.6 Timing Circuits

Timing circuits used as logic for firing pyrotechnic devices shall be designed to be fail-safe. A single failure mode shall not result in an unsafe condition.

3.9.2.7 Control Circuits

It shall be demonstrated that command and control interfaces with the host vehicle that are used for any arming or firing functions in the payload cannot be actuated or triggered by return currents flowing in the host vehicle or payload structure. Use of differential drivers and receivers, transformers or optical couplers, or other floating control circuits are possible means of accomplishing this.

Control circuits shall be electrically isolated so that a stimulus in one circuit does not induce a stimulus greater than 16.5dB below the actuation level in other any firing circuit.

3.9.2.8 Wiring and Connectors

Shielded twisted pairs shall be used for wiring unless other configurations can be shown to be more effective. Firing circuit wiring shall be routed separately (in separate trays or conduit) from all other current carrying circuits including electrical power, electrical control, RF transmission lines, and monitoring circuitry. Circuits routed through a single multi-circuit connector do not satisfy this requirement.

There shall be no splices used to join elements of ordnance cables. A connector shall be provided wherever mating or demating of a circuit is required.

The circuit assignments and isolation of pins within any EED circuit connector shall be such that any single short circuit occurring as a result of a bent pin or contamination will not result in more than 50 milliamperes (mA) or one-tenth of the no-fire current, whichever is less, applied to any electroexplosive device. There shall be only one wire per pin, and in no case shall a connector pin be used as a terminal or tie-point for multiple connections. Spare pins shall not be populated in connectors which are part of firing output circuitry.

All connectors used with the EEDs shall:

a. Be approved by the responsible NASA center

b. Have a stainless steel shell or suitable electrically conductive finish

c. Complete the shell-to-shell connection before the pins connect, and

d. Provide for 360 degree shield continuity

3.9.2.9 Qualification

All wiring, including any cable and all connectors that interface with any pyrotechnic system component must provide for the component, wiring, and connectors to satisfy the qualification tests required of the pyrotechnic component.

3.9.2.10 Shielding

The firing circuit including the EED shall be completely shielded or shielded from the EED back to a point in the firing circuit at which isolators eliminate RF entry into the shielded portion of the system. Isolators which provide 20 dB attenuation (regardless of source and load impedances) at all frequencies of the expected electromagnetic environment shall be considered acceptable. The adequacy of the RF protection provided by these isolators can also be demonstrated by test or analysis for each specific usage (i.e., the necessary protection is dependent on the configuration of unshielded circuits connected at this point and the expected electromagnetic environment).

Cable shielding shall provide a minimum of 85 percent of optical coverage. The method for determining optical coverage shall be in accordance with FED-STD-228, Cable and Wire, Insulated; Methods of Testing. Shields terminated at a connector shall provide 360 degree continuous shield continuity without gaps.

With the exception of cable shielding there shall be no gaps or discontinuities in the shielding, including the termination at the back faces of the connectors, nor apertures in any container which houses elements of the firing circuit.

Shields shall not be used as intentional current-carrying conductors, but may be multiple-point grounded to structure.

3.9.2.11 Dielectric Withstanding Voltage

The dielectric withstanding voltage between wire shields and conductors and between each connector pin must withstand a minimum workmanship voltage of at least 1,500 volts, direct current, or 150 percent of the rated output voltage, whichever is greater.

3.9.2.12 Duty Cycles

If any wiring or connector will experience loads with continuous duty cycles of 100 seconds or greater, that wiring or connector, including each connector pin, must have a capacity of 150% of the design load. If any wiring or connector will experience loads that last less than 100 seconds, all wiring and insulation must provide a design margin greater than the wire insulation temperature specification.

3.9.2.13 Pull Force

All wiring, including any cable or connector, must satisfy all its performance specifications when subjected to the pull force of no less than twice the maximum predicted level during transportation and installation and any additional handling environment that the component could experience undetected.

3.9.2.14 Redundant Circuits

Redundant circuits that can affect pyrotechnic system's reliability during flight must not share any common wiring harness or connector.

3.9.2.15 Reliability

Each connector that can affect a pyrotechnic system component's reliability during flight must not have a single failure point that would:

a. Inhibit functioning of the system during flight; or

b. Produce an inadvertent initiation of the system that would endanger the public.

3.9.2.16 Locking

All connectors must positively lock to prevent inadvertent disconnection during launch vehicle processing and flight.

3.9.2.17 Installation

The installation of all wiring, including any cable, must protect against abrasion and crimping of the wiring.

3.9.3 Safe and Arm Devices (S&A)

S&A containing internal EEDs shall be designed to meet class “R” electrical bonding (2.5 milliohms) per NASA-STD-4003.

Soldering of electrical connections shall comply with IPC J-STD-001ES, Joint Industry Standard, Space Applications Electronic Hardware Addendum to IPC J-STD-001E Requirements for Soldered Electrical and Electronic Assemblies.

3.9.3.1 Flight Termination Safe and Arm Devices

S&A devices used in the flight termination system shall conform to AFSPCMAN 91-710 and NPR 8715.5.

3.9.3.2 Non-Flight Termination System Safe and Arm Devices

S&A devices not used for flight termination shall meet, as a minimum, the following requirements.

a. The S&A device(s) shall, by means of a mechanical barrier, prevent propagation of the explosive train when one or more initiators are fired with the S&A device in the safe position.

b. The S&A device shall be capable of remote positioning from safe-to-arm and arm-to-safe through simplex command and control circuits and simplex actuation devices.

c. The S&A device shall provide remote, simplex electrical position indication. The position indicator switches shall be attached to or directly actuated by the mechanical barrier.

d. The S&A device shall provide direct visual position indication. The “S” shall be visible in the safed position and the “A” shall be visible in the armed position. The armed indication (“A”) shall not be visible unless the device is in such a position that the pyrotechnic train allows propagation past the mechanical barrier. The visible indicator shall be readily discernible at least 15 degrees from a line-of-sight normal of the center of the indicator. It shall also be readable at a distance of 1.5 m (4.92 feet) away from the S&A. The visible indicators shall be highlighted using internationally recognized colors, red background with a black "A" for “armed” and green background with a white "S" for “safe.”

e. If no visual indication of safe or arm appears in the indicator window the device is in between the safe and arm positions or partially armed. The S&A is considered “not safe” or “armed” if the indicator does not show “safe.” A partially armed S&A device shall be capable of remote electrical arming and safing.

f. The S&A device shall incorporate a positive mechanical linkage to maintain the device in either full armed or safed position. Electrical arming and both electrical and mechanical safing shall be capable of overriding this mechanical linkage.

g. The S&A device shall be provided with a mechanical lock pin which, when manually installed, shall prevent rotation of the barrier. The pin may be installed while the device is in any position between full safe and full arm and when installed shall return the device from any position to the safe position without passing through the arm position.

h. The S&A device mechanical lock pin shall not be removable when the arm command circuit is energized, but can be removed after de–energizing.
i. The S&A device shall prevent manual arming.

j. The S&A device electrical control, monitor, and EED (if internal) circuitry shall be environmentally sealed within the S&A.

k. The S&A shall have independent and isolated circuits. Connectors shall be required for EED command and monitoring and for barrier command and monitoring.

l. The ignition of one initiation path shall not ignite or dud any remaining paths. This shall be verified by qualification testing.

m. With the mechanical lock pin installed, the application of the arm command for one hour shall not degrade the electrical or pyrotechnic performance of the S&A device.

n. The S&A shall have a demonstrated cycle life of 1000 safe to arm transitions, or five times the number of transitions predicted during its design life, whichever is greater, without failure or degraded performance. The S&A shall be capable of being manually positioned to safe during any phase of this cycle life. Cycle life shall be demonstrated during qualification tests. Verification shall be by post-test disassembly and inspection.

o. The S&A shall be capable of meeting all performance requirements after application of maximum operational voltages for five (5) minutes with the mechanical lock pin installed. The S&A shall prevent degradation or premature ignition of any explosive component within the S&A when maximum operational voltages are applied to control circuits for one (1) hour with the mechanical lock pin installed.

p. Test and analysis shall be performed to determine the limits of all possible barrier misalignments relative to the safe and arm positions to establish performance margins for both inhibit reliability and energy transfer reliability.

q. All lots of rotor leads or internal ignition assemblies shall be acceptance tested as separate components. The rotor leads or ignition assemblies shall be qualified as an installed component in the S&A.

3.9.3.3 Interrupters

Interrupters do not contain integral EEDs. Interrupters are used to isolate primary explosives from downstream secondary explosives (e.g. lanyard pull initiator (LPI) from a destruct charge). An electro-mechanically actuated interrupter shall meet all applicable S&A requirements in this section.

Interrupter barrier functionality tests shall be performed to demonstrate the interrupter barrier prevents detonation propagation. Containment tests shall be performed to demonstrate the interrupter will not fragment when all interfacing and internal pyrotechnic components are initiated.

Interrupter performance margin for detonation transfer shall be demonstrated by gap test. Interrupters used in FTS shall meet the requirements of AFSPCMAN 91-710 and NPR 8715.5.

3.9.4 Explosive Transfer Lines (ETL)

ETL used in FTS shall conform to AFSPCMAN 91-710 and NPR 8715.5.

End-to-end detonation transfer is the preferred detonation transfer mode but end-to-side and side-to-end transfer modes may be used. Side-to-side detonation transfer modes shall not be used. See Figure 1 for acceptable detonation transfer modes.

As a minimum the following tests shall be performed to demonstrate detonation transfer margin for ETL interfaces where the ETLs are used as either as a donor charge or an acceptor charge.

a. A total of 10 tests shall be performed, five at no greater than ½ times the minimum design gap and five at no less than 4 times the maximum design gap[ATV1]. The test shall be performed using nominal donor and receptor charges. Satisfactory margin is demonstrated if all receptor charges are successfully detonated.

b. A total of 10 tests shall be performed to account for variations in angular and axial offset between donor and acceptor charges. The maximum design tolerance of angular and axial offset (including detonating cord end tip maximum allowable angular offset to the axis of the ferrule) shall be determined and margin shall be established by firing nominal donor and receptor charges at four times angular offset (five tests) and four times axial offset (five tests) at maximum allowable design gap. Testing may combine axial offset and angular offset or these margin conditions may be performed independently. Satisfactory margin is established if all tests are successful.

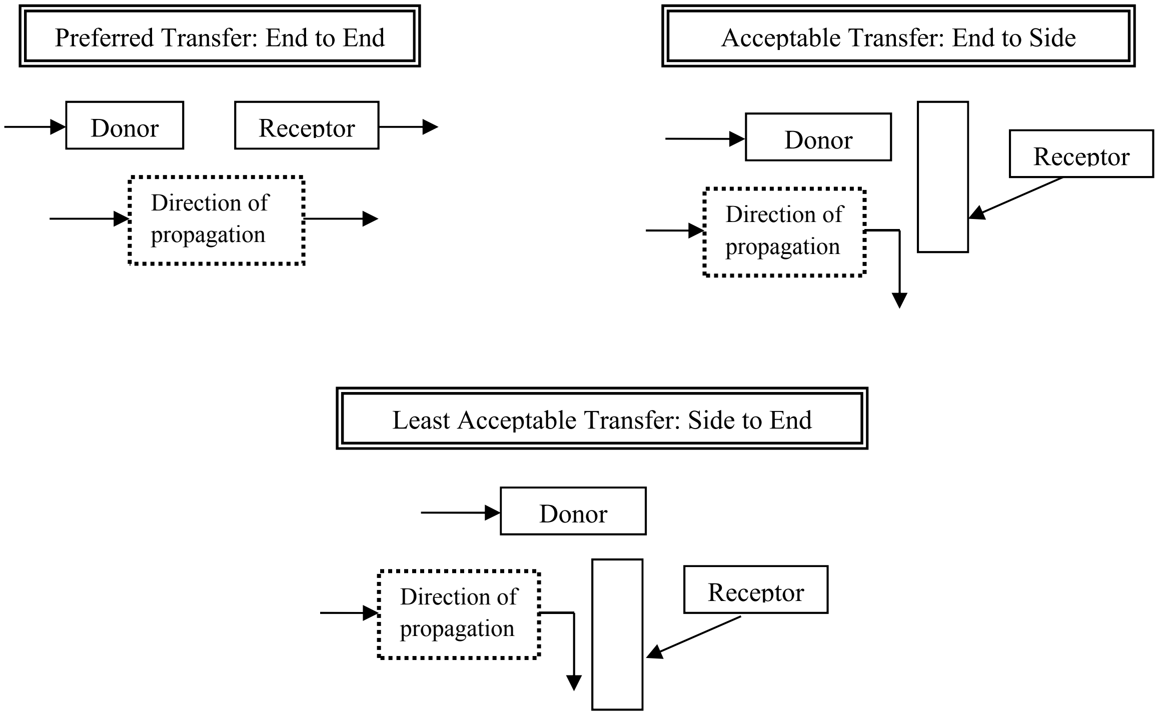

Figure 1. Acceptable Detonation Transfer Modes

The minimum bend radius, maximum and minimum lengths and the amount of slack between tie down points shall be established. Qualification dynamic environmental and functional test setups shall incorporate the minimum specified bend radii and minimum and maximum specified lengths to the first tie down point.

When ETLs are used for redundancy within a pyrotechnic train the operation of one redundant pyrotechnic train shall not disrupt the operation of the secondary pyrotechnic train.

3.9.5 Booster Charges

Booster charges are explosive charges subsequent to the first element of a pyrotechnic train that ignite or detonate a main explosive charge or increase the energy output to a subsequent charge within a pyrotechnic train. Booster charges used for FTS shall comply with AFSPCMAN 91-710 and NPR 8715.5 requirements. Performance margin for booster charges that are part of a pyrotechnic train and are not an integral part of an EED shall be demonstrated by explosive transfer margin testing. The booster charge shall have acceptable performance when initiated by a donor charge loaded to 80% of the design minimum explosive weight. The booster charge shall successfully transfer detonation to the acceptor charge when loaded to 80% of the design minimum weight. If it is impractical to reduce the booster charge explosive weight based upon the booster charge design then margin shall be demonstrated by gap or barrier tests.

3.9.6 Shaped Charges

Shaped charges used for FTS shall comply with AFSPCMAN 91-710 and NPR 8715.5 requirements.

The requirements for shaped charges apply to both the linear shaped charge, the conical shaped charge, and pancake style charges. The charge holder or locating attachment fitting for the shaped charge shall maintain the shaped charge standoff from the target material as specified in the flight configuration. The conical shaped charge shall penetrate a minimum of 150% of the specified flight target material when positioned at the specified standoff height. The linear shaped charge shall sever 150% of the specified flight target material when positioned at the specified standoff height[GKK(2]. These requirements apply for non-FTS shaped charges.

3.9.6.1 Linear Shaped Charges (LSC)

A production lot shall consist of all LSC produced in a single production run. It may consist of LSC made from more than one tube; however, only one lot of bulk explosive and tube materials shall be used in one lot of LSC. A tube shall be a length of tubing loaded with explosive material before being reduced to the required configuration. LSC charge holders shall be designed to permit inspection of the standoff or provide dimensional control of the standoff after installation or both. Provisions shall be made to ensure that no contamination enters the LSC apex area after installation into the charge holder or installation of the charge holder into the next higher assembly.

3.9.7 Frangible Devices

Frangible devices have a load carrying web, annulus, or fracture plane such as frangible nuts, separation bolts, and frangible joints. Determination and assessment of fracture critical frangible devices shall be in accordance with NASA-STD-5019, Fracture Control Requirements for Spaceflight Hardware. Nondestructive evaluation of frangible devices determined to be fracture critical shall be in accordance with NASA-STD-5009, Nondestructive Evaluation Requirements for Fracture Critical Metallic Components. Frangible devices shall be designed for a minimum yield factor of safety of 1.1 times the limit load and a design ultimate factor of safety of 1.4 times the limit load. Frangible devices shall have an adequate strength to withstand limit loads without loss of operational capability for the life of the device.

3.9.7.1 Frangible Nuts

Performance margin for the frangible nut shall be performed by function of a production nut with a web thickness 120% of the maximum web thickness of the production nut using a nominally loaded cartridge or booster charge. If multiple cartridges or booster charges are used to achieve redundancy the margin shall be demonstrated by function of a single cartridge or booster charge. This test shall be performed for each production lot of frangible nuts.

3.9.7.2 Separation Bolts

If the separation bolt is a propellant actuated device then the bolt shall be designed to withstand an internal static proof pressure of 1.2 times the maximum operating pressure without deformation or leakage and an internal burst pressure of 1.5 times the maximum operating pressure without structural failure.

Design margin for a propellant actuated separation bolt shall be demonstrated by acceptable performance when functioned with a single pressure cartridge loaded to 80% of the design minimum propellant load weight of the pressure cartridge. If the pressure cartridge design precludes down loading the propellant weight to 80% of the design minimum propellant weight then the fracture groove of the separation bolt shall be increased to a minimum of 120% of the design maximum thickness of the fracture groove and functioned with a pressure cartridge with a nominal propellant load to meet the margin requirement.

Propellant actuated separation bolts with a stroking piston shall be capable of withstanding internal pressures generated in operation with the movable part restrained in its initial position (locked shut) without rupture or the release of shrapnel, debris, or hot gases that could compromise crew safety or mission success. Where applicable, this capability shall be demonstrated with redundant charges operating simultaneously.

Design margin for a separation bolt loaded with primary and/or secondary explosives shall be demonstrated by acceptable function when the fracture groove of the separation bolt is increased to a minimum of 120% of the design maximum thickness of the fracture groove.

The separation bolt shall demonstrate acceptable performance when functioned with 120% of the pyrotechnic load regardless of whether the separation bolt is propellant actuated or actuated with primary and/or secondary explosives.

3.9.7.3 Frangible Joints (FJ)

3.9.7.3.1 Frangible Joint Ring Structure

The frangible joint ring structure shall comply with 3.9.7 for determination of fracture criticality. Verification of ring structure mechanical material properties (tensile strength, ultimate strength, percent elongation, hardness, and fracture toughness) shall be performed upon completion of machining and heat treatment processes. A sacrificial ring structure segment or excess length of flight ring structure segments shall be used for obtaining test coupons for determination of the material properties. The post-fabrication ring structure maximum and minimum material properties shall be documented by the procuring activity and approved by the appropriate NASA center.

3.9.7.3.2 Expanding Tube Assembly (XTA)

A quantitative test methodology shall be established for XTA performance prior to usage of the XTAs in the frangible joint assembly (FJA). The metrics used for XTA performance acceptance test methodology shall be physically measurable, capable of identification of low-margin performance, and capable of being used for qualification and destructive lot acceptance test (DLAT) for production lot manufacture. The XTA functional performance test specimens shall be a minimum of 18 inches in length. Non-destructive evaluation (NDE) of the XTA shall include radiographic inspection (X-Ray and N-Ray); 100 percent of the lot quantity including DLAT test specimens.

3.9.7.3.3 Frangible Joint Assembly (FJA)

The upper and lower performance boundaries, which includes combinations of MDF core load and fracture groove ligament thicknesses, shall be quantified during development testing. The upper performance boundary is defined as the minimum core load that ruptures the XTA in a FJA. The lower performance boundary is defined as the maximum core load that does not fully sever the FJA. Analytical tools/models may be used in lieu of test for evaluation of off-limit parameters to obtain FJA capability and design robustness, once the performance boundaries have been established.

Key characteristics (KC) for the FJA shall be identified within the FJA supplier design drawings. A KC is defined as:A feature of a material, process, or part (includes assemblies) whose variation within the specified tolerance has a significant influence on product fit, performance, service life, or manufacturability. Also, all critical dimensions shall be verified at incremental locations along the ring structure to insure they are within tolerance.

Each segment of the FJA shall be initiated at both ends of the segment. If redundant XTAs are used in the FJA it is acceptable to initiate only one end of each of the redundant XTAs, preferably opposing ends. The skew time between initiations of each end of a single XTA FJA segment shall be no greater than 2 milliseconds.

The qualification test or DLAT test specimens shall be a minimum of 18 inches in length and there shall be at least one test specimen in qualification test or DLAT, which correlates to a flight segment.

All FJAs shall follow the test and inspections requirements per NASA/TP-2015-218571, Test and Inspection Requirements for FJs used in Human-rated Spacecraft Applications.

Each FJA flight segment and each qualification test or DLAT test specimen shall be 100 percent radiographic inspected (X-Ray and N-Ray) as part of the NDE acceptance test.

3.9.8 Cartridge Actuated Devices (CAD)/Propellant Actuated Devices (PAD)

Cartridge/propellant actuated devices are pyrotechnically actuated devices that have moving parts and are actuated by the pressure output from one or more separable pressure cartridges. Examples include thrusters, separation nuts, pin-pullers and pin-pushers, cutters, and pyrovalves. Determination and assessment of fracture critical cartridge actuated devices shall be in accordance with NASA-STD-5019. Nondestructive evaluation of cartridge actuated devices determined to be fracture critical shall be in accordance with NASA-STD-5009.

If the CAD/PAD is designed to carry a load then the CAD/PAD shall be designed for a minimum yield factor of safety of 1.1 times the limit load and a design ultimate factor of safety of 1.4 times the limit load. These devices shall have an adequate strength to withstand limit loads without loss of operational capability for the life of the device.

The CAD/PAD shall be capable of withstanding 1.5 times the specified maximum allowable installation torque without physical damage.

CADs/PADs shall be designed to withstand an internal static proof pressure of 1.2 times the maximum operating pressure without deformation or leakage and an internal burst pressure of 1.5 times the maximum operating pressure without structural failure. Design margin for the CAD/PAD shall demonstrate acceptable performance when functioned with a single pressure cartridge loaded to 80% of the design minimum pyrotechnic output charge weight. The CAD/PAD shall demonstrate acceptable performance when actuated with a cartridge loaded with 120% of the design maximum output charge weight. If redundant cartridges are used the maximum energy test shall be performed with both cartridges loaded to 120% of the design maximum cartridge output charge weight.

The initiator shall not be used as the sole source of power for the CAD/PAD unless the design margins for minimum and maximum energy specified herein have been demonstrated.

CADs/PADs shall be capable of withstanding internal pressures generated in operation with the movable part restrained in its initial position (locked shut) without rupture or the release of shrapnel, debris, or hot gases that could compromise crew safety or mission success. Where applicable, this capability shall be demonstrated with redundant charges operating simultaneously.

3.9.8.1 Thrust Rail Separation Systems

The thrust rail separation system utilizes a series of frangible fasteners (e.g. solid rivets or bolts) mating fairings (shrouds) sections or launch vehicle staging separation rings together. A bladder is mated to either a propellant loaded external hot gas generator, or internally loaded linear explosive assembly (LEA), for gas generation and bladder inflation. The bladder is placed between the mating separation rings. When expanded from the hot gas generator the bladder causes the frangible fasteners to fracture and separation occurs at the thrust rail separation plane, with the bladder providing force to accelerate the separated structures to a desired velocity. The hot gas generator, or LEA, must be sized accordingly to the size of the bladder, which in turn, is sized to fracture the frangible fasteners and achieve the separation velocity required by a system's design. In addition to achieving a minimum velocity, system-level requirements sometimes include not inducing flexing modes in the separated structures to the extent that detrimental recontact with the vehicle occurs.

Performance margin tests shall be performed at 80% of the design minimum propellant, or LEA, mass at the cold temperature extreme. To ensure the bladder does not rupture tests shall be performed at 120% of the design maximum propellant, or LEA, mass at the hot temperature extreme.

Qualification tests, including dynamic (shock/vibration) and thermal environments followed by functional testing at high and low temperatures, shall be performed on the assembled thrust rail design. Leak requirements shall be established for the bladder and its seals, and pressure tests shall be conducted on the bladder material as well as on the completed thrust rail assembly to ensure leakage does not exceed requirements.

In the case of thrust rails utilizing internally loaded LEA initiated via ETL or Detonators, the LEA shall be redundantly initiated (initiated at both ends). Additionally, the transfer margin requirements of Para 3.9.4 apply.

Each thrust rail flight segment and each qualification test specimen shall be 100 percent radiographic inspected (X-Ray) as part of the NDE acceptance test.

To ensure debris is not generated a mechanism for capturing the fractured fasteners shall be incorporated within the thrust rail subsystem design.

If separation system tipoff is a concern frangible fastener variability shall be determined and optimized to reduce variance to within a limit such that tipoff is eliminated or reduced to a degree it is not a concern. Regardless of tipoff concerns, minimum and maximum frangible fastener strength limits shall be established, and the strength of each lot of fasteners shall be tested on a sampling basis.

A full-scale separation test, reference 4.3.2, shall be performed to ensure the axial velocity and tipoff rates are within specified requirements.

3.9.9 Through Bulkhead Initiators (TBI)

A hydrostatic leak test, in accordance with ASTM E1003, Standard Test Method for Hydrostatic Leak Testing, Pressure Drop Indication Method, shall be performed on the TBI body to ensure bulkhead integrity prior to loading of explosive or pyrotechnic materials. The leak test shall be performed at 1.2 times the maximum operating pressure. Design margin for transfer across the TBI bulkhead shall be verified by over loading and under loading the charge weights or by increasing or decreasing the bulkhead thickness or a combination thereof.
For demonstrating margin by charge weight the following is applicable.

a. The TBI shall be designed to perform acceptably and demonstrate proper transfer across the bulkhead by loading the donor and acceptor charges to a minimum of 120% of the maximum allowable charge weight in each cavity using the force method. There shall be no leakage through the bulkhead after this test.

b. The TBI shall demonstrate proper transfer across the bulkhead when both the donor and acceptor charges are loaded to a maximum of 80% of the minimum design load weight.

For demonstrating margin by the bulkhead thickness the following is applicable.

a. The TBI shall demonstrate proper transfer across the bulkhead when the bulkhead thickness is increased to 120% of the maximum design thickness and the donor and acceptor charges are loaded to nominal charge weights.

b. The TBI shall demonstrate proper transfer when the bulkhead thickness is decreased to 80% of the minimum design thickness and the donor and acceptor charges are loaded to the nominal charge weights. There shall be no leakage through the bulkhead after this test.

If the TBI is used as a pressure retaining device then the bulkhead integrity after firing shall be verified. This test shall be performed for each lot of TBIs utilized in pressure retention applications.

3.9.10 Mechanically Actuated Devices

Mechanically actuated devices used in an inadvertent separation destruct system (ISDS) or autonomous flight safety system (AFSS) shall conform to AFSPCMAN 91-710 and NPR 8715.5. Mechanical initiation shall be accomplished by using percussion primers conforming to JSC/SKD26100132, Performance Specification for National Space Transportation System (NSTS) Use of Percussion Primers. The percussion primers shall be certified to this specification prior to installation into the mechanically actuated device[ATV3]. If the mechanically actuated device is a cutter then the cutter shall demonstrate margin by cutting 120% of the maximum target material thickness. Appropriate protection should be provided to ensure electrical shorting during and after severance if electrical wires are the target material.

3.9.11 Bonding for Non-Electrically Initiated Pyrotechnic Components

Non-electrical initiated pyrotechnic components shall be designed to meet class “S” bonding (1.0 ohm) in accordance with NASA-STD-4003. Exceptions to this requirement shall be evaluated on a case-by-case basis by the appropriate NASA center.

3.9.12 Human Engineering

Pyrotechnic systems and components shall be ergonomically designed and developed to preclude human error, incorrect installation and assembly.

Pyrotechnic systems should be designed for optimum accessibility of all subsystems, assemblies, and components. Components should be located near existing access panels and work platforms, where possible. Cartridges and independently installed initiators should be located near the first point of entry to facilitate installation and change-out.

Visual indicators shall be always visible through an access in an assembled vehicle configuration. Safing pins shall be capable of installation into and removal from a completely assembled vehicle. Explosive systems protected by an electro-mechanical S&A shall be capable of being manually safed during any phase of ground operations.

3.9.13 Threaded Parts

Thread sizes shall not be duplicated if the possibility of incorrect installation exists. All threaded parts shall include a locking feature. Locking features shall be approved by the appropriate NASA center.

3.10 Materials

All materials shall be capable of withstanding the ground and flight environments specified for the device. Requirements for materials and processes shall be in accordance with NASA-STD-6016, Standard Materials and Processes Requirements for Spacecraft. All explosive materials, including propellants and pyrotechnics, shall be approved by the appropriate NASA center.

Propellants and pyrotechnic materials that are manufactured to industry-accepted or NASA standards are recommended. Only one lot of each explosive, propellant, or pyrotechnic material shall be used in the manufacture of any production lot of devices.

3.10.1 Material Selection

Parts, materials, and processes shall be selected and controlled in accordance with established and documented procedures to satisfy the requirements specified herein. Selection and control procedures shall emphasize quality and reliability to meet mission requirements and to minimize life cycle costs. An additional objective in the selection of parts, materials, and processes is to maximize commonality and thereby minimize the variety of parts, related tools, and test equipment required in the fabrication, installation, and maintenance of the vehicle. The parts, materials, and processes selected shall meet the functional performance, safety and reliability, contamination, and strength requirements of the end item or the explosive device during its design life, including all environmental degradation effects.

3.10.2 Material Compatibility

All materials used in pyrotechnic devices shall be compatible with each other to the extent that no reaction occurs that might adversely affect the component or system performance or safety.

Examples of incompatibility include, but are not limited to, use of lead azide in contact with copper or copper alloys, zinc or zinc alloys, or Cyclotetramethylenetetranitramine (HMX).

Compatibility testing shall be conducted on all explosive and component interfaces, including sealing materials, where test data or analyses for demonstrating compatibility of components is not available.

3.10.3 Explosives

The number and types of explosives (both primary and secondary) should be minimized. Each lot of high explosives shall be certified by test/analysis for conformance to applicable material specification requirements. For high explosives processed after material specification certification, test/analysis data shall be provided demonstrating processed material meets the original material specification requirements. Whenever practical, high explosives should be procured directly from the original manufacturer. A certification of conformance, including original test/analysis results from the explosive manufacturer, shall be supplied with each lot of high explosive material. The explosive material shall have a shelf life of 5 years from the date of manufacture. The shelf life of the explosive material may be extended for an additional 5 years by test/analysis of a sample of the lot of explosive material demonstrating conformance to the applicable material specification requirements. The number of shelf life extension tests/analyses for a lot of explosive material is unlimited. The use of primary explosives shall be limited to applications where it has been determined that a less sensitive material will not meet the reliability requirements of the application. In applications where Hexanitrostilbene (HNS) is used the material shall conform to JSC 65877.

3.10.4 Propellants

Each lot of propellant material used shall be accompanied by documentation stating the following as a minimum:

a. Constituents of material and percentages used

b. Particle size and dimensions

c. Heat of explosion (bomb calorimetric) test performed per MIL-STD-286, Military Standard Propellants, Solid: Sampling Examination and Testing.

The shelf life of the propellant material shall be determined by test and/or analysis. Results from the test/analysis shall be used for determining re-certification test methodology.

3.10.5 Pyrotechnic Materials

Each lot of pyrotechnic material used shall be accompanied by documentation stating the following as a minimum:

a. Constituents of material and percentages used

b. Particle size and dimensions

c. Heat of explosion (bomb calorimetric) test performed per MIL-STD-286, Military Standard Propellants, Solid: Sampling Examination and Testing, is mandatory for thermite mixtures. Applicability of the heat of explosion test for other pyrotechnic materials shall be determined by the appropriate NASA center.

The shelf life of the pyrotechnic material shall be determined by test and/or analysis. Results from the test/analysis shall be used for determining re-certification test methodology.

3.10.6 Autoignition

Pyrotechnic components shall not autoignite when exposed to thermal environments that are 30° Celsius (C) (54° Fahrenheit (F)) above the maximum predicted temperature during worst case service life.

Pyrotechnic components shall not decompose when exposed to thermal environments that are 30°C (54° F) above the maximum predicted temperature and 10°C (18° F) below the minimum predicted temperature during worst case service life.

3.10.7 Fungus Resistance

Materials that are non-nutrients to fungi, as identified in MIL-HDBK-454, General Guidelines for Electronic Equipment, Guideline 4, Fungus-Inert Materials, Table 4-I, Group I, shall be used. Lubricants shall have been demonstrated to be non-nutrient to fungi by test or analysis in accordance with MIL-HDBK-454, Guideline 4, Fungus-Inert Materials.

3.10.8 Metallic Materials

3.10.8.1 Dissimilar Metals

Dissimilar metals shall not be used in intimate contact with each other unless protected against electrolytic corrosion. Corrosion control of galvanic couples shall be in accordance with NASA-STD-6012, Table 2, Corrosion Protection for Space Flight Hardware. Galvanic couples for alloy combinations not listed in NASA-STD-6012 shall not exceed 0.25 volts.

3.10.8.2 Protective Coatings, Finishes, and Plating

All pyrotechnic components shall be finished to provide protection from corrosion in accordance with the requirements of NASA-STD-6012, Corrosion Protection for Space Flight Hardware. All corrosion-resistant steels shall be passivated after machining.

3.10.8.3 Stress Corrosion

MSFC-STD-3029, Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments, shall be used to select metallic materials to control stress corrosion cracking of metallic materials in sea and air environments.

3.10.8.4 Heat Treatment

Heat treatment of aluminum alloy parts shall meet the requirements of SAE AMS2772, Heat Treatment of Aluminum Alloy Raw Materials, SAE AMS2770, Heat Treatment of Wrought Aluminum Alloy Parts, or SAE AMS2771, Heat Treatment of Aluminum Alloy Castings.

Steel parts shall be heat-treated to meet the requirements of SAE AMS-H-6875, Heat Treatment of Steel Raw Materials, or SAE AMS2759, Heat Treatment of Steel Parts, General Requirements.

Tensile test data shall be required for component parts manufactured from material that is heat-treated after receipt from the mill. Tensile test data shall also be required for component parts that are required to withstand operating pressures or primary structural loads or both.

A minimum of three standard tensile coupons, in accordance with ASTM E8/E8M, Standard Test Methods of Tension Testing of Metallic Materials, shall be processed with the component parts. Before acceptance, the supplier shall conduct tensile tests on each coupon as defined by the procuring agency, or if no specific direction is provided, tensile testing shall be completed in accordance with ASTM E8/E8M.

The following minimum data shall be obtained from the test coupons and recorded on the lot acceptance data sheets:

a. Ultimate Strength

b. 0.2 % Offset Yield

c. Elongation

d. Reduction of Area (When required by material specification)

Failure to meet the minimum material tensile acceptance criteria shall be cause for rejection of the component parts associated with those test coupons.

For pyrotechnic device metallic component parts that are not heat-treated after machining and are not exposed to operating pressures or primary structural loads, the standard mechanical properties test report delivered with the raw material will suffice, provided all test data required by the material specification are included in the report. Caution is warranted for material properties that significantly exceed minimum specification values. Sensitivity to stress corrosion cracking, loss of ductility and fracture toughness, and degraded mechanical properties at cryogenic temperatures, may result in some alloys that are over-strengthened. For example, for quenched and tempered alloy steels, precipitation hardened steels, heat treatable aluminums etc., the durability and behavior in service environments may be adversely affected when they are strengthened significantly beyond their minimum strength requirements.

3.10.8.5 Chemical Analysis

Actual chemical analysis reports for all materials shall be required. For components where chemical analysis data are not available, the appropriate NASA center may authorize substitution of a manufacturer's Certificate of Compliance (COC).

3.10.9 Non-Metallic Materials

Where lubricants are used NASA-TM-86556, Lubrication Handbook for the Space Industry, Part A: Solid Lubricants, Part B: Liquid Lubricants and NASA/CR-2005-213424, Lubrication for Space Applications, shall be used in the evaluation and selection of lubricants. Adhesives and sealants used in pyrotechnic devices shall be compatible with the explosive materials contained within the component.

3.11 Manufacturing

3.11.1 Configuration Control

Manufacturing and process controls including referenced specifications, procedures, drawings, and supporting documentation shall establish the qualified baseline ensuring subsequent production items are equivalent in performance, quality, configuration, and reliability to initial production items used for qualification. This baseline shall be documented and controlled by the supplier. Any change to this qualified baseline shall be documented by the supplier and shall be submitted to the appropriate NASA center for approval. Approved changes to the qualified baseline shall provide the basis for flight certification for subsequent production lots.

3.11.2 Drawing Standards

Throughout the life cycle of the hardware, the design entity shall maintain revision and release configuration control of their drawings and associated files. Drawings shall comply with ASME Y14.100, Engineering Drawing Practices. The design entity is responsible for certifying appropriate internal technical reviewers for compliance.

3.11.3 Production Lot

Each piece, part, component, subassembly, or device shall be of the same design and construction, fabricated in one unchanging and essentially continuous manufacturing process and submitted for acceptance at one time. Within a production lot of devices, single melt and heat lot control shall be established for metallic components that are fractured by the action of a pyrotechnic charge. Single lot control requirements of other non-explosive components used in a lot of devices shall be determined, documented, and approved by the appropriate NASA center. Factors such as component function in end item performance and effectiveness of destructive tests in screening defective components will be considered in establishing single lot control requirements. Only one lot of each explosive or pyrotechnic material shall be used in a lot of explosively loaded components or devices. Only one lot of explosively loaded components, such as MDF, shall be used in the manufacture of a lot of the next higher assembly, such as linear charge assemblies. This restriction shall apply to all successive levels of assembly, including the final acceptance level, but shall not apply to initiator lots integrally installed (married) into cartridge assemblies.

Each lot should be sized to include flight, flight spares, test article, and age life samples for a selected number of vehicles, plus parts necessary for other uses when required. Specific direction from the appropriate NASA project office is required for deviations from these sizing requirements with respect to quantity of flight spare units. The following criteria should be considered when determining lot size:

a. Life of the part and component thereof to prevent life expiration before the last scheduled use of the lot

b. Economic benefits of large quantity procurement

c. Potential cost and schedule impact of a lot-associated failure

3.11.4 In-Process Inspection and Test

3.11.4.1 Core Charges

As a minimum, core charges (MDF, Flexible Confined Detonating Cord (FCDC), Shielded Mild Detonating Cord (SMDC), Confined Detonating Fuse (CDF), Confined Detonating Cord (CDC), and LSC) shall be tested as specified herein.

A production lot shall consist of all CDC, CDF, MDF, SMDC, FCDC, or LSC produced in a single production run. It may consist of CDC, CDF, MDF, SMDC, FCDC, or LSC made from more than one tube; however, only one lot of bulk explosive and tube materials shall be used in one lot of CDC, CDF, MDF, SMDC, FCDC, or LSC. A tube shall be a length of tubing loaded with explosive material before being reduced to the required configuration.

3.11.4.1.1 Core Weight

Test samples shall be cut from each tube. Each sample shall be a 7.62 cm (3 inch) minimum length. For core weights of 250 grains per foot or larger, 2.54 cm (1inch) minimum samples shall be taken instead of 7.62 cm (3 inch) samples. Samples shall be from each end of each tube and at other specified intervals. Intervals shall be determined by the appropriate NASA center. Each manufacturing length shall have core weight samples taken from both ends.

Linear Shaped Charge (LSC)/cord core weight samples exceeding the tolerance identified in the end item procurement specification shall result in a rejection of 30.48 m (100 foot) minimum segment on both sides of the failed sample or a manufacturing length on both sides of the failed sample, whichever is less.

3.11.4.1.2 Sheath Geometry

The MDF, CDF, or CDC sheath geometry, thickness and concentricity shall be established. The LSC sheath geometry, thickness and apex thickness shall be established.

3.11.4.1.3 Splicing

Core charges shall not be spliced.

3.11.4.1.4 Bending

When the application includes bends, bend tests shall be performed as a part of qualification and lot acceptance. A bend radius of 5 cord diameters or less, measured to the center of the cord, constitutes a bend.

Test samples shall be cut from each tube. Each test sample shall be 38.1 cm (15 inches) minimum length. Samples shall be from each end of each tube and at other specified intervals. Intervals shall be determined by the appropriate NASA center. These tests shall be performed before determining the detonation velocity.

3.11.4.1.5 Detonation Velocity

The detonation velocity shall be established for each component that uses a core charge with a secondary explosive. The established detonation velocity shall have a tolerance sufficient to detect unacceptable performance. When a lot of CDC, CDF, MDF, SMDC, FCDC, or LSC contains multiple tubes, only the tube from which the failed detonation velocity sample is taken shall be rejected. The number and location of detonation velocity samples required for a lot of CDC, FCDC, SMDC, CDF, MDF, or LSC shall be established by the responsible NASA center. Where bending is required, the detonation velocity test shall performed on the bend samples. The date the detonation velocity tests are completed shall be used for establishing the age life of all CDC, FCDC, SMDC, CDF, MDF, and LSC. The velocity of detonation test shall be completed within one year of the loading of the linear product.

3.11.4.2 Weight Verification

For each pyrotechnic component the weight of each individual charge of the explosive, pyrotechnic material or propellant shall be determined by weighing the component before and after loading. The weight of the explosive, pyrotechnic material or propellant shall be recorded in the manufacturing records. This requirement does not apply to core charges.

3.11.5 Identification and Marking

Pyrotechnic components shall be marked permanently and legibly in accordance with MIL-STD-130, Identification Marking of U.S. Military Property or MIL-STD-1168, Ammunition Lot Numbering and Ammunition Data Card. At a minimum the identification shall include the Part Number (P/N), Lot Number (L/N), vendor Contractor and Government Entity (CAGE) code, and serial number. The serial numbers within a lot of pyrotechnic components shall be consecutive and shall not be repeated from one lot of pyrotechnic components to a follow-on lot. Shipper identification tags shall show all information required by the purchase order.

3.11.5.1 Lot Designators

Lot numbers shall be assigned to each production lot in accordance with MIL-STD-1168.

3.11.6 Color Coding

Flight operational units shall be the natural color of the body material (stainless steel, aluminum, etc.). Painting pyrotechnic devices to limit reflective properties or heat absorption is not permitted unless it is approved by the respective NASA center before use. The following items shall be painted blue:

a. Inert expended devices that will not be scrapped immediately

b. Non-flight mockups or dummies of normally loaded pyrotechnic devices

c. Normally inert lot certified devices subsequently found to be discrepant by a Material Review Board (MRB)

The following items shall be painted red:

a. All loaded devices procured for testing, not intended for flight, shall be color coded at the supplier facility

b. Any live lot certified device subsequently found to be discrepant by a MRB

3.11.7 Contamination and Foreign Object Debris

Contamination control and Foreign Object Debris/Damage (FOD) are of particular concern while working with pyrotechnic systems. MSFC-STD 246, Standard Design and Operational Criteria for Çontrolled Environmental Areas, and MSFC-STD-3598, Standard for Foreign Object Damage/Foreign Object Debris (DOD) Prevention, shall be used as guidelines in all processing and handling of pyrotechnic system. Care should be taken to ensure that there is no contamination of explosive materials or FOD on the mating surfaces at the time of assembly. In all assembly operations involving explosively loaded parts, positive protective measures should be taken to ensure potentially degrading fluids, moisture, foreign materials, or other contaminants are not trapped or sealed into assemblies. To prevent contamination of the explosive material(s) with liquids, the supplier's applicable manufacturing procedures shall specify that each device shall be completely dry before sealing and that no liquids are to be used for cleaning or sealing preparation after installation of the explosive materials and before sealing. The procedures shall specify that the immediate area of explosive operations shall be free of liquids, such as methanol, Freon, solvents, oils, and alcohol. In the event that spillage of explosive material necessitates cleaning of the loading area with liquids, all parts shall be removed from the area until cleaning is completed, the area is completely dry, and the liquids have been removed. If liquids are used to clean a loaded unit after sealing and before leak testing, any unit that fails leak testing shall not be reworked and shall be rejected.

3.12 Pyrotechnic Systems Handling, Installation, and Checkout Requirements

3.12.1 Handling

Pyrotechnic system, subsystem, or component transportation, receipt, and storage shall be performed in accordance with DoD 6055.9-STD, AFMAN 24-204, Preparing Hazardous Materials for Military Air Shipments, CFR 49, Transportation, AFMAN 91-201, as applicable. Handlers and inspectors of pyrotechnic components shall be certified in accordance with MWI 3410.1, Personnel Certification Program, or equivalent.

3.12.1.1 Transportation

All motor vehicle shipments are governed by Department of Transportation (DOT) and shall comply with DOT, State, and municipal regulations. Compliance with MPR-6000.1, Transportation, or equivalent shall apply. The transportation of explosives by rail, air, vessel, and public highway shall comply with DOT regulations CFR Title 49 Sections 173.52, 174.81, 175.78, 176.83, and 177.848, and those transported by air shall comply with International Civil Aviation Organization (ICAO) Doc 9284 Technical Instructions for the Safe Transport of Dangerous Goods by Air and International Air Transport Association (IATA) Dangerous Goods Regulations.

3.12.1.1.1 Intra-Facility Transportation

Intra-facility transportation of pyrotechnic components, subsystems, or systems shall be performed in accordance with NASA-STD-8719.12, Section 5J.

3.12.1.2 Receipt

Within 30 days of receipt at the launch facility launch personnel shall facilitate a receiving inspection to ensure no damage has occurred during shipment and that the markings are accurate and legible in accordance with MWI-8715.10 section 6.1.3.1, Explosives, Propellant, and Pyrotechnics Program, or equivalent launch site requirements for receipt of pyrotechnic components. The contractor shall determine the serviceability of the assets and correctness of accompanying documentation. Upon completion of outer container inspection, the contractor shall remove the seals, open container to verify that the quantity, serial number, description part number, lot number and shelf life match the shipping documentation and conforms to requirements. If the item is acceptable, then the contractor shall reseal the container and prepare the item for storage. The contractor shall verify that containers are properly sealed before entering them into permanent storage. Inspection requirements have been met after the aforementioned items are complete and the serviceability inspection has been performed.

3.12.1.3 Storage

Pyrotechnic items onsite shall be stored in an orderly manner in accordance with section 5.5 of MWI-8715.10, Explosives, Propellants, and Pyrotechnics Program, or equivalent launch site requirements for storage of pyrotechnic devices, and incorporate the asset locations in the contractor's accountability system. Monthly inventory listings shall be provided to the contractor and the responsible NASA center personnel.

3.12.2 Installation

3.12.2.1 Service Life

A pyrotechnic component's storage, operating, or service life must not expire before flight. If the pyrotechnic component is beyond service life or it is anticipated it may be beyond service life prior to launch perform service life extension test of the pyrotechnic component in accordance with 4.5.

3.12.2.2 Grounding

Static ground points shall have a resistance to ground of 25 ohms or less. Grounding system megger checks shall not be made after initiators are installed or electrically connected, unless proper fault protection is provided, for example, place fuses in the leads.

3.12.2.3 Stray Voltage Checks

Stray voltage checks shall be performed on all launch vehicle pyrotechnic electrical connectors. These checks shall be made first with power on, then with power off, and include all pin-to-pin and pin-to-case combinations. The power on configuration requires the launch vehicle to be powered up in launch configuration. The power off configuration requires the launch vehicle to be powered down. Power off checks shall be made immediately before ordnance electrical connection. If connections are made in the same general area of the launch vehicle, power off checks shall be made on all of the connectors in that general area before a pyrotechnic component electrical connection is made. These connections shall be made before any electrical configuration or system changes, such as bringing vehicle power back up, occur.

The resulting measured signal (current, voltage, power, energy, etc.) from a stray voltage check shall not be capable of producing a current greater than 20dB below the no-fire current of the EED. The stray voltage test procedure shall specify the maximum acceptable reading. Meters which are used for stray voltage checks shall have a valid calibration seal. The integrity of the meter and test leads shall be demonstrated prior to use. Fixed or facility test instrumentation that are used in place of portable GSE shall have a procedure that verifies the system integrity prior to use.

3.12.2.4 Insulation Resistance

All current carrying components and conductors shall be electrically insulated from each other and system ground. The insulation resistance between all insulated parts, at a potential of 500V, minimum, DC, shall be greater than 2 megohms.

3.12.2.5 Wire Routing

Firing circuit wiring shall be routed separately (in separate trays or conduit) from all other current carrying circuits including electrical power, electrical control, RF transmission lines, and monitoring circuitry.

3.12.2.6 Safing Pins

Safing pins shall be installed in Safe and Arm devices while installed in the launch vehicle, unless undergoing bench or pre-installation test. Prior to installation verify S&A devices are in the SAFE position and "Remove Before Flight" safing pins are NOT removed. Safing Pins shall be removed during closeout activities.

3.12.2.7 Shielding Caps (Shorting Plugs or Faraday Caps)

All electroexplosive devices and safe and arm devices shall have shielding caps attached during storage, handling, transporting, and installation. The shielding cap shall have a solid metal outer shell which makes electrical contact with the EED case in the same manner as the mating connector for the EED.

3.12.3 Checkout

3.12.3.1 ETL

ETL end tips shall be visually inspected for evidence of damage prior to installation into the ETL port. The ETL port shall be visually inspected for foreign debris or moisture prior to installation of the ETL.

3.12.3.2 EED

EEDs shall have their bridgewire resistance measured and recorded by applying a maximum current of 10 mA or 10 % of the maximum no-fire current, whichever is less. The accuracy of the test equipment shall be at least 2 % of the true value and have an open circuit voltage of less than 1 volt.

To verify that sufficient energy is delivered by the firing circuits to initiate flight EEDs, EED simulators shall be installed in place of the flight EEDs.

EEDs shall be installed and electrically connected as late in the countdown as possible. Shielding caps shall not be removed from EEDs until electrical connection to the pyrotechnic train is to be made.

No radio transmissions are allowed within 25 feet of EEDs. These are minimum requirements which do not take into account situations where EEDs are RF sensitive and leads are unshielded. An RF analysis, per MIL-STD 1576 (based on the specific radio, type of pyrotechnics, and area involved), may be performed to reduce this requirement. The analysis shall be approved by the launch facility safety personnel. Local RF silence, within a specified control area, shall be established during electrical connection of pyrotechnic components as an additional safety precaution.

3.12.3.3 Safe and Arm Devices

For each S&A checkout test shall be performed prior to or after installation. The tests shall include:

a. visual check for signs of physical defects,

b. electrical tests which arm and safe the S&A,

c. continuity and resistance checks of EED bridgewires in both "armed" and "safe" positions,

d. tests to verify that the device cannot be electrically or manually armed when the safing pin is installed.

S&A/EED bridgewire continuity and resistance checks shall be performed within 10 work days of launch. If the S&A/EED devices have been electrically connected and the launch subsequently scrubbed, retest may be required.

A rotation test shall be performed on all launch vehicle S&As after installation and prior to final connection to the pyrotechnic train. This test shall be performed using the launch day system configuration, e.g., monitor circuitry, power sources and circuits for cycling the S&A.

The pyrotechnic train shall be disconnected from the S&A output during all checkout operations except for:

a. Single complete rotation test (safe to arm to safe)

b. Final rotation to "ARM" on the last day of the count.

When the S&A device is rotated on the pad, all personnel shall be cleared to a designated area.

3.12.3.4 Cable to Ground Resistance Verification

The resistance of the circuit shields shall be measured between the connector shell and the structure ground before connecting the circuit connector to the initiator. The resistance shall be 1 ohm or less.

3.12.3.5 Pyrotechnic Firing Circuit Resistance

The allowable firing circuit resistance for each circuit shall be established and specified in the applicable test and checkout procedure.

3.12.3.6 Arming and Firing Stimulus Verification

The capability of the firing system to deliver the required firing stimulus to the initiator shall be verified by simulated initiator firing on each firing circuit.

3.12.3.7 Pyrotechnic Firing Circuit Stray Voltage

For electrically initiated pyrotechnics, stray voltage at each pyrotechnic connector shall not exceed 0.05 volts alternating current (Vac) root mean square (RMS) or 0.05 volts direct current (Vdc). Stray voltage with firing system armed shall not exceed 0.05 Vac at each pyro connector between line and ground when loaded with a 1 ohm resistor.

3.12.3.8 Dielectric Withstanding Voltage (DWV)

For electrically initiated pyrotechnics, all pyro wiring, cables, or harnesses shall have Dielectric Withstanding Voltage (DWV) testing performed post installation, repair, rework, and/or replacement. Firing lines of pyrotechnics that are fired every mission and reused shall have a DWV test performed before final connection before each mission. DWV voltage is 1500 Vdc with a minimum 2 sec dwell time at .5 mA or 1 mA leakage current.

3.12.4 Post-Installation Requirements

Each redundant path shall be verified by test or a combination of test and analysis. For test verification, post-mating checkout shall be conducted, end-to-end, after all possible mating connections have been closed out for flight. The path tested shall be from the firing source to the initiator without risk of inadvertent ignition. Successful testing should be performed as late as possible before flight. For installations where end-to-end test is not practical, a combination of test or analysis for each unmated connection shall be performed to address mis-mated[ATV4] or bent pin condition described in 3.12.4.1.

3.12.4.1 Mis-mating or Bent Pin

For any connector or pin connection that is not functionally tested once connected as part of a pyrotechnic system or component, the design of the connector or pin connection must eliminate the possibility of a bent pin, mis-mating, or misalignment. Connector selection specifying it shall be in accordance with MIL-DTL-38999, Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification For, meets the intent of this requirement.

The design of a pyrotechnic system component must prevent undetectable damage or overstress from occurring as the result of a bent connector pin. An inadvertent initiation must not occur if a bent connector pin:

a. Makes unintended contact with another pin;

b. Makes unintended contact with the case of the connector or component; or

c. Produces an open circuit

4.0 VERIFICATION

This section delineates the verification methods (analyses, inspections, and tests) to be performed to verify that the item to be developed or offered for acceptance conforms to the requirements of this specification. The verification phases are categorized as development, acceptance, and qualification. Development includes those activities required to support the design process. Acceptance ensures the quality of the deliverable product. Qualification ensures that the design will satisfy all specified design requirements. Data from development and acceptance test programs may be used to support qualification requirements when such tests are pre-declared in the governing test documentation, approved by the appropriate NASA center, and the appropriate test rigor is applied.

Verification may be accomplished by analysis, test, inspection, or any combination thereof. The methods used to accomplish verification are defined below:

a. A - Analysis is a method of verification by using techniques and tools such as computer and hardware simulations, analog modeling, similarity assessments, and validation of records to confirm that design requirements to be verified have been satisfied. Analysis is the evaluation of the results of multiple tests and analyses at a lower level as it would apply to a higher level of assembly. Analytical methods selected for verification will be supported by appropriate rationale and be detailed in the applicable documents.

b. T - Test is a method of verification wherein requirements are verified by measurement during or after the controlled application of functional and environmental stimuli. These measurements may require the use of laboratory equipment, recorded data, procedures, test support items, or services. For all verification, qualification, and acceptance test activities, pass or fail test criteria or acceptance tolerance bands (based upon design and performance requirements) shall be specified before conducting the test. This will ensure that the actual performance of tested equipment or systems meets or exceeds specifications.

c. I - Inspection is a method of verification of physical characteristics that determines compliance of the item with requirements without the use of special laboratory equipment, procedures, test support items, or services. Inspection uses standard methods such as visuals, gauges, etc., to verify compliance with requirements.

Hardware may be inspected for the following:

a. Construction

b. Workmanship

c. Physical condition

d. Specification or drawing compliance or both

Inspection may be used to confirm that engineering drawings call out proper design and construction features (i.e., materials and processes). Inspection includes a review of the as-built drawings to confirm that a design feature has been incorporated into the design.

4.1 Quality

The quality program shall satisfy the requirements of the tailored edition of SAE AS9100, Quality Management System for Aviation, Space and Defense Organizations, for each vehicle program to ensure that all pyrotechnic components and systems are manufactured in conformance with the requirements of all applicable documents and satisfy design, qualification, and acceptance requirements. These stipulations shall be implemented and maintained for design, development, manufacturing, test, handling, transportation, storage, and installation of the pyrotechnic component.

Sampling inspection shall be in accordance with ANSI/ASQ Z1.4, Sampling Procedures and Tables for Inspection by Attributes. Whenever sampling inspection reveals one or more nonconforming items and the sampling plan does not require rejection of the lot, all items in the lot shall be inspected for the identified nonconforming characteristic.

Calibration of test equipment shall be in accordance with American National Standards Institute/ National Conference of Standards Laboratories (ANSI/NCSL) Z540.3, Requirements for the Calibration of Measuring and Test Equipment.

4.2 Development Requirements

Development tests are conducted to establish design approaches and solutions, determine interface compatibility and margin, establish validity of analytical approaches and assumptions, detect unexpected response characteristics, and demonstrate test approaches for qualification and acceptance. Development tests should incorporate variations in critical dimensions and properties to probe the expected limits allowed by the design specifications.
Development tests used to satisfy a qualification requirement shall meet the following criteria:

a.	Pre-declaration	The intent to use the test for certification is declared before conducting the test
b.	Configuration	Production configuration or approval (where allowed) for differences
c.	Facilities	Facilities have been evaluated by the appropriate readiness review authority and deemed acceptable for the planned testing
d.	Inspection	Required
e.	Test requirement/procedure /pass-fail criteria	Formally approved

f.	Acceptance, pre-functional and post-functional test	Required
g.	Documentation	Submittal of configuration description, failure reports, and test methods and results

4.3 Qualification Requirements

Qualification requirements shall be defined individually for each component, assembly, or system considering its function, complexity, redundancy, design, and maintenance requirements. These requirements can be satisfied by test, analysis, or inspection unless testing is specifically required. Pyrotechnic components used in FTS shall comply with AFSPCMAN 91-710 qualification requirements.

4.3.1 Qualification Testing

Qualification testing is conducted to verify that pyrotechnic component and systems design, materials, and manufacturing processes have produced devices that conform to design specification requirements. Qualification testing includes integrity tests that verify the hardware operates satisfactorily during and after exposure to the specified environments (e.g., functional/performance, bridgewire resistance, insulation resistance, leakage, etc). Qualification testing is a risk mitigation strategy for potential design deficiencies. The qualification test objective is to stress the hardware beyond the most severe operating and non-operating conditions expected during its service life. The additional stress ensures that positive margin exists for material and process variability.

Qualification test hardware shall be produced from the same drawings, using the same materials, tooling, manufacturing processes, and level of personnel competency as used for flight hardware. Ideally, qualification test hardware would be randomly selected from a production lot. The qualification hardware shall come from a single lot and this lot may be the first production lot. All qualification test specimens shall be processed through specific, non-destructive lot acceptance testing before qualification test.

Hardware requiring qualification by test, which is produced to identical design requirements by several manufacturing sources, shall be qualified by test for each source. Those environmental tests or stress conditions that would not be affected by a new vendor’s process or procedure need not be repeated by test. The basis for this decision shall be documented as a part of the certification process.

Environments and test sequences shall be considered and identified in a test plan and shall be subject to approval by the NASA project office associated with the procurement. Testing shall include both natural and induced environments anticipated during the service life of the component. Combined environments should be used when necessary and practical. Every natural and induced environment that may be imposed during a hardware item's operational life that can detrimentally affect the hardware's performance, strength, or life shall be included in the test program.

4.3.2 Separation Subsystem Qualification Testing

For all new Separation System designs a full-scale separation test shall be performed, after determination by MSFC Engineering and MSFC Safety and Mission Assurance (S&MA) personnel that this level of testing provides a more realistic or more practical test simulation than testing performed at the unit level or another level of assembly, to demonstrate the adequacy of a separation subsystem (for example stage separation, booster separation, payload fairing separation, etc.) to meet its performance requirements. Specifically, the scope of this paragraph does NOT apply to the Booster BSM (Booster Separation Motor) initiation system. The parameters this test will be evaluated for are: separation velocity, acceleration and angular motion; time to clear and clearances between separating hardware; flexible-body distortion and loads; amount of debris; and explosive shock levels. For a payload fairing using a pyrotechnic separation subsystem, the test demonstrates the structural integrity of the fairing and its generic attachments under the separation shock loads environment. The data from the separation test shall be used to validate the analytical method and basic assumptions used in the separation analysis. The validated method is then used to verify that requirements are met under worst-case flight conditions. The separation test is conducted to demonstrate that requirements for separation performance parameters are met. When critical off-nominal conditions cannot be modeled with confidence, at least one additional separation test shall be conducted to determine the effect on the separation process.

When force or torque margin requirements are applicable, the separation test shall be conducted to demonstrate that the margin is at least 100%. For separation subsystems involving fracture of structural elements the force or torque margin demonstrated shall be at least 50%.

Test fixtures shall replicate the interfacing structural sections to simulate the separation subsystem boundary conditions existing in the flight article. The remaining boundary conditions for the separating bodies will simulate the conditions in flight at separation, unless the use of other boundary conditions permit an unambiguous demonstration that subsystem requirements can be met. The test article shall include all attached flight hardware that could pose a debris threat if detached. When ambient atmospheric pressure may adversely affect the test results, such as for large fairings, the test shall be conducted in a vacuum chamber duplicating the altitude condition encountered in flight at the time of separation. Critical conditions of temperature, pressure, or loading due to acceleration shall be simulated or taken into account. As a minimum, instrumentation shall include high-speed cameras to record the motion of specially marked target locations, accelerometers to measure the structural response, and strain gages to verify load levels in structurally critical attachments. Debris risk shall be evaluated by conducting the test encompassing the most severe conditions that can occur in flight, or by including loads scaled from those measured in tests under nominal conditions. A post-test inspection for debris shall be conducted on the test article and in the test chamber.

4.3.3 Qualification by Analysis

Qualification by analysis is limited to situations where it is not technically practical to qualify by other methods. Such analysis shall be documented to the extent sufficient to provide for an independent evaluation of the results of the analysis. Analysis may be used for those requirements for an alternate source vendor when testing is not required.

4.3.3.1 Qualification by Similarity

Qualification by similarity is acceptable when all following conditions are met:

a. NASA Engineering[ATV5] evaluation determines that design differences between the item being qualified and the previously qualified similar item are acceptable and will have no deleterious effect on integrity and performance.

b. The previously qualified similar item was designed and qualified to equal or higher environmental stress levels and time durations than those known or anticipated for the item being qualified.

c. The item being qualified was fabricated by the same manufacturer as the similar item by using the same processes, materials, and quality control methods.

d. Documentation is provided that ensures qualification by similarity is adequate. The submitted documentation should include, at a minimum, the test specification, test procedure, and test report of the item to which similarity is claimed, a description of the differences between the items and the rationale for qualification by similarity.

4.4 Acceptance Test Requirements

Acceptance testing is required to verify acceptable functionality and performance, verify adequate workmanship and material quality, and provide evidence of overall product acceptability. Acceptance testing shall include tests that verify hardware performance during and after exposure to the specified environments.

Acceptance tests shall be performed on each lot of pyrotechnic devices. Acceptance test hardware shall be of the same configuration and manufactured under the same production process as the flight hardware.

4.4.1 Non-Destructive Acceptance Tests

Non-destructive acceptance tests shall be documented and performed in accordance with detailed test procedures.

4.4.1.1 Examination of Product

Each end item assembly shall be examined and the subassembly and component manufacturing records shall be reviewed to verify that the materials, explosive charges, design, construction, dimensions, workmanship, and marking comply with the requirements of drawings and this and other applicable specifications. Parts having defects shall be rejected individually.

4.4.1.2 Radiography

Radiography (either Neutron Radiography (N-ray) or X-Radiography (X-ray) or both) shall be used in acceptance of all pyrotechnically loaded devices. Because they are generally complementary to each other, both techniques should be used where practical and useful.

When provided in the procurement specification, each device shall be X-rayed in accordance with ASTM E1742, Standard Practice for Radiographic Examination, or ASTM E2033, Standard Practice for Computed Radiology (Photostimulable Luminescence Method), Appendix A1, to verify compliance to the assembly drawing, to determine that there are no missing or improperly oriented details, and to verify that there are no foreign objects or materials or voids in charges. The views shall be perpendicular to the longitudinal axis, and the number of views shall be the minimum number required to obtain the necessary required information. Two negatives shall be made of each view.

When provided in the procurement specification, each device shall be subjected to N–ray examination in one view in accordance with JSC 20431, NASA JSC Neutron Radiography Specification, to verify that the pyrotechnic mixture is present and oriented properly in accordance with the applicable assembly drawing. There shall be no missing or improperly oriented details, no foreign objects or materials present, and no voids in charges present. When external finishes, adhesives, potting materials, etc., reduce the resolution of the N-ray negative, the radiograph shall be made before the application of such materials. Devices loaded with loose powder shall be N-rayed in an orientation that reveals column height.

Mandatory minimum radiography requirement for pyrotechnic devices are:

a. MDF and shaped charges: X-Ray

b. ETLs: X-Ray and N-Ray

c. Booster Charges: X-Ray and N-Ray

d. EEDs: X-Ray and N-Ray

e. Separation Bolts: X-Ray (separation bolts loaded with primary or secondary explosives require both X-Ray and N-Ray)

f. CADs/PADs: X-Ray (N-Ray may also be required if designated by the appropriate NASA center, pressure cartridges for use with these devices require both X-Ray and N-Ray)

g. TBIs: X-Ray and N-Ray

h. S&A Devices: X-Ray (rotor leads require both X-Ray and N-Ray)

i. Mechanically Actuated Devices: X-Ray and N-Ray

4.4.1.3 Leakage

The actual leak rate for loaded, hermetically sealed pyrotechnic devices shall not be greater than 5 X 10^{-6} std cc/ sec of helium when measured at one atmosphere differential pressure at laboratory ambient temperature. For laboratory testing, an indicated leak rate shall be determined based on the laboratory conditions including bomb pressure, exposure time, and wait time. MIL-STD-1576 Method 1111 can be used as a reference to calculate an indicated leak rate requirement.

Environmental seals shall have a maximum allowable leak rate of 1X 10^{-2} std cm^3/ sec of helium when measured at one atmosphere differential pressure at laboratory ambient temperature.

Each TBI body shall be hydrostatic leak tested prior to loading either of the bulkhead donor or acceptor charges. Testing shall be in accordance with a procedure approved by the appropriate NASA center.

Gross leak test/inspection shall be performed on each loaded, hermetically sealed pyrotechnic device. Gross leak test/inspection shall be performed before helium leak testing. Test/inspection shall be in accordance with a procedure approved by the appropriate NASA center.

4.4.2 Destructive Lot Acceptance Test (DLAT)

The number of parts to be destructively tested from variously sized lots of pyrotechnic devices shall be as follows:

a. Loaded pyrotechnic devices that contain an integral pyrotechnic charge: The number of parts to be fired in DLAT shall be 10% of the lot or 10 units minimum, whichever is greater. Lot size equals the final number of units that are presented for formal lot acceptance. Fractional sample sizes shall be rounded upward to the next complete unit.

b. Two units minimum shall be fired by initiation of their respective pyrotechnically loaded component for DLAT of inert pyrotechnic devices. For inert pyrotechnic devices using redundant pyrotechnically loaded devices a single pyrotechnically loaded device shall be used for DLAT.

Testing shall be in accordance with a procedure approved by the appropriate NASA center.

4.4.2.1 Current and Pressure/Time Performance

The data obtained in each destructive test for pressure generating cartridges shall have actual firing current and output pressure versus time recorded.

4.4.2.2 Detonation Performance

Detonating cartridges or devices shall use a quantitative pass/fail criteria delineated in the respective component design specification such as detonation velocity, dent block measurements, swell cap expansion, explosive jet penetration, etc. Neither the device nor the initiator shall fracture, except for the portion immediately surrounding the detonating charge. LSC sub-length test specimens manufactured with the lot of LSC assemblies may be used for destructive lot acceptance tests.

4.5 Service Life Extension

Service life extension tests shall demonstrate that the performance characteristics continue to meet the lot acceptance criteria. Pyrotechnic components used in FTS shall comply with AFSPCMAN 91-710 service life extension requirements. Devices shall be functioned at the temperature environment(s) demonstrated in DLAT. Inclusion of thermal and dynamic environments prior to functional performance test shall be evaluated based upon the pyrotechnic component design. Each service life extension test shall consist of a minimum of five units each. Service life extension testing shall include quantifiable measures of performance (instead of GO/NO-GO tests) unless authorized by the appropriate NASA center. The results from the service life extension test shall be compared to the original DLAT results to verify acceptable component performance.

The initial service life of each pyrotechnically loaded component shall be a maximum of four years. The initial service life of pyrotechnic components used in FTS shall comply with AFSPCMAN 91-710. The service life shall be tracked from the date of pyrotechnic component DLAT with the following exceptions:

a. Initial service life for core charge assemblies is taken from the completion date of the original velocity of detonation on the cord. If the core charge assembly design has a booster charge that requires functional performance acceptance prior to incorporation into the core charge assembly, and was accepted previous to completion of cord velocity of detonation, then the initial service life is taken from the booster charge acceptance date.

b. Initial service life for delay assemblies using delay cord is taken from the date of completion of reciprocal burn rate.

Cyclic service life extension testing shall be performed in subsequent three-year intervals until the design life of ten years has been reached. Service life extension tests shall be performed on pyrotechnic components with an age life of ten years, or greater, within twelve months of intended use. The expiration date shall be based upon three years from the date the service life extension test was performed (for components with a service life of less than ten years) and one year from the date the service life extension test was performed (for components with a service life greater than ten years). The service life of a pyrotechnic component with an age life of less than ten years may not be extended beyond ten years (e.g. the pyrotechnic component age life is eight years at the time of the service life extension test then the service life would be extended two years). Service life extension tests may be performed an unlimited number of times until the lot of pyrotechnic components has been depleted or is determined no longer acceptable for flight.

The service life intervals for FTS components shall comply with AFSPCMAN 91-710.

LSC sub-length test specimens manufactured with the lot of LSC assemblies may be used for service life extension tests. The target material and acceptance criteria shall be the same as used for DLAT.

Testing shall be in accordance with a procedure approved by the appropriate NASA center.

4.6 Phase Reviews

Reviews shall be conducted for each pyrotechnic component. These reviews are held in three phases; an initial design review, a pre-production review, and a hardware acceptance review.

4.6.1 Initial Design Review

An initial design review shall be conducted for each pyrotechnic component to be used in a flight vehicle. An initial design review is required for new devices and those devices from other programs that require qualification for new vehicle use. The initial design review consists of a review of the proposed component design, detail design development drawings associated with the design (including fixtures and tools), manufacturing processes, materials, piece part receiving inspection plans, and development test data that supports the design meets the intended application requirements. The initial design review team shall consist of, as a minimum, MSFC Engineering and MSFC Safety and Mission Assurance (S&MA) personnel. Prime contractor engineering and quality assurance representatives shall be included when the contract is managed by the prime contractor. A successful initial design review results in authorization to proceed with the manufacture of piece parts for proposed final assembly design.

4.6.2 Pre-Production Review

A pre-production review shall be conducted for each pyrotechnic component to be used in a flight vehicle. The pre-production review consists of a review of the component design, detail design production drawings with any supporting specifications and finalized receiving inspection requirements, manufacturing procedures, qualification procedures, acceptance procedures, and packaging and shipping procedures. For pyrotechnic components that have been in production, but one year or more has elapsed since the acceptance of the last production lot and start of manufacture of the next production lot, a pre-production review is required prior to manufacture of the next production lot. The pre-production review team shall consist of, as a minimum, MSFC Engineering and MSFC S&MA personnel. Prime contractor engineering and quality assurance representatives shall be included when the contract is managed by the prime contractor. A successful pre-production review results in a baseline record of the component design documentation (including source control drawings and component specifications, supplier detail design drawings and associated supporting specifications, supplier procedures (manufacturing, test, and packaging), and supplier receiving inspection documentation). Qualification and/or production hardware shall be fabricated to the approved component design baseline documentation.

4.6.3 Hardware Acceptance Review

A hardware acceptance review shall be conducted for each pyrotechnic component to be used in a flight vehicle. A hardware acceptance review consists of a documentation review, review of radiographic film, and review of the hardware presented for acceptance. The documentation review, at a minimum, consists of review of supplier drawings (including tooling and test fixtures) along with any supporting specifications, manufacturing records (including any operating time or adhesive cure logs), qualification and/or acceptance test procedures, test data and test reports, rework information, inspection records (receiving inspection and manufacturing), discrepancy reports (DRs), purchase orders, and an as-built versus as-designed configuration log. The review shall account for all the hardware fabricated within the lot with the disposition of each component within the lot by serial number (e.g. certifiable for flight, attrition/spare, consumed in test, or scrapped). The hardware acceptance review team shall consist of, as a minimum, MSFC Engineering and MSFC S&MA personnel. MSFC direct-support contractor personnel or other Government personnel may serve as hardware acceptance review team members, in lieu of MSFC team members, if so delegated by the responsible MSFC personnel. Prime contractor engineering and quality assurance representatives shall be included when the contract is managed by the prime contractor. Lot acceptance data and a Lot Flight Certificate shall be provided as specified in the procurement contract. A successful hardware acceptance review results in an approved lot flight certificate for the hardware determined to be acceptable for flight.

4.6.4 Lot Flight Certificate

A lot flight certificate shall be issued for each lot of pyrotechnic devices that have been determined acceptable for flight by the hardware acceptance review team. The certificate shall be signed by the cognizant MSFC S&MA and MSFC Engineering personnel. Additional signatures shall include prime contractor engineering and quality representatives when the contract is managed by the prime contractor. At a minimum, each lot certificate shall contain the following:

a. The lot identification of the end items, date of the DLAT, date of velocity of detonation testing for explosive cord (as applicable), and date of reciprocal burn rate (as applicable).

b. A listing of each acceptable flight part in the lot by serial number.

c. The serialized marriage or assembly listing of all major pyrotechnically loaded components at each level of assembly.
d. The lot and serial number of pyrotechnically loaded components and subassemblies.

e. The end item shelf life expiration date based on the completion date of DLAT, or velocity of detonation testing for linear products, or reciprocal burn rate testing for delays fabricated with delay cord. The shelf life of the initiator shall not be considered in determining the shelf life expiration date for the end item.

f. For devices containing an integral initiator, such as cartridges, the bridgewire resistance of each initiator shall be recorded. The recorded value shall be transcribed from the appropriate initiator lot certificate.

g. The CAGE code

h. Deviations and waivers (list numbers on face of certificate and attach copy to certificate).

i. The L/N of the propellants or explosives loaded in the device.

j. The expiration date including the month and year only shall be recorded. The expiration date is the last day of the specified month.

5.0 PACKAGING

Preservation, packaging, and delivery of pyrotechnics shall be in compliance with one or both of the following criteria:

a. For military air shipments: AFMAN 24-204, Preparing Hazardous Materials for Military Air Shipments

b. For commercial shipments: CFR, Title 49 Code of Federal Regulations (Parts 100 through 199), Department of Transportation (DOT), and International Air Transport Association Dangerous Goods Regulations (IATA DGR) Manual

5.1 Preservation, Packaging, and Packing

Materials for preservation, packaging, and packing of pyrotechnic devices shall be selected in accordance with the Letter of Competent Authority (LCA) and Department of Transportation (DOT) regulations. Inert pyrotechnic devices are exempt from LCA shipping regulations.

Unit packages of pyrotechnically loaded devices shall have desiccant and humidity indicators per MIL-STD-2073-1, Military Practice for Military Packaging, Method 50. Card type humidity indicators per MS20003, Indicator, Humidity, Card, Three Spot, Impregnated Areas, shall be used inside the package. Except for the humidity indicators, monitoring and recording devices are not required.

5.2 Marking

The containers shall be indelibly marked legibly in such a way that the marking shall not become damaged when the containers are opened. The marking shall provide the following information:

a. Lot Number

b. Part Name

c. Part Number

d. Supplier

5.3 Shipment

One reproducible copy of the lot flight certificate shall accompany each shipment from the manufacturer to the vehicle installation site. A copy of the LCA approval, applied for by the manufacturer and issued by the DOT, shall be included in the shipment. A copy of the applicable Material Safety Data Sheet (MSDS)/ Safety Data Sheets (SDSs) [ATV6]for the hazardous material contained within the device and a copy of the Department of Defense Form (DD)250 or DD1149 shall be attached to the outside of the shipping container. All pyrotechnic devices identified with a program part, lot, or serial number is subject to these provisions.

6.0 NOTES

None.

APPENDIX A. ACRONYMS

AFMAN	Air Force Manual
AFSPCMAN	Air Force Space Command Manual
AFSS	Autonomous Flight Safety System
AMS	Aerospace Material Specifications
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASQ	American Society for Quality
ASTM	ASTM International (formerly American Society for Testing and Materials)
C	Celsius
CAD	Cartridge Actuated Device
CAGE	Contractor and Government Entity
cc	cubic centimeter
CDC	Confined Detonating Cord
CDF	Confined Detonating Fuse
CFR	Code of Federal Regulations
COC	Certificate of Compliance
cm	centimeter
CR	Contractor Report
dB	decibel
DC	Direct Current
DD250	Department of Defense Form 250
DD1149	Department of Defense Form 1149
DGR	Dangerous Goods Regulation
DLAT	Destructive Lot Acceptance Testing
DoD	Department of Defense
DOT	Department of Transportation
DR	Discrepancy Report
DTL	Detail
DWV	Dielectric Withstanding Voltage
EED	Electroexplosive Devices
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference

ETL	Explosive Transfer Line
ESD	Electrostatic Discharge
F	Fahrenheit
FCDC	Flexible Confined Detonating Cord
FJ	Frangible Joint
FJA	Frangible Joint Assembly
FTS	Flight Termination System
GSE	Ground Support Equipment
HDBK	Handbook
HLV	Heavy Lift Vehicle
HMX	Cyclotetramethylenetetranitramine
HNS	Hexanitrostilbene
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IPC	Association Connecting Electronics Industries (formerly Interconnecting)
IR	Insulation Resistance
ISDS	Inadvertent Separation Destruct System
JSC	Johnson Space Center
KC	Key Characteristic
kV	kilovolt
L/N	Lot Number
LCA	Letter of Competent Authority
LEA	Linear Explosive Assembly
LPI	Lanyard Pull Initiator
LSC	Linear Shaped Charge
m	Meter
MΩ	megohm
mA	milliAmpere
MDF	Mild Detonating Fuse
MIL	Military
MNFC	Maximum No-fire Current
MNFE	Maximum No-fire Energy
MNFP	Maximum No-fire Power
MNFS	Maximum No-Fire Stimulus
MNFV	Maximum No-Fire Voltage

MPR	Marshall Procedural Requirements
MRB	Material Review Board
MSFC	Marshall Space Flight Center
MSDS	Material Safety Data Sheet
MWI	Marshall Work Instructions
NASA	National Aeronautics and Space Administration
NCSL	National Conference of Standards Laboratories
NDE	Nondestructive Evaluation
NPR	NASA Procedural Requirements
N-ray	Neutron Radiography
NSI	NASA Standard Initiator
NSI-1	NASA Standard Initiator, Type 1
NSTS	National Space Transportation System
%	Percent
PAD	Propellant Actuated Device
P/N	Part Number
RF	Radio Frequency
RFI	Radio Frequency Interference
RMS	Root Mean Square
S&A	Safe and Arm
S&MA	Safety and Mission Assurance
SAE	SAE International (formerly Society of Automotive Engineers)
SBASI	Single Bridgewire Apollo Standard Initiator
SCB	Semiconductor Bridge Device
sec	second
SMDC	Shielded Mild Detonating Cord
SMSI	Standard Manned Space Flight Initiator
SLS	Space Launch System
STD	Standard
TBI	Thru-Bulkhead Initiator
TFB	Thin Film Bridge Device
TM	Technical Memorandum
Vac	Volt, alternating current
Vdc	Volt, direct current

X-ray	X-radiography
XTA	Expanding Tube Assembly

APPENDIX B. DEFINITIONS

Term	Description
Acceptance Testing	Tests to determine that a part, components, subsystem, or system is capable of meeting performance requirements prescribed in purchase specification or other documents specifying what constitutes the adequate performance capability for the item in question.
Acceptor	An explosive component that conducts a detonation impulse from a preceding detonating component usually called a donor.
All-Fire	The lowest energy which results in initiation of an EED within a specific reliability and confidence level as determined by test and analysis.
Apex Thickness	Thickness of the sheath at the inner apex of the LSC, i.e. the bottom of the inverted “V” or chevron angle.
Arm/Disarm Device	A mechanism to make (arm) and break (disarm) electrical continuity from the firing controller to the EED.
Booster	An explosive charge augmenting the initiating component of a linear charge assembly to cause ignition or detonation of the main explosive charge or to increase the output of the assembly.
Bridgewire	A resistance wire incorporated into an EED to convert electrical energy into heat to cause ignition of the pyrotechnic material.
Cartridge	A separable device loaded with propellant or high explosive which is used to actuate a mechanical device.

Term	Description
Certification	Consists of qualification tests, major ground tests, and other tests and analyses required to determine that the design of hardware from the component through the subsystem level meets requirements: a. Certification by Testing The process of conducting tests that normally are considered qualification tests, plus specific additional tests of components and subsystems and higher levels of assemblies required to certify that the hardware design meets established design requirements. Certification testing does not generally include development, piece-part qualification, acceptance, or checkout tests except where such tests are specifically identified as required for certification. b. Certification by Analysis Analysis performed to satisfy certification objectives when testing under simulated mission conditions is not feasible or economical, or the need exists to extrapolate test data beyond the performed test points. c. Certification by Similarity Analysis performed to show that an article is similar or identical in design, manufacturing process, and quality control to another that has been previously certified to equivalent or more stringent criteria.
Charge Holder	A holder designed to accommodate a linear or conical charge for vehicle installation. The charge holder may be intended for structural separation, detonation transfer, or destruct.
Closed Bomb	A fixed volume chamber used for testing the pressure and time characteristics of pressure cartridges
Confined Detonating Cord	A detonating cord surrounded by a flexible sheath of plastic, fiber fabric, or combination thereof that confines the effects of the explosive core. Generally used for energy transfer between multiplexed components in a pyrotechnic system.
Conical Shaped Charge	Shaped charge in a conical configuration that has a concave metal liner that when detonated is converted into a supersonic jet.
Core Charge	A high explosive material contained in a suitably configured sheath, usually of metal. A generic term for both a MDF and LSC. The basic component of a linear charge assembly as defined herein.

Term	Description
Delay Column	The component of a delay element that introduces a controlled time delay in the functioning of a series of explosive events. It consists of a length of tube primarily dependent upon the burning rate of the delay material being used and the time delay required. The column usually consists of a “first-fire” material at one end to initiate the delay mixture and a relay charge at the output end to transfer an impulse and augment the output to a succeeding element in the train.
Delay Cord	A length of tube containing pyrotechnic delay mixture drawn to a specific diameter resulting in a specified delay time. The delay column normally interfaces with a “first fire” mixture at one end and a relay charge at the opposite end for augmentation to detonating output charge.
Delay Element	An assembly that consists of an initiating element at one end, a delay cord/column in the middle, and a base charge at the terminal end to transfer an impulse to the next succeeding element in the train.
Deflagration	The very rapid chemical decomposition of a material in which the reaction front advances into the unreacted material at subsonic velocity.
Design Life	The length of time the pyrotechnic component, subsystem, or system was designed to perform acceptably throughout all phases of its intended use.
Destruct Charge	An explosive assembly used in the flight termination system to cause vehicle structural break-up or termination of thrust.
Detonation	The extremely rapid chemical decomposition of a material in which the reaction front advances into the unreacted material at greater than sonic velocity.
Detonator	A pyrotechnic device capable of initiating detonation in a subsequent high explosive component.
Development Testing	Testing performed with minimum rigors and controls to verify a design approach.
Dielectric Testing	A resistance test using alternating current.
Dielectric Withstanding Voltage	The maximum potential gradient that a dielectric material can withstand without failure.
Donor	An explosive component that conducts a detonation impulse out of a detonating charge into a succeeding high explosive charge usually called an acceptor.

Term	Description
Dud	Failure of the operation or functional capability of a device. For example, a cartridge or other device that will not function upon receipt of the prescribed initiating stimulus.
Electro-mechanical Safe/Arm	A device that electro-mechanically interrupts the firing circuit between the initiator and the final firing control device and that provides additional safety from premature firing. (Reference Arm/Disarm).
Electroexplosive Device	The first element of a pyrotechnic train. It is activated by electrical energy (joule heating) applied to an internal bridgewire that transfers energy to an explosive charge. An EED may include other explosive charges downstream of the initiating charge. Detonators, squibs, initiators, and cartridges when electrically actuated are EEDs.
End Coupler	An integral acceptor or donor charge or both built into the end(s) of a linear charge assembly.
Explosive	A generic term that includes deflagrating, detonating, and pyrotechnic materials.
Explosive Bolt	A bolt that is intended to be fractured at a predetermined point by a contained or inserted explosive charge for the purpose of releasing a load.
Explosive Lot	A specific traceable quantity of an explosive material manufactured in one unchanging and essentially continuous process using the same materials and processes, and submitted for acceptance at one time; or a specific traceable quantity of an explosive material resulting from blending two or more explosive batches, each of which was manufactured in one unchanging and essentially continuous process using the same materials and processes, and submitted for acceptance at one time.
Failure Tolerance	The capability to sustain a failure and continue to perform its intended function.
Faraday Cap	The cap applied to the connector end of an EED to provide an Electromagnetic Interference (EMI) shield to prevent inadvertent firing from RF sources. This cap does not short the pins to the bridgewire.
Flight Termination System	A pyrotechnic system that when actuated causes loss of integrity of a vehicle structural elements or propulsion systems. A FTS is used in applications requiring compliance with AFSPCMAN 91-710.

Term	Description
Igniter Cartridge	A pyrotechnic device designed to initiate burning of a fuel mixture or a propellant.
Inadvertent Separation Destruct System (ISDS)	A pyrotechnic system that initiates flight termination system destruct charges when an un-planned separation of a specific portion of a vehicle occurs. An ISDS may be required for compliance with AFSPCMAN 91-710.
Inert Device	A pyrotechnic device that contains no explosive, pyrotechnic, or chemical agent.
Initiation System	Initiation systems are components powered, controlled, and commanded by inputs from the launch vehicle. The inputs are converted into electrical, optical, or mechanical energy stimuli that are applied to the initiator.
Initiator	The primary stimulus component in all pyrotechnic devices and systems.
Installation	The assembly of a pyrotechnic device into a vehicle or another assembly in a manner such as to permit removal or disassembly; e.g., a cartridge installed into separation bolt and onto a vehicle.
Interrupter	A device that provides a barrier which prevents detonation propagation to a pyrotechnic component beyond the interrupter.
Limit Load	The maximum force expected on the structure during mission operation including intact abort.
Linear Charge/Explosive Assembly	An assembly of MDF or LSC sealed at both ends, either with or without end couplers or boosters.
Linear Shaped Charge	A metal tube containing a core of high explosive, formed into an inverted “V” or chevron shape to produce a cutting jet.
Locked-Shut Test	A test of a device designed to operate with an expanding gas volume (e.g., piston type thruster) in which the moving parts (e.g., pistons) are restrained from movement so that the initial volume remains unchanged and a high over-pressure results. This test demonstrates that the device will not rupture or fragment with restraint on the piston. Testing is performed with redundant charges firing simultaneously, when appropriate.

Term	Description
Lot Certificate	A NASA-approved document pertaining to a specific lot of a specific pyrotechnic device that lists all specific serialized parts in the lot that are certified for flight vehicle installation. It is prepared on the basis of manufacturing and acceptance data, represents the status of each device at the time of the certification activity, and is not changed as listed devices are used or subsequently undergo a flight worthiness change.
Marriage	The assembly of components, such as an EED into a cartridge, or a linear charge assembly into a charge holder, in such a manner intended to be permanent.
Marriage List	A list that defines the serial numbers installed in the next assembly. For example the marriage list for a cartridge would include the serial number for the cartridge as well as the serial number for the initiator installed into it.
Mild Detonating Fuse	A metal tube containing a core of high explosive usually of circular or similar cross-section.
NASA Standard Initiator, Type 1 (NSI)	A specific EED designed and used by NASA for multiple applications. (Previously designated as the Standard Manned Space Flight Initiator [SMSI] and the Single Bridgewire Apollo Standard Initiator [SBASI]).
No-Fire	The highest level of input energy to an EED at which initiation will not occur within a specific reliability and confidence level as determined by test and analysis.
Off-Limits Testing	Those tests designed to evaluate device performance during or after exposure to environments that are more severe than those predicted for mission use.
Percussion Primer	A device for mechanically initiating a pyrotechnic charge by an intentional, sudden pinching or crushing of the explosive material between a firing pin and the primer anvil.
Pre-installation Test	A nondestructive test, or series of tests, performed on a pyrotechnic device before its installation in a flight vehicle or test fixture.
Primary Explosive	An explosive material that is very sensitive to heat, impact, and friction. Includes azides, styphnates, nitro benzofuroxan salts, nitro tetrazoles, etc. Often used for a burning-to-detonation transfer charge.
Prime Contractor	Contractor responsible for specific elements or systems of the vehicle and flight program.

Term	Description
Production Lot	A group of new production components, devices, or assemblies of the same design, construction, and materials fabricated in one unchanging and essentially continuous manufacturing process and submitted for acceptance at one time.
Pyrotechnic Material	A chemical or mixture of chemicals designed to produce heat, gas, pressure, or shock.
Pyrotechnics	The generic term used throughout NASA in lieu of “ordnance” to avoid the connotation of weaponry as in “pyrotechnic systems.” “Pyrotechnic devices” include all devices and assemblies containing, or operated or actuated by, propellants, pyrotechnic mixtures, or explosives including items such as initiators, detonators, S&A devices, cartridges, separation bolts and nuts, pin pullers, linear separation systems, guillotines, valves, disconnects, retractors, thrusters, transfer assemblies, TBIs, shaped charges, personnel crew escape hardware containing pyrotechnic charges (including, but not limited to parachute reefing line cutters, vest inflators, raft inflators, and flares), mortars, circuit interrupters, dimple motors, oxygen candles, and igniters, but specifically excepting large rocket motors.
Qualification Test	A test structured to certify that design requirements have been met.
Random Sample	A sample selected without bias or prejudice.
Receptor	Another name for an acceptor charge.
Recommended Firing Current	A current recommended to be applied to an EED to cause initiation of the explosive charge and that provides a margin over the “all-fire” current stimulus. For example, the NSI-1 recommended firing current is specified as 5.0 amperes minimum, whereas the all-fire current is 3.5 amperes.

Term	Description
Redundancy	Single - A single-redundant system is one that will sustain one failure of an assembly or component and still retain the capability of performing the intended function. This level of redundancy is attained by adding one like assembly or component to the system. For example, if one battery is required to provide a source of firing current, one additional battery provides single-redundancy of the current source and the batteries are said to be redundant. Dual - A dual-redundant system is one that will sustain two failures of one assembly or component and still retain the capability of performing the intended function. Such a system is frequently termed “fail operational/fail-safe”. This level of redundancy is attained by adding two like assemblies or components to the system. For example, if one battery is required to provide a source of firing current, two additional batteries provide dual-redundancy of the current source and the batteries are said to be dual-redundant. Design - Design redundancy exists when redundant devices are of different designs, usually having different failure modes. For example, if an umbilical is severed by either a guillotine or an LSC, both mounted so as to perform the function, the severing system is both device redundant and design redundant.
Safe and Arm Device	A mechanical device for interrupting a linear charge assembly (safe) when required to be in the unarmed condition and aligning the charge assembly so as to render it operative (armed) when required to be ready to fire.
Secondary Explosive	Explosive materials that are relatively insensitive to heat or impact and must be initiated by a suitable primary explosive or another secondary explosive. Secondary explosives are generally more brisant and more powerful than primary explosives.
Semiconductor Bridge Initiator (SCB)	An EED that uses a film semiconductor as a bridgewire.
Sensitivity	The characteristics of an explosive or component that express its susceptibility to initiation by externally applied energy. May apply to electrical, shock, or other stimuli.

Term	Description
Service Life	The service life of an item starts at the completion of destructive lot acceptance test (or velocity of detonation acceptance for core charges or reciprocal burn rate acceptance for delay cord) and continues through all acceptance testing, handling, storage, transportation, prelaunch testing, all phases of launch, reentry or recovery, (refurbishment, retesting, and reuse, if applicable) that may be required or specified.
Squib	A general term usually meaning any one of many EEDs such as an NSI-1.
Standoff	The distance between the base of a shaped charge liner and the target material.
Target Material	Witness specimen used for evaluating performance of a detonating cutting charge such as MDF, LSC, or conical shaped charge.
Test Bomb	A chamber into which cartridges are test-fired to establish or verify performance characteristics such as the output pressure vs. operating time. These fixtures have a fixed, known volume (see also “Closed Bomb”).
Thin Film Bridge Initiator (TFB)	An EED that uses a thin film resistive element as a bridgewire.
Thru-Bulkhead Initiator (TBI)	An explosive initiator that provides a detonation transfer via a shock wave through an integral bulkhead without rupturing the bulkhead. Explosive material is packed intimately in cavities on both sides of the bulkhead.
Transfer Charge	A sealed assembly containing explosives designed to provide an alternate explosive path between linear charge assemblies as in an elongated container containing bulk explosive to bridge the gap from two end-to-end positioned charge assemblies.