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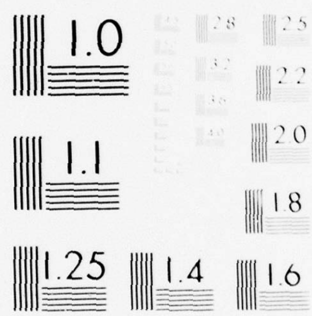

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STORAGE RELIABILITY OF MISSILE MATERIEL PROGRAM

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

Redstone Arsenal, Alabama 35809

STORAGE RELIABILITY SUMMARY REPORT

VOLUME V

OPTICAL & ELECTRO-OPTICAL DEVICES

LC-78-2 FEBRUARY 1978

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This report summarizes analyses on the non-operating reliability of missile ordnance devices. Primary non-operating data is on TV seeker components. Operating models from MIL-HDBK-217B are summarized for laser devices. This analyses is part of a research program being conducted by the U. S. Army Missile R&D Command, Redstone Arsenal, Alabama.

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STORAGE RELIABILITY

OF

MISSILE MATERIEL PROGRAM

STORAGE RELIABILITY SUMMARY REPORT

VOLUME V

OPTICAL & ELECTRO-OPTICAL DEVICES

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LIFE CYCLE ANALYSIS DEPARTMENT
HUNTSVILLE, ALABAMA

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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 dormant time as well as perform operationally in severe launch and flight environments. In addition to the stress of temperature 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 importance 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.

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 consists of a computerized data base with generic part storage reliability data and a storage reliability report library containing 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 environments. 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 containers 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).

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.

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 project maintenance actions if the missile is checked and maintained 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 indicates 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 required 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 deployment 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 definitions of the system environment and deployment scenario. This reliability life cycle modeling is based on a "wooden 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 capability of separately estimating the reliability of transportation and storage for missile materiel. Also data has indicated no difference between dormant (>0 and <10% electrical 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).

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.

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.

TABLE 1-1. REPORT CONTENTS

		Detailed Rept. Number & Date
Volume I	**Electrical and Electronic Devices**	
Section		
2.0	Microelectronic Devices	LC-78-IC1, 1/78
3.0	Discrete Semiconductor Devices	-
4.0	Electronic Vacuum Tubes	LC-78-VT1, 1/78
5.0	Resistors	-
6.0	Capacitors	-
7.0	Inductive Devices	-
8.0	Crystals	-
9.0	Miscellaneous Electrical Devices	-
10.0	Connectors and Connections	-
11.0	Printed Wiring Boards	-
Volume II	**Electromechanical Devices**	
Section		
2.0	Gyros	LC-78-EM1, 2/78
3.0	Accelerometers	LC-78-EM2, 2/78
4.0	Switches	LC-78-EM4, 2/78
5.0	Relays	LC-78-EM3, 2/78
6.0	Electromechanical Rotating Devices	-
7.0	Miscellaenous Electromechanical Devices	-
Volume III	**Hydraulic and Pneumatic Devices**	
Section		
2.0	Accumulators	LC-76-HP2, 5/76
3.0	Actuators	LC-76-HP3, 5/76
4.0	Batteries	LC-78-B1, 2/78
5.0	Bearings	-
6.0	Compressors	-
7.0	Cylinders	-
8.0	Filters	-
9.0	Fittings/Connections	-
10.0	Gaskets	-
11.0	O-Rings	-
12.0	Pistons	-
13.0	Pumps	LC-76-HP4, 5/76
14.0	Regulators	-
15.0	Reservoirs	-
16.0	Valves	LC-76-HP1, 5/76
Volume IV	**Ordnance Devices**	
Section		
2.0	Solid Propellant Motors	LC-76-OR1, 5/76
3.0	Igniters and Safe & Arm Devices	LC-76-OR2, 5/76
4.0	Solid Propellant Gas Generators	LC-76-OR3, 5/76
5.0	Misc. Ordnance Devices	-
Volume V	**Optical and Electro Optical Devices**	

2.0 Lasers

2.1 Laser Non-Operational Storage Reliability

No data on storage or non-operating characteristics of lasers is available. A missile system is in the field for which some data may become available in the near future.

2.2 Laser Operational Prediction Models

The MIL-HDBK-217B general failure rate model for lasers is:

$$\lambda_{LASER} = \lambda_{MEDIA} + \lambda_{PUMP} + \lambda_{COUPLING}$$

The models and failure rates apply to the laser peculiar items only, i.e., those items wherein the lasing action is generated and controlled. In addition to the laser peculiar items, there are other assemblies used with lasers that contain electronic parts and mechanical devices (pumps, valves, hoses, etc.). The failure rates for these parts should be determined with the same procedures as used for other electronic and mechanical devices in the equipment or system of which the laser is a part.

The laser failure rate models have been developed at the "functional," rather than "piece part," level because the available data were not sufficient for "piece part" model development.

Because each laser family can be designed using a variety of approaches the failure rate models have been structured on three basic laser functions which are common to most laser families, but may differ in the hardware implementation of a given function. These functions are the lasing media, laser pumping mechanism (or pump), and the coupling method.

Examples of media-related hardware and influence factors are the solid state rod, gas, gas pressure, vacuum integrity, gas mix, outgassing, and tube diameter. The electrical discharge, the flashlamp, and energy level are examples of pump-related hardware and influence factors. The coupling function contributors are the "Q" switch, mirrors, windows, crystals, substrates, coatings, and level of dust protection provided.

The λ_{PUMP} term in the λ_{LASER} equation is zero for helium/neon, argon ion CO_2 sealed and CO_2 flowing lasers because the pumping mechanisms for these lasers contain no laser peculiar items. Pumping is accomplished with electrical parts and circuitry. Failure rates for these parts are not included in this section but they should be included in the reliability analysis of the system equipment containing the laser. Also, some of the terms in the above general λ_{LASER} equation have modifying factors depending upon the laser type. These factors are shown in the following sub-sections.

2.2.1 Helium/Neon and Argon Ion Lasers

The failure rate model for helium/neon and argon ion lasers is presented in Figure 2.2-1.

The predominant failure mechanism is related to the gas media as reflected in λ_{MEDIA}. However, for argon ion lasers, when the tube is refilled periodically (preventive maintenance) the mirrors (as part of $\lambda_{COUPLING}$) can be expected to deteriorate after approximately 10^4 hours of operation if in contact with the discharge region.

2.2.2 Carbon Dioxide, Sealed Lasers

The failure rate model for carbon dioxide sealed lasers is presented in Figure 2.2-2.

The overfill percentage in the Gas Overfill Factor, Π_O, is based on the percent increase over the optimum CO_2 partial pressure which is normally in the range of 1.5 to 3 Torr for most sealed CO_2 lasers. The equation for Π_O is:

$$\Pi_O = -0.01\ (\%\ \text{overfill}) + 1$$

The equation for the ballast factor, Π_B, is

$$\Pi_B = (1/3)\frac{\%\text{Vol. Inc}}{100}$$

The number of active optical surfaces, Π_{OS}, is determined from Figure 2.2-5.

2.2.3 Carbon Dioxide, Flowing Lasers

The failure rate model for carbon dioxide, flowing lasers is presented in Figure 2.2-3.

The failure rate contribution of the lasing media, λ_{MEDIA}, approaches zero for carbon dioxide, flowing lasers. This is because this type of laser is much less susceptible to leaks and long term gas decomposition than a sealed system. The flowing gas also acts as a purge in removing contamination and precluding its entrapment. Therefore, except for tube breakage (which has rarely been observed) optics deterioration appears the predominant failure mechanism and this is accounted for under $\lambda_{COUPLING}$.

The failure rate contribution of the laser coupling hardware, $\Pi_{COUPLING}$, is a function of the laser beam average power output, P, in kilowatts. The $\Pi_{COUPLING}$ values shown are valid only for power levels up to one kilowatt. Beyond this range other glass failure mechanisms begin to predominate and alter the $\Pi_{COUPLING}$ values. It should also be noted that CO_2 flowing laser optical devices are the primary source of failure occurrence. A preventive maintenance program on optical devices would greatly extend laser life; however, procedures must be tailored to the individual design of each system. Typical optical cleaning methods are as follows:

1. Use dry, pressurized air and a camel hair brush to remove dust, particulates, etc.
2. Rub with high quality lens tissue using moisture from breath (if necessary).
3. Flush with distilled water and a mild laboratory detergent (if necessary).
4. Cautions -
   a. Use of special gloves for handling recommended.
   b. Careful use of 20 to 30 percent alcohol solutions with sterile cotton swabs (change swabs frequently).

The number of active optical surfaces, Π_{OS}, is determined from Figure 2.2-5.

2.2.4 Solid State Nd:YAG Rod Lasers and Ruby Red Lasers

The failure rate model for solid state neodymium doped yttrium-aluminum-garnet (Nd:YAG) rod laser and ruby red laser is presented in Figure 2.2-4.

The failure rate contribution of the lasing media, λ_{MEDIA}, is 0.1 for Nd:YAG lasers. For the ruby red laser, λ_{MEDIA} is a function of the repetition rate (Π_{REP}) and the energy density (F). The energy density is measured in Joules per $cm.^2$/pulse over the cross sectional area of the laser rod and its value is determined from the actual design parameter of the laser rod utilized.

Repetition rates for military solid state lasers are generally in the 1 to 20 pps range. Repetition rates other than shown have not been observed and corresponding Π_{REP} values certified.

The failure rate contribution of pumping mechanism, λ_{PUMP}, is highly affected by the flashlamp or flash tube contribution. It is expressed as a function of the environmental factor (Π_E) and the failure rate contribution of the flashlamp or flashtube ($\lambda_{PUMP\ HOURS}$). The value for $\lambda_{PUMP\ HOURS}$ is calculated from Figure 2.2-6 for Xenon flash lamps or Figure 2.2-7 for Krypton flashlamps.

It should be noted that although sealed systems tend to be reliable once compatible materials have been selected and proven, extreme care must still be taken to prevent the entrance of particulates during manufacturing, field flashlamp replacement, or routine maintenance/repair. Contamination is the major cause of solid state laser malfunction, and special provisions and vigilance must continually be provided to maintain the cleanliness level required. Coupling cleanliness factor, Π_C, values can vary from 1 up to 60.

The number of active optical surfaces, Π_{OS}, is determined from Figure 2.2-5.

FIGURE 2.2-1 MIL-HDBK-217B OPERATIONAL FAILURE RATE MODEL FOR HELIUM/NEON LASERS AND ARGON ION LASERS

$$\lambda = (\Pi_E \lambda_{MEDIA} + \Pi_E \lambda_{COUPLING}) \times 10^{-6}$$

λ_{MEDIA} & $\lambda_{COUPLING}$

Laser Type	λ_{MEDIA}	$\lambda_{COUPLING}$
Helium/Neon	84	.1
Argon Ion	457	6.

Π_E (Environmental Factor)

Environment	Π_E
Ground, Benign	.2
Space Flight	.2
Ground, Fixed	1.
Airborne, Inhabited	5.
Naval, Sheltered	5.
Ground, Mobile	5.
Naval, Unshelt.	5.
Airborne, Uninhab.	8.
Missile, Launch	8.

FIGURE 2.2-2 MIL-HDBK-217B OPERATIONAL FAILURE RATE MODEL FOR CARBON DIOXIDE, SEALED LASERS

$$\lambda_{CO_2\ SEALED} = (\pi_E \pi_O \pi_B \lambda_{MEDIA} + \pi_E \pi_{OS} \lambda_{COUPLING}) \times 10^{-6}$$

λ_{MEDIA}

$\lambda_{MEDIA} = 69I - 450$
I = Current (ma) through discharge tube
($10ma \leq I \geq 150$ ma)

$\lambda_{COUPLING}$

$\lambda_{COUPLING} = 10.$

π_O (Gas Overfill Factor)

CO_2 Overfill Percent	π_O
0	1.00
25	0.75
50	0.50

π_E (Environmental Factor)

Environment	π_E
Ground, Benign	.2
Space Flight	.2
Ground, Fixed	1.
Airborne, Inhabited	5.
Naval, Sheltered	5.
Ground, Mobile	5.
Naval, Unsheltered	5.
Airborne, Uninhab.	8.
Missile, Launch	8.

π_B (Ballast Factor)

Percent of Ballast Volumetric Increase	π_B
0	1.0
50	0.58
100	0.33
150	0.19
200	0.11

π_{OS} (Number of active Optical Surfaces)

See Figure 2.2-5

FIGURE 2.2-3 MIL-HDBK-217B OPERATIONAL FAILURE RATE MODEL FOR CARBON DIOXIDE, FLOWING LASERS

$$\lambda_{CO_2\ FLOWING} = (\Pi_E \lambda_{MEDIA} + \Pi_E \Pi_{OS} \lambda_{COUPLING}) \times 10^{-6}$$

λ_{MEDIA}

$\lambda_{MEDIA} = 0$

$\lambda_{COUPLING}$

Power (kilowatts)	$\lambda_{COUPLING}$
.01	3
.1	30
1.0	300*

*Does not apply for power levels over 1.0 kilowatts.

Π_E (Environmental Factor)

Environment	Π_E
Ground, Benign	.2
Space Flight	.2
Ground, Fixed	1.
Airborne, Inhabited	5.
Naval, Sheltered	5.
Ground, Mobile	5.
Naval, Unsheltered	5.
Airborne, Uninhab.	8.
Missile, Flight	8.

Π_{OS} (Number of active Optical Surfaces)

See Figure 2.2-5

FIGURE 2.2-4 MIL-HDBK-217B OPERATIONAL FAILURE RATE MODEL FOR SOLID STATE Nd:YAG ROD LASERS AND RUBY RED LASERS

$$\lambda = (\Pi_E \lambda_{MEDIA} + \lambda_{PUMP} + \Pi_E \Pi_C \Pi_{OS} \lambda_{COUPLING}) \times 10^{-6}$$

λ_{MEDIA} (Nd:YAG Rod Laser)

$\lambda_{MEDIA} = 0.1$

λ_{MEDIA} (Ruby Red Laser)

$\lambda_{MEDIA} = (\Pi_{REP})\ (43.5\ F^{2.52})$

F = Energy density in Joules per cm^2/pulse over the cross sectional area of the laser beam.

Π_{REP} (Repetition Rate Factor)

Repetition or Pulse Rate (Pulses per sec.)	Π_{REP}
1	3600
5	18000
10	36000
15	54000
20	72000

λ_{PUMP}

$\lambda_{PUMP} = \Pi_E\ \lambda_{PUMP\ HOURS}$

$\lambda_{PUMP\ HOURS}$

Lamp	See Figure
Xenon	2.2-6
Krypton	2.2-7

$\lambda_{COUPLING}$

$\lambda_{COUPLING} = 16.3$

Π_E (Environmental Factor)

Environment	
Ground, Benign	.2
Space Flight	.2
Ground, Fixed	1.
Airborne, Inhabited	5.
Naval, Sheltered	5.
Ground, Mobile	5.
Naval, Unsheltered	5.
Airborne, Uninhab.	8.
Missile, Launch	8.

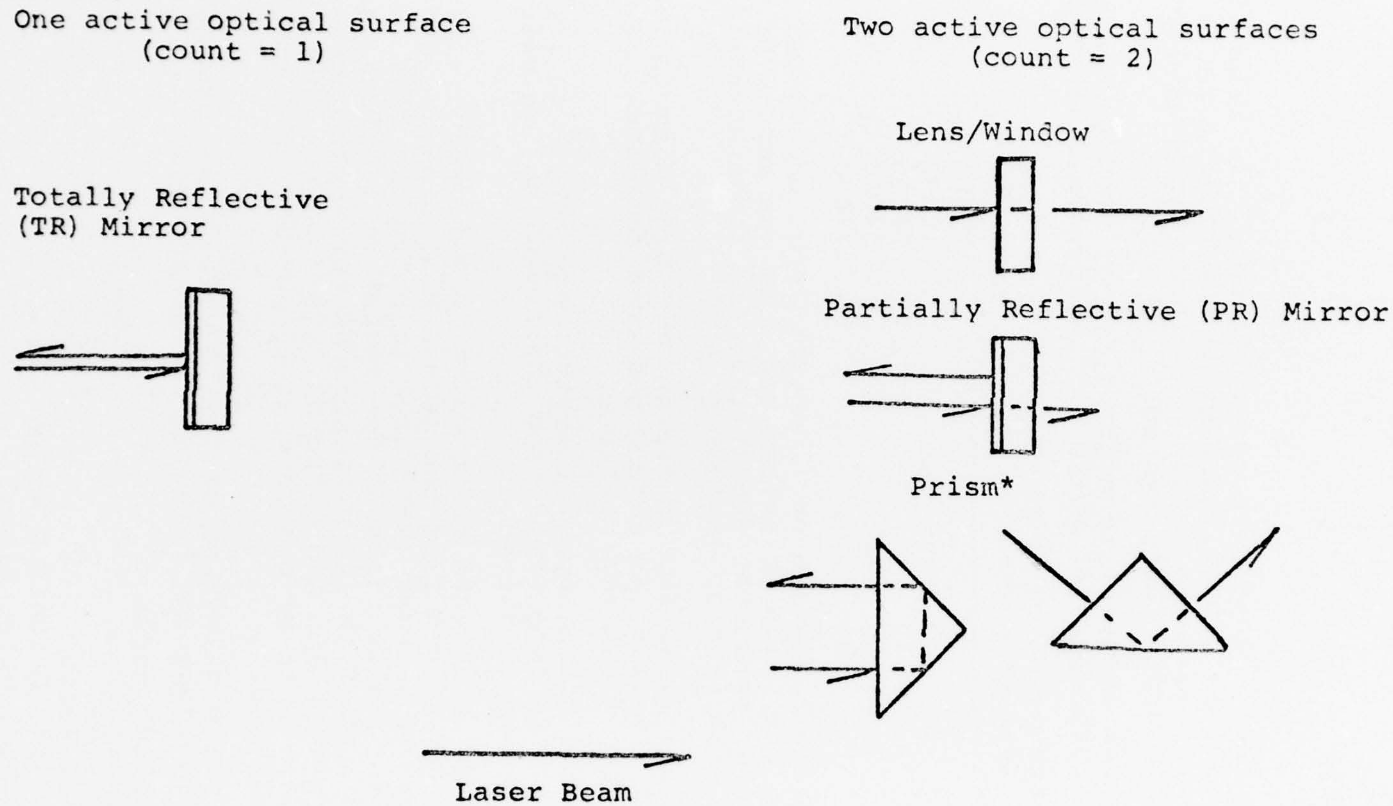
Π_{OS} (Number of Active Optical Surfaces)

See Figure 2.2-5

Π_C (Coupling Cleanliness Factor)

	Π_C
Rigorous cleanliness procedures, equipment, and trained maintenance personnel. Plus bellows provided over optical train.	1
Minimal precautions during opening, maintenance, repair, and testing. Plus bellows provided over optical train.	30
Minimal precautions during opening, maintenance, repair, and testing. No bellows provided over optical train.	60

FIGURE 2.2-5 EXAMPLES OF ACTIVE OPTICAL SURFACES AND COUNT



*Prism has only 2 active surfaces, because interior surfaces are not subject to external particulate contamination.

Only active optical surfaces are counted. An active optical surface if one with which the laser energy or beam interacts. Internally reflecting surfaces are not counted.

FIGURE 2.2-6 DETERMINATION OF $\lambda_{PUMP\ HOURS}$ FOR XENON FLASHLAMPS

$$\lambda_{PUMP\ HOURS\ XENON} = (\Pi_{REP}) \left[2000 \left(\frac{E_j}{dL\ \ T} \right)^{8.58} \right] (\Pi_{COOL})$$

where:

$\lambda_{PUMP\ HOURS\ XENON}$ is the failure rate contribution of the xenon flashlamp or flashtube* in failures/million operating hours. The flashlamps evaluated herein are linear types used for military solid state laser systems.

Π_{REP} is the pulse or repetition factor used to convert from failures per 10^6 pulses to failures/million hours.

Repetition or Pulse Rate (Pulses per second)	Π_{REP}
1	3600
5	18000
10	36000
15	54000
20	72000

E_j is the flashlamp or flashtube input energy per pulse in joules and its value is determined from the actual or design input energy parameter except that for input energy levels equal to or less than 30 joules, $E_j = 30$.

d is the flashlamp or flashtube inside diameter in millimeters, and its value is determined from the actual design parameter of the flashlamp utilized.

L is the flashlamp or flashtube arc length in inches, and its value is determined from the actual design parameter of the flashlamp utilized.

T is the truncated pulse width in microseconds, and its value is determined from the actual design parameter of the pulse forming network (PFM) used to pulse the flashlamp or flashtube. Pulse tails do not affect reliability, and the maximum value of T is 100 microseconds for any truncated pulse width exceeding 100 microseconds. For shorter duration pulses, pulse width is to be measured at 10 percent of the maximum current amplitude.

Π_{COOL} is the cooling factor due to various cooling media immediately surrounding the flashlamp or flashtube.

Cooling Media	Π_{COOL}
Gas, Air	1.0
Gas, Inert	1.0
Liquid, Deionized Water	0.1
Liquid, Water-Glycol	0.1
Liquid, Fluorocarbon	0.1

Note: Typical values for Xenon flashlamps in military Nd:YAG rangefinders and designators are $E_j = 40$ joules, d = 4 millimeters, L = 2 inches, and T = 100 microseconds. The repetition rate ranges from 1 to 20 pps, and the lamps are normally liquid cooled.

FIGURE 2.2-7 DETERMINATION OF $\lambda_{\text{PUMP HOURS}}$ FOR KRYPTON FLASHLAMPS

$$\lambda_{\text{PUMP HOURS KRYPTON}} = (625)\left(10^{(0.9\frac{P}{L})}\right)(\Pi_{COOL})$$

$\lambda_{\text{PUMP HOURS KRYPTON}}$ is the failure rate contribution of the krypton flashlamp or flashtube in failures/million operating hours. The flashlamps evaluated herein are the continuous wave (CW) type and are most widely used for commercial solid state applications. They are approximately 7mm in diameter and 5 to 6 inches long. Average power is typically 4 KW.

P is the average input power in kilowatts, and its value is determined from the actual design parameter for the flashlamp utilized.

L is the flashlamp or flashtube arc length in inches, and its value is determined from the actual design parameter of the flashlamp utilized.

Π_{COOL} is the cooling factor due to various cooling media immediately surrounding the flashlamp or flashtube.

Cooling Media	Π_{COOL}
Gas, Air	1.0
Gas, Inert	1.0
Liquid, Deionized Water	0.1
Liquid, Water-Glycol	0.1
Liquid, Fluorocarbon	0.1

3.0 Television Seeker Components

3.1 Non-Operating Reliability Data

Non-operating data was available from two sources and one missile program on television seeker components. This data is shown in Table 3-1. Each data source is discussed below.

TABLE 3-1. TV NON-OPERATING DATA

COMPONENT TYPE	SOURCE	NO. OF DEVICES	MILLION PART NON-OP. HOURS	FAILURES	NON-OP. λ IN FITS
Vidicon Electron Tube	B	41	.275	0	<3636.
	Missile I	2070	20.59	3	145.7
TOTAL VIDICON		2111	20.856	3	143.8
Video Signal Detector Assy.	A	-	.610	0	<1639.
	Missile I	2070	20.59	1	48.6
TOTAL DETECTOR		2070	21.200	1	47.2
Lens Assy.	B	40	.115	0	<8696.
	Missile I	2070	20.59	0	<48.6
TOTAL LENS		2110	20.705	0	<48.3
Sun Shutter Assy.	Missile I	2070	20.59	7	340.
Vidicon Cable	Missile I	2070	20.59	1	48.6

3.1.1 Source A Data

Source A represents a reliability study performed under contract to RADC in 1973. This source provides no information regarding storage conditions, times, or individual programs. No failures were recorded for these devices.

3.1.2 Source B Data

The storage data under Source B actually represents standby data in an orbiting satellite environment. No failures were recorded for these devices.

3.1.3 Missile I Data

Missile I data consists of 2,070 missiles stored for periods from 1 month to 40 months for an average storage period of 14 months. Approximately 80 percent of the missiles were stored in U. S. depots while the remainder were stored at various bases around the country. In this data, 3 failures were recorded on the vidicon tube, one failure on the video signal detector, seven failures on the sun shutter assemblies.

Two of the three vidicon tube failures were recorded as 1) will not focus and 2) defective sun diode.

The sun shutter assembly failures were recorded as sticking in the closed position. Analyses indicated that this is an age-related problem. The grease on the bearings is drying up and causing the shutters to stick.

3.2 Operational Predictions

No operational data has been identified for these devices.