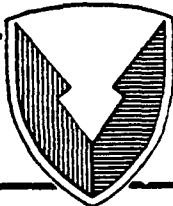


TECHNICAL REPORT RD-ST-91-16

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EXPLODING FOIL INITIATOR QUALIFICATIONS

Jeffrey A. Lienau
Structures Directorate
Research, Development, and Engineering Center

AUGUST 1993

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) <p>The Electronic Safety and Arming Device technology has been pressed into use before many of the design specifications could be completed. MIL-STD-1316D the basic S&A safety guide requires in-line detonators to be qualified in accordance with MIL-I-23659, yet 23659 was based primarily on qualifying hot bridge wire devices and is poor to qualify the in-line detonator of choice the Exploding Foil Initiator (EFI). The report proposes changes to 23659 to qualify EFI's and EBW's. To make the specification consistent with the EFI technology and 1316 safety requirements, the proposed changes require statistical analysis testing at temperature extremes, qualifying the fire set with the detonator, and evaluating the detonators probability to deflagrate (burn). Specific language is suggested to substitute/add to paragraphs currently in MIL-I-23659. The report contains explanations for the proposed changes, and some description of how the information should be applied.</p>			
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PREFACE

MIL-I-23659 is a initiator qualification specification commonly used by MICOM. MICOM has reviewed MIL-I-23659 and is proposing changes to qualify the Exploding Foil Initiator (EFI). While it was noted that the current MIL-I-23659 needs general revision, the proposed changes are only for the EFI. MIL-STD-1316D requires that MIL-I-23659 is used to qualify in-line initiators such as the EFI. MIL-STD-1316D specifies the No-Fire potential of the detonator shall be above 500 volts. Further, 1316D specifies a S&A is armed when it has a probability to fire of 0.005. To meet these 1316D specifications requires knowledge of the Electronic S&A initiator statistical properties. Statistical evaluation of the detonator firing properties is currently optional in MIL-I-23659 so it is proposed, revised, and made a requirement. MIL-I-23659 limits testing to ambient temperatures. The firing properties of the older conventional detonators are not significantly influenced by temperature change, but the EFI is. Therefore, the proposed changes include statistical and all-fire testing at temperature.

MIL-STD-1316D uses Maximum No-Fire Stimulus (MNFS), as a measure of the safety provided by the S&A. MNFS is used in five different specifications, including MIL-I-23659, with four separate values. To avoid confusion, it is proposed FESWG send a letter to the custodians of these standards proposing that the 1316D value for MNFS is used in all specifications and standards.

MIL-I-23659 currently only evaluates the initiator firing properties, not the firing circuit. EFI firing properties are significantly influenced by firing circuit component variations (known to vary by up to 20%). Detonator statistical all fire properties, acquired from a single set, are inadequate since the firing set variables are not included. The best solution qualifies the firing circuit and the detonator as a unit according to MIL-I-23659, i.e. test several hundred firing sets, not just the initiators. For some programs this may be impractical, so when detonator qualification uses a reusable firing circuit, a procedure is proposed to calibrate its electrical features. When comments are received and incorporated for the current draft of the revision to MIL-I-23659 (expected circa March 1991), it will be proposed to the Army community as the standard to apply until an official revision to MIL-I-23659 is completed.

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. DISCUSSION	2
A. EFI Reported Firing Characteristics	2
B. EFI Configurations	4
C. Applications for 23659 Data	5
D. What's in 23659 Now?	7
E. Memo from First Discussion	7
F. Statistical Detonator Data	9
G. Historical 23659 Patterns etc	12
H. MIL-STD-1512	13
I. Other Comments	14
J. Proposed Changes	15
III. CONCLUSIONS AND RECOMMENDATIONS	20

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Basic EFI Configuration	21
2	Capacitive Discharge	22
3	EFI Firing Circuit Model	23
4	EFI Firing Current	24
5	Proper Firing Current and Slow Rising Firing Current	25
6	Newer EFI Configurations	26
7	Electrical Analogies to Mechanical Environments	27
8	ESAD Tests and Pass/Fail Criteria	27
9	Intent of Test Samples – 23659	28
10	Intent of Test Samples – Proposed Revision	29
11	Which MNFS	30
12	MASS – Firing Stimulus and MASS – Deflagration	31
13	MASS – Deflagration Current Waveform	32
14	1512 Initiator Test Matrix Sample	33
15	Test Divisions	34

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
1	Engineering Design Test Schedule	35
2	List of Possible Environments	36
3	Original Proposed Test Matrix	37
4	Proposed Test Matrix	38
5	Minimum Test Matrix	39

I. INTRODUCTION

A straw-man is proposed to update MIL-I-23659 to include the Exploding Foil Initiator (EFI). Since we all have different opinions, this is a straw-man, subject to change. Considerations included in the recommendations include:

- a. The physics of the EFI – how does it work, why is it different from a conventional detonator?
- b. What configurations of EFI are we likely to see currently and in the near future?
- c. What is 23659 used for? What is most significant?
- d. Finally, what historic pattern exists from 23659 and other specifications that we may want to follow?
- e. Review of the detonator qualification in MIL-STD-1512.
- f. Industry manufacturing and government needs.

The EFI in the ESAD are rapidly becoming the basis for the S&A industry. The government has a reputation of still being in conference discussing the requirements after it was fielded. While there will be several EFI's developed by the time this report can be published, there are a lot of programs we can influence.

Much of the basis for this was formed as an update of materials at an informal 30 August 1990 meeting at NSWC on MIL-STD-23659 discussing the addition of EFI qualification.

Based on the 30 August meeting, and follow-on with contractors and personnel in the government and DOE, the following is proposed as a straw-man for changing MIL-I-23659, and recommended to the Army as a waiver requirement for detonator qualification.

It is noted that at a 8 November 1990 meeting the direction of the changes in 1316D were altered from that in the current Navy supplemental guidelines. The state of "Armed" was changed from Maximum Acceptable Safe Stimulus (MASS) to Maximum No Fires Stimulus (MNFS). The proposed recommendations are believed consistent with MIL-STD 1316D, which is in the final stages of ratification at this moment.

5. Technical personnel have not concurred on a method of reporting firing data that relates to the functioning physics. Capacitor voltage is the preferred method but has several drawbacks. Voltage is accurate only if the qualification tests include a statistical evaluation of the fire sets. Since the MII Specification calls only for the qualification of a detonator, changes will be required to include the fire set. This reporting inhibits common use of the EFI with varied Fire Sets, promoting sole source.

6. Proper means of reporting EFI firing data may already be used with the EBW, which are specified according to the current and energy at the burst point. At first the author did not feel these data were credible, because reporting watts for a transient pulse is not a technically accurate procedure, but it is much more accurate than a capacitor voltage. We should begin to report data that can be related to the functioning properties.

7. It is felt that the firing properties are bounded by definable factors including the current rise rate and capacity of the firing circuit to maintain the firing current at the fire point.

8. Recommended Action: To insure that a detonator qualification can be repeated, the firing characteristics of the firing circuits used in qualification must be recorded at a central point. All contractors already collect this data, we are just asking that it be reported.

a. Reusable detonator qualification firing circuit characteristics should be calibrated by a ring down for different temperatures, and voltages. This will give some confidence that when the firing circuit is damaged, or a component is replaced, we can be sure the new circuit is similar to the old one being replaced.

b. Single shot fire sets or circuits that are closely confined in a configuration (e.g. wooden round fire sets that prevent replacing the detonator) should be tested as a unit for the statistical tests. This should apply even if the components are reusable. Fire set statistical evaluation by limited testing and satisfactory analysis would also be acceptable to the author.

9. A government laboratory should investigate improvements to EFI statistical firing properties, with a goal of separating the fire set from the detonator, like conventional detonators. If the fire circuit is properly characterized, including ring-down tests, and we obtain the nominal firing time of the detonator then we can at least approximate the point on the ring-down where the detonator fired. Whether this is sufficient to help evaluate data that can help evaluate the EFI independent of the fire set remains to be seen, but the data can't help but be better than just a voltage. Ultimately, it is suggested the qualification of the detonator can be bounded by two typical firing circuits, one predominantly inductive and the other resistive. Qualification of the detonator can be accomplished applicable to any fire sets between the bounded characteristics by testing the EFI for specific characteristics of both fire sets. If we characterize the new firing sets as programs proceed, the detonator could be qualified for application in any fire set that has ring-down characteristics bounded by those previously characterized.

10. New warheads (less detonator) can be designed containing all the explosives. The HNS-IV is not in the detonator, but it is in the warhead. Using the enclosed tests the detonator might be qualified without any explosive if a means of measuring the output is developed. One potential method proposed by MICOM's EMR department, uses a Piezo-electric receptor to measure the flyer impact. Such a device could measure the total impulse, but may fail to satisfactorily represent the flyer size/surface shape.

B . EFI Configurations

1. The common detonator is a device with a pair of wires leading to an explosive cup, an electrical pulse produces a shock wave. The EFI is regarded by many as a detonator without the explosive because the flyer output also produces a shock wave. Tradition places an explosive in a detonator, all the current configurations have an explosive, and all the contractors are testing their detonators with explosive receptors. The only practical method of measuring the output of an EFI is with an explosive. There are hazards from the EFI's interface with the explosive (deflagration) that are not measurable without the explosive's presence. The greatest reason to use the explosive though is the testing interface. In this report, an EFI contains an explosive pellet. The EFI does not really have a pair of wires. The wires can be separated schematically, but not practically. The common wire is a flat printed circuit cable called a strip line and the connection requires a relatively large contact surface because of the high currents/low inductance.

2. Current EFI's are not always easily separable from the Fire Set. While the shape varies, the major difference between units is that some EFI's can be removed from the Fire Set and others cannot. Some have the firing capacitor or the switch permanently mounted on the same printed cable as which forms the detonator. The EFI cannot always be handled as a separate component.

3. Potential configurations in the near future (Fig. 6) include wide application of highly integrated designs with components permanently mounted with the detonator, using single shot switches and other built-in components. While the current EFI's have mean firing values of 1500 volts or so, most personnel expect this voltage to drop in the future to at least 800 or 1000 volts, as in EBW's. While the mean all-fire for an EBW is advertised lower in voltage than an EFI the correct fire set will achieve a firing characteristics that are very similar to the EFI - 1500 volt threshold.

4. Finally, the EFI must have a relatively tuned fire set matched to the detonator characteristics. The EFI is known to be more sensitive to matching the firing circuit than the EBW.

a. There is an implication that the current detonators are optimally tuned to the fire sets (sometimes), and the competitors design will not work with different fire sets (I consider this nonsense, as all detonators have a preferred fire set, that does not mean they cannot be competitive. We have not tested competitors designs with each other's fire sets. Many of those currently built will probably work within another's ESAD with little change). The concept of a tuned set has effectively and neatly sold the idea of sole source acquisition for a major element of an ESAD.

b. The fact that the detonator is tuned to the fire set is pertinent, since it points out that the fire set and the detonator determine the Firing Properties, not the detonator alone. Tests of the detonator are currently performed using only one fire set over and over to establish the statistics. The armed state of the S&A using the EFI and other features are projected directly from this data. If the data are taken without evaluating the fire set statistics, as well as the detonator, we are basing the safety and reliability on only half the variables.

5. The prevailing thought about the EBW detonator is that it is very hard to initiate, more so than the EFI. While I have not personally fired any, it is understood the EBW is easier to initiate, compared to the EFI, when fired through a fire set similar in design to that used for

the EFI. Providing the EBW is used with a fire set that provides a no-fire level above 500 volts (MIL-STD 1316D requirement); the EBW is believed perfectly acceptable to the Army, and it is the author's choice for a detonator in the MICOM in-house ESAD. The EBW is currently unacceptable to the Navy, something the author is investigating.

6. After reviewing a presentation sponsored by Dave Overman, I'm convinced some other devices can be safe if installed inside the right package. Perhaps an extremely small package (such as one half cubic inch) that is not repairable, or contains a detonator that is directly or indirectly (as through a resistor) accessible. The package should be treated as an initiator rather than as a system containing an initiator (only devices with acceptable explosives could be accepted in this category). This would simplify qualification of configurations of EFI's and devices that would separately be unacceptable in-line such as SCB's. It is possible to design a package that would pass the 23659 requirements, and contains unacceptable materials such as primary explosives. Therefore, if a package can be treated as a detonator, to be acceptable in-line it must also meet all the initiator in-line requirements of 1316D or 1901.

7. The safest form of an ESAD is where the firing energy is directly derived from the environment. Second, while current EFI's fire with a mean firing point of 1500 volts or so, the newer designs can be expected to be much lower, perhaps as low as 750 volts. While in the existing ultra-conservative designs during EMRH, no energy has been detected in the firing energy source (capacitor), this undoubtedly will not continue. We do not want to reject a design merely because we don't have meaningful requirements. So, it is important to establish Pass/Fail criteria to either produce a hazardous output, or impact the designs reliability.

8. Conclusions: We must either test the detonator separately from the fire set, and establish the relationship between the fire set statistics and the detonator, or test the fire set and the ESAD as a unit for detonator qualification. We cannot assume that the qualification of the detonator can be generalized, and then reduce or eliminate testing for subsequent applications using different fire set components.

C. Applications for 23659 Data

Uses for the test data derived from 23659-D include data to give us warm feelings about:

- Reliability of the design regarding manufacturing defects.
- Reliability following exposure to environments.
- Confidence about various destructive safety environments.
- Confidence about various non-destructive environments.
- Establish All-Fire and No-Fire statistical data to determine pass/fail Criteria for tests of several applications.
- Establish statistical data to confirm acceptable design margin for the all fire in the given application.

1. There seems to be two central controversial points that personnel may disagree about; (1) Should the 23659 tests only be system specific, and (2) is there a need to provide statistical data about the detonator as part of qualification.

2. We think of some component qualification tests performed as a confidence builder that the hardware will later pass in system tests, it is argued as such that the component need not be exposed to more environments than are expected in the eventual system. Setting aside the issue of whether the component test promotes unnecessary sole source hardware or promotes

repeat qualifications where one can do the job, missile system tests are usually performed in such small quantities that it is not clear whether its the component test or the system test that provides confidence that the other test was accurate. It is recommended that the component tests are performed to reduce the risks of the system tests. System level tests are performed late in a program, some after the hardware has been fielded; we cannot afford to have a serious failure in a system test. Component tests should be performed in such a manner to justify continuing the program should the system test fail, i.e., limit catastrophes.

3. In today's programs, tests are often tailored to match the system requirements/environments not a common one, often the desired margin in the component test is lost. Some intend to improve the test by making it more system oriented; the problem is that there is not sufficient government personnel to review proposed materials, tests that eliminate design margin are accepted instead of making improvements. Contractors often use the tailored tests to reduce the manufacturers risk unnecessarily and to promote sole source hardware. Currently every ESAD contractor has his own special EFI sole source. Detonators, screws, capacitors, and other components should be competitive. System specific tests should be used at the component level only when there is an obvious reason to not use a standard one, not the other way around. The author notes that the production volume of an item can significantly influence qualification tests. The procedures to test a detonator for a missile that will only have a thousand rounds built, should be very different from the detonator for a projectile built in the millions, quantitative information is very different.

4. Statistical data are expected. 23659 is referenced in MIL-STD 1512 for statistical test procedures. The first test of fifty devices in Table 1 are finally tested according to paragraph 4.4.6. The document unfortunately leaves the test open to interpretation, being vague about whether the test is 4.4.6 (statistical) or 4.7 an all-fire test. I believe the intent was the statistical test establishing the baseline data to predict the all-fire level used in later tests. Otherwise, why put this test first rather than combine the quantity to the last test in the sequence? The statistics of the all-fire/no-fire tests are used to establish MASS the basis for most pass/fail safety tests and the MNFS the threshold of arming. More is presented about the uses for statistical data later. Statistical data from engineering tests is unacceptable since it is unofficial.

5. Tests for the ESAD are still being developed. The physics of electronics are that it is more sensitive to electrical noise than mechanical, and some changes in the test emphasis should occur. An outline of test analogies is shown in Figure 7.

6. Some tests and the proposed pass/fail criteria for future MICOM programs are shown in Figure 8.

7. 23659 is used for more than just warheads. Reliability is important for propulsion systems. It is unacceptable if undefined level: lower than EMRH dud the weapon. The basic 23659 device was the 1A-1W No-Fire hot bridge wire squib. The safe input level for this device is below the input that would damage the initiator, the opposite of the EFI. The EFI can be damaged by inputs long before it reaches the statistically predicted safe MNFS level. The design driver for the units is often reliability, not safety.

8. Conclusions: The tests of 23659 should provide statistical data to project firing properties of the detonator, and evaluate the probable reliability of the device.

D. What's in 23659 Now?

1. Reviewing Table 1, it is read left to right. Each group of devices starts at the top of column and is exposed to the indicated environments proceeding down the column. The speculated purpose of the tests (it is not stated in the document) are listed in Figures 10 and 11.
2. Basically, the sequence left to right seems to; establish the baseline properties of the device, test it for various environments, conclude by testing a numerically significant quantity of detonators.
3. The test furnish reliability firing data for 364 initiators, 298 are required to show .01 at 95 percent confidence. Tests are performed one at a time without exposing an initiator to more than one environment, as would occur in real life.

E. Memo from First Discussion

At an August 1990 meeting the properties of MIL-I 23659 were discussed for changes to apply to an EFI. For interest, the following is a copy of a memo prepared at the time that records the meeting results.

Comment Format

Variations on the requirements listed in 23659C are shown as:

Title of the Test/Requirement:

Interpretation of the requirement/test intent.
Recommendations for application to an EFI

- a. Dielectric withstanding voltage: 4.4.1 & 3.4.1 –
Manufacturing screen test to eliminate devices with a case insulation resistance less than 5 megohms at 500 volts.
EFI – Require the EFI tested according to IAW MIL-STD 202 method 301. At 5000 volts the maximum should be less than 2 micro-amperes.
- b. Radiographic: 4.1.3.2 & 3.3.12 –
Intent – Manufacturing X-ray screen to insure there are no gross problems visible.
EFI – glue and particles of explosive are a concern, but are not visible in an x-ray. Replace this with is a sampled visual inspection.
- c. Leakage: 4.1.3.3 & 3.3.14 –
Intent – Manufacturing screen test to verify the unit will have acceptable field storage properties.
The EFI has no meaningful seal to humidity, since it can pass readily through plastics. The test is not regarded as useful and can be deleted.
- d. Resistance: 4.4.2 & 3.4.2 –
Manufacturing screen to verify the resistance is according to design tolerances in a completed unit.

Use a four terminal resistance probe (or equal).
Measure the resistance to 1% at the connector input terminals.

- e. Static Discharge: 4.4.3.2 & 3.4.3.4.2 –
Safety and reliability test for human ESD discharge.
Perform the test from strip-line to case.
- f. Stray Voltage: 4.4.3.3 & 3.4.3.2.3 –
A safety test for minor stray current – 100ma @ .3 sec 2 per second
up to 2000 inputs.
For a class C device this is where we would want (MASS B)
a one-ampere one watt no-fire equivalent for reliability and
a 500 volt no-fire test equivalent for safety.
- g. Power current of stimulus at 70 F: 4.4.3.1 , 4.4.5.1, 3.4.3.2.1, 3.4.3.4.1 –
Test for the maximum no-fire stimulus
Test for compliance to MASS A – see the attached memo on MASS
- h. 40 foot drop: 4.6.1 & 3.5.1 –
Safety test for primary explosives
Due to concern for future potential EFI configurations
the test should be retained with the test performed in a
fixture (2x2x2) rather than bare component drop.
- i. 6 foot drop: 4.6.2 & 3.5.2 –
Reliability test for bench drop
Retain
- j. Shock: 4.6.3 & 3.5.3
Reliability drop test
Determine the maximum mechanical shock the unit will tolerate using a
Hopkinson Bar test and functioning following exposure to the shock. Pulse
width should be 50 microseconds minimum with a maximum rise rate of 10
microseconds. 200 G's is the minimum lower limit for the test. The
maximum shock shall be reported as part of qualification. One ESAD
manufacturer already performs this test.
- k. Vibration: 4.6.4 & 3.5.4 –
Reliability vibration test
Test according to 23659C
- l. Temperature Shock Humidity Altitude: 4.6.5 & 3.5.5
A reliability environmental exposure test.
Use the MIL-STD-331 28 day test; it is important to perform
functional testing within a few hours of exposure to humidity.
- m. Cook-off: 4.6.6.1 & 3.5.6 –
Intent of an insensitive munitions requirement for the detonator – slow
cook-off
Delete

- n. Temperature Exposure: 4.6.6.2 & 3.5.7 –
Reliability test for high temperature storage reliability –
explosives stability test.
Store the EFI for 12 hours at 165 °F, then functionally
test following five minutes at 225 °F.
- o. Salt Fog: 4.6.7 & 3.5.8 –
Reliability in salt-fog exposure
Delete.
- p. Min 50 *Milli sec All Fire, hot, cold & ambient: 4.4.4, 4.4.6, 4.7 & 3.4.3
Reliability All-Fire Test .99 @ 95 percent confidence.
 - 4.4.4 Determines if a Class A device meets the all fire requirements with
an input of 5 amperes or less following temperature conditioning.
 - 4.4.6 Determines the Class B minimum all fire stimulus by statistical
analysis, units shall be preconditioned to – 80 °F

Conduct a Langley test predicting the mean firing stimulus (current rise
rate to exceed a specified minimum current). It is recommended that at
least 50 units are tested cold. Data from MICOM experience showed
the worst case conditions for an EFI are 4.4.7. Verifies the perfor-
mance of a Class B device following exposure to environmental
conditioning.

Test at the maximum and minimum input levels (current rate + peak
current) at which the vendor wishes to sell his product. Test levels
should be above the predicted minimum reliable level predicted by the
statistical evaluation of the EFI, based on LAT acceptance criteria.

F. Statistical Detonator Data

The tests in 23659 quantitatively provide some confidence that the detonator has reliability to a level of .99. About 300 all-fire tests are required to demonstrate .99 reliability at 95 percent confidence, 600 for .995. A reliability of .99 is probably the practical limit of what can be demonstrated, stricter requirements can only be projected. Most MICOM programs require reliabilities well beyond .99, MIL-STD-1316D defines arming at the probability to not fire of .995, and the safety criteria the author supports is a probability to not fire of .999999 @ 95 percent confidence; no one will fire enough devices to quantitatively show these probabilities, they can only be protections based on statistical data.

1. ARMED – MNFS

a. The greatest source of continuing controversy during the discussions on 1316D was what constitutes armed and safe. The level originally proposed to represent ARMED in 1316D was MASS which is a 10⁻⁶ probability to function. This was unacceptable to the author and others. The author proposed using a high probability such as .9 commensurate with the current mechanical S&A's, but this also was unacceptable. It was decided to make both mechanical and electronic S&A's safer than in the past at safe separation by making the state of armed MNFS a probability to fire of .005 at 95 percent confidence.

b. Which MNFS? MNFS stands for Maximum No-fire Stimulus, but the definition has several values in different standards as shown in Figure 12a and 12b. Most of the personnel in fuzing are familiar with the MIL-STD-1385 figures since it forms the pass/fail criteria for EMR tests. The definition in 1385 only applies to safety. The test pass/fail criteria in 1385 is 15 percent of MNFS for safety tests and 45 percent for reliability tests. The 1385 criteria was desired maintained by many in the community so they would not have to adjust to another new requirement.

c. The Armed Recommendation: The measure of armed is dictated by 1316 as MNFS the energy corresponding to a probability to fire of .005. This must be projected for the EFI by the voltage on the firing capacitor. We have yet to confront the ITOP test procedures that specify measuring safe separation by firing rounds at a all-fire target, impractical with the 1316D definition or armed (it is not easy to make an ESAD fire on arm either).

d. The author's concerns in defining armed in 1316D stemmed from the short range reduction in weapon usefulness at close ranges if the required probability to fire was too low for safe separation. Armed is a voltage on the firing capacitor, so it takes time and distance to charge the capacitor from safe separation to the all-fire level. The circuits that charge the capacitor are limited in rate (current technology limits total charge time to about 50 msec), so a low safe separation voltage would be restrictive to the weapon system minimum target engagement distance. The author is satisfied with the compromise that was reached.

2. SAFE - MASS

a. The controversy over what is SAFE at this writing appears to be arriving at a conclusion with MASS endorsed by the Navy WSESRB to represent safe (the safety features must also be safe). The author endorses MASS to represent SAFE.

b. 23659 currently lists MNFS, and we might have used 15 percent of MNFS as safe as in MIL-STD-1385. Fifteen percent of MNFS is 15 percent of the voltage that corresponds to a .01 probability to fire what ever safety that provides; remember we can't depend on the device under test having the same statistical characteristics for the EFI's that this proposed 23659 change was based on.

c. MASS is defined as a probability to fire of 10^{-6} , a predictable value, and using statistical data it is a value that is the same for each detonator regardless of the configuration. While the current writing of MIL-STD-1316D has not implemented MASS in a definition of SAFE, no one can deny that for test pass/fail criteria some definition of SAFE is required. I believe MASS is pretty good and the arguments should be over the margin on MASS, which is 95 percent confidence necessary in predicting MASS if the test criteria has margin built in. What is proposed includes both the confidence level, and margin, but MASS is defined by test only for electrical inputs (which are believed acceptable for either the EFI or EBW).

d. MASS generically means any input; light, mechanical, heat, pressure, etc. Most initiators are designed with a firing circuit, and for practical reasons the firing circuit is designed to produce the desired output with the minimum of energy. The firing circuit often is not optimized, but is usually not far off, compared to initiating the device with shock or heat. Therefore, it is the firing stimulus I would argue is likely close to the lowest energy that can create a function. The only tests sited here are electrical, and I do not propose additional at this time. Devices that are unique (such as the SCB) would have to pass tailored tests that should include special environments of concern. Paragraph 4 where MASS is proven does not refer directly to MASS, only to the sub-elements of MASS that are examined; firing stimulus, and deflagration.

3. MASS – Firing Stimulus

a. Requirements to be SAFE – MASS is represented in the proposed specification as MASS – Firing Stimulus and MASS Deflagration as shown in Figure 12. 1316D requires the in-line detonator to be insensitive to a 500 volt input. This is satisfied by a 10-6 (or less) no-fire level with 500 volts on the firing capacitor. This assures safety if 500 volts accidentally leaks into the firing circuit.

b. Recommendation – MASS-Firing Stimulus (Detonation is the primary concern). Limit the energy stored in the firing circuit. The statistics of the qualification firing potential/current should predict 10-6 No-Fire at or above 500 volts at 95 percent confidence. A safety test pass/fail criteria can be conveniently met by 15 percent of 500 volts, or 75 volts on the firing capacitor avoiding any complicated calculations. Theoretically, the voltage corresponding to a 10-6 firing probability is all that is necessary, which could be 1000 volts for a particular detonator. Seventy-five volts is recommended partly because I haven't met anyone who is comfortable with declaring a firing capacitor safe with 1000 volts on it (despite the math), and I haven't met a contractor who's uncomfortable with 75 volts as a pass/fail level. If an input energy form other than stored electricity is used then the user must develop a method to measure that energy for tests consistent with 15 percent of the 10-6 probability to fire. Consistent with MIL-STD-1385, 15 percent of MASS-Firing Stimulus should not degrade reliability. Since many firing switches do not work at 75 volts, they can be substituted in the test circuit with a FET, SCR or something that does work at 75 volts. This test needs work.

c. Some personnel doubt the data indicating only the high speed conventional firing signal can create a detonation in an EFI. However, there is some reason to doubt past data. For example, while thousands of EFI's have been fired, few were tested using an input that represents an accident.

4. MASS – Deflagration

a. Can an EFI Deflagrate? An original claim was that the EFI could not deflagrate (it is noted Lawrence Livermore personnel reported in January 1987 a violent reaction from an EFI exposed to line levels). The author asked Motorola what happens to an EFI when it is plugged into the wall? Motorola obliged and the results were disturbing to some people. Tests by the Navy at China Lake showed that it can happen and some designs, when plugged into a 120 volt wall source, created a sustained electrical arc at the EFI bridge.

b. Intent of the MASS Deflagration test. A DOE study is widely cited as a rationale that it is a waste of time to refine the probability of the EFI to detonate, deflagrate, or something between. While I have several criticisms about the EBW study, I feel we have better things to spend money on than studying details of various configurations of EFI's (there are too many variations to investigate them all). The point is that the concern is for safety, not performance. We are not concerned about the absolute lowest firing input. Rather, we need to define a point that is very probable to be safe. The 1A-1W requirement we have used for years hardly has a detailed technical foundation, but it has worked. The EFI needs a usable test standard. The expressed optimism about the EFI is not intended to extend to other unknown devices. It is felt that tests for undefined inputs is an application specific concern.

c. The other 1316D concern is for either detonation or deflagration from 500 volts from an unrestrained source, a value that is supported by several safety personnel. The ARMY interprets the 500 volt deflagration concern to apply only at the ESAD level. That is,

initiators alone are not usually required to not deflagrate when plugged into a 500 volt wall outlet. Five hundred volts from an unrestrained energy source (line currents) applies to the external leads of the ESAD, or subsystems such as the firing unit for a tandem front warhead. The detonator alone may be required to pass a 500 volt tests if the firing leads are exposed outside the ESAD (the case with some multiple detonator warhead configurations). Regardless of whether the detonator is independently required to prevent deflagration, we need to know what input threshold levels can create a deflagration.

d. MASS-Deflagration: There has been little investigation of deflagration, and probably will not be much in the future. However, the author is aware of no cases where deflagration occurred when the bridge was intact (I have not evaluated the EBW, but expect results that are very similar to the EFI). The heat that can be practically generated in fifty milliohms will not cause a reaction. Once the bridge opens, all sorts of possibilities exist; arc across the bridge, arc to the case, the explosive burns, the plastic case burns, etc. The source of the heat is the arc not the bridge. MASS-Deflagration is proposed measured by an electrical input that opens the bridge.

e. Deflagration Input. What sort of an input signal is likely to create a deflagration? Radar, slipped screwdrivers, a short to a test instrument, or possibly a ground loop are a few of the signals that can cause deflagration. Based on my experience and discussions with MICOM's radar personnel the typical input is neither DC or simple AC. Some complex or transient waveform is likely.

f. Recommended Deflagration test input. The author attempted to retain the relative simplicity of the 1A-1W DC input, and achieve an input that is transient. The recommended input is shown in Figure 13, about 10 percent of the phase of a 60 hertz signal. The test is to expose the current to the EFI, increasing the current until the bridge opens.

g. Proposed MASS-Deflagration PASS/FAIL test. Just because the bridge opens does not mean the initiator would deflagrate so the author is satisfied with PASS/FAIL MASS-Deflagration test criteria of 15 percent of the projected current that will open the bridge, provided the detonator is tested with an input of MASS B showing it does not impact the reliability of the device. The test level could be predicted by the statistics of the point of deflagration. Fifteen percent of the mean current is considered consistent with 15 percent of MNFS in MIL-STD-1385, and the current would be measured by the heat rise in the bridge, and then measured in a manner similar to that used today in heat detonators, or perhaps by IR detection. While this criteria has not been tested, measuring a temperature change at 15 percent of a current that fuses copper should be practical, still some tailoring may be necessary.

G. Historical 23659 Patterns etc

1. While 23659 has a basic set of test purposes to maintain, it also appears to have a pattern. Not all programs (or any) conduct the tests according to what I believe was the original intent; in particular the tests appear intended performed in sequence not in parallel. The intent of the requirements often can only be guessed at, and MIL-I-23659 is no exception. The sequence logically was to first examine devices for visible defects, then test some to form the baseline data to predict the all fire input requirements; then test units to prove the quality and reliability. Conducting the tests in sequence is not popular today because it takes longer; it is more popular to accept increased technical risk to reduce schedule. Reviewing Table 1 (from the existing 23659), the statistical data from the first column furnishes a baseline of information to confirm the later

test levels for all-fire and no-fire. The detonator is exposed to the baseline tests to be used later and verified as acceptable. The subsequent tests then expose the detonator to a variety of environments ending in the functioning a quantity of units.

2. 23659 is designed to test hardware for acceptable design safety, performance, and manufacturing quality. Performance variations are usually detected by qualitative tests such as statistical sensitivity, the dent produced by the explosive, or a quantity of hardware. The EFI has a significant number of design variables that are independent. Another way of saying this is that there is not one test that adequately verifies the independent performance requirements. Rather than test quantities that is several times that consumed in the existing 23659, some of the confidence level for these requirements are proposed based on statistical projections not go/no-go tests. The quantities of the proposed new Class B, are not consistent with those in the original document and are based on technical concern. T, H, & ALT and cold functioning are environments of unique concern so deserve emphasis in the form of larger test quantity.

3. Some are concerned that we should go slow with changes until a review is complete. It is not clear 23659 has ever been used to qualify a Class B device. If so, then I'd be interested in how the 23659 test in paragraph 4.4.5.1 was performed. The test requires a statistical evaluation predicting the no-fire level for the initiator. The test is very vaguely described. Presumably to determine the maximum no-fire level statistically, there would be some failures and/or test samples would be damaged. This test is used in the matrix table as non-destructive. Test devices are required to fire reliably following the test. What the test probably meant is exposure of the device to the MNFS no-fire input, where it should be reliable after the test.

H. MIL-STD-1512

MICOM has been using MIL-STD-1512 in our systems for years, usually without explaining why. The MIL-STD-1512 has two basic uses, one is for the qualification of squibs, and the other for the design and qualification of S&A's for propulsion systems. Some of the features are interesting but the document does not apply well to today's systems. It is believed that the more important feature in the standard is test 303 - Electro-Magnetic Analysis of Electro Explosive Systems, but this is only indirectly related to this report.

1. Among the more interesting features of the document is the stress it places on statistical evaluations. The MIL-STD refers to 23659 as the reference for statistical tests for materials that probably have been removed from the specification. 1512 comments that Brucceton procedures are poor for evaluations requiring accuracy in the standard deviation. Statistical procedures are expected used to determine the all-fire and no-fire levels, but they are included in the qualification test. The author strongly recommends such tests are part of qualification as documented reportable data.

2. The MIL-STD requires EED's to be both reliable and safe at temperatures 50 percent above the highest the system will be exposed to. The standard does not specify 50 percent of Fahrenheit or Celsius, but otherwise it is a parallel to the 225 °F test in 23659. Too bad neither document states why the high temperature penalty test is important. Particularly, why is the initiator required functionally reliable at temperatures well above most systems? The test recommended in this report deletes reliability as a requirement, but retains the interpreted test intent. It is noted that some missile systems reach 225 °F in flight and would require reliability above that temperature.

3. Another test that is not explained is thermal time constant. The test (method 206) states it is extremely valuable from both cost and quality, but again fails to explain why.

4. Insight was gained from the EED qualification plan, because as many as 24 tests with varying sequence are exposed to the EED's during qualification, (Fig. 14). Several countries stress varied test sequencing. The bulk of the 1512 all-fire devices are exposed to varied sequential environments, 185 devices providing reliability data. 378 test samples are consumed in various safety tests, mostly defining the electrical insensitivity of the device, thermal time constant, RF sensitivity, Direct current susceptibility, etc. 1512 places unusual emphasis on the initiators insensitivity to E³.

5. Some tests required in the MIL-STD have been forgotten today or left to trust. Of these a shelf life test should be added to new EED designs, but the bulk initiators tested are recommended exposed to some sequenced environmental tests rather than the benign all-fire that is in 23659. Still, EFI's have not been effectively tested for storage.

I. Other Comments

1. Resistance - Resistance is checked in the basic 23659 after several tests, it appears the intent is not only to verify that resistance can be measured without damaging the detonator (as the existing 23659 resistance requirement specifies), but also to verify that the detonator has not created an open circuit from the previous test. The recommended requirement corrects the basic test requirement for Class B devices and further specifies a measure of evaluating a non-damaging environment beyond performing an All-Fire test. It may be desirable to put a note in Section 6 to use a four terminal probe or equal for the resistance measurement.

2. The proposed requirements are considered reasonable, but not all have been verified by test as practical. The temperature rise of the bridge with 15 percent of MASS-Deflagration has not been tested yet. While 15 percent of the current that opens the 1 percent of the bridges almost have to be non-destructive, 75 volts on the firing capacitor may not be on all designs, it requires testing. Another caution is that while currently few, if any, contractors are concerned about generating 75 volts or even five volts on the firing capacitor during an EMROH test, only one or two designs have been tested, and they have not had any simplification. The voltage that creates industry concern has yet to be established based on human reaction.

3. Design margin in component and subsystem tests should exist, and system specific tests usually eliminate that margin. If a product is tested in large quantities, the design margin can probably be reduced or eliminated, but for missiles where the entire production can be a thousand rounds, design margin should be substituted for the confidence provided by quantity. Missile qualification tests should demonstrate design margin. The purpose of application specific tests should not be to reduce all environments to what we think is in the system. The Qualification and other tests (first Article, LAT, etc.) are usually very similar. These tests have one element in common, they should not only demonstrate the hardware meets the system requirements, but also that the hardware is built to expected standards. There have been several instances where the tailoring reduced test requirements below that expected for reasonable quality. This concern is easiest to explain using a circuit example. A simple voltage divider circuit built with two 1 percent resistors should have a precision no worse than 2 percent, yet if the system requirements are only 10 percent, based on the system needs we could justify a test that passes poor quality hardware. An electrically initiated Class B detonator should meet certain minimum standards no matter what the application is. The tests proposed include both a minimum standard tests and application specific tests.

4. One comment was that radiographic examination may intend to expose the initiator to nuclear environments and so should be retained. That and other comments suggest there are advantages of radiographic examination that are not obvious. A visual inspection was included only if radiographic examination is impractical.

5. The effects of humidity on the EFI are a concern to a number of personnel, and some contractor data exists predicting degrading effects from humidity. In particular, the EFI has potential concerns because it cannot be hermetically sealed. Initially, the author felt a dielectric breakdown test during the humidity test was critical since so many EFI materials are potentially susceptible, such as the stripline material kapton (hygroscopic). However, the presence of a high voltage spike is likely to occur only after initiator installation where the munition structure would provide some protection (the firing stimulus is tested during the all-fire). Modern munitions rarely have the initiator leads exposed, so this test should be added if a program finds a need (the program can also solve the problem of how to conduct the test, credibly, without mediating the intent of the humidity test by drying the test specimen).

6. There is some interest in stray currents and insuring the initiator is not damaged from exposure to currents typical of a ohmmeter. This concern is felt answered by the MASS deflagration test where currents substantially above meters is tested.

J. Proposed Changes

1. The government has a reputation of being in conference when action is required. 23659 needs a great deal of revision, and based on experience, some year that may happen. This report is proposed to fill the gap for the current technology, but save major revisions as another task. Actually the greater revision is not 23659, its all the other documents that tell us how to qualify a detonator. How can we stop proliferating requirements? The issue should not only be improving the current specification but eliminating an old one such as MIL-STD-1512.

2. The following paragraphs are proposed as a straw-man for Class B devices in 23659, and is recommended to the Army AFSRB similar to the waiver guidelines for 1316.

a. For reader interest, the first table considered for the change is shown in Table 2. The table was based on the original 23659, and was followed mostly to accomplish similarity to the original in 23659. The reader will note that the table is messy and confusing in 23659. After reading various test proposal, and especially that proposed by Hollingsworth for a cancelled program called GLTR, the author became convinced that the test matrix could stand some major modifications.

b. The list of tests recommended is summarized in Figure 10. The recommended 23659 tests in Table 3 are divided in several intended functional sections as shown in Figure 15. The total All-Fire quantity demonstrates the original 23659 reliability of .01 at 95 percent confidence, while keeping the total quantity about the same.

1). The matrix begins with some informational tests to define or confirm previously assumed data for MASS, MNFS, and All-Fire Stimulus.

2). Then a large quantity of detonators are exposed to the minimum tests standards recommended for any detonator. The intent of the standard test sequencing shows design margin. It is borrowed from both MIL-STD-1512, and the matrix proposed by Hollingsworth.

3). Many of the safety tests are not necessary for every system or detonator configuration (e.g. "We don't mind performing forty foot drop bare, the detonators will just flutter down like a leaf."), as such these are grouped. These tests are required only if so stated in the system requirements.

4). The final group of tests are the application specific tests. The intent of showing blank system specific tests are intended to be additional tests as required, not a wash of the standard tests. A suggested list of application specific environments is shown in Table 4. These tests are recommended to be applied to all tested devices with some degree of sequencing in the final test with verification tests (resistance measurement, MASS, etc) at various points. Among those that should be considered for importance are environments that can influence the explosive sensitivity, temperature/humidity, chemical environment (i.e. gasoline vapors).

5). The vibration tests were not closely investigated by the author. However, both captive carry vibration, and flight vibration should not normally be required for a detonator typically designed to withstand thousands of G's of shock. One vibration test should be adequate, and the one in 23659 is not proposed changed.

6). The Temperature, Humidity, and Altitude test is considered reasonable for any missile. Some contend that desiccate reduces humidity to a lower level, eliminating frost and high humidity, unless the desiccate is very near the fuze. I have seen evidence the claim of protection by desiccate is often only marginally true (desiccate is typically at the back of a round to reduce the aging of the propellant). If someone claims otherwise, ask to see thermal T&H cycle data where the humidity might be lower (occasionally higher), but the actual peak values can be as bad as in an uncontrolled environment. Despite system requirements, however, a reasonable detonator should tolerate these environments. Initiators that are exposed to the Temperature, Humidity, and Altitude test would be baked dry by the temperature conditioning requirements of the Functional test – 4.7. Therefore, the report proposes changing the functional test to require initiators that have been exposed to humidity, to be temperature conditioned continuing the humidity exposure.

7). A Dielectric Withstanding Voltage test should be performed after or during the humidity test. This test would be difficult to perform, and further poses some problems to define. It is recommended that it is added and later incorporated within the Temperature, Humidity, and Altitude test – not at the end. The test is not included in the straw-man.

a. For simple applications, if the detonator was not qualified acceptably on a previous program, the minimum recommended EFI qualification is shown in Table 5.

b. Specific rewording and additional paragraphs are listed below.

SHOCK – Require a shock level consistent with the system application.

3.5.3. Shock. The initiator shall be capable of withstanding the worst case shock conditions expected for a specific application. The initiator shall have a level minimum, and shall be tested as specified in 4.6.3. After being subjected to the test the initiator shall meet the performance requirements when fired.

4.6.3. Shock. To determine if the initiators ... test vehicle.

4.6.3.1. Class A. If the test is conducted ... to this test.

4.6.3.2. Class B. The initiator shall be exposed to a shock pulse with a duration, level, and shape that matches the specification requirement as closely as possible without employing explosive means to generate the shock pulse (such as a Hopkinson Bar test to simulate an explosive shock wave). Initiators shall be free from visible damage and shall perform satisfactorily in functional tests following this test.

DIELECTRIC WITHSTANDING VOLTAGE – Change 500 volts to 5000. Tailoring is suggested if the firing potential is above 2500 volts, or below 1000 volts.

4.4.1. Dielectric Withstanding Voltage. To determine if the initiator meets the dielectric withstanding voltage of 5000 volts + or – 100 volts d.c. shall be applied for 60 seconds between shorted pairs of leads and metal surfaces—areas that normally contact the initiator insulation – such as the explosive case. These tests shall be conducted in accordance with MIL–STD–202, Method 301. The leakage current shall be measured with an accuracy of 5 percent and shall not exceed 2 micro–amperes.

VISUAL AND RADIOGRAPHIC INSPECTIONS Use visual inspection if radiographic is impractical.

3.3.12. Radiographic or Visual Inspection. Initiators shall be examined for defects by either radiographic examination such as x–ray, neutron bombardment, gamma rays, etc. as specified in 4.1.2.2. or visually if radiographic is impractical. Visual inspection reports and radiographic plates shall be identified by date, initiator part number, lot number, and serial number.

4.1.2.2. Visual or Radiographic Examination. Initiators shall be examined for defects either by radiographic means or by visual inspection as defined by paragraph 3.3.12. Initiators with material that is impractical to examine by radiographic means shall be recorded by photographic means.

ELECTRICAL COOK–OFF SUSCEPTIBILITY Electrical Cook–off Susceptibility is a test to determine the point at which a detonator could react for a 500 volt input from an high power source. It is also a system specific test recommended required when the initiator leads are exposed outside the ESAD.

3.4.3.6 Maximum Acceptable Stray Current. When required by system specifications, the initiator including the first explosive of the explosive train, in paragraph 3.4.3.5, shall not produce an explosive reaction from exposure to 500 vac 400 hertz sources with at least a 100 ampere current capacity, according to the definitions of paragraph 6.2.9. The stray current susceptibility shall be established for all detonators, regardless of system requirements according to paragraph 4.4.7.

4.4.7 Electrical Cook–Off. To determine the maximum acceptable stray current as required by 3.4.3.6, the bridge circuit shall be energized from an AC source having a current capacity not less than 100 amperes. The voltage shall be varied according to the requirements of the statistical test used. In each case, the voltage shall be adjusted to within 2 percent of the required value. For initiators having more than one bridge, only one bridge shall be energized. Initiators used for this test shall be temperature conditioned for a minimum of 12 hours at 70 degrees Fahrenheit plus or minus 5 degrees. Initiators exposed to the Temperature, Humidity, and Altitude test of paragraph 4.6.5 shall be temperature conditioned prior to the functioning in a chamber that maintains the sea level humidity conditions of the Temperature, Humidity, and Altitude test, i.e. 95 percent RH for hot tests, 50 percent RH for ambient, and achieved humidity

for cold tests.

3.5.7 Cook-Off Thermal. An initiator that is exposed to an increasing thermal environment, the test unit shall have no reaction other than burning.

4.6.6.2 Cook-Off Thermal. Perform the test in accordance with MIL-STD-2105.

MAXIMUM ACCEPTABLE SAFE STIMULUS

6.2.9 Maximum Acceptable Safe Stimulus (MASS). The greatest stimulus which does not create an explosive reaction in more than 10-6 of all initiators of a given design at a level of confidence of 95 percent. 15 percent of MASS shall not degrade the reliability of the initiator.

3.4.3.4.1 Any device exposed to 15 percent of the maximum safe firing stimulus as determined in paragraph 4.4.6 shall not be degraded in functioning reliability.

3.4.3.4.3 Any device exposed to 15 percent of the maximum safe current stimulus as determined in paragraph 4.4.5.1 shall not be degraded in functioning reliability.

4.4.5.3 MASS. Initiators shall be exposed to 15 percent of the maximum safe firing stimulus and maximum safe current stimulus in compliance with paragraphs 3.4.3.4.1 and 3.4.3.4.3. Samples shall be temperature conditioned to thermal equilibrium according to the test, ambient and 150 °F are used in the proposed Table 3 for 23659.

4.4.5.1. Deflagration Threshold. To determine the maximum safe current stimulus, a 60 hertz current pulse shall be applied to the bridge circuit until the bridge of the device opens. The test current pulse shall be the last 10 +/- 2 percent of the phase of a half sine 60 hertz wave form with a maximum rise time of one microsecond. The current shall be applied to the input leads of the initiation device under test beginning at a low RMS current increasing 25 percent per minute until the bridge of the device opens. The initial current should be adjusted so the test requires about five minutes to complete. Should the device have more than one bridge, only one bridge shall be energized for this test. Initiators used for this test shall be temperature conditioned at 70° F (+/- 5) for a minimum time of 12 hours. The maximum safe current is the RMS current that is statistically predicted to open 1 percent of the bridges.

ALL-FIRE The operational temperatures common for most missiles are -45° and +145°. A five degree margin is recommended as reasonable.

3.4.3.5. All-Fire Stimulus, Class B. Firing units including all components that statistically influence the variation in firing stimulus are considered an initiator for purposes of determining the Minimum 50 Millisecond All-Fire Stimulus. The minimum all-fire stimulus shall be determined as defined in paragraph 4.4.6 and shall predict an acceptable statistical probability to fire, according to the system requirements, for the all fire stimulus used in 3.6.

4.4.6. Firing Properties, Class B. To determine the minimum All-Fire Stimulus and the Maximum Safe Firing Stimulus as required by 3.4.3.5 and 3.4.3.4.1 the bridge circuit shall be energized from the power supply (firing unit) of the unit of intended application or from a source which simulates that supply. The normal controlling initiation variable according to the physics of the device under test (Eg. capacitor voltage current pulse, light intensity) shall be chosen and varied according to the requirements of the statistical test used. In each case, the parameter varied shall be adjusted to within two percent of the required value. For initiators having more than

one bridge, only one bridge shall be energized. Initiators used for this test shall be temperature conditioned for a minimum time of 12 hours at the test temperature. The initiator and the fire unit shall temperature conditioned ambient, maximum hot, and minimum cold for either -50°F or lower, $+150^{\circ}\text{F}$ or higher, and 75°F plus or minus two degrees. Should the firing unit be only a simulation or reused for several shots – then the firing unit shall be calibrated according to 6.2.11 and its firing properties reported, as well as the statistical firing parameters of the application firing unit.

6.2.10 Firing Unit. A firing unit is the firing energy storage device (such as a capacitor), the firing energy interrupter, and the initiator.

6.2.11. Firing Unit Calibration. A firing unit shall be calibrated measuring and recording those parameters such as current rise rate, time, or inductance required to predict variations in the initiator firing properties. The properties shall be recorded according to the qualification test procedures at the temperature extremes, normal controlling initiation variable extremes (such as voltage), and for circuit repeatability.

NON-DESTRUCTIVE TESTS

3.5.2. Six Foot Drop. The initiator shall not fire or be damaged when dropped from a height of six feet as specified in 4.6.2. After being subjected to the drop test, the initiators shall meet the design performance requirements when test fired and Class B initiators shall not exhibit a 5 percent statistically significant change in resistance when tested as specified in 4.4.1, or 4.4.2.

3.5.4. Vibration. The initiator shall be capable of withstanding vibration conditions as specified in 4.6.4. After being subjected to the vibration test, the initiator shall meet the design performance requirements when fired. Class B initiators shall not exhibit a 5 percent statistically significant change in resistance when tested as specified in 4.4.1, or 4.4.2. Temperature conditioning in the test shall be $+150^{\circ}\text{F}$ or higher, ambient, and -50°F or lower.

3.5.5 Temperature-Shock/Humidity/Altitude. The initiator shall be capable of withstanding temperature-shock/humidity/altitude cycling conditions as specified in 4.6.5 and shall meet the design requirements when test fired and Class B initiators shall not exhibit a 5 percent statistically significant change in resistance when tested as specified in 4.4.1, or 4.4.2. Temperature conditioning in the test shall be $+150^{\circ}\text{F}$ or higher, ambient, and -50°F or lower.

3.3.15 Leakage – Class B. Hermetic initiators should meet the requirements of para 3.3.14. Non-hermetic initiators should meet the requirements of the system as tested by paragraph 4.1.2.4.

4.1.2.4 Leakage – Non Hermetic Devices: Conduct test in accordance with MIL-STD 331A, Test 118, Paragraph 5.2, Gross leak test.

III. CONCLUSIONS AND RECOMMENDATIONS

It is believed all the major elements for EFI qualification are contained in this proposal. It is recommended the Army agree to a 23659 waiver requirement for our programs. Further, there is a lot of data needed. It is recommended that the AFSRB request new and existing programs to report test data as it supports safety requirements such as MNFS, and MASS.

These materials are recommended to the custodian of 23659 as a straw-man to change the Class B requirements. It is recommended that we do not wait until we have reached perfection to implement changes.

Corrections and constructive criticism are welcome. Please send copies to:

COMMANDER ARMY MISSILE COMMAND
AMSMI-RD-ST-WF
REDSTONE ARSENAL, AL 35898

ALSO, the 23659 custodian,

Engineering Specifications And Standards Department
Naval Air Engineering Center
Philadelphia, PA. 19112

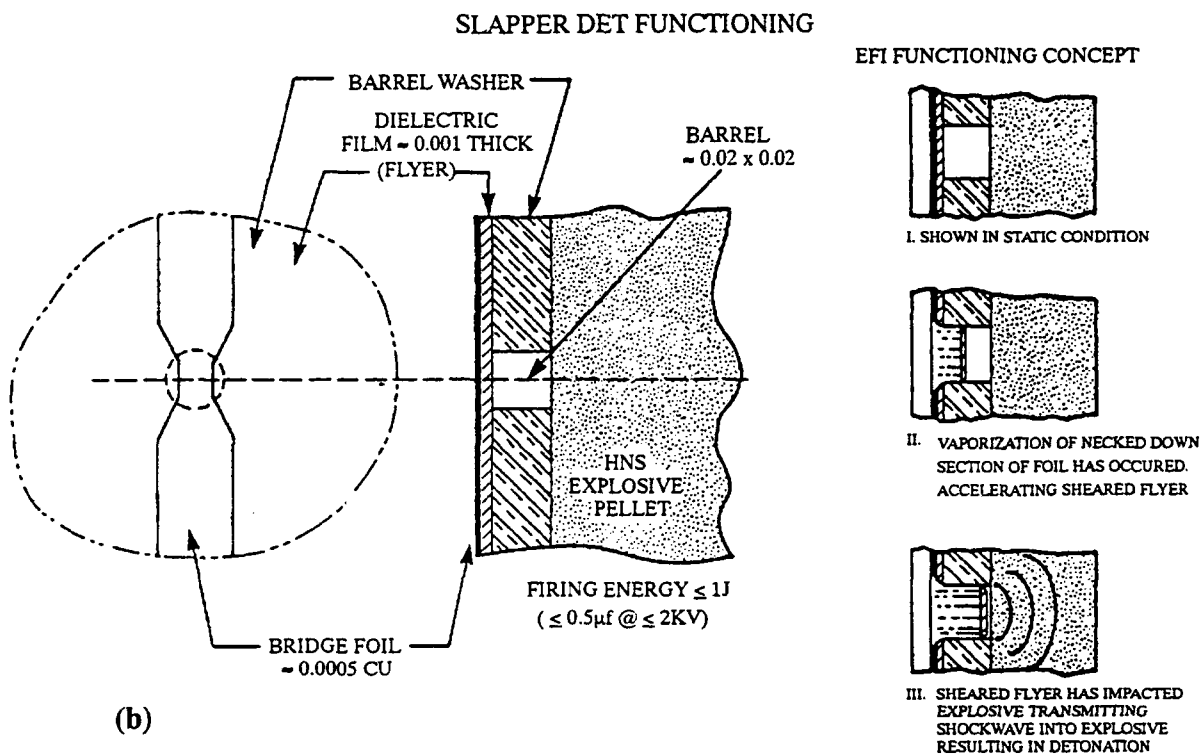
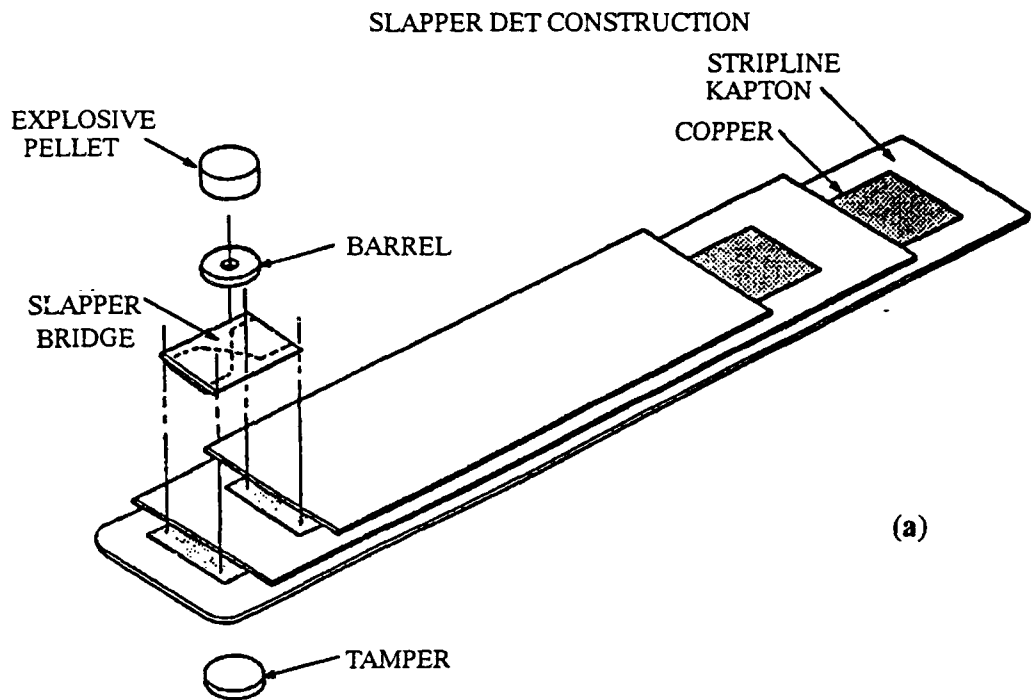


Figure 1. Basic EFI Configuration

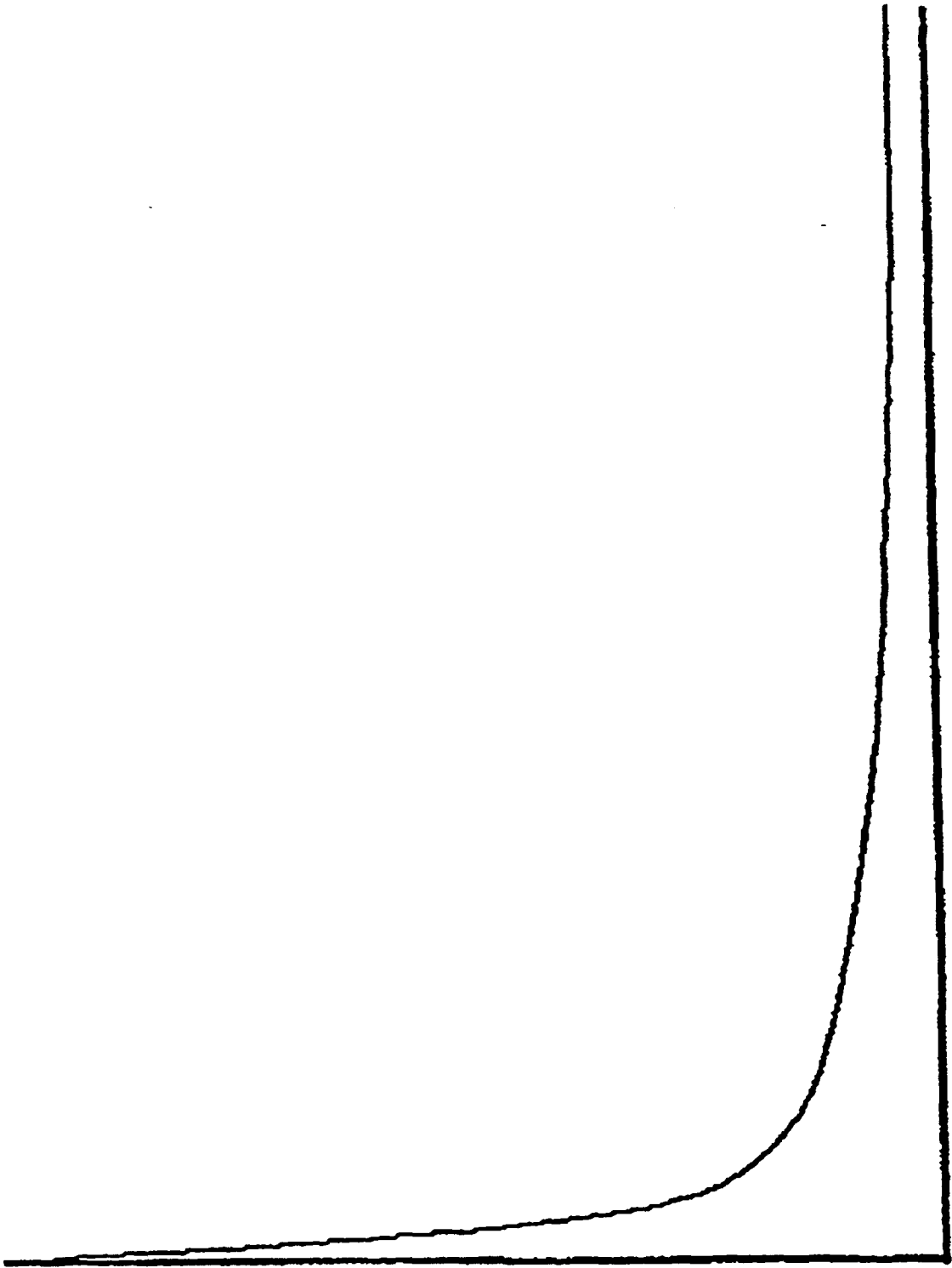


Figure 2. Capacitive Discharge

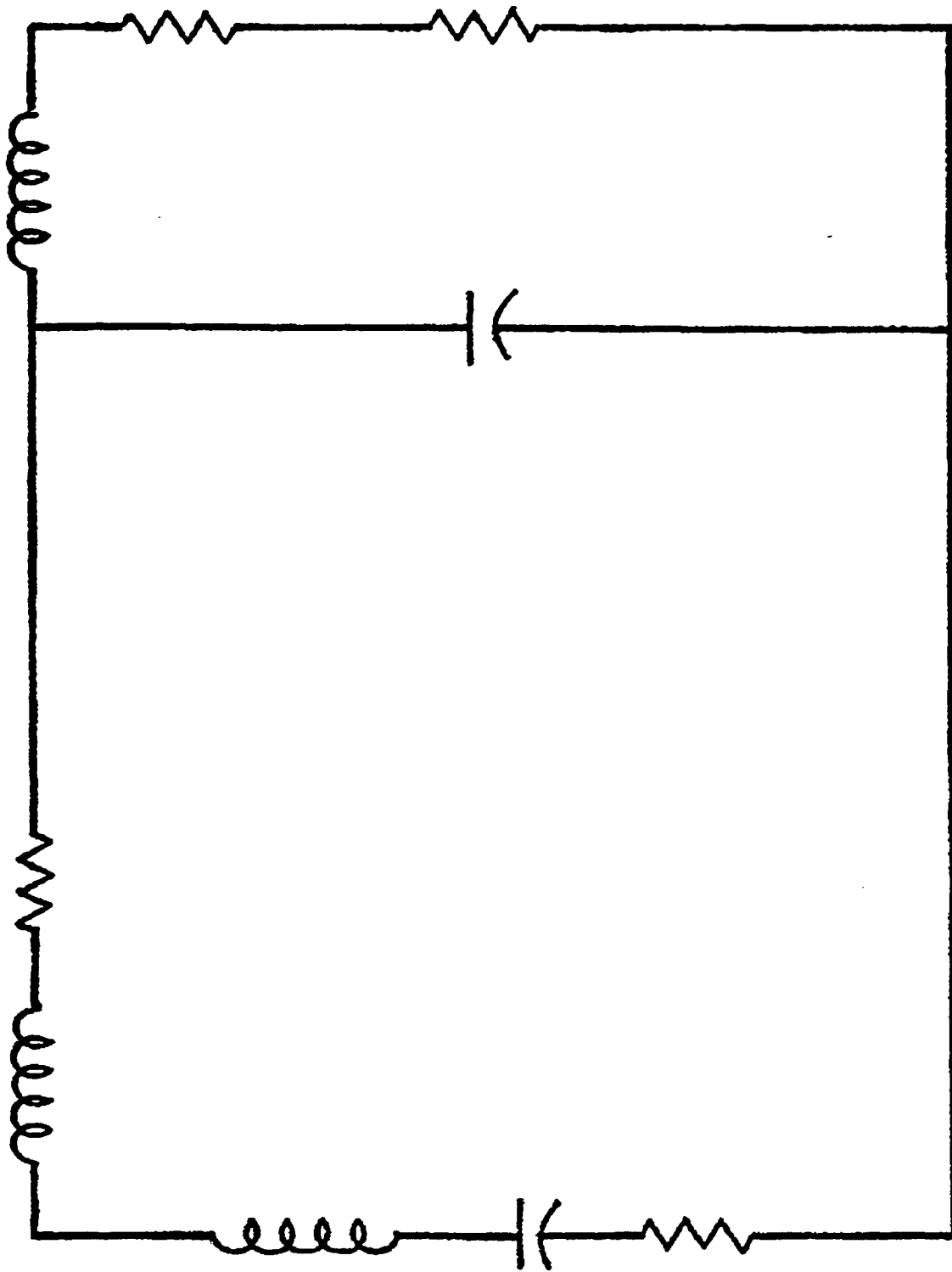


Figure 3. *EFI Firing Circuit Model*

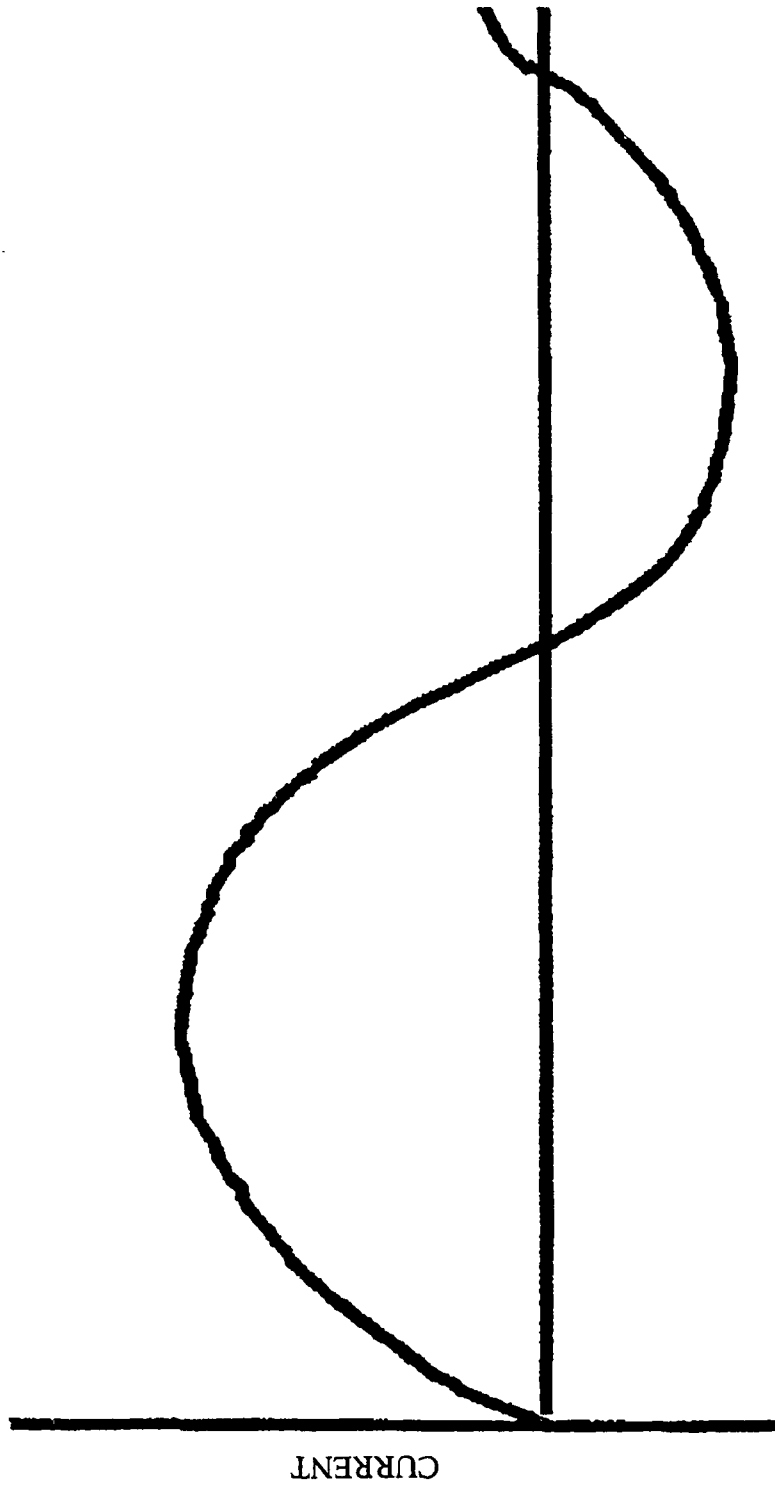


Figure 4. EFI Firing Current

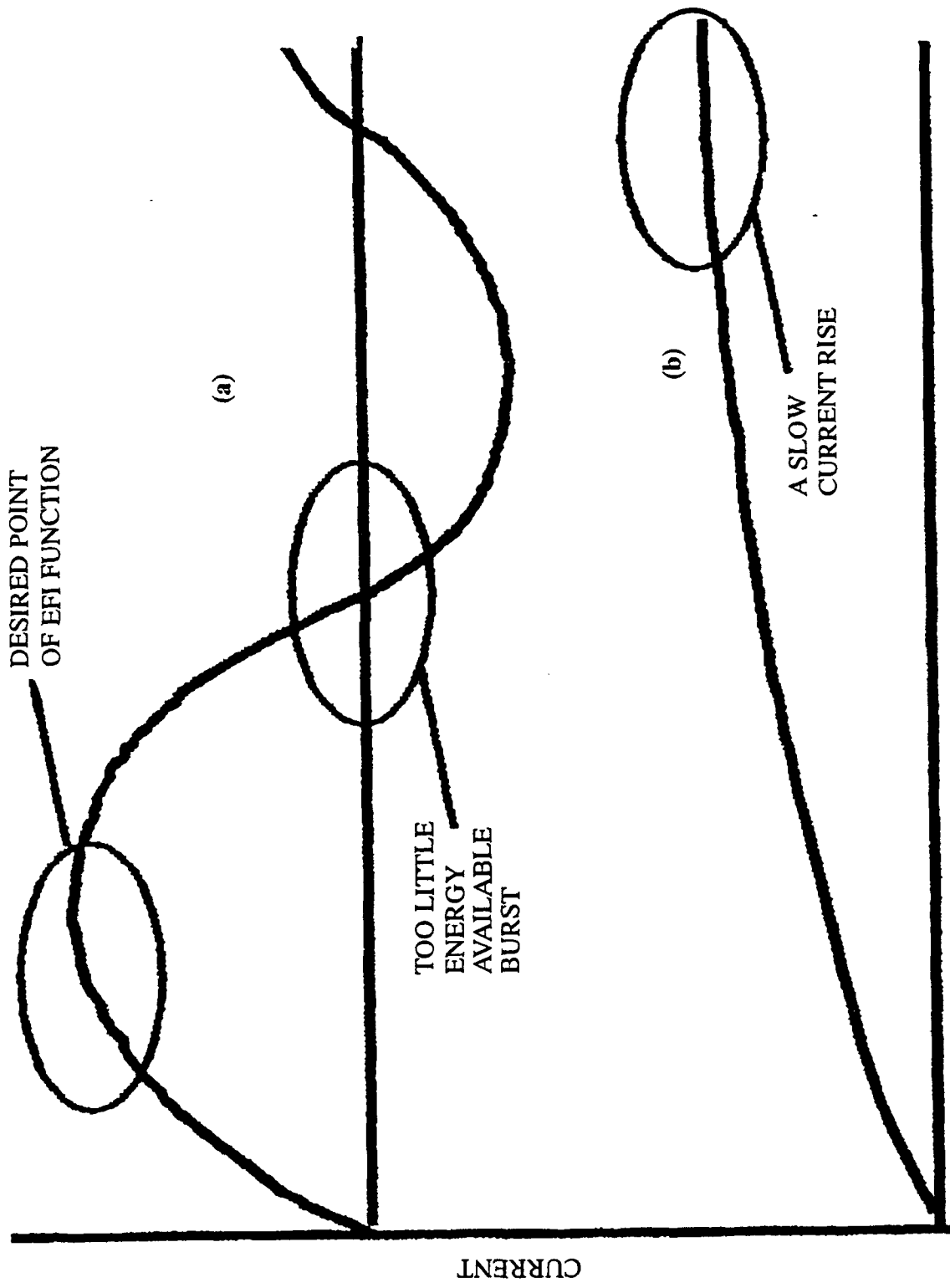


Figure 5. Proper Firing Current and Slow Rising Firing Current

Qualification of What?



ESAD



FIRE SET



ESAD



DETONATOR

Figure 6. Newer EFI Configurations

<u>Mechanical</u>	<u>Electrical</u>
- 40 Foot Drop	- Helicopter ESD/EMR
- Trans VIB	- System Noise
- Flight Vibration	- Power Transients
- Only Secondary Explosives In-Line	- 1A/1W No-Fire 500 V No-Fire
- Jolt & Jumble	- 500 VAC No-Fire
- Six Foot Drop	- Stray Voltage Handling ESD

Figure 7. Electrical Analogies to Mechanical Environments

<u>Test</u>	<u>Configuration</u>	<u>Pass/Fail</u>
System Noise	ESAD	No Compromise of Safeties by Analysis, Mass During Tests
Handling ESD	ESAD, Detonator	No-Damage

(a)

<u>Test</u>	<u>Configuration</u>	<u>Pass/Fail</u>
Lightening/EMR	Munition	Mass
500v No-Fire	23659 Test Configuration	10 EXP-6 @-95% Projection
500 VAC	ESAD	Mass
Emp/Nuclear Rad	ESAD/Munition	Mass

(b)

Figure 8. ESAD Tests and Pass/Fail Criteria

GROUP (LEFT TO RIGHT)

HYPOTHESIZED INTENT* - CLASS B

50

Baseline test group that shows safety during inspection tests, determines the Maximum No-Fire Stimulus, then determines the All Fire Stimulus

6

Safe during forty foot drop

6

Baseline that shows samples exposed to non destructive tests are still reliable

20

Sample For Shock

20

Sample For Vibration

20

Sample for Temp-Shock/Humidity/Altitude

20

Sample to establish the cookoff temperature

20

Demonstrate safety at high temperatures during inspection tests, then reliable at high temperature

20

Test for Salt-Fog environment

20

Same as previous high temperature group without human ESD

2 EACH 9 TIMES

2 each Shock & Vib in each plane

*Intent of paragraphs see memo on pgs 8 & 9

Figure 9. Intent of Test Samples - 23659

<u>GROUP</u>	<u>INTENT</u>
20	Inspection group & demonstrates that inspections tests are safe
30 each HOT, COLD, AMB	Statical firing properties to predict the Maximum No-Fire Threshold – MASS A, and the All Fire Stimulus
20	Determines MASS B, Deflagration
150	Statistical reliability sample exposed to base-line environments
6	Forty Foot Drop Safety Test
6	Cook-Off Electrical
6	Cook-Off Thermal
150	Statistical reliability sample exposed to system specific environments

Figure 10. Intent of Test Samples – Proposed Revision

SPEC	1385	1512	23659
TITLE	MNSF, MNFP, MNFC, MNFP, MNFV	NO-FIRE CURRENT	NO-FIRE STIMULUS
RQMT	STIMULUS RE- QUIRES 99.9% NO-FIRE @ 95% CONFIDENCE	NO-FIRE OR <i>DEGRADE WITH</i> A RELIABILITY OF 0.995 @ 95% CONFIDENCE	STIMULUS REQUIRES 99.9% NO-FIRE @ 95% CONFIDENCE
TEST MARGIN	HAZARDS 15% OF MNFV RELIABILITY 45% OF MNFV		

(a)

STD-322B
NO-FIRE STIMULUS

99% NO-FIRE
@ 85% CONFIDENCE

STD-1316-D
MAXIMUM NO-FIRE
STIMULUS

99.5% NO-FIRE
@ 95% CONFIDENCE

WSESRB RQMT's
MAXIMUM ACCEPTABLE
SAFE STIMULUS MASS

10 EXP-6 PROB TO FIRE
@ 95% CONFIDENCE

PROJECTED BY
ANALYSIS & TEST

(b)

Figure 11. Which MNFS

MASS – FIRING SENSITIVITY

PURPOSE IS INSENSITIVITY TO STRAY VOLTAGE ON THE FIRING CAPACITOR

CALCULATE THE VOLTAGE @
10 EXP-06 PROBABILITY TO FIRE
@-95% CONFIDENCE MUST BE
ABOVE 500 VOLTS

TESTS – FOR THE EFI OR EBW DIS-
CHARGE 75 VOLTS FROM THE FIRING
CAPACITOR

MASS – DEFLAGRATION

PURPOSE IS INSENSITIVITY TO STRAY CURRENTS

DETERMINE THE THRESHOLD OF
TRANSIENT CURRENT THAT OPENS
THE BRIDGE

TEST 2 – DEFLAGRATION THRESHOLD
TEST – 15% OF THE CURRENT THAT
OPENS THE BRIDGE

Figure 12. MASS – Firing Stimulus and MASS – Deflagation

DATE: 25-SEP-90 TIME: 17:13:20
DSA 602 DIGITIZING SIGNAL ANALYZER

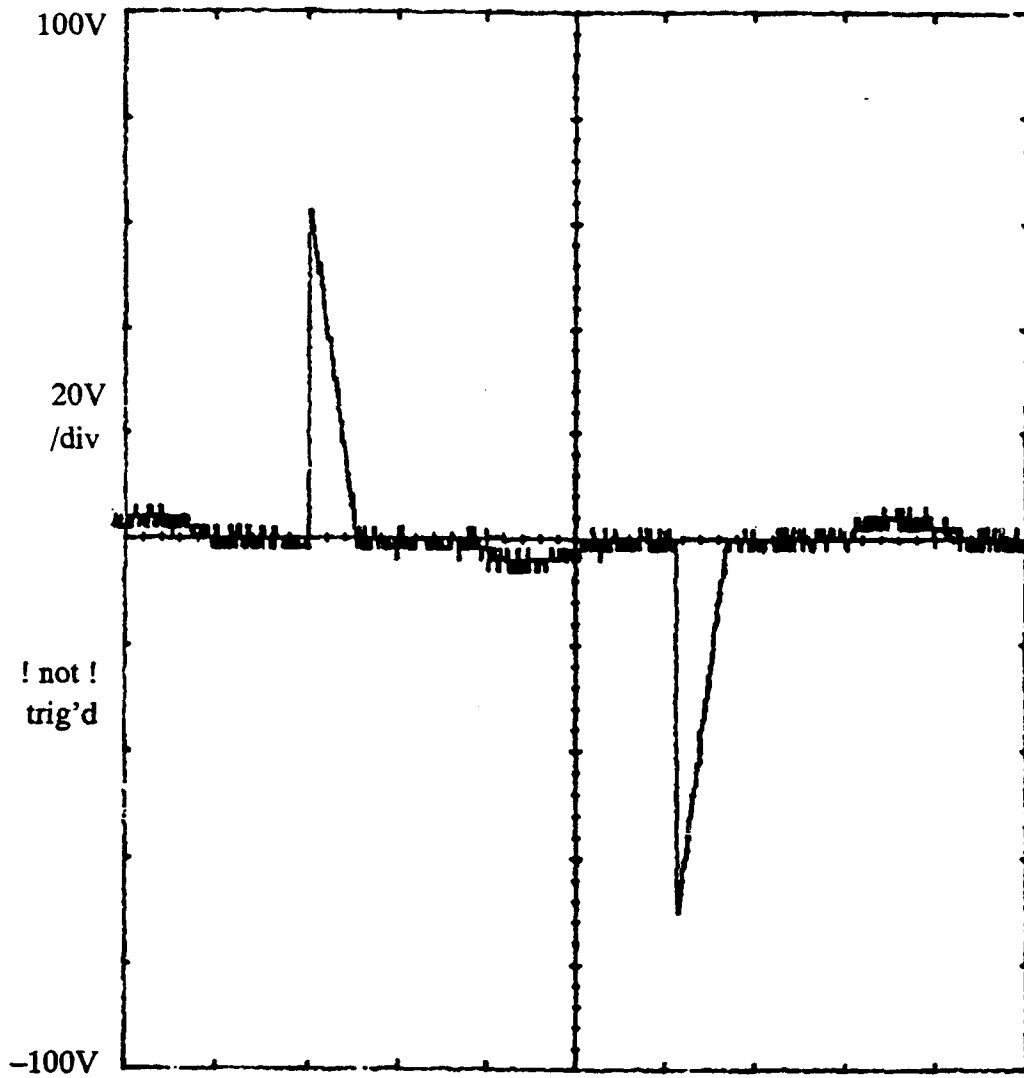


Figure 13. MASS - Deflagration Current Waveform

Test method	Number of Units Required ¹											
	50	50	50	5	10	20	45	50	30	33	180	40
101. <u>Visual inspection</u>	2,16	2,16	2,16	2,9	2,10	2,20	2	2	2	2	2	2
102. <u>Dimensional</u>	1,15	1,15	1,15	1,8	1,9	1,19	1	1	1	1	1	1
103. <u>Radiographic</u>	6,19	6,19	6,19	6,13	6,14	6,23	6	6	6	6	6	6
104. <u>Temperature and humidity</u>	10	10	7			7						
105. <u>Temperature-altitude</u>	12	12	12									
106. <u>Thermal shock</u>						11						
107. <u>Moisture resistance</u>						9						
108. <u>Salt spray</u>						10						
109. <u>Fungus</u>						12						
110. <u>Space simulation</u>						13						
111. <u>Seal effectiveness</u>						14						
112. <u>Steady-state acceleration</u>	11	11	11			15						
113. <u>Vibration</u>	9,14	8,14	9,14			16						
114. <u>Shock</u>	7,13	9,13	10,13	7		17						
115. <u>Accoustical noise</u>						17						
116. <u>Terminal strength</u>	22	22	22									
117. <u>Insulation resistance</u>	3,17	3,17	3,17	3,10	3,11	3,21	3	3	3	3	3	3
118. <u>Shelf life</u>						18						
119. <u>Transportation vibration</u>	8	7	8									
201. <u>Bridgewire</u>	4,18	4,18	4,18	4,11	4,12	4,22	4	4	4	4	4	4
202. <u>Verification of 1 amp/1 watt characteristics</u>	5,20	5,20	5,20	5,12	5,13	5	5	5	5	5	5	5
203. <u>Direct current sensitivity</u>							7					
204. <u>Radio frequency impedance</u>								7				
205. <u>Static discharge sensitivity</u>					8				7			
206. <u>Thermal time constant</u>				14			8	8		7		
207. <u>Radio frequency sensitivity</u>											7	
208. <u>Direct current susceptibility</u>												7
209. <u>Dent test</u>	21	21	21		15	24						

¹ - Dual bridgewires require 50 percent more electroexplosive initiators.

Figure 14. 1512 Initiator Test Matrix Sample

TEST	PARA	20	30	30	30	30	20	50	50	50	6	6	6	50	50	50	TOTAL
DIELECTRIC WITHSTANDING	4.4.1	X	X	X	X	X	X	X	X	X							448
RESISTANCE	4.4.2	X	X	X	X	X	X										448
LEAKAGE	4.1.2.4	X															20
RADIOGRAPHIC/VISUAL	4.1.2.2	X															20
FIRING PROPERTIES-AMBIENT	4.4.6		X														30
FIRING PROPERTIES -- + 150 F	4.4.6			X													30
FIRING PROPERTIES -- - 50 F	4.4.6				X												30
DEFLAGATION THRESHOLD	4.4.5.1						X										20
SIX FOOT DROP	4.6.2							X	X								150
VIBRATION	4.6.4							X	X								150
SHOCK	4.6.3.2							X	X								150
RESISTANCE	4.4.2							X	X								150
TEMP, HUMIDITY, & ALT	4.6.5							X	X								150
MASS - 150 F	4.4.5.3							X	X								50
ALL-FIRE AMBIENT	4.7							X									50
ALL-FIRE +150 F	4.7							X									50
ALL -- -50 F	4.7								X								50
FORTY FOOT DROP	4.6.1									X							6
COOK-OFF-ELECTRICAL	4.4.7										X						6
COOK-OFF-THERMAL	4.6.6.2											X					6
SYSTEM SPECIFIC TEST																	
SYSTEM SPECIFIC TEST																	
SYSTEM SPECIFIC TEST																	
ALL-FIRE AMBIENT	4.7													X			50
ALL-FIRE HOT	4.7														X		50
ALL-FIRE COLD	4.7															X	50

SYSTEM SPECIFIC TESTS

SYSTEM TAILORED TESTS

REQUIRED INTRODUCTORY TESTS

REQUIRED RELIABILITY TESTS

Figure 15. Test Divisions

Table 1. Engineering Design Test Schedule

TEST	REF. PARA.	NUMBER OF INITIATORS (GROUPS)																TOTAL		
		50	6	6	20	20	20	20	20	20	20	20	20	20	20	20	20		20	
Dielectric withstanding Voltage	4.4.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	176	416
Radiographic	4.1.3.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	416
Leakage	4.1.3.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	416
Resistance	4.4.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	416
Static Discharge	4.4.3.2	X																		50
Resistance	4.4.2	X																		50
Stray Voltage	4.4.3.3	X																		50
Resistance	4.4.2	X																		50
Power Current or Stimulus 70 °F	4.4.3.1 4.4.5.1	X																		50
Resistance	4.4.2	X																		50
40 Foot Drop	4.6.1		X																	6
6 Foot Drop	4.6.2			X																6
Shock	4.6.3			X																38
Vibration	4.6.4			X																38
Temperature-Shock/Humidity/ Altitude	4.6.5				X															32
Cook-Off	4.6.6.1					X														20
High Temperature Exposure	4.6.6.2						X													20
Salt Fog	4.6.7							X												20
Radiographic	4.1.3.2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	84
Resistance	4.4.2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	124
Leakage	4.1.3.3		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	84
Static Discharge	4.4.3.2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	124
Resistance	4.4.2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	124
Power Current or Stimulus 70 °F	4.4.3.1 or 4.4.5.1		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	104
Power Current or Parameters 225 °F	4.4.3.1 or 4.4.5.1																			40
Resistance	4.4.2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	144
Min. 50 Milli sec. All-Fire 70 °F	4.4.4	X																		298
Min. 50 Milli sec. All-Fire 80 °F	4.4.6																			46
Min. 50 Milli sec. All-Fire 225 °F	4.7																			46

Table 2. List of Possible Environments

VERIFICATIONS

VISUAL
RADIOGRAPHIC
DIMENSIONAL
RESISTANCE

ENVIRONMENTS

ALTITUDE
NUCLEAR
SHOCK
FLIGHT VIBRATION
TRANSPORTATION
VIBRATION
5 FOOT DROP
HOT, COLD, & AMB
THERMAL SHOCK
SALT FOG
HUMIDITY
ACCELERATED AGING
HERO
RF SENSITIVITY
SOLVENTS
EXTREME TEMPERATURE
STORAGE
KNOWN STRAY CURRENTS
ACOUSTICAL
SPACE
ACCELERATION

TESTS

ALL-FIRE/NO FIRE
STATISTICS
DAMAGE THRESHOLD
TEMPERATURE
MASS
THERMAL TIME
CONSTANT

Table 3. Original Proposed Test Matrix

Test	Para	20	30	30	6	6	24	20	40	20	50	20	110	2	2	2	2	2	2	2	2	2	2	2	Total
Dielectric Withstanding	4.4.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	424
Resistance	4.4.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	424
MNFS	4.4.5.3												X												110
Power Current	4.4.5.1												X												110
Static Discharge	4.4.3.2												X												110
6 Foot Drop	4.6.2				X								X	X	X	X	X	X	X	X	X	X	X	X	134
40 Foot Drop	4.6.1				X																				6
Temp, Humid, & Alt	4.6.5							X																	40
Vibration	4.6.4						X																		38
Shock	4.6.3.2					X						X	X	X	X	X	X	X	X	X	X	X	X	X	24
High Temperature	4.6.6.2								X																20
Dielectric Withstanding	4.4.1							X																	20
Static Discharge	4.4.3.2				X			X	X	X	X	X													106
Resistance	4.4.2				X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	234
MNFS	4.4.5.3				X			X	X	X	X	X													134
Power Current	4.4.5.1				X			X	X	X	X	X													134
MNFS 225 F	4.4.5.3								X																20
Power Current 225 F	4.4.5.1								X																20
Resistance	4.4.2				X			X	X																56
Firing Properties Ambient	4.4.6		X																						30
Firing Properties Cold	4.4.6		X																						30
Firing Properties Hot	4.4.6			X																					30
Dielectric Withstanding	4.4.1											X													20
Deflagration Threshold	4.4.7											X													20
Resistance	4.4.2												X	X	X	X	X	X	X	X	X	X	X	X	18
Radiographic/Visual	4.1.2.2	X																							20
All Fire Ambient	4.7				X		X	X	X				X	X											206
All Fire Cold	4.7										X			X											56
All Fire Hot	4.7								X					X											26

Table 4. Proposed Test Matrix

Test	Para	20	30	30	30	20	50	50	50	50	6	6	6	50	50	Total
Dielectric Withstanding	4.4.1	X	X	X	X	X	X	X	X	X						448
Resistance	4.4.2	X	X	X	X	X	X	X	X	X						448
Leakage	4.1.2.4	X														20
Radiographic/Visual	4.1.2.2	X														20
Firing Properties-Ambient	4.4.6		X													30
Firing Properties -- +150 F	4.4.6			X												30
Firing Properties -- -50 F	4.4.6				X											30
Deflagration Threshold	4.4.5.1					X										20
Six Foot Drop	4.6.2						X	X	X	X						150
Vibration	4.6.4						X	X	X	X						150
Shock	4.6.3.2						X	X	X	X						150
Resistance	4.4.2						X	X	X	X						150
Temp, Humidity, & Alt	4.6.5						X	X	X	X						150
Mass - 150 F	4.4.5.3								X							50
All Fire Ambient	4.7						X									50
All Fire +150 F	4.7							X								50
All Fire -50 F	4.7								X							50
Forty Foot Drop	4.6.1									X						6
Cook-off Electrical	4.4.7										X					6
Cook-off Thermal	4.6.6.2											X				6
System System Test																
System System Test																
System System Test																
All Fire Ambient	4.7													X		50
All Fire Hot	4.7													X		50
All Fire Cold	4.7														X	50

Table 5. Minimum Test Matrix

Test	Para	20	30	30	30	30	20	50	50	50	50	50	Total
Dielectric Withstanding	4.4.1	X	X	X	X	X	X	X	X	X	X	X	430
Resistance	4.4.2	X	X	X	X	X	X	X	X	X	X	X	430
Leakage	4.1.2.4	X											20
Radiographic/Visual	4.1.2.2	X											20
Firing Properties-Ambient	4.4.6		X										30
Firing Properties - +150 F	4.4.6			X									30
Firing Properties -- -50 F	4.4.6				X								30
Deflagration Threshold	4.4.5.1					X							20
Six Foot Drop	4.6.2							X	X	X	X	X	150
Vibration	4.6.4							X	X	X	X	X	150
Shock	4.6.3.2							X	X	X	X	X	150
Resistance	4.4.2							X	X	X	X	X	150
Temp, Humidity, & Alt	4.6.5							X	X	X	X	X	150
Mass -150 F	4.4.5.3								X				50
All Fire Ambient	4.7							X					50
All Fire +150 F	4.7								X				50
All Fire -50 F	4.7									X			50
All Fire Ambient	4.7									X			50
All Fire Hot	4.7										X		50
All Fire Cold	4.7											X	50

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