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STORAGE RELIABILITY OF MISSILE MATERIEL PROGRAM, MISSILE SYSTEM--ETC(U)

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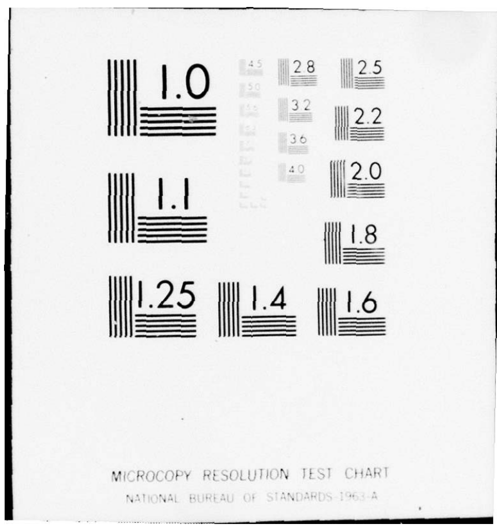
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STORAGE RELIABILITY OF MISSILE MATERIEL PROGRAM

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

Redstone Arsenal, Alabama 35809

MISSILE SYSTEMS BATTERY ANALYSIS

LC-78-B1 FEBRUARY 1978

PRODUCT ASSURANCE DIRECTORATE

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This report documents findings on the non-operating reliability of silver zinc and thermal batteries. Field data and shelf life data is included. This information 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

MISSILE SYSTEMS BATTERY ANALYSIS

LC-78- B1 FEBRUARY 1978

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U. S. ARMY MISSILE R&D COMMAND

REDSTONE ARSENAL, AL

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LIFE CYCLE ANALYSIS DEPARTMENT

HUNTSVILLE, ALABAMA

ABSTRACT

This report documents findings on the non-operating reliability of missile system batteries. Long term non-operating data has been analyzed and failure rate predictions have been made.

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.

This report is one of several to be issued on missile materiel. For more information, contact:

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SECTION 1

INTRODUCTION

Materiel in the Army inventory must be designed, manufactured and packaged to withstand long periods of storage and "launch ready" non-activated or dormant time. 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. These requirements generate the need for special design, manufacturing and packaging, and product assurance data and procedures. The U. S. Army Missile Command has initiated a research program to provide the needed data and procedures.

This report covers findings from the research program on missile system batteries. The program approach on these devices has included literature and user surveys, data bank analyses, data collection from various military systems and special testing programs.

Failure rate predictions have been derived from the storage time data and failure mode and mechanism knowledge.

SECTION 2

SUMMARY

This section summarizes data collected and analyzed for missile battery types. Data was available on two basic missile batteries; silver-zinc and thermal. These have been the auxiliary power sources on U. S. missiles. The thermal and silver-zinc batteries provide power necessary for operations of the guidance section once the missile is fired.

A complete summary of the battery data analysis is shown in Table 2-1 for silver-zinc and Table 2-2 for thermal batteries.

TABLE 2-1. SUMMARY OF SILVER-ZINC BATTERY STORAGE DATA

DATA SOURCE	BATTERY TYPE	QTY.	ENV.	FAIL.	STORAGE HRS. (10^6)	FAILURE RATE IN FITS
B	Silver Zinc (primary)	483	Shelf	0	13.8	<72.5
B	" "	510	Service	0	9.8	<102.0
TOTAL		993		0	23.6	<42.4

Table 2-1 represents cumulative data of 993 batteries resulting in no failures and an overall failure rate of 42.4 fits.

TABLE 2-2. SUMMARY OF THERMAL BATTERY STORAGE DATA

DATA SOURCE	BATTERY TYPE	QTY.	ENV.	FAIL.	STORAGE HRS. (10^6)	FAILURE RATE IN FITS
B	A	163	Field	0	9.1	<110.0
C	B	37	Field	1	1.5	<666.0
TOTAL		200		1	10.6	<94.3

Table 2-2 represents a cumulative of 10.6 million storage hours and one failure for the 200 batteries tested. This results in an overall failure rate of <94.3 fits for thermal batteries.

A survey of industry reveals that batteries have not been a storage reliability problem in missile use. A storage service life of better than 14 years is not uncommon and better than 20 years for shelf life batteries.

SECTION 3
DESCRIPTION

Silver-zinc and thermal batteries have been the principal auxiliary power source on U. S. missiles. In these applications, the system remains inert during storage and is activated at missile launch.

3.1 Thermal Batteries

The thermal battery provides all power necessary for operation of the guidance section once the missile is fired. Figure 3-1 is an example of the thermal battery which is described.

The thermal battery also supplies electrical power to the fuze and fires the sustainer rocket squibs. This battery is hermetically sealed and completely inactive until fired by an electrical squib. Consequently, it has a long shelf life. The battery becomes fully active within 0.5 second after activation power is applied. During operation it provides a peak current of 13 amperes and an average current of 2.3 amperes at 40 $\pm$ 5 volts for 11 seconds. The entire unit is contained in a cylinder 2.235 inches in diameter by 2.15 inches in length with a weight of 0.75 pounds. Heat pads are sandwiched between battery cells to reduce activation time. The battery is ignited by electric squibs which ignite pyrotechnic paper. The pyrotechnic paper generates temperatures of the order of 2000°F which melt electrolyte salts contained in the cells. The melted salts provide the required electrochemical action. Activation power for the squibs is 20 watts for 100 milliseconds, supplied by the launcher battery.

3.2 Silver-Zinc Batteries

Silver-zinc primary batteries remain inert during storage and are activated by the transfer of electrolyte from a tank or coil into the cells.

The negative plate often consists of electrodeposited zinc on a base material which may be silver-soil or silver-plated copper mesh. Sintered zinc is also used for the

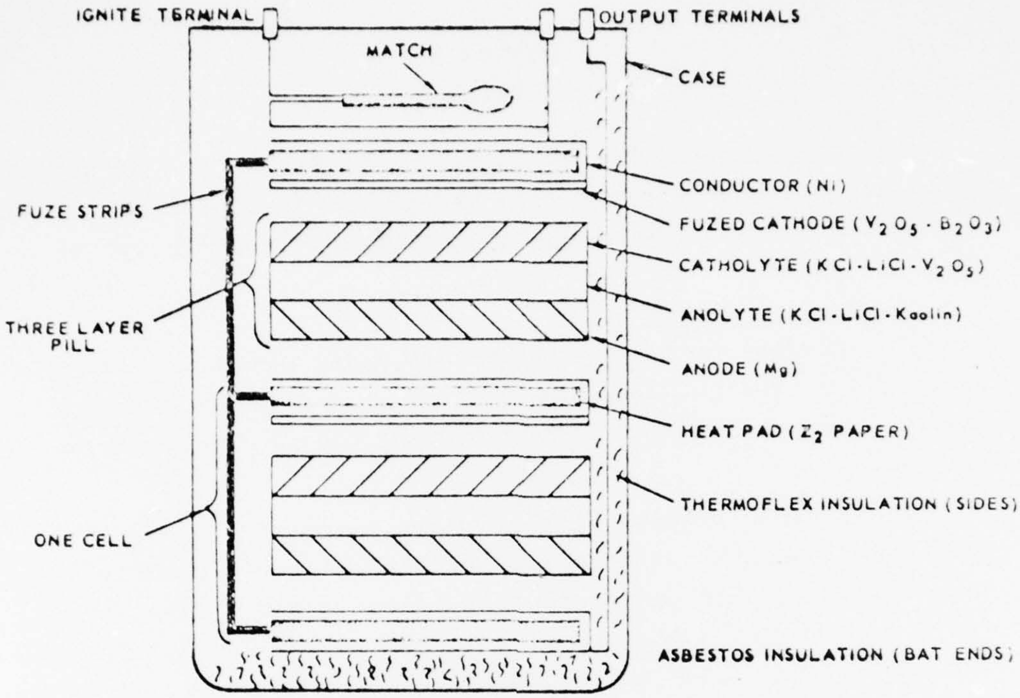


FIGURE 3-1. THERMAL BATTERY

negative plate to provide more surface area per unit of projected area.

The positive plate is silver oxide, AgO (or, as sometimes shown, Ag_2O_2), constructed on a silver foil, expanded silver foil, silver screen, or a copper wire mesh which has been nickel or silver plated. A paste of silver oxide and water is applied to this screen and baked until it is dry. Electrolytic treatment of the plate establishes the peroxide state of the silver.

The electrolyte is a solution of potassium hydroxide in water, the concentration varying from 20 to 45-percent KOH, the optimum concentration of KOH for low-termperature operation being approximately 31 percent.

Separator materials are required to provide a space for the electrolyte around the plates and to prevent shorting of the plates. The membrane must be constructed of a material which allows ion exchange to take place between the plates while still preventing the soluble particles of zinc and silver from migrating to the opposite electrodes. Materials normally used for this purpose are glass cloth, asbestos paper, or various cellulose materials.

The overall chemical reaction will produce about 4 Faradays of electricity in the average battery. The Faraday is defined as the amount of electricity required to liberate one gram-equivalent of a metal from its ions and is equal to approximately 96,500 coulombs per gram-equivalent. If the chemical reaction proceeds to completion, four (4) Faradays of electricity will be produced per gram atomic weight of silver peroxide.

The silver-zinc cell has a very high energy density, up to 80 w-hr per pound up to 4 w-hr per cubic inch. The nominal cell voltage under load is 1.5 v, while the maximum current density is approximately 2.5 amp/in.^{2} of projected plate area.

This battery has two unfavorable characteristics: 1) the active stand time at normal or higher ambient temperatures is limited to a few hours; and 2) the capacity decreases rapidly at temperatures below about 30°F. While progress has been made in improving performance at low temperatures, the practical solution to the problem has been to add heat to the cell immediately after filling or to continuously heat the electrolyte reservoir.

A typical set of specifications for a missile power source application for this battery is as follows:

Electrical Characteristics

Nominal capacity	50 ampere-hours
Open-circuit voltage	35-37 volts
Nominal operating voltage	26-30 volts
Activation method	Electrical
Stand after activation	8 hours
Shelf life	Up to 5 years

Typical Application

Activation speed	6 seconds
Power output	8,400 watts
Discharge rate	300 amps
Discharge time	10 minutes
Discharge voltage	28 volts
Watt-hours per pound	19.2 w-hr/lb
Watt-hours per cubic inch	1.08 w-hr/in.[3]

SECTION 4
THERMAL BATTERY ANALYSIS

Data was obtained from surveillance programs on two different thermal batteries. Batteries ranged in age from 3 years to 10 years and had been stored in various field environments. Total battery storage hours, failures and resulting failure rates are summarized in Table 4-1. Details on the surveillance programs are given in the following sections.

TABLE 4-1. THERMAL BATTERY NON-OPERATING DATA

BATTERY	NO. OF UNITS	MISSILE STORAGE HRS.	NO. OF FAILURES	FAILURE RATE IN FITS	90% ONE-SIDED LIMIT
A	163	9.1	0	110.	254.
B	37	1.5	1	666.	2594.
TOTALS		10.6	1	94.	367.

4.1 Thermal Battery A

A surveillance program initiated in early 1965 evaluated the reliability and performance characteristics of thermal battery A after approximately ten years of storage.

Annual laboratory tests and analyses of these batteries were conducted. The laboratory tests consisted of testing batteries that were temperature conditioned to -40°F or +130°F. Prior to testing, the batteries were temperature conditioned for a minimum of eighteen hours and tested within two minutes after removal from the conditioning chamber. The following observations were obtained for each battery during the test:

(1) Voltage rise time to 7.0 volts (prior to application of resistive load).

(2) Time to reach maximum voltage (prior to application of resistive load).

(3) Maximum voltage level (prior to application of resistive load).

(4) Voltage immediately after load is applied.

(5) Time voltage level below 7.0 volts immediately after load is applied, if applicable.

(6) Service time (time battery is producing at least 7.0 volts after load is applied).

The batteries utilized in these tests (163) were obtained from field service stocks and from the rocket motors used in the Surveillance Program. These batteries varied in age from 3 to 10 years. It should be noted that the batteries utilized in these tests had a mixed storage location history. For example, most of the batteries obtained from field service stocks had been stored in either Hawaii or Ikinawa as well as in several unknown CONUS locations. The Surveillance batteries, however, were generally stored in Alaska, the Panama Canal Zone or Blue Grass Army Depot in addition to other unknown storage locations. It is also pointed out that some batteries, both field service and surveillance, had a totally unknown storage location history. As a result of this condition, no attempt was made to determine if storage location had any statistically significant effect on battery performance.

4.1.1 Thermal Battery A Surveillance Tests

The surveillance functioning tests consisted of two phases: (1) Laboratory testing of individual batteries, (2) Pedestal spin rocket ignition tests. In the laboratory testing of individual batteries each battery is subjected to a 0.7 ohm resistive load 0.40 seconds after being activated. The application of a load 0.40 seconds after battery activation duplicates actual rocket firing conditions as a resistive load is applied when the firing circuit is complete which is at 0.40 seconds after the rocket makes its initial ascent up the launcher. Activation of the battery is accomplished by removing the safety and holding pins from the battery thereby permitting the spring activated firing pin to strike the percussion primer of the battery. Traces of voltage versus time was recorded during each battery test.

The surveillance criteria developed for determining satisfactory battery performance in the laboratory phase of testing required that the battery shall be continuously producing at least 7.0 volts after the load is applied for an interval of at least 0.15 seconds. The criteria further indicates that the battery must begin producing the 7.0 volts between the time the load is applied (0.40 seconds after activation) and 0.05 seconds after the load is applied (0.45 seconds after activation).

The pedestal spin rocket ignition phase of the test was conducted in order to subject the batteries to a simulated rocket firing environment. In this phase, a battery support assembly containing two batteries connected in parallel was mounted in a bolted down Pedestal and by withdrawing the safety and holding pins the batteries were activated in order to ignite the eight spin rockets contained in the pedestal. The measure of performance utilized in this phase was the ignition delay times of the spin rockets. The ignition delay of each spin rocket was determined as the interval from 0.40 seconds after battery activation (the time at which the circuit from the battery to the spin rockets is complete) until the time the spin rocket in functioning produces a nozzle pressure of 100 psi. The performance criteria in this phase indicated that all eight spin rockets had to have produced this nozzle pressure within 0.450 seconds after battery activation. Spin rockets igniting within this time will properly impart spin to the rocket.

4.1.2 <u>Thermal Battery A Test Results</u>

Table 4-2 & 4-3 summarize the test results on batteries from two manufacturers. This program resulted in 9.0 million battery storage hours with no failures giving a failure rate of less than 110 fits.

TABLE 4-2.

SUMMARY OF SURVEILLANCE TEST RESULTS (MANUFACTURER A)

No.	Battery Age (yr.)	Test Temp. (°F)	Rise Time to 7 Volts (sec.)	Time to Reach Max. Volt. (sec.)	Maximum Voltage (volts)	Voltage[a] Immediately After Application of Load (volts)	Time Below 7 V. After Load Applied (sec.)	Service[b] Time (sec.)
1	3.0	- 40	.06	.26	26.0	15.5	-	2.28
2	3.0	- 40	.07	.33	[illegible]	14.0	-	2.05
3	3.0	- 40	.02	.36	25.0	15.5	-	2.11
4	4.0	- 40	.11	.31	25.5	14.0	-	2.12
5	4.0	- 40	.20	.34	[illegible]	14.5	-	2.20
6[c]	4.0	- 40	.21	.39	25.0	12.0	-	1.89
7	4.0	- 40	.08	.39	25.5	14.5	-	2.31
8	4.0	- 40	.09	.39	25.5	14.5	-	2.10
9	4.0	- 40	.10	.39	23.5	13.5	-	2.05
10	4.0	- 40	.11	.40	25.0	11.5	-	2.22
11	4.0	- 40	.08	.39	25.0	14.0	-	1.88
12	4.0	- 40	.10	.40	26.0	15.0	-	2.01
13	4.0	- 40	.08	.40	25.0	13.5	-	2.26
14	4.0	- 40	.11	.40	26.0	15.0	-	2.07
15	4.0	- 40	.19	.33	26.5	13.5	-	[illegible]
16	4.0	- 40	.09	.40	26.0	15.0	-	2.06
17	4.0	- 40	.10	.40	25.5	14.0	-	2.50
18	4.0	- 40	.09	.39	25.5	12.5	-	2.23
19	4.0	- 40	.08	.40	25.5	15.0	-	1.94
20	4.0	[illegible]	.14	.40	25.5	9.5	-	2.10
21	4.0	- 40	.13	.40	24.5	12.5	-	2.20
22	5.5	- 40	.23	.39	25.0	10.0	-	2.24
23	5.5	- 40	.23	.36	25.5	12.5	-	2.03
24	5.5	- 40	.21	.37	26.0	6.0	.02	2.10
25	6.0	- 40	.14	.39	24.5	10.0	-	2.22
26	6.0	- 40	.09	.40	24.0	14.0	-	2.25
27	6.0	- 40	.09	.41	24.5	14.5	-	2.28
28	6.0	- 40	.10	.41	24.5	14.0	-	2.34
29	6.0	- 40	.11	.41	23.0	13.5	-	2.19
30	6.0	- 40	.10	.40	24.0	14.0	-	2.37
31	6.0	- 40	.10	.39	24.0	12.5	-	2.20
32	6.0	- 40	.19	.41	25.2	11.6	-	2.26
33	6.0	- 40	.09	.39	24.0	12.0	-	2.30
34	6.0	- 40	.08	.40	25.0	15.0	-	2.22
35	6.0	- 40	.11	.40	25.0	14.5	-	2.26
36	6.0	- 40	.20	.39	25.5	14.5	-	2.10
37	6.0	- 40	.11	.41	25.5	15.0	-	2.12
38	6.0	- 40	.20	.41	25.5	14.5	-	2.17
39	6.0	- 40	.33	.41	24.5	13.5	-	2.19

TABLE 4-2 (cont'd)

SUMMARY OF SURVEILLANCE TEST RESULTS (MANUFACTURER A)

No.	Battery Age (yr.)	Test Temp. (°F)	Rise Time to 7 Volts (sec.)	Time to Reach Max. Volt. (sec.)	Maximum Voltage (volts)	Voltage[a] Immediately After Application of Load (volts)	Time Below 7 V. After Load Applied (sec.)	Service[b] Time (sec.)
40	6.0	- 40	.11	.39	24.0	12.0	-	2.20
41	6.0	- 40	.12	.40	23.5	11.5	-	2.20
42	6.0	- 40	.11	.39	24.5	13.0	-	2.22
43	6.0	- 40	.10	.41	26.0	13.5	-	2.27
44	6.0	- 40	.11	.41	25.0	14.5	-	2.19
45	6.0	- 40	.09	.41	25.5	14.5	-	2.33
46	6.5	- 40	.25	.39	22.0	5.5	.01	1.90
47	6.5	- 40	.21	.39	23.0	5.0	.01	1.95
48	6.5	- 40	.22	.38	23.5	5.5	.01	2.00
49	6.5	- 40	.18	.29	23.5	6.0	.01	1.96
50	6.5	- 40	.18	.39	23.0	5.5	.01	1.90
51	6.5	- 40	.18	.30	24.0	6.5	.01	2.10
52	6.5	- 40	.21	.39	24.0	5.0	.02	2.00
53	6.5	- 40	.22	.38	23.5	5.5	.02	2.14
54	5.5	- 40	.21	.38	22.5	5.0	.02	1.93
55	6.5	- 40	.22	.39	22.5	4.5	.02	2.15
56	6.5	- 40	.24	.31	23.5	4.5	.02	2.20
57	6.5	- 40	.21	.38	23.5	3.5	.02	1.93
58	6.5	- 40	.24	.39	23.0	4.0	.02	1.90
59	6.5	- 40	.19	.39	23.5	4.5	.02	2.10
60	6.5	- 40	.23	.39	23.0	5.0	.02	1.94
61	6.5	- 40	.21	.39	23.0	5.5	.02	1.90
62	6.5	- 40	.24	.38	23.0	5.0	.02	1.92
63	6.5	- 40	.23	.39	22.5	4.0	.02	1.90
64	6.5	- 40	.24	.39	23.0	5.0	.03	1.90
65	6.5	- 40	.21	.38	22.5	3.5	.03	1.91
66	6.5	- 40	.23	.32	22.5	4.0	.03	2.16
67	5.5	- 40	.24	.39	24.0	4.0	.03	2.03
68	6.5	- 40	.24	.39	23.0	3.5	.03	2.17
69	6.5	- 40	.23	.39	21.0	3.0	.03	2.13
70	6.5	- 40	.22	.39	22.0	4.0	.03	2.03
71	6.5	- 40	.24	.39	23.0	4.5	.03	2.10
72	6.5	- 40	.25	.38	23.5	3.5	.03	2.14
73	6.5	- 40	.23	.38	23.0	4.0	.03	1.92
74	6.5	- 40	.21	.39	24.0	4.5	.03	2.10
75	6.5	- 40	.23	.39	22.5	3.0	.04	2.10
76	6.5	- 40	.26	.39	21.5	3.0	.05	1.79
77	6.5	- 40	.25	.39	23.5	2.5	.06	2.05
78	6.5	- 40	.26	.33	21.5	2.0	.06	1.97
79	6.5	- 40	.24	.33	23.0	2.5	.06	1.97

TABLE 4-2 (cont'd)

SUMMARY OF SURVEILLANCE TEST RESULTS (MANUFACTURER A)

No.	Battery Age (yr.)	Test Temp. (°F)	Rise Time to 7 Volts (sec.)	Time to Reach Max. Volt. (sec.)	Maximum Voltage (volts)	Voltage[a] Immediately After Application of Load (volts)	Time Below 7 V. After Load Applied (sec.)	Service Time[b] (sec.)
80	6.5	- 40	.21	.40	23.0	7.0	-	1.95
81	7.5	- 40	.25	.34	25.0	9.5	-	2.10
82	7.5	- 40	.22	.31	25.0	10.0	-	2.10
83	7.5	- 40	.21	.38	24.0	5.0	.04	2.20
84	7.5	- 40	.26	.39	25.0	5.5	.03	2.30
85	7.5	- 40	.23	.39	25.0	4.5	.03	2.30
86	7.5	- 40	.21	.39	22.0	5.0	.03	2.24
87	7.5	- 40	.25	.40	24.0	5.0	.03	2.23
88	7.5	- 40	.20	.39	22.0	5.5	.03	2.34
89	7.5	- 40	.24	.39	24.0	5.0	.02	2.30
90	7.5	- 40	.27	.39	25.0	2.5	.07	2.05
91	7.5	- 40	.25	.40	22.0	2.5	.07	1.67
92	7.5	- 40	.26	.40	25.0	4.0	.05	1.87
93[c]	7.5	- 40	.20	.40	26.0	12.0	-	1.73
94	9.5	- 40	.21	.39	25.5	8.5	-	1.81
95[c]	9.5	- 40	.25	.40	24.5	6.0	.01	1.74
96	9.5	- 40	.27	.40	25.0	4.0	.03	1.84
97	9.5	- 40	.21	.40	25.0	7.0	-	1.91
98[c]	9.5	- 40	.25	.40	25.0	7.5	-	1.89
99	9.5	- 40	.25	.40	24.5	4.0	.04	1.83
100	9.5	- 40	.25	.40	24.5	3.0	.05	1.78
101	9.5	- 40	.22	.41	25.0	7.5	-	1.82
102	9.5	- 40	.24	.40	25.0	6.5	.01	1.85
103	9.5	- 40	.23	.41	24.5	7.0	-	1.79
104	9.5	- 40	.23	.41	24.5	8.0	-	1.80
105	9.5	- 40	.25	.41	25.0	6.5	.01	1.80
106	9.5	- 40	.24	.41	25.0	7.0	-	1.79
107	9.5	- 40	.27	.41	25.0	7.0	-	1.88
108	9.5	- 40	.24	.41	25.0	10.0	-	1.71
109	10.0	- 40	.16	.41	23.6	12.7	-	2.14
110	10.0	- 40	.16	.29	21.7	8.9	-	1.92
111	10.0	- 40	.15	.41	15.1	5.7	.01	1.68
112	10.0	- 40	.14	.39	21.2	11.8	-	1.78
113	3.0	130	.05	.40	26.0	18.7	-	2.08
114	3.0	130	.04	.40	26.0	18.5	-	2.23
115	3.0	130	.03	.22	26.0	18.5	-	2.08
116	4.0	130	.10	.39	26.0	19.0	-	2.14
117	4.0	130	.10	.39	26.0	18.5	-	1.83
118	4.0	130	.09	.39	26.0	17.5	-	2.21
119	4.0	130	.12	.40	26.0	17.5	-	1.58

TABLE 4-2 (cont'd)

SUMMARY OF SURVEILLANCE TEST RESULTS (MANUFACTURER A)

No.	Battery Age (yr.)	Test Temp. (°F)	Rise Time to 7 Volts (sec.)	Time to Reach Max. Volt. (sec.)	Maximum Voltage (volts)	Voltage[a] Immediately After Application of Load (volts)	Time Below 7 V. After Load Applied (sec.)	Service[b] Time (sec.)
120	4.0	130	.10	.39	26.0	17.5	-	1.61
121	4.0	130	.12	.38	26.0	17.5	-	1.17
122	4.0	130	.10	.38	26.0	18.0	-	2.20
123	4.0	130	.11	.39	26.0	16.5	-	2.02
124	5.5	130	.13	.39	26.5	20.0	-	1.14
125	5.5	130	.20	.39	26.0	18.0	-	1.93
126	5.5	130	.12	.39	26.5	19.0	-	1.96
127	6.0	130	.16	.41	26.0	16.0	-	2.27
128	6.0	130	.09	.40	25.5	17.5	-	2.29
129	6.0	130	.11	.40	25.5	17.5	-	1.75
130	6.0	130	.13	.40	25.5	17.0	-	1.12
131	6.0	130	.11	.40	25.0	17.5	-	1.98
132	6.0	130	.08	.40	25.0	17.0	-	2.55
133	6.0	130	.12	.40	25.0	17.0	-	2.01
134	6.0	130	.12	.40	25.0	17.5	-	2.22
135	6.0	130	.08	.40	25.0	17.0	-	2.46
136	6.0	130	.10	.40	25.5	17.0	-	2.54
137	6.0	130	.10	.40	25.0	17.5	-	2.22
138	7.5	130	.18	.37	26.0	12.5	-	2.38
139	7.5	130	.15	.37	25.0	10.5	-	2.46
140	7.5	130	.14	.38	26.0	12.0	-	2.28
141	7.5	130	.15	.37	26.0	18.5	-	1.72
142	7.5	130	.11	.37	27.0	19.5	-	1.65
143	7.5	130	.18	.38	25.5	11.0	-	2.32
144	7.5	130	.12	.39	26.5	17.0	-	1.65
145	7.5	130	.15	.39	26.5	17.0	-	1.76
146	10.0	130	.16	.37	17.9	7.0	-	1.41
147	10.0	130	.12	.41	21.5	10.3	-	1.67
148	10.0	130	.14	.43	18.9	7.5	-	1.32

a. The voltage dropped to the level shown in this column when the 0.7 ohm load was applied. This load was applied 0.40 second after activation of the battery.

b. Time battery producing at least 7.0 volts after application of load.

c. Indicates batteries in which firing pin hung-up in bracket on initial test attempt.

TABLE 4-3.

SUMMARY OF SURVEILLANCE TEST RESULTS (MANUFACTURER B)

No.	Battery Age (yr.)	Test Temp. (°F)	Rise Time to 7 Volts (sec.)	Time to Reach Max. Volt. (sec.)	Maximum Voltage (volts)	Voltage[a] Immediately After Application of Load (volts)	Time Below 7 V. After Load Applied (sec.)	Service[b] Time (sec.)
1	2	- 40	.03	.32	26.1	17.3	-	2.43
2	4	- 40	.08	.30	46.4	26.3	-	1.25
3	4	- 40	.09	.21	30.1	18.9	-	1.23
4	4	- 40	.09	.33	30.8	18.5	-	1.18
5	4	- 40	.09	.29	31.3	21.1	-	1.19
6	4	- 40	.09	.35	31.5	21.2	-	1.46
7	4	- 40	.10	.28	30.4	18.2	-	1.24
8	6	40	.09	.31	31.0	18.0	-	1.31
9	6	- 40	.12	.32	31.0	16.0	-	1.17
10	6	- 40	.12	.29	31.0	17.0	-	1.07
11	6	- 40	.10	.31	31.0	18.5	-	1.24
12	6	- 40	.12	.28	31.0	16.5	-	0.96
13	6	- 40	.11	.28	31.0	18.0	-	1.24
14	6	- 40	.09	.29	32.0	18.5	-	1.40
15	6	- 40	.10	.28	31.0	17.5	-	1.05

a. The voltage dropped to the level shown in this column when the 0.7 ohm load was applied. This load was applied at 0.40 second after activation of the battery.

b. Time battery producing at least 7.0 volts after application of the load.

The Surveillance test indicated that although reductions in voltage output have occurred with this battery as it has aged, this battery was still found to be serviceable after 10 years of storage. The most significant effects that age has had on battery performance have been the increase in the battery rise time to 7 volts and the substantial reduction in voltage that the battery is producing immediately after application of the resistive load.

It was concluded from the results of these tests that the electrical output of the battery after 10 years of storage is still sufficient to properly ignite the spin rockets even under the most severe temperature conditions (-40°F). It has been shown, however, that aging of the battery is reducing its electrical output and thus it is considered extremely important that Surveillance tests be continued in order to carefully monitor this reduction so that the limiting life of these batteries can be determined.

4.2 Thermal Battery B

A surveillance program initiated in early 1965 evaluated the reliability and performance characteristics of thermal battery B after seven years of storage under several environmental conditions. In this program, annual functioning test and analyses of these batteries were conducted.

The functioning test consisted of tests of batteries that were temperature conditioned to -40°F. Prior to testing, the batteries are temperature conditioned for a minimum of 18 hours and tested within 2 minutes after removal from the conditioning chamber. The following observations are obtained for each battery during the test:

(1) Current rise time to 10.0 amperes (seconds)
(2) Time to reach maximum amperes (seconds)
(3) Maximum current (amperes)
(4) Service time (seconds)

The batteries tested were obtained from storage in Alaska, Canal Zone, and Blue Grass representing arctic, tropical and temperate environments, respectively. Approximately fifteen batteries are tested each year. To date, thirty-seven batteries that had been stored in the above storage sites have been tested. These batteries at test time varied in age from 3 to 7 years.

4.2.1 Thermal Battery B Surveillance Tests

In the Surveillance functioning tests all batteries were removed from the battery assemblies and were individually tested. A generator which produces 24 volts DC output was used to activate the electric squib of the battery. A 1.00 $\pm$ .02 ohm resistive load was applied to the battery output terminals before activation. The battery specification required that the battery supply a minimum of 10.0 amperes to the 1.00 $\pm$ .02 ohm load within 1.0 seconds after activation and continue to supply a minimum of 10.0 amperes until 2.0 seconds after activation. In other words, the maximum allowable rise time under load conditions is 1.0 second and the service life minimum requirement is 1.0 second after the current has risen to 1.0 amperes.

4.2.2 Thermal Battery B Test Results

Table 4-4 gives a summary of surveillance test results of Thermal Battery B. Table 4-5 shows a comparison of electrical performance of batteries from different manufacturers and different storage locations.

One failure was recorded for battery No. 9 in Table 4-4. The battery failed to meet the rise time requirement.

This program resulted in 1.5 million battery storage hours with one failure giving a failure rate of 666.0 fits.

The results of the initial three years of the surveillance tests for Thermal Battery B have indicated that the battery is still effective after approximately seven years of dormancy. It should be noted that the battery manufacturers had indicated a shelf life of 5 years for this battery. The serviceability of this battery was based on the fact that of all 37 batteries

TABLE 4-4.

SUMMARY OF SURVEILLANCE TEST RESULTS

No.	Date Tested	Battery Manufacturer	Storage Location	Battery Age (mon.)	Test Temp. (°F)	Current Rise Time to 10 amps (sec.)	Maximum Current (amps)	Time to Reach Max Current (sec.)	Service* Time (sec.)
1	Feb 65		CZ	36	-40	0.80	17.0	-	7.0+
2	"	A	CZ	36	-40	0.71	17.0	-	7.0+
3	"		CZ	36	-40	0.82	18.5	-	7.0+
4	"		CZ	36	-40	0.76	17.0	-	7.0+
5	"		BG	48	-40	1.00	17.5	-	7.0+
6	"	B	BG	48	-40	0.86	18.0	-	7.0+
7	"		BG	48	-40	0.73	18.5	-	7.0+
8	"		BG	48	-40	0.73	18.5	-	7.0+
9	Mar 66	B	BG	72	-40	1.06	17.0	1.71	4.5+
10	"		CZ	72	-40	0.88	18.0	1.69	4.5+
11	"		CZ	48	-40	0.93	19.0	1.41	4.5+
12	"	A	CZ	48	-40	0.77	18.5	1.29	4.5+
13	"		CZ	48	-40	0.76	18.0	1.27	4.5+
14	"		CZ	48	-40	0.72	16.0	1.10	4.5+
15	"	B	CZ	48	-40	0.71	18.0	1.02	4.5+
16	"		CZ	48	-40	0.65	18.0	0.88	4.5+
17	"		CZ	48	-40	0.78	17.5	1.57	4.5+
18	"	A	CZ	48	-40	0.77	17.0	1.52	4.5+
19	"	B	CZ	48	-40	0.67	17.5	1.06	4.5+
20	"	A	CZ	60	-40	0.83	18.0	1.52	4.5+
21	Apr 67		AL	60	-40	0.72	18.5	1.51	2.5+
22	"	A	AL	60	-40	0.79	18.0	1.54	2.5+
23	"		BG	72	-40	0.78	17.5	1.44	2.5+
24	"		BG	72	-40	0.75	18.0	1.42	2.5+
25	"	B	BG	60	-40	0.69	18.0	1.30	2.5+
26	"		BG	60	-40	0.64	17.5	1.38	2.5+
27	"		BG	78	-40	0.89	16.5	2.10	2.5+
28	"		BG	78	-40	0.97	16.5	1.88	2.5+
29	"		AL	54	-40	0.71	18.0	1.37	2.5+
30	"	A	AL	54	-40	0.75	17.5	1.54	2.5+
31	"		AL	54	-40	0.77	17.5	1.49	2.5+
32	"		AL	54	-40	0.76	17.5	1.63	2.5+
33	"		CZ	60	-40	0.77	16.5	1.30	2.5+
34	"		CZ	60	-40	0.76	16.5	1.31	2.5+
35	"		AL	60	-40	0.78	16.5	1.62	2.5+
36	"	B	CZ	60	-40	0.63	16.5	1.05	2.5+
37	"		CZ	60	-40	0.66	17.5	1.09	2.5+

Storage Locations: AL - Alaska
BG - Blue Grass
CZ - Canal Zone

* The service time is the time the battery is producing a current of at least 10 amps. The service time for all batteries tested was in excess of the specification requirement (1.0 sec.). The exact service time for the individual batteries was not available since instrumentation utilized during these tests recorded the service time only during the initial few seconds of the test.

TABLE 4-5.

COMPARISON OF ELECTRICAL PERFORMANCE OF DIFFERENT MANUFACTURERS AND DIFFERENT STORAGE LOCATIONS (conditioning temperature: -40°F)

Manufacturer	B		A	
Storage Location	Blue Grass	Canal Zone	Canal Zone	Alaska
Average Battery Age (months)	62	56	47	57
Average Current Rise Time to 10.0 Amp. (sec.)	0.83	0.70	0.78	0.75
Std. Dev. of Current Rise Time (sec.)	0.1380	0.0921	0.0554	0.0299
Overall Average Current Rise Time (sec.)	0.78		0.77	
Overall Std. Dev. of Current Rise Time (sec.)	0.1246		0.0484	
Average Maximum Current (amperes)	17.6	17.6	17.4	17.6
Std. Dev. of Maximum Current (amperes)	0.7006	0.5845	0.9093	0.6267
Overall Average Maximum Current (amperes)	17.6		17.5	
Overall Std. Dev. of Maximum Current (amperes)	0.6642		0.8260	
Average Rise Time to Max Current (sec.)	1.60	1.13	1.37	1.53
Std. Dev. of Rise Time to Max Current (sec.)	0.2991	0.2832	0.1517	0.0875
Overall Avg. Rise Time to Max Current (sec.)	(a)		1.44[b]	
Overall Std. Dev. of Rise Time to Max Current (sec.)	(a)		0.1494	

NOTE: The service time for all batteries was in excess of the specification requirement (1.0 second). The exact service time of the individual batteries was not obtained. However, the instrumentation utilized during the three tests indicated that the service time was in excess of 2.5 seconds, 4.5 seconds, and 7.0 seconds respectively.

a) A significant age effect on rise time to maximum current was noted. The rise time varied from 0.91 seconds for 4-year-old batteries to 1.82 seconds for 6 1/2-year-old batteries.

b) No age effect on rise time to maximum current was noted with Manufacturer A batteries.

previously tested only one failed to conform to the performance requirements, i.e., the batteries were capable of supplying a minimum of 10 amperes within 1.0 second after activation and continued to supply a minimum of 10 amperes until 2.0 seconds after being activated. The battery which did not meet the performance requirements had a rise time to 10 amps .06 seconds above performance limits. This battery, however, functioned properly in all other respects and thus the slightly longer rise time was considered to be of no consequence.

The statistical analysis of the data compiled during the surveillance tests indicated that neither age nor manufacturer-storage location had a significant effect on the maximum current or the current rise time to 10 amps of these batteries. The average current rise time to 10 amps for batteries that varied in age from 3 to approximately 7 years was .77 seconds and the average maximum current produced was 17.5 amps. The analysis of the time to maximum current, however, indicated the following: (1) a significant difference between battery manufacturers occurred and (2) an aging effect with manufacturer A batteries was noted. The significant difference between the battery manufacturers was reflected in the comparison of the results obtained with 4 1/2-year-old batteries in which manufacturer A batteries required 1.1 seconds to reach maximum current (17.6 amps) while manufacturer B batteries required 1.4 seconds to reach maximum current (17.5 amps). The aging effect occurring with manufacturer A batteries indicated that the time to reach maximum current varied from 0.9 seconds for 4-year-old batteries to 1.8 seconds for 6 1/2-year-old batteries. It is noted that although the time to reach maximum current was significantly affected by age in the case of the manufacturer A batteries, no significant age effect occurred in the current rise time to 10 amps, the more important time parameter. The significant time to maximum current which is a more comprehensive measure of the battery time during its activation phase has thus given some indication that aging may be beginning to have some effect on the electrical output of these batteries. Although no statistical analysis of the battery service times was carried out, it was observed that all batteries produced current in excess of 10 amps for at least 2.5 seconds.

SECTION 5

SILVER-ZINC BATTERY ANALYSIS

Data was collected pertinent to the effect of long-term storage on battery reliability for silver-zinc primary batteries of four manufacturers and three missile programs. This data is analyzed by the three data sources A, B and C. Data type A was collected prior to 1963 and data types B & C were collected in March 1975. Total battery storage hours, failures and resulting failure rates are summarized in Table 5-1. Details on the data analysis are given in the following section.

TABLE 5-1. * SILVER-ZINC BATTERY NON-OPERATING DATA

BATTERY	NO. OF UNITS	STORAGE HRS. (10^6)	NO. OF FAILURES	FAILURE RATE IN FITS	90% ONE-SIDED LIMIT
B	483	13.8	0	72.5	167.4
C	510	9.8	0	102.0	235.6
TOTALS		23.6	0	23.6	97.9

* Data Type A is given in the following analysis but is not included in this table. Type A data is considered obsolete since it was collected prior to 1963.

5.1 Silver-Zinc Battery (Source A)

Data collected for silver-zinc batteries of source A was prior to 1963. In all cases, these batteries were produced for military applications and meet military specifications. Data from source A is shown in Table 5-2, Data Sample No. 1 through 24. This data resulted in 61 failures during 7.97 million storage hours and resulted in a failure rate of 627.0 fits. However, this data is not considered representative of current battery technology and is not used in the summary and recommendations.

Source	Data Sample No.	Name of Part	No. of Parts Tested	Storage Time	Storage Environment	No. of Failures	Type of Failure	Remarks
A	1	Silver-zinc primary battery (squib-activated)	1	54 months	Ambient	None	(Not applicable)	Positive plates were found to contain 81.88% divalent silver oxide on autopsy.
A	2	Silver-zinc primary battery (squib-activated)	1	37 months	Ambient	None	(Not applicable)	Positive plates were found to contain 78.74% divalent silver oxide on autopsy.
A	3	Silver-zinc primary battery (squib-activated)	1	33 months	Ambient	None	(Not applicable)	Positive plates were found to contain 91.73% divalent silver oxide on autopsy.
A	4	Silver-zinc primary battery (squib-activated)	1	27 months	Ambient	None	(Not applicable)	Positive plates were found to contain 95% divalent silver oxide on autopsy. 95% AgO is initial percent.
A	5	Silver-zinc primary battery (squib-activated)	15	6 months	6 @ ambient; 9 @ 130° F	3	2 failed discharge duration spec.; 1 failed rise time spec.	
A	6	Silver-zinc primary battery (squib-activated)	14	12 months	5 @ ambient; 9 @ 130° F	1	Failed discharge duration spec.	
A	7	Silver-zinc primary battery (squib-activated)	8	18 months	3 @ ambient; 5 @ 130° F	1	Failed discharge duration spec.	
A	3	Silver-zinc primary battery (squib-activated)	5	24 months	2 @ room temp.; 3 @ 130° F	None	(Not applicable)	
A	9	Silver-zinc primary battery (squib-activated)	108	3-4 years	Missile field conditions	54	Failed discharge duration spec.; failed rise time spec.	No failures occurred for storage periods less than 39 months.
A	10	Silver-zinc primary battery (squib-activated)	178	30-36 months	Missile field conditions	2	Excess rise time	
A	11	Silver-zinc primary battery (squib-activated)	20	2-68 weeks	185° F	None	(Not applicable)	Positive plates contain 60% of original divalent silver oxide after 1-2 weeks.

TABLE 5-2. PRIMARY BATTERY STORAGE DATA SUMMARY

Source	Data Sample No.	Name of Part	No. of Parts Tested	Storage Time	Storage Environment	No. of Failures	Type of Failure	Remarks
A	12	Silver-zinc primary battery (squib-activated)	24	2-68 weeks	140° F	None	(Not applicable)	Positive plates contain 60% of original divalent silver oxide after 8-10 weeks.
A	13	Silver-zinc primary battery (squib-activated)	16	16-64 weeks	125° F, but 4 hours per day at 165° F	None	(Not applicable)	Positive plates contain 60% of original divalent silver oxide after 8-10 weeks.
A	14	Silver-zinc primary battery (squib-activated)	20	4-72 weeks	80° F	None	(Not applicable)	No noticeable change in capacity was noted at 72 weeks.
A	15	Silver-zinc primary battery (squib-activated)	8	32-64 weeks	-40° F and +20° F	None	(Not applicable)	Discharge lives varied from 14.25 to 17.18 minutes for an initial value of ~20 minutes.
A	16	Silver-zinc primary battery (squib-activated)	85	26-31 months	Ambient	None	(Not applicable)	
A	17	Silver-zinc primary battery (squib-activated)	5	1-4 years	50° F to 110° F	None	(Not applicable)	
A	18	Silver-zinc primary battery (squib-activated)	3	6-12 months	50° F to 120° F	None	(Not applicable)	
A	19	Silver-zinc primary battery (squib-activated)	3	46 months	-65° F	None	(Not applicable)	
A	20	Silver-zinc primary battery (squib-activated)	3	46 months	160° F	None	(Not applicable)	
A	21	Silver-zinc primary battery (squib-activated)	2	46 months	75° F	None	(Not applicable)	
A	22	Silver-zinc primary battery (squib-activated)	1	18 months	Ambient	None	(Not applicable)	

TABLE 5-2. (cont'd)- PRIMARY BATTERY STORAGE DATA SUMMARY

Source	Data Sample No.	Name of Part	No. of Parts Tested	Storage Time	Storage Environment	No. of Failures	Type of Failure	Remarks
A	23	Silver-zinc primary battery (squib-activated)	2	10 months	Ambient	None	(Not applicable)	
B	24	Silver-zinc primary battery (squib-activated)	22	6 months	Ambient	None	(Not applicable)	
B	25	A (Silver zinc)	45	11.5 yrs. 13.24 " 14.14 " (1575.14 total yrs)	Pure Shelf Life	None		Shelf Life - No heater power had been applied except for thermostat check-out $\lambda \leq 72.47$
B	26	B (Silver zinc)	47	7-10 yrs. 9.76 million hrs.	Service Life	None	-	$\lambda^{-9} < 102$
C	27	C (Silver zinc)	1	15.3 yrs. 7 yr. service	Service Life	None	-	-

TABLE 5-2. (cont'd) PRIMARY BATTERY STORAGE DATA SUMMARY

5.1.1 DATA SAMPLE NO. 1: BATTERY SHELF-LIFE TEST

An "autopsy" was performed on a silver zinc, squib-activated primary battery after 54 months of storage in the environment of the manufacturer's plant. The positive plates were found to contain 81.88 percent divalent silver oxide. A detailed visual examination of the plastic parts, separator materials, negative plates, and potting revealed no degradation due to the 54 months of storage. The gas generator was successfully fired after removal. The O-rings which were in contact with the 32-percent solution of potassium hydroxide electrolyte were tested with the following results.

	O-Rings From KOH	Equivalent New O-Rings
Tensile Strength	1400 psi	1033 psi
Elongation	170%	190%

A visual examination revealed no signs of attack on the rubber by the potassium hydroxide solution. Some compression set was noted in the O-rings.

5.1.2 DATA SAMPLE NO. 2: BATTERY SHELF-LIFE TEST

An "autopsy" was performed on a silver zinc, squib-activated primary battery after 37 months of storage. The battery was stored for the first 11 months in the environment of the manufacturer's plant, followed by 26 months of unsheltered storage on the roof of the plant where the temperature varied from -25°F to 160°F. The battery was protected only by its stainless steel canister. No visible degradation of canister potting, plastic parts, cells, or activator was noted. The positive plates were analyzed and found to contain 78.74 percent divalent silver oxide. The O-rings were sent to the manufacturer for analysis with the following results.

	New O-Rings	Test O-Rings	Percent Gain or Loss	Specification MIL-P-5315A Requirement
Tensile Strength	970 psi	1260 psi	+29%	784-1064 psi
Modulus	470 psi	528 psi	+12%	
Elongation	240%	197%	-18%	190-240%

The gas generator was disassembled by its manufacturer without finding evidence of anything that would prevent it from functioning normally. A slight discoloration of the gas generator propellant was noted.

5.1.3 DATA SAMPLE NO. 3: BATTERY SHELF-LIFE TEST

An "autopsy" was performed on a silver zinc, squib-activated primary battery after 33 months of storage. The battery was stored for the first 7 months in the environment of the manufacturer's plant, followed by 26 months of unsheltered storage on the roof of the plant where the temperature varied from -25°F to 160°F. The battery was protected only by its stainless steel canister. No visible degradation of canister potting or plastic parts was noted. The positive plates were analyzed and found to contain 91.73 percent divalent silver oxide. The MS29513 O-rings were sent to the manufacturer for analysis with the following results.

1. Hardness change, +3 degrees (Shore A scale)
2. No change in tensile strength
3. Elongation change, -30 percent
4. Specific gravity results were satisfactory

The gas generator was disassembled by its manufacturer without finding evidence of anything that would prevent it from functioning normally. A calorimeter test performed on the propellant showed a slight decrease in heat of explosion (approximately 5 percent).

5.1.4 DATA SAMPLE NO. 4: BATTERY SHELF-LIFE TEST

An "autopsy" was performed on a silver zinc, squib, activated primary battery after 27 months of storage in the environment of a warehouse where the temperature varied between 40°F and 110°F, with a relative humidity of up to 98 percent. No signs of corrosion were noted on the outside of the activator. All elastomeric O-ring seals were still good, as was the Teflon diaphragm which was noted to be similar to its original size, shape, and flexibility. An adequate coating of lubricant remained on all O-rings. The O-rings met the requirements of Specification MIL-P-5315A. The potassium hydroxide electrolyte was removed and subjected to a chemical analysis. It was found to be within present specifications for concentration, carbonate pickup, and trace elements. The positive plates were found to contain 95 percent silver peroxide, compared to a normal of 93 to 97 percent at the time of manufacture. The negative plates were found to contain 95 percent pure metallic zinc compared to a normal of 90 to 98 percent at the time of manufacture. The pure silver foil connectors showed no visible corrosion, and no corrosion was evident in any soldered electrical connectors. Moisture content in the active material was undetectable. The above analysis would indicate a capacity loss of 1.5 percent as a maximum and no change in activation time, wet stand capability, or voltage levels as a result of the 27-month storage period.

5.1.5 DATA SAMPLES NO. 5, 6, 7, and 8: BATTERY SHELF-LIFE TEST

Data Samples No. 5, 6, 7, and 8 resulted from tests performed by a manufacturer as part of a battery storage program for a particular battery series. The failure rate is generally higher than for similar batteries removed and tested after 3 to 4 years in a field missile, as in Data Samples No. 9 and 10. One reason for this is the more severe temperature test and storage conditions at the manufacturer's plant. Another explanation for the poorer performance is that an extra plate was added in the same battery case which increased the proximity of the silver oxide and separator materials, thus accelerating separator burning. The storage temperatures were ambient and 130°F. The test temperatures were -40, -30, +40, +80, +130, and +150°F. In general, the failure criterion was failure to meet the battery specifications except that it was under the minimum voltage during the first 22 seconds of discharge.

5.1.6 DATA SAMPLE NO. 9: MISSILE BATTERY DORMANCY TEST PROGRAM

This data sample resulted from tests by the manufacturer to investigate the field storage capability of a given battery series. The batteries were removed from missiles which had been in the field from 3 to 4 years. One hundred-eight of these units were tested over a period of a year (15 per month) through the various environments of vibration, shock, thermal shock, and activated stand. Seventy-two of these batteries were tested after a 2-hour activated stand period. Because of a bad heater design, the batteries could not meet the specifications after the 2-hour activated stand period. These 72 batteries were therefore removed from the test sample, leaving a net quantity of 108 batteries. As a result of these tests, a "split heater" was designed which would maintain the activation system of the battery at its optimum operational temperatures without exposing the cell block to moderately high temperature. The battery has the following specifications:

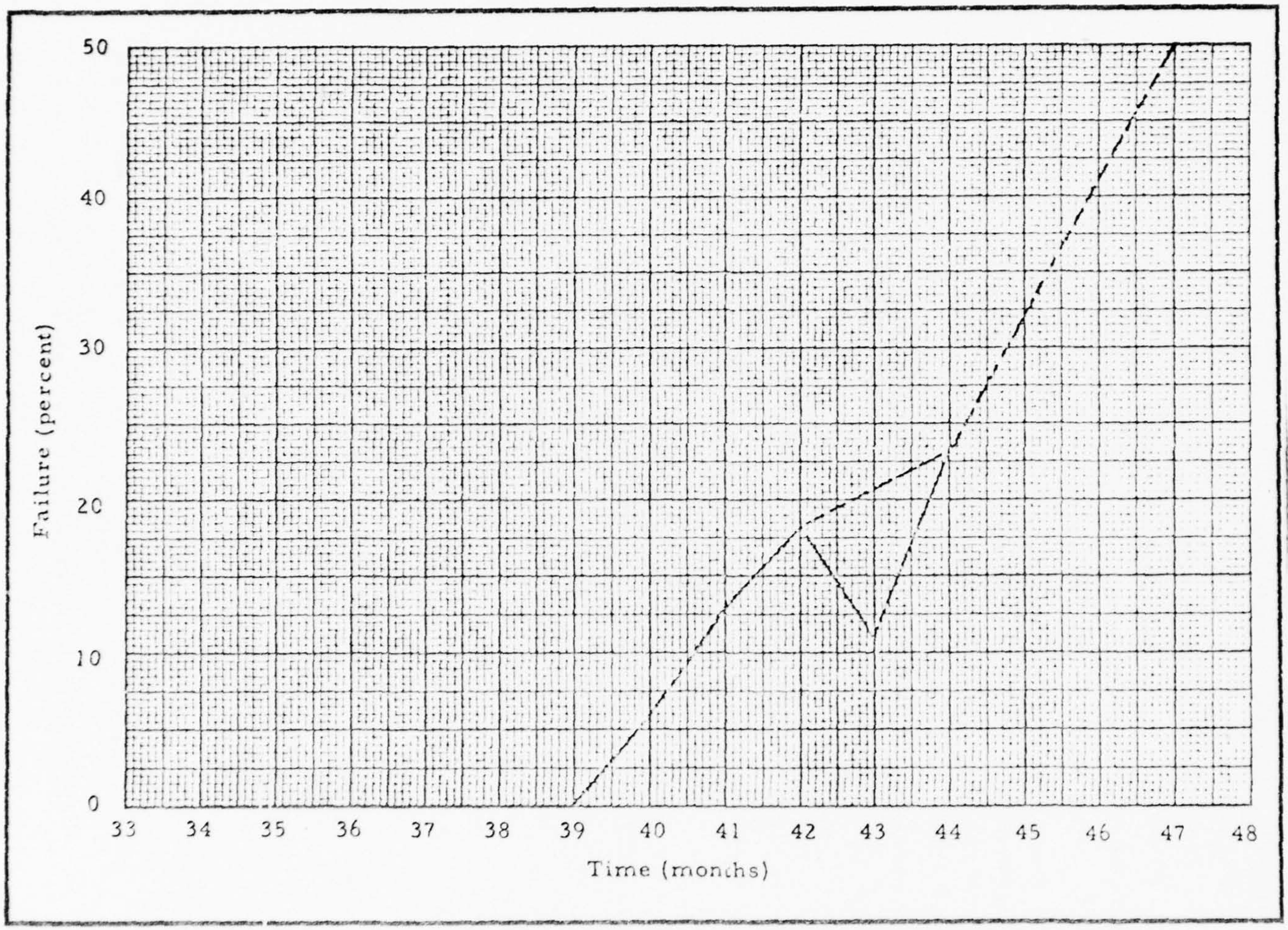
Rise time: <0.50 second
Active life: >90 seconds
Voltage: 13.2 to 14.6 volts

Figure 5-1 illustrates the storage capability. The graph is based on the above sample of 108 batteries. No failures occur until 39 to 40 months, at which time failures begin to occur. It can be stated, then, that the field storage life of this battery is 39 to 40 months.

5.1.7 DATA SAMPLE NO. 10: MISSILE BATTERY DORMANCY TEST PROGRAM

Data Sample No. 10 resulted from tests by the manufacturer to investigate the field storage capability of a given battery series. The batteries were removed from missiles which had been in the field from 30 to 36 months. The battery has the following specifications:

Rise time: <0.50 second
Active life: >90 seconds
Voltage: 13.2 to 14.6 volts



- PERCENT OF FAILURE VERSUS STORAGE TIME

FIGURE 5-1.

Valid tests through the environments of vibration, shock, and thermal shock were performed on 178 batteries. One hundred seventy-four of the batteries met specifications. Two batteries had rise times in excess of 0.75 second (0.76 and 0.81 second) at a -50°F test temperature and were considered failures. This judgment is considered severe in view of the low test temperature. One battery tested at -50°F had a rise time of 0.58 second. Another battery tested at -50°F had an active life of 81 seconds. These latter two batteries were not considered failures because they performed only slightly out of specifications at -50°F, an extremely low temperature for a silver zinc battery with respect to performance. No batteries tested at room temperature (130°F or 150°F) failed to meet specifications.

5.1.8 DATA SAMPLES NO. 11, 12, 13, 14, & 15: BATTERY SHELF-LIFE TEST

Data Samples No. 11, 12, 13, 14 and 15 result from a contract the manufacturer had with the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey, to test 28-volt batteries in order to obtain an indication of the shelf life of this battery series. The storage program was originally designed with the intention of storing batteries at severely high temperatures so that their operational failures would occur in reasonably short lengths of time. Battery malfunction was reached in only one case, that of 185°F after 8 to 12 weeks. It was found that the gas generator and not the battery was the cause of the failure to produce power. Stated results by the manufacturer of this test program are as follows:

1. The battery possesses reliability of performance after at least 72 weeks of storage at room temperature.
2. The battery will perform reliably after at least 68 weeks at 140°F.
3. The battery will deliver its required capacity after at least 64 weeks at a continuous ambient temperature of 120°F plus 4 hours per day soak at 165°F.
4. Performance is assured up to 8 weeks at 185°F.

The battery cells will lose about 40 percent of their original capacity after 1 to 2 weeks at 180°F, or 8 to 10 weeks at 140°F. This is caused by the thermal decomposition from divalent silver oxide (Ag_2O_2) to silver monoxide (Ag_2O) in the positive plates. After these periods of time, however, this decomposition ceases almost completely, or levels off to a very gradual decrease in battery capacity because silver monoxide is thermally stable up to 300°F.

5.1.9 DATA SAMPLE NO. 16: BATTERY SHELF-LIFE TEST

Data Sample No. 16 represents the results of tests performed on 85 silver zinc primary batteries. Activation was initiated by squibs and carried out by compressed air. In 12 units, a leak in the air pressure indicator developed which reduced the air pressure below the level required for activation. The associated batteries were found to be in operable condition. The storage period was 26 to 31 months at ambient conditions.

5.1.10 DATA SAMPLE NO. 17: BATTERY SHELF-LIFE TEST

Data Sample No. 17 represents the results of tests performed on five batteries of a given battery series. The battery specifications are as follows:

Electrical Characteristics	
Nominal Capacity	20 ampere-hours
Open circuit voltage	33.5 volts
Nominal operating voltage	24-27 volts
Activation method	Mechanical
Shelf life (dry)	3 years
Stand after activation	1 hour
Typical Application	
Activation speed	2-5 seconds
Power output	3,400 watts
Discharge rate	135 amps
Discharge time	12 minutes (average)
Discharge voltage	25 volts (average)
Watt-hours per pound	34.4 w-hr/lb
Watt-hours per cubic inch	1.68 w-hr/in.^{3}

No battery failures occurred. The storage period was 1 to 4 years and the storage temperature 50°F to 110°F.

5.1.11 DATA SAMPLE NO. 18: BATTERY SHELF-LIFE TEST

Data Sample No. 18 represents the results of tests performed on three silver zinc primary batteries of a given series. The storage period was 6 months to 1 year, and the storage temperature was 50°F to 120°F. No battery failures occurred.

5.1.12 DATA SAMPLES NO. 19, 20, and 21: BATTERY SHELF-LIFE TEST

Data Samples No. 19, 20 and 21 represent data from tests run on a fuse power pack containing a silver zinc, squib-activated primary battery. The battery is rated at approximately 300 ampere-minutes. It has 7-, 21-, and 28-volt sections. There were eight units, none of which failed. The storage period was 46 months. Three units were stored at -65°F, three units were stored at +160°F, and two units were stored at +75°F.

5.1.13 DATA SAMPLES NO. 22, 23, and 24: BATTERY SHELF-LIFE TEST

Data Samples No. 22, 23, and 24 represent data from tests run on silver zinc, squib-activated primary battery power supply for fuses. The 28-volt cell pack (with a 7-volt tap) can deliver up to 60 amperes with less than a 4-volt drop between -65° and +165°F, and has a nominal capacity of 250 ampere-minutes. Compressed gas is the propelling medium for injection of the electrolyte. Over 200 units were tested. A few of the units tested had been on the shelf for some time. One was 18 months old, two were 10 months old, and 22 were 6 months old. All performed normally.

5.1.14 DATA SAMPLES NO. 25, 26 and 27:

This data was a result of surveillance tests completed March 1975. Tests were conducted on Silver-Zinc Shelf and Service Life Batteries.

The report was a third of a series intended to reliably establish true shelf and service life criteria for batteries in the particular missile system. See report (Reference 6) Silver Zinc Battery Shelf & Service Life Report.

The latest series of surveillance tests was completed in March 1975. This test included 45 pure shelf life batteries of ages 11.5, 13.24 and 14.14 years and 67 batteries of known service life between 7 to 10 years. One battery with greater than 7 years service life was also tested at a total age of 15.3 years. All batteries met the activation performance requirements.

5.2 Silver-Zinc Battery Analysis (Source B)

Data from source B, data points 25, 26 and 27, Table 5-2, is from observation data of the silver-zinc battery shelf and service life analysis. The purpose of this analysis is to establish the minimum shelf life and minimum service life for silver-zinc batteries.

The analysis of the silver-zinc battery performance parameter requirements during activation into a 2.2 ± 0.1 ohm resistive load:

a) 23.0 volts minimum at 1.2 seconds

b) operating time of 6.0 minutes minimum to a terminal voltage of 25.0 volts

c) 30.5 volts maximum

This series of surveillance tests were completed in March 1975. From Table 5-2, data point 25, forty five pure shelf life batteries of ages 11.5, 13.24 and 14.14 years and 67 batteries of known service life between 7 to 10 years. One battery, data point no. 27, with greater than 7 years service life was also tested at a total age of 15.3 years. All batteries met the activation performance requirements specified above.

5.2.1 Shelf Life Batteries

A shelf life battery is one to which no heater power has been applied except for thermostat checkout and one which has undergone storage at ambient temperature.

To summarize the analysis, shelf life batteries, for 99% probability with 99% confidence, will meet their activation requirements up to the following specified ages:

1. 23.0 volts at 1.0 seconds - 23 years.
2. 25.0 volts minimum for 60 minutes - 26 years.

This correlates to a failure rate of 72.47 failures/10^{-9} storage hours. Maximum voltage appears independent of shelf life, service life or battery age.

5.2.2 Silver Zinc Battery Service Life

Based upon the data, it can be stated that the service life of the battery can be established at 14 years. This is a minimum service life for silver-zinc batteries, wherein it can be stated with 95% confidence that an average of at least 99% of the batteries will meet their specified activation performance requirements or 102.0 failures/10^{-9} storage hours.

5.3 Analysis

5.3.1 Shelf Life Batteries

A shelf life battery is one to which no heater power has been applied except for thermostat checkout and one which has undergone storage at ambient temperature.

The mean activation voltage $\bar{Y}$, at 1.0 seconds for shelf life is given in Table 5-3 by contract and battery age. Also included in the table are the standard deviation(s), sample size (N), and the one-sided 99% confidence limits (C.L.). The 99% C.L. states with 99% confidence that the true battery population mean for the activation voltage is greater than the tabulated value shown. These values were calculated using the following equation:

$$99\% \text{ C.L.} = \bar{Y} - 2.33 \text{ S}/\ \text{N}$$

Similarly, Table 5-4 presents shelf life data for the battery life in minutes (after activation) to the specified terminal voltage of 25.0 volts.

The mean regression line calculated for the time dependent data for the shelf life activation voltage at 1.0 seconds is Y = 28.7439 - .0978X, and likewise for the respective one-sided 99% CL points, Y + 28.5354 - 0.1061X. These equations are based on the data extending up to 13.24 years. The lower one-sided confidence bands around the mean regression line describing the lower one-sided 99% confidence level points. The confidence bands around the 99% CL points can be interpreted as follows: At any given age, we have a 100 (1 - α)% confident that at an average, at least 99% of the batteries will exhibit an activation voltage, at 1.0 seconds, greater

TABLE 5-3

SHELF LIFE BATTERIES

VOLTAGE AT 1.0 SECONDS

MANUFACTURER/ DATE	$\bar{Y}$	S	N	99%C.L.	BATTERY AGE(YRS)
2399(8/68)	28.090	0.664	38	27.8390	0.01
30087(8/66)	28.760	0.557	62	28.5952	0.01
29960(4/66)	29.209	0.525	46	29.0286	0.01
19813(8/65)	29.323	0.502	48	29.1542	0.01
2399	27.335	0.700	20	26.9703	2.0
30087	28.615	0.616	60	28.4297	2.0
29960	29.363	0.580	46	29.1637	2.0
19813	28.651	0.672	45	28.4176	2.0
29263(6/64)	27.878	0.704	26	27.5360	9.0
29150(4/64)	27.293	0.456	24	27.0761	9.0
29128(11/68)	27.378	0.583	22	27.0884	9.0
20522(7/63)	28.520	0.510	15	28.2132	11.5
07340(5/61)	27.410	0.510	15	27.1032	13.24
07002(9/60)*	28.590	0.390	15	28.3554	14.14

* Not employed in regression analysis

TABLE 5-4.

SHELF LIFE, BATTERIES

BATTERY LIFE (MINUTES) TO 25.0 VOLTS TERMINAL

MANUFAC-TURER	$\overline{Y}$	S	N	99% CL	BATTERY AGE (YRS)
2399	21.99	2.34	38	21.1055	0.01
30087	18.72	1.55	62	18.2613	0.01
29960	17.68	1.55	46	17.1475	0.01
19813	19.81	1.94	48	19.1576	0.01
2399	18.57	0.96	21	18.0819	2.0
30087	16.72	1.55	60	16.2538	2.0
29960	15.67	1.31	46	15.2200	2.0
19813	18.58	1.73	45	17.9791	2.0
29263	13.91	1.51	22	13.1599	9.0
29150	15.30	1.69	19	14.3966	9.0
29128	18.86	1.61	22	18.0602	9.0
20522	17.48	2.68	15	15.8677	11.5
* 07340	18.12	1.50	15	17.2176	13.24
* 07002	20.77	1.68	15	19.7593	14.14

*Not employed in regression analysis (see Table 5-5).

than that shown by the confidence band. We can thus predict, with a specified confidence at what age will less than 99% of the shelf life batteries fail to meet the specified minimum activation voltage of 23.0 volts at 1.0 seconds after activation. For 95% confidence, the 23.0 voltage activation requirement at 1.0 seconds will be met at a predicted battery age of 28 years.

For these shelf life batteries, the equations describing battery life to a terminal voltage of 25.0 volts are of the exponential form $Y = ae^{bx}$ since they provided greater correlation for the data than did the linear regression form. The equations describing shelf life batteries minutes to a terminal voltage of 25.0 volts with respect to battery age, for the mean data and the 99% CL points are:

$$Y - 18.63\ e^{-0.0145X} \qquad \text{and } Y = 18.19\ e^{-0.0185X}$$

respectively. The age at which an average of at least 99% of the shelf life batteries, with 99% confidence, will exhibit 25.0 volts or greater after 6.0 minutes is approximately 26 years.

5.3.2 Service Life Batteries

The mean activation voltage at 1.0 seconds for service life batteries is given in Table 5-5 and the battery activation life to a terminal voltage of 25.0 volts is given in Table 5-6. To determine pure shelf life degradation with respect to time, the mean observed values ($\bar{Y}$'s), for each contract and age, are those after extrapolation back into time by the number of years that the batteries have seen shelf life. Since the mean shelf life regression line for the activation voltage was calculated to be $Y = 28.7439 - 0.0978X$, the slope is -0.0978 and therefore the service life mean activation voltage is increased by 0.0978 times the number of years of shelf life. Table 5-5 represents the extrapolated data where the actual battery service life differs from its test age. The maximum increase for any one contract is relatively small; 0.31 volts for manufacturer 17480 (Table 5-5). Similar extrapolation was performed on the mean activation life (Table 5-6) to 25.0 volts using the mean exponential shelf life degradation equation.

TABLE 5-5.

SERVICE LIFE BATTERIES
VOLTAGE AT 1.0 SECONDS

MANUFACTURER/ DATE	$\bar{Y}$	S	N	99% CL	SERVICE LIFE(YRS)	TEST AGE
2399(8/68)	28.090	0.664	38	27.8390	0.01	0.01
30087(8/66)	28.760	0.557	62	28.5952	0.01	0.01
29960(4/66)	29.209	0.525	46	29.0286	0.01	0.01
19813(8/65)	29.323	0.502	48	29.1542	0.01	0.01
2399	28.6482	0.5852	56	28.4660	2.0	2.0
30087	28.1792	0.8106	60	27.9354	2.0	2.0
29960	29.2674	0.6075	46	29.0587	2.0	2.0
19813	28.60	0.58	40	28.3863	2.0	2.0
17480(7/62)	27.7328	0.7065	30	27.4322	4.0	6.17
20416(1/63)	27.2947	0.2240	9	27.1207	6.0	7.33
30087	27.1503	0.8025	15	26.6672	7.0	8.25
** 29960	29.0643	0.0707	2		8.17	8.84
* 19813	29.2815	0.7240	23	28.9298	8.25	9.40
29150(4/64)	27.9804	0.9195	3	26.7434	8.3	10.63
* 29263(6/64)	29.0161	0.8693	18	28.5787	8.5	10.33
* 29263	28.8775	0.7569	4	28.0958	9.13	10.17
** 29263	28.21		1		10.17	10.25
** 06403	26.91		1		> 7.0	15.3

* Not employed in regression analysis (See Table 5-8).
** Not employed in regression analysis due to sample size.

TABLE 5-6.

SERVICE LIFE BATTERIES

BATTERY LIFE(MINUTES) TO 25.0 VOLTS TERMINAL

MANUFACTURER/ DATE	$\bar{Y}$	S	N	99% CL	SERVICE LIFE(YRS)	TEST AGE (YRS)
2399	21.99	2.34	38	21.1055	0.01	0.01
30087	18.72	1.55	62	18.2613	0.01	0.01
29960	17.68	1.55	46	17.1475	0.01	0.01
19813	19.81	1.94	48	19.1576	0.01	0.01
2399	16.41	0.78	22	16.0225	2.0	2.0
30087	14.50	1.20	60	14.1390	2.0	2.0
29960	14.16	1.23	46	13.7374	2.0	2.0
19813	15.74	1.12	48	15.3633	2.0	2.0
17480	16.17	0.80	30	15.8323	4.0	6.17
20416	16.22	1.85	9	14.7824	6.0	7.33
30087	13.35	1.07	15	12.7041	7.0	8.25
29960	12.04	0.87	2		8.17	8.84
19813	13.43	1.00	23	12.9430	8.25	9.40
29150	15.60	0.47	3	14.9662	8.3	10.63
29263	14.10	0.84	18	13.6412	8.5	10.33
29263	12.78	0.50	4	12.1990	9.13	10.17
29263	14.45		1		10.17	10.25
06403	14.75		1		>7.0	15.3

TABLE 5-7.

SERVICE LIFE BATTERIES

MAXIMUM VOLTAGE

MANUFAC-TURER	$\bar{X}$	S	N	99%	95%x99%	SERVICE LIFE	TEST AGE
30087	29.01	0.21	15	29.14	29.82	7.0	8.25
17480	29.23	0.17	29	29.30	29.81	4.0	6.17
19812	29.38	0.30	23	29.53	30.43	8.25	9.40
29263	29.39	0.23	22	29.50	30.20	8.5	10.33
29128	28.55	0.24	22	28.67	29.40	0.0	9.0
29150	29.04	0.30	24	29.18	30.08	0.0	9.0
29263	29.09	0.29	23	29.23	30.11	0.0	9.0
20522	29.10	0.18	15	29.21	29.80	0.0	11.5
07340	29.26	0.24	15	29.40	30.19	0.0	13.24
07002	29.15	0.12	15	29.22	29.61	0.0	14.14
06403	29.01	1				>7.0	15.3

The mean regression line is Y = 28.8810 - 0.1904X, the regression line for the 99% CL points is Y - 28.6990 - 0.2523X, and the one-side 95% confidence band about the 99% CL regression line crosses the critical parameter of 23.0 volts at approximately 14.5 years. This indicates that with 95% confidence, an average of at least 99% of the batteries will exhibit 23.0 volts or greater at 1.0 seconds after activation up to a total battery service life of 14.5 years.

The regression of the data is also exponential based on greater correlation than linear regression. The regression equation describing the 99% CL points is $Y = 17.5602\ e^{-0.0352X}$ and the critical parameter (6 minutes) crossover point for 95% confidence is at a battery service life age of approximately 20.5 years.

5.3.3 Maximum Voltage

All presently available data for shelf and service life maximum voltage after activation is presented in Table 5-7. Due to the small number of observations for both shelf and service life and on the narrow time frame for these observations, separate meaningful regressions cannot be performed. The Bell-Doksum Test** was therefore used to determine if the maximum voltages, regardless of battery age, for the shelf and service life batteries represented two independent samples (**reference: Conover, Practical Nonparametric Statistics). From the tests, the hypothesis, that the two populations have identical means is accepted; inferring that maximum voltage is independent of battery shelf or service life conditions. Furthermore, applying the Spearman rank correlation test to all the mean observations ($\bar{X}$'s) for both shelf and service batteries, the hypothesis was accepted that there is no correlation between the maximum voltage and battery age. Thus, we can assume that maximum voltage of the batteries is a function only of the contract under which they were manufactured and not dependent of shelf life, service life or battery age.

For the maximum voltages, Table 5-7 also gives the one-sided 99% confidence limits and the one-sided 95% by 99% tolerance limits. The 95% by 99% tolerance limits indicate that the probability is 95% that at least 99% of the batteries will have a maximum voltage less than the values shown.

5.3.4 Summary

a. Shelf life batteries, for 99% probability with 99% confidence, will meet their activation requirements up to the following specified ages:

(1) 23.0 volts at 1.0 seconds - 23 years

(2) 25.0 volts minimum for 6.0 minutes - 26 years

b. Service life batteries, for 99% probability with 95% confidence will meet their activation requirements up to the following specified ages:

(1) 23.0 volts at 1.0 seconds - 14.5 years

(2) 25.0 volts minimum for 6.0 minutes - 20.5 years

c. Maximum voltage appears independent of shelf life, service life or battery age.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

6.0 Conclusions

6.1 Silver-Zinc Batteries

The critical limiting shelf and service life parameter for the silver zinc battery life is the 23.0 volts minimum at 1.0 seconds. The total shelf life of the silver zinc batteries can be established at 21.0 years since at this age there still remains one year of service life.

Total service life of the silver zinc battery can be established at 14.0 years.

Failure rates of <72.47 fits and <102.0 fits have been established for shelf-life and service life batteries respectively.

6.2 Thermal Batteries

6.2.1 Type A Thermal Battery

The surveillance tests of the Type A battery have indicated that although reductions in voltage output have occurred with this battery as it has aged, this battery was still found to be serviceable after 10 years of storage. The most significant effects that age has had on battery performance have been the increase in the battery rise time to 7 volts and the substantial reduction in voltage that the battery is producing immediately after application of the resistive load.

The tests of these batteries revealed that batteries that have bar connected brackets have a reduced space between the brackets and on occasion (approximately 6% of the time) this reduced space results in the firing pin hanging-up in the brackets. By hanging-up in the brackets, the firing pin is prevented from striking the primer and as a result the battery fails to function. The reduced space between the bar connected brackets, however, can easily be corrected by simply spreading the brackets. This spreading was carried out with the batteries that hung-up in the initial firing attempt and all batteries functioned normally when retested.

In addition to the battery results indicated above, these tests showed that the hot products of combustion passing through the pedestal manifold assembly that is produced by six battery initiated spin rockets will properly ignite the other two spin rockets contained in the pedestal when these two spin rockets have igniter failures (completely failing to function or very slow burning igniters).

It may thus be concluded from the results of these tests that the electrical output of the battery after 10 years of storage is still sufficient to properly ignite the spin rockets of the missile type even under the most severe temperature conditions (-40°F).

6.2.2 Type B Thermal Battery

The results of the initial three years of the surveillance tests for Type B thermal battery have indicated that the battery is still effective after approximately seven years of dormancy. It should be noted that the battery manufacturers had indicated a shelf life of 5 years for this battery. The serviceability of this battery was based on the fact that of all 37 batteries previously tested only one failed to conform to the performance requirements, i.e., the batteries were capable of supplying a minimum of 10 amperes within 1.0 second after activation and continued to supply a minimum of 10 amperes until 2.0 seconds after being activated. The battery which did not meet the performance requirements had a rise time to 10 amps .06 seconds above performance limits. This battery, however, functioned properly in all other respects and thus the slightly longer rise time was considered to be on no consequence.

The statistical analysis of the data compiled during the surveillance tests indicated that neither age nor manufacturer-storage location had a significant effect on the maximum current or the current rise time to 10 amps of these batteries. The average current rise time to 10 amps for batteries that varied in age from 3 to approximately 7 years was .77 seconds and the average maximum current produced was 17.5 amps. The analysis of the time to maximum current, however, indicated the following: 1) a significant difference between battery manufacturers occurred and 2) an aging effect with certain batteries was noted. The significant difference between the battery manufacturers was reflected in the comparison of the results obtained with 4 1/2-year-old batteries in one manufacturer's batteries required 1.1 seconds to reach maximum current (17.6 amps) while another manufacturer's batteries required 1.4 seconds to reach maximum current (17.5 amps). The aging effect occurring with one type battery indicated that the time to reach maximum current varied from 0.9 seconds for 4-year-old batteries to 1.8 seconds for 6 1/2-year-old batteries. It is noted that although the time to reach maximum current was significantly affected by age in the case of the other batteries, no significant age effect occurred in the current rise time to 10 amps, the more important time parameter. The significant time to maximum current which is a more comprehensive measure of the battery time during its activation phase has thus given some indication that aging may be beginning to have some effect on the electrical output of these batteries. Although no statistical analysis of the battery service times was carried out, it was observed that all batteries produced current in excess of 10 amps for at least 2.5 seconds.

As indicated in this report the performance requirement utilized as a basis for determining satisfactory battery performance was obtained from the battery specification (MIL-G-2550) rather than being a requirement directly related to battery performance in its ignition role. In view of this occurrence, criteria is being developed which will directly relate the performance of the battery to its requirements for rocket ignition purposes. This requirement will be based on the minimum battery electrical output necessary for proper ignition. Criteria of this nature will be most useful in evaluating the effectiveness of the battery when considerable aging of the battery occurs and particularly when the effect of a parameter that has fallen below specification limits must be determined.

6.3 Recommendations

6.3.1 Silver-Zinc Batteries

The results of the analysis for shelf and service life of silver zinc batteries depicting remaining battery service life after known shelf life should be used to obtain optimum utilization of batteries. Where definite shelf life is uncertain for a period of time, total service life should be assumed for this period.

Further surveillance testing of these batteries should be continued at periodic intervals. Present plans have surveillance testing to be conducted on silver zinc batteries up to an age of 20 years at intervals of less than two years.

The following failure rates should be used for prediction:

BATTERY	ENVIRONMENT	FAILURE RATE (FITS)
Silver Zinc	Shelf Life	<72.47
Silver Zinc	Service Life	<102.0

6.3.2 Thermal Batteries

It has been shown that for both Types A and B batteries, that aging of the battery is reducing its electrical output and thus it is considered extremely important that surveillance tests be continued in order to carefully monitor this reduction so that the limiting life of these batteries can be determined.

The batteries in stockpiles with bar connected brackets should be examined for clearance between the firing pin and the brackets and that all batteries that may result in a firing pin hang-up be further spread to prevent this occurrence.

The following failure rates for prediction of thermal battery reliability should be used:

BATTERY TYPE	ENVIRONMENT	FAILURE RATE (FITS)
A	Shelf	<110.0
B	Shelf	<666.0

	TOTAL (General)	<94.0

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