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Characteristics and Development Report for the MC3714 Thermal Battery

Gregory L. Scharrer and Frank P. Lasky
Battery Development Division
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

This report describes the design intent, design considerations, system use, development, product characteristics, and early production history of the MC3714 Thermal Battery. This battery has a required operating life of 146 s above 24.0 V with a constant current load of 0.5 A. It is activated when the MC3830 Actuator initiates the WW42C1 Percussion Primer in the battery. The MC3714 employs the Li(Si)/LiCl-KCl/lithiated FeS₂ electrochemical system. The battery is a hermetically sealed right-circular cylinder with an antirotation ring brazed to the base of the cylinder. The battery is 50 mm long and 38.1 mm in diameter. The mass of the battery is 165 g. The battery was designed and developed to provide the power for the W82 JTA Telemetry System.

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Characteristics and Development Report for the MC3714 Thermal Battery

Introduction

The MC3714, part number 318936 (Figure 1), is a mechanically activated thermal battery for the W82 Telemetry System.

The task of developing the MC3714 was assigned by Bob Wehrle, Division 2522, to Greg Scharrer and Frank Lasky of Division 2522. The GEND development engineer was Dave Jacobs, and Don Hardy was the GEND product engineer. Larry Humphries, Division 8141, was the systems organization contact and was responsible for writing the interface control document (CD239294). Ed Paboucek and Howard Devaney, both of Division 2542, designed the MC3830 Actuator¹ that attaches onto the battery. Reuben Weinmaster and Nick Durand, both of Division 2512, were responsible for the WW42C1 Primer² that activates the battery.

A brief overview of the principles of thermal battery operation is presented below for the benefit of those who are unfamiliar with thermal batteries.

A thermal battery is a thermally activated primary battery that contains a fused-salt electrolyte (LiCl-KCl eutectic in the MC3714) and an ignitable heat source (Fe/KClO₄). The MC3714 thermal battery uses the Li(Si)/LiCl-KCl/lithiated FeS₂ electro-

chemical system.³ There are 16 active cells in the MC3714. Each cell is comprised of a stainless-steel anode collector, Li anode, electrolyte-bearing separator, lithiated FeS₂ cathode with Grafoil backing and an iron-potassium perchlorate heat source. The Grafoil backing serves as the cathode current collector. An excess of iron in the heat source provides intercell connection. The heat source and the active cell components are formed by hydraulically pressing appropriate powders into thin wafers, commonly called "pellets."

Battery ignition is achieved by a mechanical input to the WW42C1 primer in the battery. The primer output is directed down the center-hole into the battery. That output ignites the heat pellets throughout the battery pellet stack. The heat released from the heat pellets raises the battery temperature to approximately 550°C within one-half second.

At temperatures above 352°C, the solid, electrochemically inactive electrolyte becomes molten, with good ion transport capability. This permits the ionic transfer necessary to complete the electrochemical circuit. Unless the anode and/or cathode are depleted, the electrochemical reaction will proceed as long as the electrolyte remains above its melting point.

A more complete discussion of thermal battery operation is given in Reference 4.

Figure 1. Cutaway View of the MC3714

Design Intent

1. Activation. The MC3714 is activated by the MC3830 Actuator. This actuator initiates the WW42C1 Percussion Primer in the battery header.
2. Voltage Rise. The electrical potential must reach 24.0 V within 0.5 s after activation.
3. Voltage Regulation. The output voltage must remain between 24.0 and 32.0 V while being discharged through a 0.500-A constant current load.
4. Activated Life. The voltage regulation must be maintained for at least 146 s.
5. Temperature. The MC3714 must function over the temperature range of -40°C to 54°C .

6. Reliability. The probability that the MC3714 will provide the required output must be at least 0.997.

7. The design goal for the MC3714 storage life is 25 years.

The MC3714 requirements are summarized in Table 1.

Table 1. MC3714 Electrical Requirements

Voltage rise to 24.0 V	500 ms
Maximum voltage	32.0 V
Voltage at required life	24.0 V
Time above 24.0 V	146 s
Load	0.500 A

Next Assembly Use

The MC3714 is mated to the MC3830 to become the battery and actuator assembly (Part No. 239294). The MC3830 screws into the boss on the MC3714 header. A right-hand thread is used so the actuator twists in instead of out when the W82 starts spinning. In addition, a bead of epoxy is placed on the last two threads of the actuator before it is screwed into the battery header. This ensures the actuator will stay in place through all the assembly, transportation, and functional environments of the telemetry system.

The battery and actuator assembly are mounted in the next assembly, as shown in Figure 2. The battery is on the centerline of the artillery shell. The battery and actuator assembly (Part No. 239294) are mounted in the back end of the telemetry assembly. A silicone rubber sleeve is fitted over the battery to protect the telemetry components from the battery heat. The electrical leads are soldered onto the battery terminals and the wires are potted in place.

When the artillery shell is fired, the high acceleration unlocks the firing pin in the MC3830 and drives it into the WW42C1 Primer in the header. This initiates the primer. The primer output activates the battery.

Design Considerations

General

The principal consideration was the effect of the high (18,000 rpm) spin rate on the battery. The cell diameter was kept as small as possible to minimize the centrifugal force on the molten electrolyte. In addition, the power leads were isolated from the stack as much as possible to prevent cells from shorting to the leads (this would occur if electrolyte leaked through the insulation and touched the leads).

Figure 2. Battery and Actuator Mounted in the Telemetry System

The high spin dictated the type of wrapping insulation used in the battery. There was room to put a Min-K[®] sleeve around the battery, but the high centrifugal force pulverized this material. Fiberfrax[™] insulation was used because it could survive the environment and adequately insulate the battery.

A standard thin-cell separator (60% electrolyte/40% binder) was used. No modifications to the binder content or the pellet geometry were needed to keep the molten electrolyte from being thrown out of the cell.

The battery program schedule is shown in Table 2.

Table 2. MC3714 Development Schedule

Event	Date
Conceptual Design Review	11/85
Long Lead Advanced Engineer/ Release (AER)	4/86
Prototype Design Review	7/86
AER	9/86
Producibility Design Review	6/88
Complete Engineering Release (CER)	6/88
Preproduction Start	9/88
Production Start	10/88
Tool-Made Sample (TMS)	10/88
Re-TMS Testing	12/88
Qualification Evaluation Release (QER)	1/89
Production Complete	1/89
First Production Unit (FPU)	1/89

Header Design

The MC3714 header had to have two features that most battery headers do not have. First, it had to have a very tight tolerance (diameter tolerance: +0.0000, -0.0005 in.) pocket to hold the primer—no other primer-activated thermal battery has the primer housed in the header. Second, it had to provide a mechanical mounting point for another component (the MC3830). The mechanical mounting feature was designed early in the program. It was decided that the MC3830 would screw into a threaded boss on the header. An O-ring is placed in a groove at the bottom of the boss to keep contaminants out of the firing pin-primer interface. The primer pocket is the standard size for the WW42C1 Primer.

The header also has an angled groove on the bottom side to keep the encapsulation from separating from the header during the setback acceleration (16,000 g, 10 ms). Testing on an air gun (16,000 g, 1 ms) showed that the encapsulation could break away from the header and cause a battery failure by breaking the power leads. The addition of the angled groove ensures that the potting will not break away from the header. The groove is similar to the one used on the MC3077 Thermal Battery.⁶

Primer Selection

The WW42C1 Primer was selected for use because it was the only primer available that could ignite the entire battery stack through the center-hole. Generally, one of two primers is used in thermal batteries—a low-temperature primer (the WW42C1, which replaced the M42G) or a high-temperature primer (the G16, which replaced the 44G16). The high-temperature primer is used on batteries that are exposed to temperatures above 70°C. All other batteries use the low-temperature primer.

Fortunately, the WW42C1 has a much more energetic and consistent output than its predecessor, the M42G. The M42G could not consistently ignite the entire battery stack through the center-hole. The slower activation method using fuse strips (fuse strips are placed on the perimeter of the stack) would have been used if the WW42C1 had not been developed, and the MC3714 would have had trouble meeting its rise time requirement. The WW42C1 was not developed specifically for the MC3714. However, the WW42C1 was available and appropriate for this application and the MC3714 header needed minor modifications only to incorporate it.

Encapsulation

Normally, the battery terminals are located on a bolt circle that is smaller than the cell diameter. This allows a cylindrical shaped encapsulant to hold the power leads and provide the stacking surface for the cell components. This geometry is shown in Figure 3. However, the presence of the threaded boss on the header forced the terminals to be located on a relatively large bolt circle. A conical shaped encapsulant was used so the power leads could be encased and the stacking surface could still be the same diameter as the pellets. This geometry is shown in Figure 4.

Figure 3. Cylindrical Encapsulant

Figure 4. Conical Encapsulant

Battery Stack

The battery contains 16 active cells—the greatest number that could be used without exceeding the 32-V limit. A lithiated cathode was used to prevent the occurrence of a voltage transient in excess of 32 V. At the header end, a heat pellet is offset from the encapsulation by a small Fiberfrax insulator. The purpose of this heat pellet is to cause the thermal monitor to open. The ends of the stack were otherwise symmetrical until the Lot 1 design change.

Tester Considerations

The background load of the telemetry system is a maximum of 400 mA, and there are pulse loads adding not more than 100 mA to the battery load. This load was consolidated into a 500-mA requirement to simplify testing.

Monitor

The Texas Instruments 4BTR Thermostatic Switch is used to indicate the state of the battery (i.e., fired or unfired). This switch has a reliability requirement separate from the battery function because it cannot meet the battery reliability requirement (0.997). The switch reliability requirement is 0.95.

The monitor has functioned very reliably in this battery. There was one failure (at low temperature) in development and none in production. One reason for this unusually good performance is the dedicated heat input provided to the monitor.

The monitor is held in the header encapsulant (refer to Figure 1). A thin insulator and a heat pellet are placed between the potting and a Min-K insulator. A hole in the insulator exposes the monitor to the heat pellet. Two disks of $Zr/BaCrO_4$ are placed in this cavity in the insulator. This provides a consistent, large heat input to the monitor. However, this same scheme is used in other batteries with disappointing results. It is not clear why the monitor works in this application but not in other similar applications.

Therefore, a stick-on temperature indicator is attached to the side of the battery to give further

assurance that a discharged battery will not be used in a flight unit. This indicator changes from white to black at about 90°C. This was added to the battery late in development because of the erratic history of the 4BTR monitor.

Unique Characteristics

This battery has three unique features. First, it is the only thermal battery that holds the percussion primer in its header. Other primer-fired batteries, such as the MC3246⁶ and the MC3929, hold the primer in the opposite end of the battery from the header. Second, it is the only thermal battery in production with a hermetically sealed primer interface (the MC3246A will go into production in late 1989 and it will have a similar interface). Third, it is the only battery that has a separate reliability specification for its monitor.

The primer had to be in the header because the base end of the battery rests on a flat surface. Thus, the free end of the battery, the header, must be used for both the output terminals and the actuator input. Other primer-activated thermal batteries either have threaded holes (not through holes) in a thick plate that also holds the primer, or they have a circumferential mounting feature (e.g., a bracket attached to the side of the battery).

The primer interface was hermetically sealed by laser-welding a 0.13-mm-thick stainless-steel disk over the primer cavity after the primer was inserted. Testing done by Nick Durand, Division 2512, showed that the all-fire velocity of the firing pin was not changed by the addition of this disk.⁷ The monitor has its own reliability specification because it is much less reliable than the battery, and it was not practical to jeopardize the acceptance of the battery based on the unreliability of the monitor. This decision was justified by the next assembly use of the monitor: it is checked only before the battery and actuator are assembled into a telemetry unit at Allied-Signal, Kansas City Division. Thus, the probability of the battery's being accidentally activated was so small that a lower reliability for the monitor was acceptable.

Development

The MC3714 program was started and stopped on several occasions. The last restart of the MC3714 program was in early 1985. The battery had 15 cells and an unlithiated cathode at that time. The battery stack is shown in Figure 5.

Even though these units had a center hole, fuse strips were used to ensure that all heat pellets were ignited. The insurance was needed because the M42G Primer could not reliably ignite all the heat pellets. However, it created a potential failure mode. If the primer ignited all the heat pellets, then the fuse strips could cause overheating of the cells by adding heat to an already hot area. The fuse strips were eliminated after the WW42C1 Primer replaced the M42G.

Since the operating life was inadequate and the voltage vs. time curve could not be flattened by using a better insulating wrap, one cell was added to the battery. This extended the battery life by raising the voltage vs. time curve. At the same time, the cathode was changed to the (then) new lithiated material, which eliminated the initial voltage transient inherent in FeS_2 cathodes and produced a more consistent end of life. However, failures were still common, even after this change was made.

The failures were all the result of poor thermal management. The next change was designed to correct this problem. A 0.76-mm-thick Fiberfrax insulator was placed between the adjacent heat pellets at both ends of the stack. This new stack configuration is shown in Figure 6.

There were still failures after this change, but they were less frequent. In addition, battery performance, as measured by active life and the voltage at 146 s, was improved. Postmortem examination of the failed batteries showed that overheating was still a problem and it seemed to be focused on the inside diameter of the most negative anode.

The inside diameter (ID) of the encapsulant was decreased once to ensure that all the heat pellets would be ignited. Later, it was increased to its original size because it was evident that the primer could reliably activate the battery. It was thought at that time that decreasing the encapsulant ID had contributed to the battery noise and anode damage. It was also thought that the heat from the primer was the cause of the anode damage. Both of these concepts were later proved incorrect.

At the end of development, the anode damage was thought to be under control because no batteries had noise after the last design change, which increased the encapsulant ID.

ANODE=15EA
 SEPARATOR=15EA
 CATHODE=15EA
 S/S COLLECTOR=14EA
 S/S WTAP=2EA
 FF=2EA (.030 OR .050)
 MIN-K=2EA(1/8")
 HEAT=20EA
 3 WRAPS FF BLANKET
 200IBS PRESSURE ON STACK
 1442 MATCH
 OR WW42C1 PRIMER

Figure 5. MC3714 Initial Battery Stack Assembly

MC3714 STACK ASSEMBLY

WRAP

TAPE

BLANKET (1)

TAPE

WELD LEAD

TAPE

BLANKET (2)

TAPE

* DESIGN CHANGE

Figure 6. Stack With Separation of Double Heat Pellets (continued on next page)

16 CELLS

Figure 6. (concluded)

Heat Balancing

The heat balance is normally specified by dividing the total calorific input of one heat pellet by the total weight of one cell. The heat balance is unique for every thermal battery. It is determined experimentally through an iterative process. The optimum heat

balance for the MC3714 was determined to be 100 cal/(g-cell). This corresponds to a heat pellet weight of 0.93 g using the 86/14 (86% Fe, 14% KClO_4) heat powder. This heat powder has a calorific output of 260 cal/g.

Environmental Testing

The only active test environment was spin. This was dictated by CD239294. Flight test results were used to qualify the design to its use environment, since the use environments were too extreme to simulate in a laboratory

Aging Test

Eight batteries were built with a separator containing 4% LiO (Ref. 8) to simulate 25 years of aging. These "aged" batteries performed as well as the "unaged" batteries. These batteries were tested on the GEND spin tester. The data for this test are shown in Table 3.

GEND Development

GEND development activities started in October 1985. All the various configurations of the battery were constructed and tested at GEND. In addition, many of the SNL batteries were tested at GEND because GEND had the only acceptable spin tester.

The reliable operation of the spin tester was critical to the success of this program.

All the GEND development test data are in the Department 2520 HP3000 database system. The data were also transmitted into the Product Test Data (PTD) system maintained by Department 2820. The GEND data presented at the Producibility Design Review will be shown here. All the GEND batteries were tested in the spin environment.

The Producibility Design Review was held on June 24, 1988. At this meeting, GEND presented data showing pellet yields (Table 4), a statistical summary of battery performance (Table 5), and a battery cost estimate (Table 6). The cost data are based on a total build of 139 batteries, which will yield 29 deliverable

batteries. These data are shown in the tables that follow. The producibility assessment was also presented. The battery was given a producibility assessment of "A" by GEND. This assessment means the battery can be produced with existing equipment and techniques and is expected to meet its requirements easily.

Table 3. SNL Aging Test Data

Serial Number	Test Temp. (°C)	Rise Time (V)	Peak Voltage (V)	Voltage at Life (V)	Active Life (s)
(Spec.)		(500)	(34)	(24)	(146)
146	54	140	30.84	29.17	333
148	54	152	29.43	27.19	308
149	54	140	30.79	29.16	332
150	54	150	30.76	28.84	312
144	-40	225	28.97	26.99	204
145	-40	182	29.87	27.38	197
147	-40	178	30.03	27.93	220
151	-40	200	29.77	27.33	197

Table 4. GEND Development Pellet Yields

Pellet	Accepted	Rejected	Yield (%)
Anode	1198	291	80.4
Separator	1645	91	94.7
Cathode	1418	82	94.5
Heat	1075	14	98.7

Table 5. GEND Development Performance Summary

	Required	Minimum	Mean	Maximum	Sigma	K-factor
-40°C: 21 units						
Rise time (ms)	500	168	177	190	6.73	47.9
Peak voltage (V) 32.0	29.9	30.1	30.9	0.25	7.8	—
Voltage at 146 s (V)	24.0	26.9	27.4	27.9	0.3	11.8
Time above 24.0 V (s)	146	181	197	217	11.8	4.4
54°C: 28 units						
Rise time (ms)	500	124	136	150	6.2	58.99
Peak voltage (V) 32.0	30.0	30.8	31.1	0.2	5.68	—
Voltage at 146 s (V)	24.0	26.2	28.3	28.8	0.6	7.4
Time above 24.0 V (s)	146	195	269	300	20.9	5.9

Table 6. Estimated Cost of Lot 1 Batteries

Cost Element	Total Cost (\$)
Material	24,852
Labor	48,612
Direct support	24,306
Lot Cost	97,771

not manufactured with a constant displacement of the stack.

Component Parts

The component parts are summarized in Table 7. This table lists the principal dimensions and drawing control number for all the parts that make up the MC3714.

Product Characteristics

This battery conforms to the thermal battery design guide (DG10177, Issue B) except the battery is

Table 7. MC3714 Component Parts Summary

Component Part	Drawing No.	Diameter (mm)	Thickness (mm)	Weight (g)	Number Required	Total Weight (g)
Base	349530-200	38.10	3.17	24.1	1	24.1
Case	324410-207	38.10	0.508	24.0	1	24.0
Anit-spin ring	380610-200	38.10	5.50	15.67	1	15.67
Header	349522-200	38.10	8.26	40.9	1	40.9
encapsulated Header	384053-200	25.40	1.27	0.27	1	0.27
insulator						
Heat	349548-200	25.40	0.448	0.93	22	24.2
Anode	349546-200	25.40	0.35	0.19	16	4.76
Separator	349545-200	25.40	0.296	0.264	16	7.38
Cathode	349544-200	25.40	0.33	0.563	16	9.57
Grafoil	349545-200	25.40	NA	NA	16	0.10
Collector	370512-200	25.40	0.127	0.48	15	12.64
Collector w/lead	370511-200	25.40	0.127	0.57	2	1.76
Shim	332807-202	36	NA	NA	AR	0.43

		Length (mm)		Width (mm)		
Insulation wrap	370611-200	114	20.32	35.5	1	2.3
Insulation wrap	370612-201	114	20.32	35.5	1	4.7

Max. weight of the MC3714 = 166 g

Assembly

To begin the stack assembly, an encapsulated MC3714 header is inverted and placed on a stacking fixture. The battery components are then stacked on to the inverted header as specified in the Stack Assembly Drawing (349542) (Figure 6).

The battery stack is then placed on the press. The stack should be straightened before any load is put on it. A ram with the same diameter as the nominal pellet diameter is used to load the stack. The stack force should be maintained at 890 ± 225 N until the battery is wrapped.

The battery is first wrapped with glass tape. Then a 2-mm-thick Fiberfrax blanket is wrapped around the battery. Another glass-tape wrap is applied. The stack leads are then resistance-welded to the appropriate leads from the header. A strip of mica is placed between the welded leads and the blanket. Another glass-tape wrap is applied, and two layers of the 2-mm Fiberfrax blanket are wrapped around the stack. A final glass-tape wrap is applied. The completed stack assembly is placed into a case assembly, and the header is welded to the case to complete the assembly of the MC3714.

Battery Temperatures

To record the external temperatures of the battery, thermocouples were attached to the outside of the battery at the locations shown in Figure 7. The data recorded are shown in Figure 8.

All temperature data were recorded at 1 s intervals using an HP3852 Data Acquisition/Control Unit controlled by an HP150 Personal Computer. Type "K" thermocouples were used for all tests. These tests were not performed in a spin environment because that capability did not exist.

Figure 7. External Thermocouple Locations

MC3714 TEMPERATURE PROFILE

+54°C

BASE

CASE

HEADER

MC3714 TEMPERATURE PROFILE

-40°C

BASE

CASE

HEADER

Figure 8. External Temperatures During Discharge

Performance Characterization

The discharge load for the MC3714 is 500 mA constant current. To characterize the MC3714 discharge capability, one battery was discharged at each temperature (-40°C or 54°C) at the following constant current loads: 250 mA, 1 A, 2 A. Two open-circuit tests were also performed. The data for these tests are shown in Figures 9a-9e.

(a) MC3714 at -54°C , 0.5-A load

(b) MC3714 at $+54^{\circ}\text{C}$, 0.25-A load

(c) MC3714 at -40°C , 0.25-A load

(d) MC3714 at $+54^{\circ}\text{C}$, 1.0-A load

(e) MC3714 at -48°C , 1.0-A load

Figure 9. Performance at Various Loads

Mass Properties

The center of gravity and moment of inertia for each of the three major axes were determined using expended batteries. The axes and datums used are shown in Figure 10. The mass properties data are listed in Table 8. These data were generated by the Rotational Dynamics Division (Division 7543).

MASS PROPERTIES REPORT

Test Item Description MC3714
Data Classification Unclassified

Test Date(s) 10/19/89

Weight

Weight = 365 lbs

Center of Gravity (CG)

X = 9.44 in.

Y = 7.57 in.

Z = 7.51 in.

Moment of Inertia (MOI)

I_{XX} = 113 lb in²

I_{YY} = 243 lb in²

I_{ZZ} = 239 lb in²

Datum (s)

Figure 10. Axes and Datums for Mass Properties

Table 8. MC3714 Mass Properties

Center of Gravity		Moment of Inertia	
Axis	Location (cm)	Axis	Inertia (g-cm ²)
X	1.880	XX	632.6
Y	1.875	YY	635.6
Z	2.512	ZZ	295.8

Production History

This battery went into production in late September 1988. A TMS was conducted the week of October 17, 1988. During the testing for the TMS, a voltage dropout occurred on a battery tested at 54°C. Post-mortem of the battery showed that the first cell (i.e., the most negative anode) overheated. Electrolyte from the first cell leached through the insulating wrap and briefly shorted to the positive power lead. The short occurred 5 s into the discharge and lasted about 3 ms. An evaluation program was immediately begun to determine what design change could eliminate the overheating that was observed.

Lot 1 Design Change

It was obvious that there was an excessive heat transient that resulted in either moderate damage to the first cell, gross damage to the first cell accompanied by voltage perturbations (i.e., "noise"), or failure of the battery. The moderate damage is illustrated in Figure 11. The gross damage is illustrated in Figure 12. It was also obvious that the heat transient was not grossly excessive for the following reasons: First, batteries tested cold (i.e., at -40°C) showed minor-to-moderate damage to the first anode only. There were never any voltage perturbations, gross damage to the anode, or failure of batteries. Second, the gross damage and associated noise occurred on only 10% of the batteries tested hot (i.e., 54°C). There were no failures in this design configuration until the TMS.

Since the noise was infrequent, it was believed that the heat management in the battery was marginal at 54°C and that variations in the primer output accounted for variations in the occurrence of noise. This belief determined the approach that would be taken to solve the battery overheating problem.

The design evaluation program began by building batteries with minor design changes that attempted

Figure 11. Moderate Damage to the Anode

Figure 12. Gross Damage to the Anode

to moderate the primer output. One modification was to enlarge the inside diameter of the Min-K insulator at the header end of the stack. The idea was to trap a portion of the primer output in the Min-K cavity and effectively reduce the output of the primer. This change had no effect on the overheating problem. Another modification was to put a current collector with a small ID (~3 mm) in the stack close to the primer. This was another attempt to effectively reduce the output of the primer. This also had no effect on the overheating problem.

Another approach was to implement a modification that had proved successful on another program. An additional current collector was used on the first anode as a heatsink. This eliminated the overheating problem; the first anode from a hot battery looked like the first anode from a cold battery. However, the heatsinking proved excessive when this design was tested at low temperature; two units failed the activated life requirement.

The next idea was to invert the battery stack. This resulted in the most negative anode's being at the base end of the battery instead of at the header end. Batteries tested this way had the same damage to the most negative anode as noninverted batteries. This showed that the overheating was caused by the heat transfer from the "dummy cells" (i.e., the heat pellets and insulation between the stack and the header). This test defined the source of the problem.

The only question remaining was whether the overheating was caused by an excessive amount of heat transfer or an excessive rate of heat transfer from the buffer area to the first cell. Since the most positive anode was exposed to approximately the same heat input as the most negative anode without visible damage, it was concluded that the heat transfer rate was excessive. The heat transfer rate to the most positive anode was moderated by both the masses of the cathode and separator pellets and the thermal

capacitance of the separator pellet (which goes through a phase change). Since a capacitive element, the extra collector, had already been tried without success, a resistive element, an extra Fiberfrax insulator, was chosen to reduce the heat transfer rate from the buffer area to the most negative anode.

An additional Fiberfrax insulator was placed between the "dummy cell" heat pellets and the battery stack (Figure 6). This eliminated the overheating problem and made the battery performance more consistent.

Production Summary

The first production lot of the MC3714 was complete as of January 1989. This lot was built at GEND in December 1988 and January 1989. Table 9 shows the lot build summary. There was only one reject, a build error, and this was tested as a daily lot sample unit. This resulted in a 100% yield for the lot. The daily lot sample performance data are summarized in Table 10 and the re-TMS data are listed in Table 11.

The life of program build for the MC3714 is presently scheduled to be 144 delivered units.

Table 9. Lot 1 Production Summary

Total Fabricated	100
Preproduction/TMS	28
Daily Lot Samples	50
WR	25
Rejects	1
1 stack error (used as lot sample)	
Lot Yield	100%

Table 10. Lot 1 Performance Summary

	Required	Minimum	Mean	Maximum	Sigma	K-factor
-34°C: 25 units						
Rise time (ms)	500	155	167	200	9.70	34.31
Peak voltage (V)	32.0	29.89	30.14	31.26	0.07	25.43
Voltage at 146 s (V)	24.0	26.96	27.36	27.57	0.15	21.92
Time above 24.0 V (s)	146	195.5	218.6	236.5	9.50	7.64
60°C: 25 units						
Rise time (ms)	500	120	131	140	6.85	53.81
Peak voltage (V)	32.0	30.55	30.69	30.78	0.06	22.97
Voltage at 146 s (V)	24.0	27.90	28.13	28.35	0.12	33.71
Time above 24.0 V (s)	146	284.0	302.42	319.2	9.19	17.01

Table 11. Lot 1 Re-TMS Data

Serial Number	Test Temp. (°C)	Rise Time to 24 V	Peak Voltage	Voltage at 146 s	Time Above 24 V
113	-40	180	30.12	27.31	210.3
115	-40	170	30.01	27.36	215.2
116	-40	190	30.06	27.31	206.9
120	-40	180	29.94	27.23	204.1
122	-40	180	29.99	27.25	208.9
112	54	140	30.56	28.21	305.2
114	54	140	30.62	28.20	308.3
117	54	140	30.61	27.87	286.3
119	54	145	30.60	28.12	299.1
121	54	130	30.54	28.01	288.0
123	54	130	30.58	28.04	289.2

END

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