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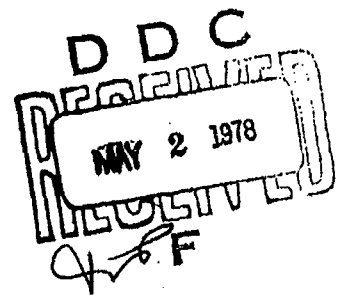
U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

Redstone Arsenal, Alabama 35809

STORAGE RELIABILITY

OF

MISSILE MATERIEL PROGRAM

STORAGE RELIABILITY SUMMARY REPORT

VOLUME IV

ORDNANCE DEVICES

LC-78-2   FEBRUARY 1978

PRODUCT ASSURANCE DIRECTORATE

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Storage Reliability Analysis Summary Report Volume IV Ordnance Devices		5. TYPE OF REPORT & PERIOD COVERED Final, June 1974 to Jan. 1978
		6. PERFORMING ORG. REPORT NUMBER LC-78-2, Vol. IV
7. AUTHOR(s) Dennis F. Malik		8. CONTRACT OR GRANT NUMBER(s) DAAK40-74-C-0853
9. PERFORMING ORGANIZATION NAME AND ADDRESS Raytheon Company, Equipment Division 3322 S. Memorial Parkway Huntsville, Alabama 35801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Headquarters, U. S. Army Missile R&D Command, ATTN: DRDMI-QS, Redstone Arsenal, AL 35809		12. REPORT DATE Jan 1978
		13. NUMBER OF PAGES 63
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Reliability, Storage, Missile Materiel, Failure Rates, Failure
Mechanisms, Operation, Ordnance, Solid Propellant, Rocket Motors,
Gas Generators, Igniters, Safe & Arm Devices, Explosive Components

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report summarizes analyses on the non-operating reliability of
missile ordnance devices. The analyses are part of a research
program being conducted by the U. S. Army Missile R&D Command,
Redstone Arsenal, AL. The objective of the program is the develop-
ment of non-operating (storage) reliability prediction and assurance
techniques for missile materiel. Included are analyses of solid
propellant rocket motors, gas generators, igniters, safe and arm
devices, and other explosive devices. Reliability models are

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20. Abstract (continued)

developed for each component type. This report updates and replaces
Report LC-76-2 dated May 1976.

STORAGE RELIABILITY

OF

MISSILE MATERIEL PROGRAM,

STORAGE RELIABILITY SUMMARY REPORT
VOLUME IV
ORDNANCE DEVICES

LC-78-2   FEB━━━━ ━━78

LC-78-2-VOL-4

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HEADQUARTERS
U. S. ARMY MISSILE R&D COMMAND
REDSTONE ARSENAL, ALABAMA

IN COMPLIANCE WITH
CONTRACT NO. DAAK40-74-C-0853
DATED 4 JUNE 1974
DATA ITEM SEQUENCE NO. 3

RAYTHEON COMPANY
EQUIPMENT DIVISION

LIFE CYCLE ANALYSIS DEPARTMENT
HUNTSVILLE, ALABAMA

ABSTRACT

This report summarizes analyses on the non-operating reliability of missile materiel. Long term non-operating data has been analyzed together with accelerated storage life test data. Reliability prediction models have been developed for various classes of devices.

This report is a result of a program whose objective is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. The analysis results will be used by U. S. Army personnel and contractors in evaluating current missile programs and in the design of future missile systems.

The storage reliability research program consists of a country wide data survey and collection effort, accelerated testing, special test programs and development of a non-operating reliability data bank at the U. S. Army Missile R&D Command, Redstone Arsenal, Alabama. The Army plans a continuing effort to maintain the data bank and analysis reports.

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1.0   INTRODUCTION

1.1   Missile Reliability Considerations

Materiel in the Army inventory must withstand long
periods of storage and "launch ready" non-activated or dor-
mant time as well as perform operationally in severe launch
and flight environments. In addition to the stress of tem-
perature soaks and aging, they must often endure the abuse of
frequent transportation and handling and the climatic extremes
of the forward area battlefield environment.

Missiles spend the majority of the time in this non-
operating environment. In newer missile systems, complexity
is increasing significantly, longer service lives are being
required, and periodic maintenance and checkouts are being
reduced. The combination of these factors places great im-
portance on selecting missile materiels which are capable of
performing reliably in each of the environments.

The inclusion of storage reliability requirements in the
initial system specifications has also placed an importance
on maintaining non-operating reliability prediction data for
evaluating the design and mechanization of new systems.

1.2   Storage Reliability Research Program

An extensive effort is being conducted by the U. S. Army
Missile Research & Development Command to provide detailed
analyses of missile materiel and to generate reliability
prediction data. A missile material reliability parts count
prediction handbook, LC-78-1, has been developed and provides
the current prediction data resulting from this effort.

This report is an update to report LC-76-2 dated May, 1976.
It provides a summary of the analyses performed under the
storage reliability research program and background information
for the predictions in LC-78-1. Included are summaries of real
time and test data, failure modes and mechanisms, and conclusions
and recommendations resulting from analysis of the data. These
recommendations include special design, packaging and product
assurance data and information on specific part types and part
construction.

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For a number of the part types, detailed analysis
reports are also available. These reports present details
on part construction, failure modes and mechanisms, parameter
drift and aging trends, applications, and other considerations
for the selection of materiel and reliability prediction of
missile systems.

The U. S. Army Missile Research & Development Command also
maintains a Storage Reliability Data Bank. This data bank con-
sists of a computerized data base with generic part storage
reliability data and a storage reliability report library con-
taining available research and test reports of non-operating
reliability research efforts.

For the operational data contained in this report, the user
should refer to the following sources: MIL-HDBK-217B, Military
Standardization Handbook, Reliability Prediction of Electronic
Equipment; Reliability Analysis Center (RAC) Microcircuit
Failure Rates; RADC-TR-69-458, Revision to the Nonelectronic
Reliability Handbook; and the Government-Industry Data Exchange
Program (GIDEP) Summaries of Failure Rate Data.

1.3 Missile Environments

A missile system may be subjected to various modes of
transportation and handling, temperature soaks, climatic
extremes, and activated test time and "launch ready" time
in addition to a controlled storage environment. Some studies
have been performed on missile systems to measure these en-
vironments. A summary of several studies is presented in
Report BR-7811, "The Environmental Conditions Experienced by
Rockets and Missiles in Storage, Transit and Operations"
prepared by the Raytheon Company, dated December 1973.

In this report, skin temperatures of missiles in con-
tainers were recorded in dump (or open) storage at a maximum
of 165°F (74°C) and a minimum of -44°F (-42°C). In non-
earth covered bunkers temperatures have been measured at a
maximum of 116°F (47°C) to a minimum of -31°F (-35°C). In
earth covered bunkers, temperatures have been measured at
a maximum of 103°F (39°C) to a minimum of 23°F (-5°C).

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Acceleration extremes during transportation have been measured for track, rail, aircraft and ship transportation. Up to 7 G's at 300 hertz have been measured on trucks; 1 G at 300 hertz by rail; 7 G's at 1100 hertz on aircraft; and 1 G at 70 hertz on shipboard.

Maximum shock stresses for truck transportation have been measured at 10 G's and by rail at 300 G's.

Although field data does not record these levels, where available, the type and approximate character of storage and transportation are identified and used to classify the devices.

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1.4 System Level Analysis

The primary effort in the Storage Reliability Research
Program is on analysis of the non-operating characteristics
of parts. In the data collection effort, however, some data
has been made available on system characteristics.

This data indicates that a reliability prediction for
the system based on part level data will not accurately pro-
ject maintenance actions if the missile is checked and main-
tained periodically. Factors contributing to this disparity
include test equipment reliability, design problems, and
general handling problems. In many cases, these problems are
assigned to the system and not reflected in the part level
analysis.

In general, a factor of 2 should be multiplied by the
device failure rate to obtain the maintenance rate. Three
system examples are described below:

1.4.1 System A

For system A, a check of 874 missiles in the field in-
dicates 142 failed missiles. These failed missiles were taken
to a maintenance facility. At the maintenance facility, no
fault could be found in 51 of the missiles. Two missiles
faults were corrected by adjustments. This left 89 failures
which could be attributed to part failure. The parts were
failure analyzed and the analysis indicated 19 failures to
be a result of electrical overstress. These failures were
designated design problems.

Therefore only 70 (49%) of the original 142 failures
were designated as non-operating part failures.

1.4.2 System B

For system B, 26 missile failures were analyzed. Of
these no fault was found in 2 missiles; adjustments were re-
quired for 2; external electrical overstress or handling
damage was found in 10; a circuit design problem was assigned
to 1, and component failures were assigned to 11.

1.4.3 Gyro Assemblies

An analysis of gyro assembly returns indicated that two
thirds of the returns were attributed to design defects,

mishandling, conditions outside design requirements, and to
erroneous attribution of system problems.

Therefore, only 33 percent of the returns were designated
as non-operating part failures.

1.5 Limitations of Reliability Prediction

Practical limitations are placed in any reliability
analysis effort in gathering and analyzing data. Field
data is generated at various levels of detail and reported in
varying manners. Often data on environments, applications,
part classes and part construction are not available. Even
more often, failure analyses are non-existant. Data on low
use devices and new technology devices is also difficult to
obtain. Finally in the storage environment, the very low
occurrence of failures in many devices requires extensive
storage time to generate any meaningful statistics.

These difficulties lead to prediction of conservative or
pessimistic failure rates. The user may review the existing
data in the backup analyses reports in any case where design
or program decision is necessary.

1.6 Life Cycle Reliability Prediction Modeling

Developing missile reliability predictions requires
several tasks. The first tasks include defining the system,
its mission, environments and life cycle operation or de-
ployment scenario.

The system and mission definitions provide the basis
for constructing reliability success models. The modeling
can incorporate reliability block diagrams, truth tables
and logic diagrams. Descriptions of these methods are not
included here but can be studied in detail in MIL-HDBK-217B
or other texts listed in the bibliography.

After the reliability success modeling is completed,
reliability life cycle prediction modeling for each block
or unit in the success model is performed based on the defi-
nitions of the system environment and deployment scenario.
This reliability life cycle modeling is based on a "wooden

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round" concept in order to assess the missile's capability
of performing in a no-maintenance environment. The general
equation for this modeling is:

$$R_{LC} = R_{T/H} \times R_{STOR} \times R_{TEST} \times R_{LR/D} \times R_{LR/O} \times R_L \times R_F$$

where:

R_{LC} is the unit's life cycle reliability

$R_{T/H}$ is the unit's reliability during handling and
transportation

R_{STOR} is the reliability during storage

R_{TEST} is the unit's reliability during check out and
test

$R_{LR/D}$ is the unit's reliability during dormant launch
ready time

$R_{LR/O}$ is the unit's reliability during operational
(>10% electronic stress) launch ready time

R_L is the unit's reliability during powered launch
and flight

R_F is the unit's reliability during unpowered flight

The extent of the data to date does not provide a cap-
ability of separately estimating the reliability of trans-
portation and storage for missile materiel. Also data has
indicated no difference between dormant (>0 and <10% electri-
cal stress) and non-operating time. Therefore, the general
equation can be simplified as follows:

$$R_{LC}(t) = R_{NO}(t_{NO}) \times R_O(t_O) \times R_L(t_L) \times R_F(T_F)$$

where: R_{NO} is the unit's reliability during transportation
and handling, storage and dormant time (non-
operating time)

t_{NO} is the sum of all non-operating and dormant time

R_O is the unit's reliability during checkout, test
or system exercise during which components have
electrical power applied (operating).

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t_O is the sum of all operating time excluding launch and flight

R_L is the unit's reliability during powered launch and flight (Propulsion System Active)

t_L is the powered launch and flight time

R_F is the unit's reliability during unpowered flight

t_F is the unpowered flight time

t is the sum of t_{NO}, t_O, t_L and t_F

The values R_{NO}, R_O, R_F are calculated using several methods. The primary method is to assume exponential distributions as follows:

$$R_{NO}(t_{NO}) = e^{-\lambda_{NO}t_{NO}}$$

$$R_O(t_O) = e^{-\lambda_O t_O}$$

$$R_L(t_L) = e^{-\lambda_L t_L}$$

$$R_F(t_F) = e^{-\lambda_F t_F}$$

The failure rates λ_{NO}, λ_O, λ_L and λ_F are calculated from the models in the following sections. λ_{NO} is calculated from the non-operating failure rate models. The remaining failure rates are calculated from the operational failure rate models using the appropriate environmental adjustment factors. Each prediction model is based on part stress factors which may include part quality, complexity, construction, derating, and other characteristics of the device.

Other methods for calculating the reliability include wearout or aging reliability models and cyclic or one shot reliability models. For each of these cases, the device section will specify the method for calculating the reliability.

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1.7 Reliability Predictions During Early Design

Frequently during early design phases, reliability predictions are required with an insufficient system definition to utilize the stress level failure rate models. Therefore, a "parts count" prediction technique has been prepared. It provides average base failure rates for various part types and provides K factors for various phases of the system deployment scenario to generate a first estimate of system reliability. This prediction is presented in Report LC-78-1.

1.8 Summary of Report Contents

The report is divided into five volumes which break out major component or part classifications: Volume I, Electrical and Electronic Devices; Volume II, Electromechanical Devices; Volume III, Hydraulic and Pneumatic Devices; Volume IV, Ordnance Devices; and Volume V, Optical and Electro Optical Devices. Table 1-1 provides a listing of the major part types included in each volume.

1.9 Extent of Volume IV Update

Only minor additions have been made to section 5. This volume has been included as part of the update to the entire LC-76-2 series.

TABLE 1-1. REPORT CONTENTS

2.0 Solid Propellant Motors

A typical solid propellant unit has the following prin-
cipal components: propellant, hardware and igniter. The
hardware may include the motor body, combustion chamber,
nozzle or mounting pads. The igniter is included in a sep-
arate analysis in Section 3.0.

Solid propellants are chemicals, in a plastic-like cake
form, which produce hot, high pressure gases by means of a
combustion process. There are several types of propellants.
For modern missiles, these can be broken into two major classes:
Composites and double base.

The main ingredients in a composite propellant are a fuel
and an oxidizer. Often these consist of crystalline, finely
ground oxidizers dispersed in a matrix of a fuel compound.

The double base propellant contains unstable chemical
compounds, such as nitrocellulose or nitroglycerin, which are
capable of combustion in the absence of all other material.
This type sometimes called homogeneous propellants contains
no crystals, but uses chemical fuel that contains enough
chemically bonded oxidizer materiel to sustain combustion.

Most of the solid propellants contain from four to eight
different chemicals. In addition to the principal ingredients
(fuel and oxidizer), small percentages of additives are used
to control the physical and chemical properties of the solid
propellant. Additives have been used for the following typi-
cal purposes: 1) accelerate or decelerate the burning rate
(catalyst); 2) increase chemical stability to avoid deteriora-
tion during storage; 3) control various processing properties
of propellant during fabrication (curing time, fluidity for
casting, wetting agent, etc.); 4) control radiation absorp-
tion properties of burning propellant; 5) increase physical
strength and decrease elastic deformation; 6) minimize tem-
perature sensitivity.

2.1 Effects of Prolonged Storage

2.1.1 Composite Propellant

Mechanical stresses from transportation and temperature extremes and repeated temperature stresses can have deteriorating effects on propellant properties.

Cracks, voids, and tearing in the propellant material are a major result of these environments. The primary cause for these defects in composite propellants are: the difference in the thermal expansion between the propellant grain and the motor body and inhibitors; and the temperature stress at the oxidizer-filler interface.

At low temperature, physical changes cause propellants to become hard and brittle, and thus very susceptible to cracking due to shock loads. When the propellant is in this brittle condition, expansion or other physical changes which occur as the temperature rises may cause cracking. The hardening of a case-bonded charge at low temperature may result in the charge coming away from the case. The repeated expansion and contraction with cyclic temperature changes can cause deterioration of the charge.

The deterioration may get worse with increasing duration of exposure to a given set of ambient conditions, and may be accelerated at wider temperature extremes.

Tensile stress at the oxidizer-filler interface in composite propellants may lead to the formation of voids around the oxidizer particles. Once void formation has started, it propagates to the vicinity of neighboring particles to produce a band or region of these failures.

At high temperatures, chemical and physical changes in the propellant may cause a serious reduction in the value of the coefficient of elasticity. The inhibitor may also deeriorate at high temperature. When the motor is fired, the charge may deform excessively or portions may even break loose. This can increase the burning area and pressure causing out of spec, thrust and burn-times or even cause the motor to burst. Portions of propellant which break loose can also

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block the motor nozzle and result in a catastrophic failure.

Humidity can sometimes accelerate this deterioration. Motors are normally provided with humidity sealing to prevent ingress of moisture to the propellant.

Cracks in the propellant will increase the burning surface areas, which increases pressure and causes out of specification conditions.

2.1.2 Double-Base Propellant

Double-base propellants are prone to the same types of deterioration as described for composite propellants with the exception of the void formation at the oxidizer-filler interface. The double-base propellant is a homogeneous mixture and does not have the solid oxidizers in the grain.

However, in double-base propellants, nitrocellulose decomposes slowly but continuously, releasing oxides of nitrogen. The rate of decomposition is accelerated by the presence of these oxides. Certain materiels called "stabilizers" can combine chemically with the oxides and remove them. The stabilizer does not prevent decomposition but retards the rate after it has commenced. This decomposition can create grain defects in the form of gas bubbles or cracks.

2.1.3 Hardware

Corrosion has been reported as a major effect of storage. Seals at the igniter and the nozzle have deteriorated from corrosion. Movable fin mechanisms have corroded preventing proper operation of these devices. Also handling of the missile has resulted in damage and contamination of these control mechanisms.

2.2 Reliability Prediction

The data collected to data shows no solid propellant motor failure which would have failed the mission requirements. Since the data indicates that the motors are definitely deteriorating with age, a failure rate prediction based on the number of hours in storage would be meaningless. Therefore, reliabilities based on binomial confidence levels for the number of successes during the fifth and tenth year were

calculated. Table 2.2-1 gives the reliabilities for con-
fidence levels of 50% and 90%.

The variation in the reliabilities in Table 2.2-1 is
strictly a function of the number of data samples available
for each classification and the predictions are considered
conservative. The measured reliability for all the units was
1.000.

Based on each program analysis, the recommended service
lives for the propellant units were 11 to 14 years for the
double base, single thrust units; 9 to 11 years for the double
base, dual thrust units; 8 to 11 years for the composite,
single thrust units; and 11 years for the composite, dual
thrust unit.

TABLE 2.2-1. PROPELLANT UNIT RELIABILITY
(excludes Ignition System)

| Classification | Reliability | | | |
| | 50% Confidence | | 90% Confidence | |
	5 Yrs.	10 Yrs.	5 Yrs.	10 Yrs.
Double Base, Single Thrust	.930	.925	.795	.790
Double Base, Dual Thrust	.952	*	.850	*
Composite, Single Thrust	.992	.924	.972	.790
Composite, Dual Thrust	.944	*	.827	*
All Motors	.994	.964	.981	.890

*No data available at 10 years.

2.3 Data Analysis

Detailed data from surveillance of eight missile programs
has been collected and analyzed. Out of 13,636,700 hours of unit
storage, ballistic data from 326 static firings indicated 43
failures to meet original acceptance specifications. No catas-
trophic failures were reported. Analysis of the 43 specification
failures by program personnel indicated that in each case, the
missile was capable (if only marginally) of performing its in-
tended mission. Therefore, no solid propellant unit was con-
sidered failed. Analysis of motor igniters is included in
Section 3.0.

2.3.1 Data Classification

Table 2.3-1 summarizes the data on the solid propellant units.
Four programs (A, B, C and D) utilized double base propellants
while the remainder used composite propellants. Program A and
B propellants were extruded; programs C, D, E, F_1 and G_1 were cast;
and programs F_2, G_2 and H were case bonded. Three programs (C, D
and E) used the propellants in a dual thrust configuration.

The subscripts 1 and 2 on programs F and G refer to different
propellant configurations for the same missile program.

For three programs (E, G_2 and H), the data was broken out by
manufacturer (designated A and B). In all three cases, a definite
difference in propellant characteristics was identified between the
different manufacturers. Also in a few cases, differences were
identified between propellant lots from the same manufacturer.

These statistics are further summarized in Table 2.3-2 by
four major classifications: Double base propellant (single and
dual thrust); and composite propellants (single and dual thrust).

Between these four major classifications, the average age of
the units is relatively close except for the dual thrust composite
motors which are about two years younger than the rest.

For both double base and composite propellants, the dual
thrust motors show a significantly higher percent of specification
failures than the single thrust motors. In both cases, the dual
thrust motors are also the largest motors in the sample.

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TABLE 2.3-1. SOLID PROPELLANT UNIT STORAGE DATA

PROGRAM	PROPELLANT	TI*	NO. OF UNITS	STORAGE HOURS	ACCEP. SPEC. FAILURES	MISSION FAILURES	UNIT AGE (MONTHS)
A	Single Thrust; Double Base, Extruded	1	106	5,377,180	12	0	19 to 169
B	Single Thrust; Double Base, Extruded	2	17	471,580	1	0	28 to 52
C	Dual Thrust, Double Base, Cast	3	4	70,080	2	0	96
D	Dual Thrust, Double Base, Cast	3	26	1,138,800	18	0	12 to 168
E	Dual Thrust, Composition, Cast	3	(A) 31 (B) 7	822,710 218,270	5 0	? 0	11 to 80 36 to 52
F_1	Single Thrust, Composition, Cast	2	19	664,300	0	0	26 to 75
G_1	Single Thrust, Composition, Cast	2	16	689,850	0	0	50 to 73
F_2	Single Thrust, Composition, Case Bonded	2	4	105,120	0	0	32 to 40
G_2	Single Thrust, Composition Case Bonded	2	(A)17 (B)32	494,210 1,297,940	0 4	0 0	9 to 61 32 to 68
H	Single Thrust, Composition, Case Bonded	2	(A)24 (B)23	1,156,320 1,130,040	1 0	0 0	12 to 72 12 to 72

* Total Impulse Range: 1: <10,000 lb-sec
                        2: 10,000 to 50,000 lb-sec
                        3: >50,000 lb-sec

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TABLE 2.3-2. STORAGE DATA BY MAJOR CLASSIFICATION

Classification	No. of Units	Unit Storage Hours	Specification Failures		Average Age of Units
			No.	Percent	
Double Base					
Single Thrust	123	5,848,760	13	10.6	65 months
Dual Thrust	30	1,208,808	20	66.7	55 months
Composite					
Single Thrust	135	5,537,780	5	3.7	56 months
Dual Thrust	38	1,040,980	5	13.2	37 months

The double base propellants overall show a significantly higher percent of specification failures as compared to the composite propellants.

2.3.2 Degradation with Age

Six of the eight missile programs projected degradation of ballistic parameters with age. Table 2.3-3 shows the average percentage change in 10 years for each ballistic parameter for the four classes of motors analyzed. Also shown are maximum and minimum changes observed. Ballistic parameters are defined as follows:

a) Action Time - time interval between reaching a specified initial chamber pressure and reaching that same pressure as the burn decays.

b) Maximum Pressure - highest pressure at any point on the pressure-time trace.

c) Maximum Thrust - highest thrust value at any point on the thrust-time trace.

d) Average Thrust - value obtained by dividing the area under the thrust-time trace by the action time.

e) Total Impulse - area under the entire thrust-time curve generally expressed in pound-seconds.

TABLE 2.3-3. BALLISTIC PARAMETER DEGRADATION WITH AGE

CLASSIFICATION/PARAMETER	Average % Change for 10 Years	Maximum Change	Minimum Change
Double Base, Single Thrust			
Action Time	+15.0	+20.0 -4.0	-0.1
Total Impulse	- 2.0	+ 1.7 - 5.1	*
Double Base, Dual Thrust			
Action Time	+25.0	+30.0	+4.4
Maximum Pressure	-10.0	-19.4	-2.3
Maximum Thrust	-11.0	-20.8	-3.8
Total Impulse	-16.0	-30.0	-0.6
Composite, Single Thrust			
Action Time	*	+22.3 -19.7	*
Maximum Pressure	*	+5.0 -27.5	-0.3
Maximum Thrust	+1.6	+22.3 -5.2	+0.1
Average Thrust	+0.4	+24.5 -14.5	+0.3
Total Impulse	*	+1.9 -2.3	*
Composite, Dual Thrust			
Action Time	-0.5	+3.3 -8.5	*
Maximum Pressure	+3.7	+7.0 -2.9	+0.9
Average Thrust	-0.3	+11.2 -7.0	+0.5
Total Impulse	-0.8	+0.9 -1.5	+0.1

*Value either zero or less than 0.1%.

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2.3.3 Handling and Environment Problems

Besides the general aging characteristics of the materiels described earlier, several problems were noted in the field environment. These included corrosion, particularly important at the control surfaces, contaminated or dirty control mechanisms, and bent or damaged surfaces.

2.3.4 Program Data

Summarized data on each of the missile programs for which surveillance data was available is included in the following sections.

2.3.4.1 Program A

The solid propellant for program A is an extruded double base grain single thrust configuration.

The surveillance included 148 motors. Thirty units had been stored in a humid, salt water environment for ten years. Severe rust and corrosion at the contact bond, nozzle and fin assembly resulted in a decision to destroy these units.

Tests of propellant grains from eight motors indicated a general trend toward increasing tensile strength and decreasing elongation with age.

Static firing tests of 106 motors were conducted. These included 67 motors, 2 to 4 years old; 34, 10 to 12 years old; and 6 prototypes, 14 years old. Twelve specification failures were noted and are described in Table 2.3-4.

TABLE 2.3-4. PROGRAM A SPECIFICATION FAILURES

Age in Months	Preconditioning Temperature - °F	Failure
32	165	Failed minimum total impulse
32, 33, 33, 35, 37 42, 42, 114, 116	165	Exceeded maximum action time
144	-30	Failed minimum ignition delay
162	-30	Exceeded maximum ignition delay

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2.3.4.2 Program B

The solid propellant for program B is an extruded double base grain in a single thrust configuration.

The motor required two major reworks during its deployment - the first corrected a fin-pad weld cracking problem and the second delt with a grain shrinkage problem.

Before this rework, several motors had failed due to high pressure after conditioning at high temperature. It was probable that the malfunctions were caused by reduced mechanical properties which allowed grain collapse and subsequent nozzle blockage. No serious problem has been reported with the reworked grains.

Sixteen motors were tested in a surveillance test. Motor ages were nine to ten years; age since rework was three to four years. One motor, age 106 mo. (42 mo. since rework), exceeded the maximum pressure specification. The amount exceeded was very small and would not have caused an error in the missiles trajectory.

No trends in ballistic parameters could be estimated due to the rework condition of the motors since acceptance.

2.3.4.3 Program C

The solid propellant for program C is a cast double base grain in a dual thrust configuration.

The motor required a major rework during its deployment to overcome a drop in delivered impulse due to chemical aging. As a corrective action, metal was removed from the nozzle to decrease the units weight.

Visual and radiographic inspection of four motors (ages 96 months) revealed slight cracks along the axial spars. Two had received the rework as described; two had not.

Static firings of the four boosters were conducted. The two motors which had been reworked exceeded the maximum action time specification.

An insufficient sample size was available to develop trends in ballistic parameters.

2.3.4.4 Program D

The solid propellant for program D is a cast, double base
grain in a dual thrust configuration.

The surveillance consisted of an accelerated test program
which approximately doubles the aging time of the propellants.
One accelerated storage cycle included 3 weeks at 70°F, 16 weeks
at 100°F, 3 weeks at 70°F and 4 weeks at 40°F.

A total of twenty-six units were static fired over a period
of 7 years: 4 each at 6, 12, 18, 24 and 36 months, and 2 each at
48, 66 and 84 months.

A total of eighteen units failed one or more specifications
as indicated in Table 2.3-5.

TABLE 2.3-5.   PROGRAM D SPECIFICATION FAILURES

Age in Months Actual (Extrapolated)	Preconditioning Temperature - °F	Failure
6 (12)	-30	Exceeded maximum action time
12 (24)	-20	
6 (12); 12 (24); 12 (24); 18 (36); 18 (36)	-30 -30	Exceeded maximum action time and failed minimum total impulse
24 (48); 24 (48); 36 (72); 36 (72); 48 (96); 66 (132); 84 (168)	10	
24 (48); 24 (48); 36 (72); 36 (72)	120	Failed minimum total impulse

Definite aging trends in ballistic performance were
indicated with action time increasing with age and maximum
pressure, maximum thrust and total impulse decreasing with age.
In all but one case, the trend appears to level out at from 1
to 8 years.

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2.3.4.5 Program E

The solid propellant for program E is a cast, composite
grain in a dual thrust configuration.

Twenty-eight units were involved in surveillance testing
ranging in age from 1 to 7 years with the average age being
4-1/4 years.

Static firings of 19 units resulted in 5 failures to
meet acceptance specifications as shown in Table 2.3-6.

TABLE 2.3-6   PROGRAM E SPECIFICATION
FAILURES

Age in Months	Preconditioning Temperature - °F	Failure
30; 51; 63; 75	20°F	Failed minimum total thrust
36	130°F	Exceeded maximum pressure

Trends indicate that the booster impulse has increased
with age while sustainer and total impulse have decreased.
The trend in decreasing total impulse appears to level out
at from 3 to 6 years.

2.3.4.6 Program F

The solid propellant for program F is a cast, composition
grain with a single thrust capability. Two propellant config-
urations were monitored in the surveillance tests. Configura-
tion one is a free-standing, cartridge-type grain consisting
of a cylindrical tube cast on an integral, fiberglass rein-
forced support tube. Configuration two is a case bonded grain
with a five star grain pattern. Both propellant configurations
are ammonium perchlorate and aluminum composites.

External examination of 23 motors revealed minor cases
of rust and dirty fin slots. Radiographic inspection re-
vealed two motors with separations at the forward end cap
exceeding 3/8 inch, and four motors with small cracks in
the aft case phenolic insulator.

Nineteen configuration one motors ranging in age from
2 to 6 years with an average age of 4 years and four con-
figuration two motors, average age 3 years, were static fired.

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All ballistic parameters were within specification. Insufficient data was available to develop trends.

2.3.4.7 Program G

The two solid propellant configurations for program G are identical to those for program F. Table 2.3-7 gives statistics on the units involves in the surveillance.

TABLE 2.3-7. PROGRAM G SURVEILLANCE UNITS

Configuration	Manufacturer	Qty.	Age Range	Average Age
1	-	16	4-6 yrs.	5 yrs.
2	A	17	1-5 yrs.	3 1/3 yrs.
2	B	32	3-6 yrs.	4 1/2 yrs.

The defects indicated in Table 2.3-8 were identified in the X-ray inspection.

Of the motors static fired, which had identified defects in the X-ray inspection, only two failed to meet acceptance specifications.

TABLE 2.3-8. PROGRAM G DEFECTS IDENTIFIED IN X-RAY INSPECTION

Configuration	Manufacturer	No. of Motors Defective	No. Static Fired	No. Failed Specs.	Defect
1	-	1	1	0	Crack in aft phenolic region near weather seal
1	-	1	1	0	End cap severely cracked
2	A	6	2	0	Voids (up to 5/16 in. max) and/or porosity in the grains
2	B	2	1	0	Small voids throughout grain
2	B	3	0	0	Aft end boot to case separations
2	B	3	3	2	Abnormally thick regions in liner

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Results of static firings of the configuration 1 test
motors and the configuration 2 test motors for manufacturer
A indicated no specification failures. Four specification
failures for samples from manufacturer B, configuration 2
were identified and are shown in Table 2.3-9.

TABLE 2.3-9. PROGRAM G_{2B} SPECIFICATION FAILURES

Age in Months	Preconditioning Temperature-°F	Failure
66	-65	Exceeded maximum average thrust
48, 61	160	Failed minimum average thrust
66	160	Exceeded maximum average thrust and maximum thrust specifications.

Trends in ballistic aging characteristics were combined
for programs F and G. The general trend is toward decreasing
action time and total impulse and increasing max thrust and
max pressure.

2.3.4.8 Program H

The surveillance consisted of an accelerated test program
identical to that described for program D. A total of 47
units were static fired over a period of six years: 4 at 6
months; 8 at 12 months; 3 at 18 months; 6 at 24 months; 4 at
30 months; 8 at 36 months; 4 at 48 months; 6 at 60 months;
and 4 at 72 months.

X-ray inspection of 35 motors indciated an area of un-
bondedness between the end initiator and the motor tube on
one motor.

Eighteen motors were static fired successfully.

Twelve motors were put through environmental testing be-
fore static firing.

Mechanical properties tests of propellant samples in-
dicated the tensile strength remains relatively constant with
age where as elongation at rupture decreases with age.

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Aging trends in ballistic parameters were estimated for the non-environmentally tested motors and indicated an increasing max thrust with age.

2.3.5 Failure Modes and Mechanisms

Table 2.3-10 summarizes the failure modes exhibited during the static firing tests. The failure definition is failure to be within original acceptance specifications.

2.3.5.1 Double Base Propellant

For double base propellant 76% of the failures exceeded the maximum action time specification and 57% failed the minimum total impulse specification. (There is overlap in the failures since some units failed more than one specification.) Three other failures appeared to be random occurrences.

In double base propellants the trend toward increasing action time and decreasing performance parameters can be attributed to the general decomposition of the propellant ingredients with age. Although the major propellant ingredients are inherently unstable, the stabilizers added to the propellant mix generally prevent rapid decomposition and maintain ballistic parameters for the life of the missile.

TABLE 2.3-10. SPECIFICATION FAILURE MODES

Single Thrust, Double Base

    9 units exceeded maximum action time specification
    1 unit failed minimum total impulse specification
    1 unit exceeded maximum ignition delay specification
    1 unit failed minimum ignition delay specification
    1 unit exceeded maximum thrust specification

Dual Thrust, Double Base

    4 units exceeded maximum action time specification
    12 units exceeded maximum action time and failed
        minimum total impulse specifications
    4 units failed minimum total impulse specification

Single Thrust, Composite

    1 unit failed minimum average thrust specification
    2 units exceeded maximum average thrust specification
    1 unit exceeded maximum thrust specification
    1 unit exceeded maximum ignition delay specification

Dual Thrust, Composite

    4 units failed minimum total impulse specification
    1 unit exceeded maximum pressure specification

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2.3.5.2 Composite Propellants

For composite propellants, the failure modes summarized in Table 2.3-10 represent a relatively small sample and are fairly random. In general, they follow the trend toward decreasing action time and total impulse and increasing maximum thrust and pressure.

These trends can be generally attributed to cracking, voiding, or tearing in the propellant grain; separations between grain and body or inhibitor; and changes in the elasticity coefficient of the propellant. In all these cases, the surface area can be increased resulting in a shorter burn time, higher pressure and thrust and lower total impulse. With the small number of specification failures, these trends do not appear to significantly affect the missiles useful life.

2.3.6 Other Propellant Defects Identified

In addition to the failure modes identified from static firing, other defects in the propellant units were identified in the surveillance tests. These are summarized in Table 2.3-11.

TABLE 2.3-11. PROPELLANT UNIT DEFECTS SUMMARY

DEFECT	TEST
Single Thrust, Double Base Motor	
Fin Pad weld cracking (reworked)	Visual
Grain Shrinkage (reworked)	Visual
Hot gas seal at igniter post failure (reworked)	Static Firing
Severe rust and corrosion after 10 years in humid, salt storage environment	Visual
Missing O-ring	X-Ray
Increasing Tensile Strength, decreasing elongation	Mechanical
Dual Thrust, Double Base Motor	
Stabilizer decrease with age	Chemical
Propellant brittle with age	Mechanical
Burning rate near inhibitor lower	Strand Burn

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TABLE 2.3-11. PROPELLANT UNIT DEFECTS SUMMARY
(cont'd)

DEFECT	TEST
Single Thrust, Composite Motor	
Unbondedness between: Inhibitor and motor tube; propellant and liner; and forward end cap and propellant	X-Ray
Cracking: Aft phenolic region; end cap; insulator	X-Ray
Uneven liners and liners with abnormally thick regions	Visual & X-Ray
Increasing elongation at rupture	Mechanical
Slipped cushion in transportation container	Visual
Improper electrical grounds in transportation container	Visual
Voids and/or porosity in grain	X-Ray
Dirty and corroded fin slots	Visual
Dual Thrust, Composite Motor	
Light Corrosion	Visual
Voids in propellant	X-Ray
Combustion instability: loose insulation; retained weather seal	Static Firing
Cracked grains (MOD in Grain pattern)	X-Ray

2.4 Conclusions and Recommendations

The data analyzed for solid propellant motors indicated no motor failures which would have failed the mission requirements. Until more data is collected, it is recommended that the following reliability prediction be used for solid propellant units:

5 Year Reliability:	.994 at 50% confidence
	.981 at 90% confidence
10 Year Reliability:	.964 at 50% confidence
	.890 at 90% confidence

Igniters are not included in this prediction. See
Section 3.0 for analysis of igniters.

The data also indicated that the composite propellant
shows significantly less deterioration with age than the
double base propellant. Therefore, composite propellants
should be considered for all applications.

Dual thrust motors were indicated in the data to under-
go more doterioration with age than single thrust motors.

Missile systems design should compensate for changes
in motor performance.

Surveillance programs have proven to be invaluable
aids to detect excessive aging of propellants and to initiate
early correction for maximum system life.

2.5 Reference

The information in Section 2 is a summary of document
number LC-76-OR1, "Solid Propellant Motor Analysis," dated
May 1976. Refer to that document for details of data
collection and analysis as well as technical descriptions
of solid propellant motors.

3.0 <u>Igniters and Safe and Arm Devices</u>

Igniters are rapid burning devices which develop a
sudden evolution of heat and gas and in some cases hot parti-
cles. The gas produces a sharp pressure peak which may be
of greater magnitude than the operating pressure of the rocket
motor or gas generator.

The igniters are initiated by means of an electric
squib. At least two squibs are used per igniter for reliabil-
ity. Basically, the squib consists of a body in which are
imbedded two electric leads, a bridge wire which shorts the
leads and is heated by the passage of an electric current,
and a heat-sensitive materiel normally applied as a bead to
the bridge wire. A small booster charge of black powder or
other pyrotechnic mixture may be part of the squib for ini-
tiation of the igniter. This charge and burnout wire are
encased in a metal cup crimped tightly to prevent contami-
nation. The squibs are designed not to fire until a certain
critical electrical energy is applied. This allows continuity
testing without danger of premature ignition. It also prevents
the squib from firing from stray induced currents from elec-
tronic gear or power lines in the area.

Two basic types of igniters are used in current missile
systems: pyrotechnic and pyrogen igniters.

Pyrotechnic mixtures range from black powder with
powdered metals to metal oxidants. A black powder/magnesium
mixture is used in several igniters for which data has been
collected. Metal oxidants have become replacements for
black powder in some of the newer ignition systems. The most
common mixtures contain magnesium, aluminum or boron powder
and potassium nitrate or perchlorate. Granular mixtures
usually react too rapidly, so the mixtures are generally
pressed into pellets.

The igniter container has been made of tin or plastic.
For large rockets, a perforated tube may be used to contain
the pyrotechnic. It may be half or more of the length of

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motor grain. In other designs, a plastic or metal can is
used. The cover of the can ruptures at the initiation and
the hot gases are released to the propellant grain.

The pyrogen igniter is a small rocket motor used to
ignite the main motor. The design used for pyrogens, in
general, similar to the main charge. The exhaust from the
pyrogen is directed via a nozzle into the center performation
of the main motor; usually from the forward end. Fast burning
propellants are used at moderately high pressures to obtain
a high mass discharge rate. For very large motors, the use of
a pyrogen provides a better method of ignition.

The pyrogen is initiated by squibs and a pyrotechnic
primer. Igniter charges generally consist of double base
propellant materials such as nitrocellulose and nitroglycerin.

The safe and arm (S&A) device electrically isolates the
igniter to prevent premature ignition of the propellant motor
or gas generator and to allow for electrical testing of
the ignition circuitry. In some cases, the S&A device also
mechanically isolates the initiator (squibs and primer mix-
ture) from the pyrotechnic mixture or pyrogen motor.

Data has been collected on three types of S&A devices:
inertial rotary type; manual rotary type; and motor driven
rotary type.

The inertial S&A device is used in the upper stage of a
multistage missile. Acceleration of the booster stage provides
the energy ᵤo activate the inertial device.

The manual rotary S&A device is activated for small
missiles before or after it is loaded into the launcher.

The motor driven rotary S&A device is used for remote
actuation.

3.1 Failure Mechanisms
3.1.1 Igniters

The igniter generally experiences two categories of
failure mechanisms. The first category is failures asso-
ciated with the initiator, including failure of the lead
wires and bridge wires in the squib. These failures usually

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lead to non-ignition. The failures may be a result of quality defects, handling damage, contamination or corrosion.

The second category is an aging characteristic in which pyrotechnic and/or propellant mixtures deteriorate with age. This deterioration generally results in a decrease in igniter pressure and long ignition delays. The deterioration may progress to a point of non-ignition.

The degradation of the ordnance materials with age may result from several causes. Package leaks caused by inadequate seals or cracked cases can allow moisture to deteriorate the materiels. In addition, pyrogen propellants are subject to long term decomposition. This decomposition is alowed by the addition of stabilizers in the propellant mix.

3.1.2 Safe and Arm Devices

The S&A device exhibit failure mechanisms such as those for switches in other applications. These include deformed, broken or loose contacts and contact springs, defective welds and/or solder joints, contamination, contact corrosion, and defective or damaged lead wires.

Possible aging mechanisms have also been noted which degrade arming times. This degradation is caused by corrosion of sliding surfaces and degradation of seals and packing.

3.2 Igniter and Safe and Arm Devices Reliability Models

Analysis of the data indicated that the reliability of these devices has two components; a time dependent component and a random component. A reliability model defined as a function of both characteristics was developed.

$$R(t)_{S\&A\ device} = [R(t)_{aging}] \times [R(t)_{random}]$$

Figure 3.2-1 gives the igniter reliability prediction model. Figure 3.2-2 gives the safe and arm device model.

For programs which periodically test devices and replace them when specification failures exist, the replacement rate will be higher than that noted in the reliability calculations.

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FIGURE 3.2-1.   IGNITER RELIABILITY PREDICTION MODEL

$R(t)_{igniter} = [R(t)_{aging}] \times [R(t)_{random}]$

$R(t)_{random} = \exp(-\lambda t)$

Classification	R(t) Aging				λ	
	50% confidence		90% confidence		50% Confidence	90% Confidence
	5 yrs.	10 yrs.	5 yrs.	10 yrs.		
Solid Rocket Motor Pyrogen Igniters	.998	.986	.994	.954	65×10^{-9}	129×10^{-9}
Solid Rocket Motor Pyrotechnic Igniters	.995	.991	.984	.969	65×10^{-9}	129×10^{-9}
Gas Generator Igniters	.997	.979	.991	.934	65×10^{-9}	129×10^{-9}

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FIGURE 3.2-2. SAFE AND ARM DEVICE RELIABILITY PREDICTION MODEL

$$R(t)_{S\&A \; device} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

Classification	R(t) aging				λ	
	50% confidence		90% confidence		50% confidence	90% confidence
	5 yr.	10 yr.	5 yr.	10 yr.		
Inertial S&A	.992	.976	.975	.923	134×10^{-9}	207×10^{-9}
Manual S&A	1.000	1.000	1.000	1.000	134×10^{-9}	207×10^{-9}
Motor Driven S&A	.964	.954*	.948	.912*	134×10^{-9}	207×10^{-9}

*Extrapolated from 1 through 6 year data.

The models for specification reliability for igniters and safe and arm devices are shown in Figures 3.2-3 and 3.2-4 respectively.

3.3 Data Analysis

Data from surveillance of fourteen missile programs has been collected and analyzed.

Approximately 45 million unit storage hours of solid propellant motor igniters indicated 4 failures which would have failed to ignite the motor in 452 static firings and 952 missile firings. Of this data, 15 million unit storage hours with 295 static firings contained ballistic parametric data. Five specification failures were indicated, 3 of which would not have failed the mission requirements.

Approximately 17 million unit storage hours of gas generator igniters indicated no failures which would have failed to ignite the gas generator in 332 static firings. Of this data, 14 million unit storage hours with 274 static firings contained ballistic parametric data. Six specification failures were reported, none of which would have failed the mission requirements.

Approximately 75 million unit storage hours of safe and arm devices indicated 45 failures which would have failed the motor ignition requirements in 2212 unit tests. Ten units failed to arm and 35 units armed in insufficient time to meet mission requirements. Of this data, 65 million unit storage hours with 2016 unit tests, recorded arming times and circuit resistances. One hundred forty seven specification failures were indicated. These failures occurred on motor driven rotary safe and arm switches. Thirty five of these specification failures would have failed the mission requirements.

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FIGURE 3.2-3. IGNITER SPECIFICATION RELIABILITY PREDICTION MODEL

$$R(t)_{igniter} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = exp(-\lambda t)$$

Classification	R(t) aging				λ	
	50% Confidence		90% Confidence		50% confidence	90% confidence
	5 yr.	10 yr.	5 yr.	10 yr.		
Solid Rocket Motor Pyrogen Igniters	.987	*	.960	*	65×10^{-9}	129×10^{-9}
Solid Rocket Motor Pyrotechnic Igniters	.982	.975	.958	.942	65×10^{-9}	129×10^{-9}
Gas Generator Igniters	.964	.935	.950	.870	65×10^{-9}	129×10^{-9}

*No data at 10 years.

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FIGURE 3.2-4. SAFE & ARM DEVICE SPECIFICATION RELIABILITY PREDICTION MODEL

$$R(t)_{S\&A\ device} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

Classification	R(t) aging				λ	
	50% Confidence		90% Confidence		50% Confidence	90% Confidence
	5 yrs.	10 yrs.	5 yrs.	10 yrs.		
Inertial S&A Device	.950	.840	.905	.730	134×10^{-9}	207×10^{-9}
Manual S&A Device	1.000	1.000	1.000	1.000	134×10^{-9}	207×10^{-9}
Motor Driven S&A Device	.890	.809*	.880	.800*	134×10^{-9}	207×10^{-9}

*Extrapolated from 1 through 8 year data.

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3.3.1 Data Classification
3.3.1.1 Igniters

Table 3.3-1 summarizes the data on solid propellant motor igniters and gas generator igniters. Four programs (Al, B, H and I) utilized pyrogen igniters for motor ignition. Six programs (A2, C, D, E, F and G) used pyrotechnic devices. The igniters in programs J, K, L and M represent gas generator igniters.

These statistics are further summarized in Table 3.3-2 by three classifications: pyrogen solid rocket motor igniters; pyrotechnic solid rocket motor igniter; and gas generator igniters. Note in Table 3.3-2 that each classification contains two lines of data. The first line represents total unit storage hours and failures which would have failed mission requirements. The second line is a subset of this data which represents ballistic parameter tests with failures to meet original acceptance specifications.

The numerical data indicates the pyrogen igniter to be more reliable in storage than the pyrotechnic igniter. However, this data could be misleading. The four failures reported for pyrotechnic igniters were quality and handling related defects and included three broken wires and an electrical short caused by incomplete potting of a radiation interference filter assembly. Any of these failures could have occurred in the pyrogen igniters as well.

Long term storage does appear to affect pyrotechnic igniters more than pyrogen igniters. However, due to insufficient samples of failures, no conclusion can be reached at this time.

The gas generator igniters are essentially identical devices to the pyrotechnic motor devices except for size and pressure requirements. The data shows no gas generator igniter failures which would have failed the mission requirements. Six failures to meet original acceptance specifications were identified.

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TABLE 3.3-1. IGNITER STORAGE DATA

Program	Application/Igniter Type	No. of Units	Storage Hrs.	Accep. Spec. Failures	Simulated Mission Failures	Age of Units (Months)
A1	Solid Rocket Motor Igniter/Pyrogen	21	992,070	0	0	65
A2	Solid Rocket Motor Igniter/Pyrotechnic	74	5,007,070	2	2	93
B	Solid Rocket Motor Igniter/Pyrogen	34	1,542,490	0	0	62
C	Solid Rocket Motor Igniter/Pyrotechnic	65	2,490,030	-	0	52
D	Solid Rocket Motor Igniter/Pyrotechnic	13 23	314,630 769,420	0 -	0 0	33 46
E	Solid Rocket Motor Igniter/Pyrotechnic	38	1,040,980	-	0	38
F	Solid Rocket Motor Igniter/Pyrotechnic	51 31	2,198,760 1,527,160	1 -	0 2	59 67
G	Solid Rocket Motor Igniter/Pyrotechnic	102	5,007,070	2	0	67
H	Solid Rocket Motor Igniter/Pyrogen	74	473,770	-	0	9
I	Solid Rocket Motor Igniter/Pyrogen	878	23,526,075	-	0	37
J	Gas Generator Igniter	18	635,100	-	0	48
K	Gas Generator Igniter	86 40	4,075,590 2,346,220	0 -	0 0	65 80
L	Gas Generator Igniter	59	2,949,200	0	0	68
M	Gas Generator Igniter	129	6,640,810	6	0	71

TABLE 3.3-2.   IGNITER STORAGE DATA BY MAJOR CLASSIFICATION

Classification	No. Units	Storage Hrs.	Spec. Failures	Simulated Mission Failures	Avg. Unit Age
Solid Rocket Motor Igniter					
Pyrogen	1007 (55)	26,534,405 (2,534,560)	NA (0)	0 (NA)	36 (63)
Pyrotechnic	397 (240)	18,355,120 (12,527,770)	NA (5)	4 (NA)	63 (72)
Gas Generator Igniter	332 (274)	16,646,920 (13,665,600)	NA (6)	0 (NA)	69 (68)
TOTALS	1736	61,536,445	—	4	—

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3.3.1.2 Safe and Arm Devices

Table 3.3-3 summarizes the storage data on safe and arm
devices. Programs A1 and A2 utilize inertial switches;
Programs C and D manual switches; and Program N motor driven
rotary switches.

The motor driven rotary switch shows a relatively high
failure rate as compared with the other switches. These
switches were the only ones tested in a separate test pro-
gram from the igniter, arming and safing times were monitored.
Nine of the failures were indicated as catastrophic. The
35 specification mission failures were failures to arm in the
necessary time to meet mission requirements. One hundred
twelve additional specification failures were identified which
would have fulfilled mission requirements. These switches
showed definite aging trends in arming and safing times.

3.3.2 Aging Trends

3.3.2.1 Successes vs. Age

A comparison of successes and failures versus age of the
igniters shows no apparent trend. Failures were distributed
fairly randomly by age, however no devices under 4 years of
age failed. A definite aging trend was indicated for the
motor driven device. The percent of successful tests show
a marked decrease with the age of the unit. A possible aging
trend is also indicated for the inertial S&A device. No
trend was analyzed for manual rotary devices since no mission
or specification failures were reported.

3.3.2.2 Performance Parameters vs. Age

Five of the missile programs were able to project aging
trends for individual ballistic parameters using the static
firings at acceptance testing as a baseline.

The pyrogen igniters showed the least change with age
(less than 2%) for burn time, maximum pressure and average
pressure. The burn time increased while the maximum and
average pressures decreased. These trends are identical to

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TABLE 3.3-3.   SAFE AND ARM DEVICE STORAGE DATA

Program	Type	No. Units	Storage Hrs.	Accep. Spec. Failures	Simulated Mission Failures	Avg. Unit Age
A1	Inertial	21	992,070	0	0	65
A2	Inertial	74	5,007,070	10	1 (C)	93
C	Manual Rotary	65	2,490,030	-	0	52
D	Manual Rotary	13 23	314,630 769,420	- -	0 0	33 46
N	Motor Driven	2016	65,104,320	147	9(C) 34 (S)	44
TOTALS						
	Inertial	95	5,999,140	10	1 (C)	87
	Manual Rotary	101	3,574,080	-	0	48
	Motor Driven	2016	65,104,320	147	9(C) 35 (S)	44

C = Catastrophic Failures

S = Specification Failures

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those described for double base solid propellant motors in
Section 2.0. The trends are attributed to the inherently
unstable propellant decomposing with age.

The pyrotechnic igniters showed larger changes with age
than the pyrogen motor igniters. Data from programs F and G
were separated from programs A2, C and D due to the much
larger changes. Program F utilized accelerated testing and
the extrapolation to real time may be inaccurate. All of the
programs show an increase in ignition delay with age (up to
500%). This increase is due to two factors: the change in
igniter ballistic characteristics and a change in the solid
rocket motor ballistic characteristics. Maximum pressure
and time to maximum pressure decreased for the pyrotechnic
igniters except for programs F and G which showed an increase
in these parameters.

The gas generator igniters showed a decrease in the three
parameters measured: maximum pressure, time to maximum pressure
and ignition delay.

For the motor driven rotary safe and arm device, a large
trend in increasing arming time was seen (approximately 13%
increase per year).

3.3.3 Failure Modes and Mechanisms

Table 3.3-4 summarizes the failure modes experienced
during the igniter static firing tests. Catastrophic failures
are defined as failures to functionally perform and specifi-
cation failures are defined as failures to be within original
acceptance specifications.

The catastrophic failures were caused by quality and
handling problems and were not related to age of the units.
The nine specification failures were generally related to
aging effects.

Table 3.3-5 summarizes the failure modes exhibited by
safe and arm devices during tests. The failure of the inertial
device was caused by a manufacturing defect. Specific failure
causes were not given for the motor driven devices.

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Table 3.3-4. Igniter Failure Modes

Catastrophic Failures

Pyrotechnic Igniters

    2 units - broken wire in harness
    1 unit - broken squib bridge wire
    1 unit - igniter electrical circuit shorted by
             RIF screen

Specification Failures

Pyrotechnic Igniters

    1 unit exceeded maximum peak pressure specification
    2 units failed minimum ignition delay specification

Gas Generator Igniter

    6 units failed lower circuit resistance specification

Table 3.3-5. Safe and Arm Device Failure Modes

Catastrophic Failures

Inertial S&A Device

    1 unit - blocked switch movement due to improperly
             manufactured cover

Motor Driven S&A Devices

    57 units exceeded mission arming time requirements

Specification Failures

Inertial S&A Devices

    6 units exceeded maximum arming time specification
    4 units failed minimum arming time specification

Motor Driven S&A Devices

    147 units failed maximum arming time specification

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3.3.4 Other Defects Identified

Table 3.3-6 lists other defects noted in the devices,
however, none of these were detrimental to the device tests.
As can be noted, these defects range from quality problems
to handling problems to possible aging problems.

Table 3.3-6. Other Unit Defects

Igniters

     6 units frayed wiring harness
    28 units cracked cover plate
     2 units rust present
     3 units wiring harness damaged
     2 units improperly installed igniter connecting cables
    Twisted grains
    Hot gas seal defective
    Potassium nitrate depletion in igniter

Safe and Arm Devices

    Screws loose on gear train of inertial device
    Cover plate improperly placed
    Improperly placed safe and arm decal on manual switch

3.4 Conclusions and Recommendations

The data analyzed for igniters and safe and arm devices
indicated both random type and aging type failures. A consider-
able amount of data was analyzed on age related degradation.
However, for a number of devices, the lack of a large failure
sample tends to make the reliability predictions conservative.
Until more data is available, it is recommended that the reliabil-
ity prediction models in figures 3.2-1 and 3.2-2 be used.

The data indicated that the pyrogen igniters show less
deterioration with age than the pyrotechnic igniters. Therefore,
pyrogen igniters should be considered for all applications.

Missile system design should compensate for age changes
in igniters performanced.

Surveillance programs to detect excessive aging of igniters
are recommended.

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3.5 Reference

The information in Section 3 is a summary of document number LC-76-OR2, "Igniters and Safe and Arm Device Analysis," dated May 1976. Refer to that document for details of data collection and analysis and technical description of the devices.

4.0 Solid Propellant Gas Generators

A typical solid propellant gas generator has the following principal components: propellant, hardware and igniter. The hardware may include the generator body, combustion chamber, hot gas outlet or mounting pad, filter, and relief valve. The igniter is included in Section 3.0.

The solid propellants are used in gas generators to pro-vide hot gas as an energy source. They are used primarily for driving turbines or auxiliary power devices. Usually the flame temperature of gas generator propellants is appreciably lower than that of rocket propellants, so that the gas can be used in uncooled piping and uncooled machinery. This means that such a propellant usually contains more fuel and less oxidizer.

Two or more mixtures or types of fuel may be used in a single generator to create a specific pressure time profile. A common example, is the use of booster pellets at the start of the gas generator operation to overcome inertia of moving parts in the turbine.

The types of propellants used can be broken into two major classes: composites and double base.

The main ingredients in a composite propellant are a fuel and an oxidizer. Often these consist of crystalline, finely ground oxidizers dispersed in a matrix of a fuel com-pound.

The double base propellant contains unstable chemical compound, such as nitrocellulose or nitroglycerin, which are capable of combustion in the absence of all other material. This type sometimes called homogeneous propellants contains no crystals, but uses chemical fuel that contain enough chemically bonded oxidizer materiel to sustain combustion.

Most of the solid propellants contain from four to eight different chemicals. In addition to the principle ingre-dients (fuel and oxidizer), small percentages of additives are used to control the physical and chemical properties of the solid propellant. Additives have been used for the following typical purposes: 1) accelerate or decelerate the

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burning rate (catalyst); 2) increase chemical stability to
avoid deterioration during storage; 3) control various pro-
cessing properties of propellant during fabrication (during
time, fluidity for casting, wetting agent, etc.); 4) control
radiation absorption properties of burning propellant;
5) increase physical strength and decrease elastic deformation;
6) minimize temperature sensitivity.

4.1 Effects of Prolonged Storage

Mechanical stresses from transportation and temperature
extremes and repeated temperature stresses can have deterio-
rating effects on propellant properties.

Cracks, voids, and tearing in the propellant materiel
are a major result of these environments. The primary cause
for these defects in composite propellants are: the difference
in the thermal expansion between the propellant grain and
the motor body and inhibitors; and the temperature stress at
the oxidizer-filler interface.

At low temperature, physical changes cause propellants
to become hard and brittle, and thus very susceptible to
cracking due to shock loads. When the propellant is in this
brittle condition, expansion or other physical changes which
occur as the temperature rises may cause cracking. The hard-
ening of a case-bonded charge at low temperature may result
in the charge coming away from the case. The repeated ex-
pansion and contraction with cyclic temperature changes cause
deterioration of the charge.

The deterioration may get worse with increasing duration
of exposure to a given set of ambient conditions, and may be
accelerated at wider temperature extremes.

Tensile stress at the oxidizer-filler interface in com-
posite propellants may lead to the formation of voids around
the oxidizer particles. Once void formation has started, it
propagates to the vicinity of neighboring particles to pro-
duce a band or region of these failures.

At high temperatures, chemical and physical changes in
the propellant may cause a serious reduction in the value of

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the coefficient of elasticity. The inhibitor may also deteriorate at high temperature. When the generator is fired, the charge may deform excessively or portions may even break loose. This can increase the burning area and pressure causing out of spec, pressure and burn times or even causing the case to burst. Portions of propellant which break loose can also block the gas nozzle tube and result in a catastrophic failure.

Humidity can sometimes accelerate this deterioration. Gas generators are normally provided with humidity sealing to prevent ingress of moisture to the propellant.

Cracks in the propellant will increase the burning surface areas, which increases pressure and cause out of specification conditions.

Double-base propellants are prone to the same types of deterioration as described for composite propellants with the exception of the void formation at the oxidizer-filler interface. The double-base propellant is a homogeneous mixture and does not have the solid oxidizers in the grain.

However, in double-base propellants, nitrocellulose decomposes slowly but continuously, releasing oxides of nitrogen. The rate of decomposition is accelerated by the presence of these oxides. Certain materiels called "stabilizers" can combine chemically with the oxides and remove them. The stabilizer does not prevent decomposition but retards the rate after it has commenced. This decomposition can create grain defects in the form of gas bubbles or cracks.

4.2 Reliability Prediction

The data collected to date shows no gas generator failure which would have failed the mission requirements. Since the data indicates that the motors are definitely deteriorating with age, a failure rate prediction based on the number of hours in storage would be meaningless. Therefore, reliability based on binomial confidence levels for the number of successes experienced was calculated.

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No distinct difference is apparent at this time between composite and double base propellant units. More specification failures occurred in the double base propellant, however, these units showed the least ballistic parameter aging trends. Therefore, the specification failures are apparently a function of the particular program application.

Table 4.2-1 gives the gas generator reliability at 50% and 90% confidence levels. The estimates are conservative since no mission failures were experienced.

The variation in the reliabilities in Table 4.2-1 is strictly a function of the number of data samples available for each classification. The measured reliability for all the units was 1.000.

Based on each program analysis, the recommended service lives were given as 6 years for one unit and 12 years for the other two units.

TABLE 4.2-1. GAS GENERATOR RELIABILITY
(excludes ignition system)

RELIAB'LITY

50% Confidence		90% Confidence	
5 Yrs.	10 Yrs.	5 Yrs.	10 Yrs.
.991	.925	.972	.775

4.3 Data Analysis

Data from surveillance of three missile programs has been collected and analyzed. Out of 5,828,320 hours of unit storage, ballistic data from 116 static firings indicated 7 failures to meet original acceptance specifications. No catastrophic failures were reported. Analysis of the 7 specification failures by program personnel indicated that in each case, the gas generator was capable of providing sufficient gas pressure to perform its intended mission.

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4.3.1 Data Classification

Table 4.3-1 summarizes the data on the gas generators.
Program A utilizes a double base propellant while programs
B and C use composite propellants.

The double base propellant shows more specification
failures than the composite. However, the double base pro-
pellant data included units older than the composite pro-
pellants and most of the specification failures were in the
older units. In addition, the double base unit is smaller
than the composite units.

4.3.2 Aging Trends

4.3.2.1 Successes vs. Age

A comparison of successes and failures versus age of the
gas generators was made. The double base propellant generator
shows a definite aging trend beginning in units at age 9 years.
No aging trend is apparent in the data for composite propel-
lant generators, however, no data is available past nine years.

4.3.2.2 Ballistic Parameters vs. Age

The three missile programs were able to project aging
trends for individual ballistic parameters using the static
firings at acceptance testing as a baseline.

Program A shows a decrease in burn time, early pressure
and the pressure time integral over the burn time. The late
pressure however shows an increase. Two mechanisms can be
postulated to explain these trends. As with the double base
solid propellant motor, a slow decomposition of the fuel is
experienced with age. This generally accounts for reduced
ballistic pressure and burn time. Radiographic inspection of
the gas generators in program A indicated cracked inhibitors
and separation of the inhibitor from the propellant. For two
units this resulted in erratic burning and abnormal pressures.
The general increase in late maximum pressure could be a
result of the breakdown of the inhibitor.

Program B (a composite fuel generator) shows an increase
in burn time and a slight increase in early maximum pressure.

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TABLE 4.3-1. GAS GENERATOR STORAGE DATA

Program	Propellant	No. of Units	Unit Storage Hours	Accept. Spec. Failures	Simulated Mission Failures	Age of Units (Months)	Avg Press/ Burn Time (PSI/Sec)
A	Double Base	58	2,902,480	5	0	25 to 135	450/35
B	Composite	18	579,620	1	0	34 to 53	1000/60
C	Composite	40	2,346,220	1	0	37 to 100	500/100
TOTALS							
	Double Base	58	2,902,480	5	0	25 to 135	
	Composite	58	2,925,840	2	0	34 to 100	

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Decreases were experienced in late maximum pressure, minimum
pressure, and the time to the 900 PSIG level.

Program C (also a composite fuel generator) shows almost
opposite trends from program B. An increase in average pres-
sure and time to early maximum pressure was reported while
burn time and early maximum pressure decreased.

The composite solid propellant motor analysis indicated
a general trend toward decreasing burn time and total impulse
and increasing pressures and thrusts. Program B does not
follow this trend.

Program C, however, did experience a decrease in burn
time and an increase in average pressure. This trend may
be partially explained by the radiographic tests which in-
dicated separation of the inhibitor from the propellant grain.
The decrease in early maximum pressure was attributed to relief
valve opening at lower pressures.

4.3.3 Failure Modes and Mechanisms

Table 4.3-2 summarizes the failure modes and mechanisms
experienced by the three programs. The two primary failure
mechanisms identified were inhibitor aging and pressure
relief valve aging. The effects of these aging characteristics
were discussed in the previous section.

Other defects noted in visual examination of these de-
vices included a slight amount of rust, loosening of a pheno-
lic liner, and damaged moisture seals.

4.3.4 Program Data

4.3.4.1 Program A

Fifty-eight units were tested. Thirty-nine of the units
were from 2 to 5 years old and nineteen from 8 to 11 years old.
The five specification failures occurred in the older units.

4.3.4.2 Program B

Eighteen units were tested ranging in age from 3 to 5
years old. The one specification failure occurred in a unit
46 months old.

4.3.4.3 Program C

Forty units were tested. Four units were less than four
years old while the remainder were from 6 to 9 years old.

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TABLE 4.3-2. FAILURE MODES & MECHANISMS

PROGRAM A

Modes

3 units failed minimum burn time specifications and
exceeded the late maximum pressure time function

2 units exceeded the late maximum pressure specification

Mechanisms

Cracks in inhibitors and separation of inhibitor from
propellant grain were indicated

PROGRAM B

Modes

1 unit failed the minimum pressure specification

Mechanisms

No mechanisms were identified

PROGRAM C

Modes

1 unit failed the minimum pressure specification

Mechanisms

Special tests indicated a pressure relief valve opening
at low pressures. Inhibitor separations from the
propellant grain were also noted

The one specification failure occurred in a unit 78 months old.

4.4 Conclusions and Recommendations

The data analyzed for solid propellant gas generators indicated no failures which would have failed the mission requirements. Until more data is collected, it is recommended that the following reliability prediction be used for solid propellant units:

5 Year Reliability:	.991 at 50% confidence
	.972 at 90% confidence
10 Year Reliability:	.925 at 50% confidence
	.775 at 90% confidence

The data indicated no significant difference between the types of generators.

Missile systems design should compensate for changes in motor performance.

Surveillance programs have proven to be invaluable aids to detect excessive aging of propellants and to initiate early correction for maximum system life.

4.5 Reference

The information in Section 4 is a summary of document number LC-76-OR3, "Solid Propellant Gas Generator Analysis," dated May 1976. Refer to that document for details of data collection and analysis and technical description of gas generators.

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5.0 Miscellaneous Ordnance Devices

This section contains storage reliability data and analysis on miscellaneous ordnance devices.

Non-operational hours, failures and failure rate information is summarized in Table 5-1 for the different devices. Detailed information was not available on the devices to assess failure mechanisms.

Failure 5-1 presents recommended failure rates for reliability prediction. The failure rates for explosive bellows, explosive bolts, explosive timers are considered conservative since no failures were reported for these devices.

TABLE 5-1. STORAGE DATA ON MISCELLAENOUS
ORDNANCE DEVICES

Device	Storage Hrs. $\times 10^6$	Failures	Failure Rate dn Fits*
Electric Igniters	516.5	10	19.4
Explosive Actuators (one bridge wire)	130.	1	7.7
Explosive Actuators (two bridge wires)	77.1	0	<13.0
Explosive Bellows	65.6	0	<15.2
Explosive Bolts	16.3	0	<61.3
Explosive Motors (one bridge wire)	15.5	0	<64.5
Explosive Motors (two bridge wires)	8.4	0	<119.0
Explosive Switches (one bridge wire)	288.1	1	3.5
Explosive Switches (two bridge wires)	126.9	1	7.9
Explosive Timers	28.2	0	<35.5
Zero Impulse Bolt	1.08	0	926.0
Pin Puller	1.87	0	535.0
Surface Fuse	.59	2	3390.
Energy Generator	1.61	3	1863.

*Failures per billion hours

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FIGURE 5-1.   MISCELLANEOUS ORDNANCE DEVICE FAILURE RATES

λ_p (Device Failure Rate)

Device	λ_p
Electric Igniters	$.019 \times 10^{-6}$
Explosive Actuators	$.063 \times 10^{-6}$
Explosive Bellows*	$.015 \times 10^{-6}$
Explosive Bolts*	$.061 \times 10^{-6}$
Explosive Motors*	$.042 \times 10^{-6}$
Explosive Switches	$.005 \times 10^{-6}$
Explosive Timers*	$.035 \times 10^{-6}$
Zero Impulse Bolt*	$.926 \times 10^{-6}$
Pin Puller*	$.535 \times 10^{-6}$
Surface Fuse	3.390×10^{-6}
Energy Generator	1.863×10^{-6}

*Estimates considered conservative.

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