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ACTIVE PRIMARY LITHIUM THIONYL CHLORIDE BATTERY FOR ARTILLERY APPLICATIONS

Abstract

Sandia National Laboratories and Eagle Picher Industries have successfully developed an Active Lithium Thionyl Chloride (ALTC) power battery for unique artillery applications.

Details of the design and the results of safety and performance will be presented.

INTRODUCTION

Sandia National Laboratories had need of a power battery for Artillery Fired Atomic Projectile (AFAP) programs for use in telemetry systems. The telemetry systems transmit various data concerning, the function of projectile components, and/or the environments which the projectile is experiencing during gun launch in the artillery tube and/or in flight. The Active Lithium Thionyl Chloride (ALTC) battery must be capable of meeting the stringent requirements of nuclear ordnance and surviving the harsh dynamic environments associated with artillery applications. The Laboratories and Eagle Picher Industries engaged in a program to design and develop a flat plate ALTC power battery as a replacement for the no-longer-produced reserve ammonia battery.

DEVELOPMENT GOALS

Typical requirements for a telemetry power source in an Artillery Fired Atomic Projectile are: (1) 28 volts, (2) continuous current of 0.6 amperes, (3) three minute operational life, (4) five year desired storage life, (5) operation at temperatures of -35 C to 55 C. The most severe dynamic environmental conditions are those corresponding to the 155 mm projectile, which develops 60 to 300 rps axial spin, setback acceleration forces of 1400 to 17,000 g's (velocity change of approximately 220 ft/sec to 3150 ft/sec), and angular acceleration of up to 340,000 radians/sec^2.

The electrochemical system, Li/$SOCl_2$ was used for this development program. Development goals were to define problem areas, provide corrective solutions and deliver approximately 100 each fully-functional flight quality batteries capable of meeting or exceeding the telemetry program requirements. Fabrication techniques, process variables and materials were evaluated to achieve optimum performance for an artillery environment.

CELL DESIGN

The cell is a disc shape, 44.5 mm (1.75 inch) in diameter and 3.7 mm (0.145 inch) thick. There is a single 3.17 mm (0.125 inch) diameter stainless steel glass insulated terminal centrally located in the cell cover. The activation fill hole is also contained in the cell cover. Both cell case and cover are made of 304 stainless steel (Figure 1).

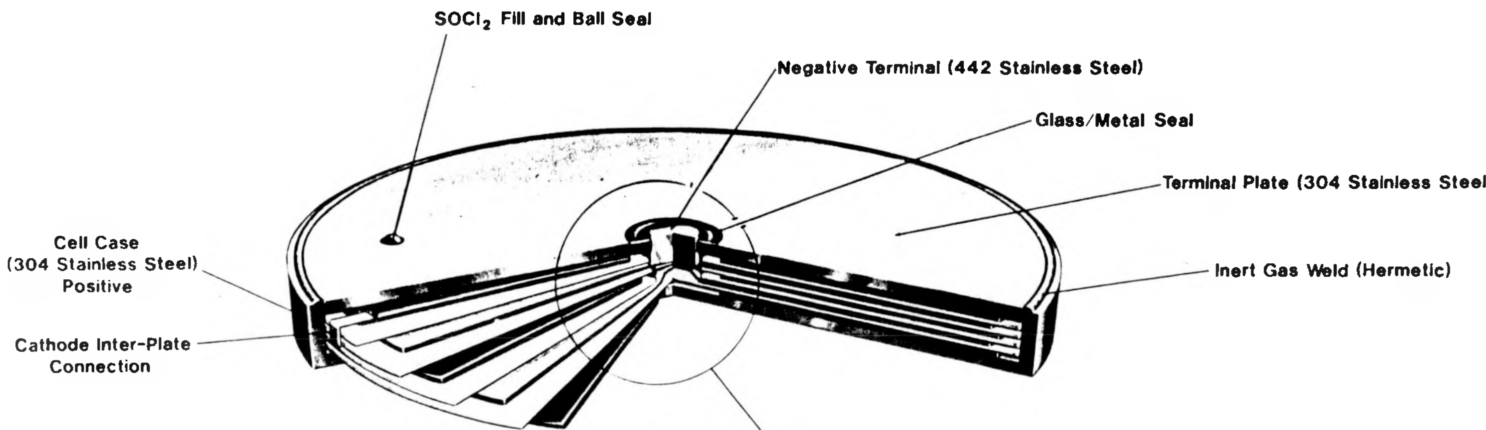
The cell consists of three cathodes and two anodes separated by Dexter glass material 0.254 mm (0.010 inch) thick. Each cathode is 40.4 mm (1.59 inch) in diameter, 0.254 mm (0.010 inch) thick, and consists of carbon black on an expanded metal nickel grid. Each anode is 39.1 mm (1.54 inch) in diameter, 0.254 mm (0.010 inch) thick, and consists of lithium foil laminated to each side of a 0.076 mm (0.003 inch) thick nickel foil current collector (Figure 1).

Figure 1: Sectional view of the Active Lithium Thionyl Chloride Single cell.

The cells are vacuum activated by evacuating the cell prior to being filled with approximately 2.15 milliliters of 1.5 molar lithium tetrachloroaluminate in thionyl chloride ($LiAlCl_4/SOCl_2$) to which sulfur dioxide (SO_2) is added. Following filling, a stainless steel sphere is interference fitted into the cell fill hole which provides the hermetic seal (Figure 1). The cells are subjected to a 4.5 ohm resistive load for 15 seconds within five minutes after activation. The cells are stored at -35 C and a second "burn-in" at -35 C is performed for 120 seconds within 24 hours after activation. The cells are then ready for assembly into the battery.

BATTERY DESIGN

Ten individual cells are connected in series within a cell stack assembly. Three 0.254 mm (0.010 inch) thick 44.5 mm (1.75 inch) diameter pieces of unclad G-10 circuit board material are used to electrically isolate the adjacent cells from each other (Figure 2). The cell stack assembly is housed in a 304 stainless steel cylindrical container, 50.5 mm (1.99 inch) long and 50.8 mm (2.0 inch) in diameter. Centrally located on one end of the battery container is a 25.4 mm diameter, 4.5 mm thick projection that includes the next assembly alignment and anti-rotation



SINGLE CELL
ARTILLERY DEVELOPMENT
ACTIVE LITHIUM THIONYL CHLORIDE (ALTC)

Plate Area	Physical
Carbon Cathode: 50 cm^2	Diameter: 45 mm
Lithium Anode: 47 cm^2	Height 3.7 mm
	Mass: 26 g

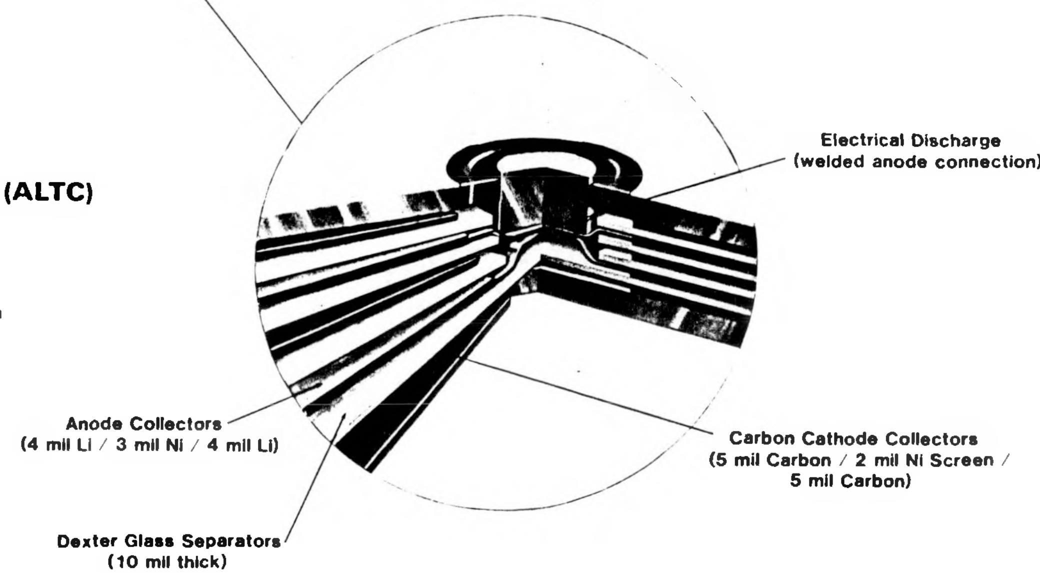


FIGURE 1

features of the battery. The opposite end of the battery is open, the cell stack is placed into the container and encapsulated with Scotchcast 88 resin. The battery case contains three rectangular safety vent windows each 31.8 mm by 9.4 mm. The encapsulating material fills the vent windows as well as the free volume surrounding the cell stack. The complete battery assembly is shown in Figure 2 The ALTC battery has a volume of 106 cm^3 including the antirotational fixture and a mass of 455 grams.

Figure 2: Sectional view of the Active Lithium Thionyl Chloride ten cell battery.

CELL SAFETY TESTING

Cell safety testing consisted of four types of tests:

1. Incineration
2. Cell reversal
3. Electrical Heat Tape
4. Short circuit

The incineration tests were conducted by placing activated cells over an open flame. A thermocouple was securely fastened adjacent to each cell. All cells "bowed" outward in the center of the cell cover approximately 1.5 mm, but did not vent, lose integrity, or expel internal components.

The cell reversal test was conducted on three cells which had previously been discharged at a constant current of 600 mA to 2.0 volts. The cells were then placed in a 50 C oven for a minimum of 24 hours prior to being subjected to a constant current of 600 mA at 55 C. One cell vented through the glass/metal seal of the cell cover at twenty-four minutes. The cell voltage was -9.2 volts and the cell temperature was 83.3 C. When the test was stopped the temperature immediately began to fall. The other two cells were normal and no venting was observed.

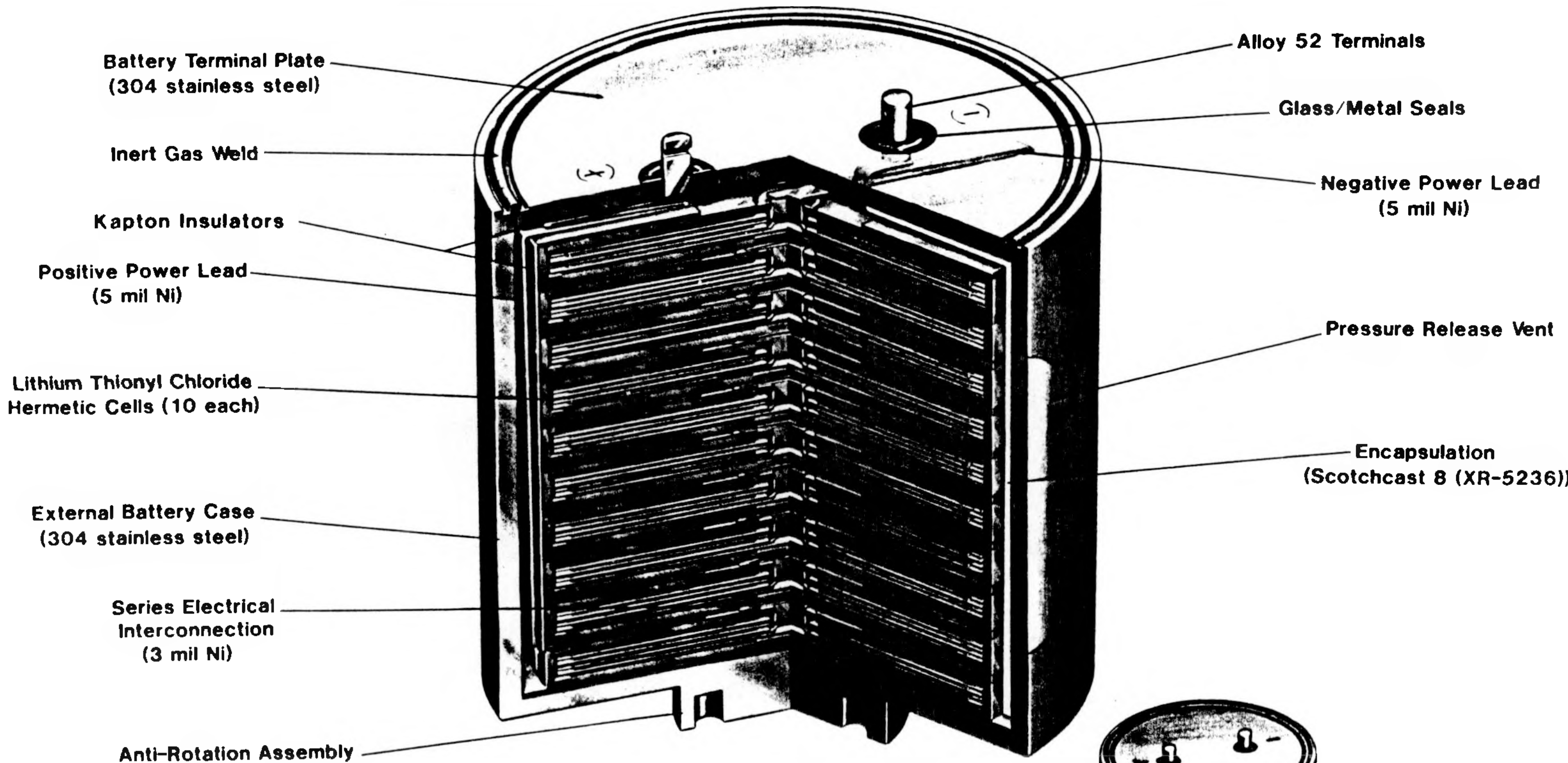
A heat tape test was conducted on four cells. Each cell was wrapped with several loops of resistance wire. Two cells were unrestrained and two cells were restrained. The unrestrained cells reached a maximum temperature of 190 C within thirty minutes. These cells swelled and were internally shorted and only minor venting occurred at the glass/metal seal. The restrained cells each reached a maximum temperatures of 400 C within twenty-four minutes and both cells vented at the glass/metal seal.

The short circuit test was conducted on two cells using a 0.001 ohm load. Both cells discharged at approximately 4.0 amperes. Venting occurred passively through the glass-to-metal seal.

BATTERY SAFETY TESTS

DEVELOPMENT BATTERY FOR ARTILLERY

TELEMETRY POWER - P/N 378938-00
ACTIVE LITHIUM THIONYL CHLORIDE (ALTC)
POWER BATTERY



Volume: 103 cm^3	**Mass:** 545 g
Energy: 20 WH	**Capacity:** 45 A·m
Power: 18 W	**Voltage:** 30 V

FIGURE 2

Two types of battery safety tests were conducted in addition to the required DOT shipping tests:

1. Heat Tape
2. Short Circuit

The heat tape test was conducted on two batteries. Each battery was wrapped with thirty-two loops of resistance wire. In each case the battery was heated for approximately thirty-five minutes, a temperature of 180 C and an open circuit voltage of 37 volts were reached. At this time each battery vented with smoke and flame. The internal gas pressure from venting cells forced the encapsulation material from the battery case vent slots. This relieved the internal battery pressure. Although the battery case was blackened by smoke and flame, all cells were contained within the battery case, which remained intact.

The short circuit test was conducted at room temperature on two batteries. One was discharged across 0.01 ohm and the other battery was discharged across 1.0 ohm. The battery tested at 0.010 ohm reached a maximum current of 16 amperes at 6 minutes and a maximum battery case temperature of 189 C at 12 minutes, which resulted in venting similar to the heater wire testing.

The battery tested across 1.0 ohm reached a maximum current of 4.5 amperes a 4.0 minutes and a maximum battery case temperature of 161 C at 17 minutes. This battery remained on load for 65 minutes. Examination of the battery revealed that a passive venting had occurred through small holes in the encapsulation exposed to the vent slots in the battery case. There was no smoke, flash, flame or report.

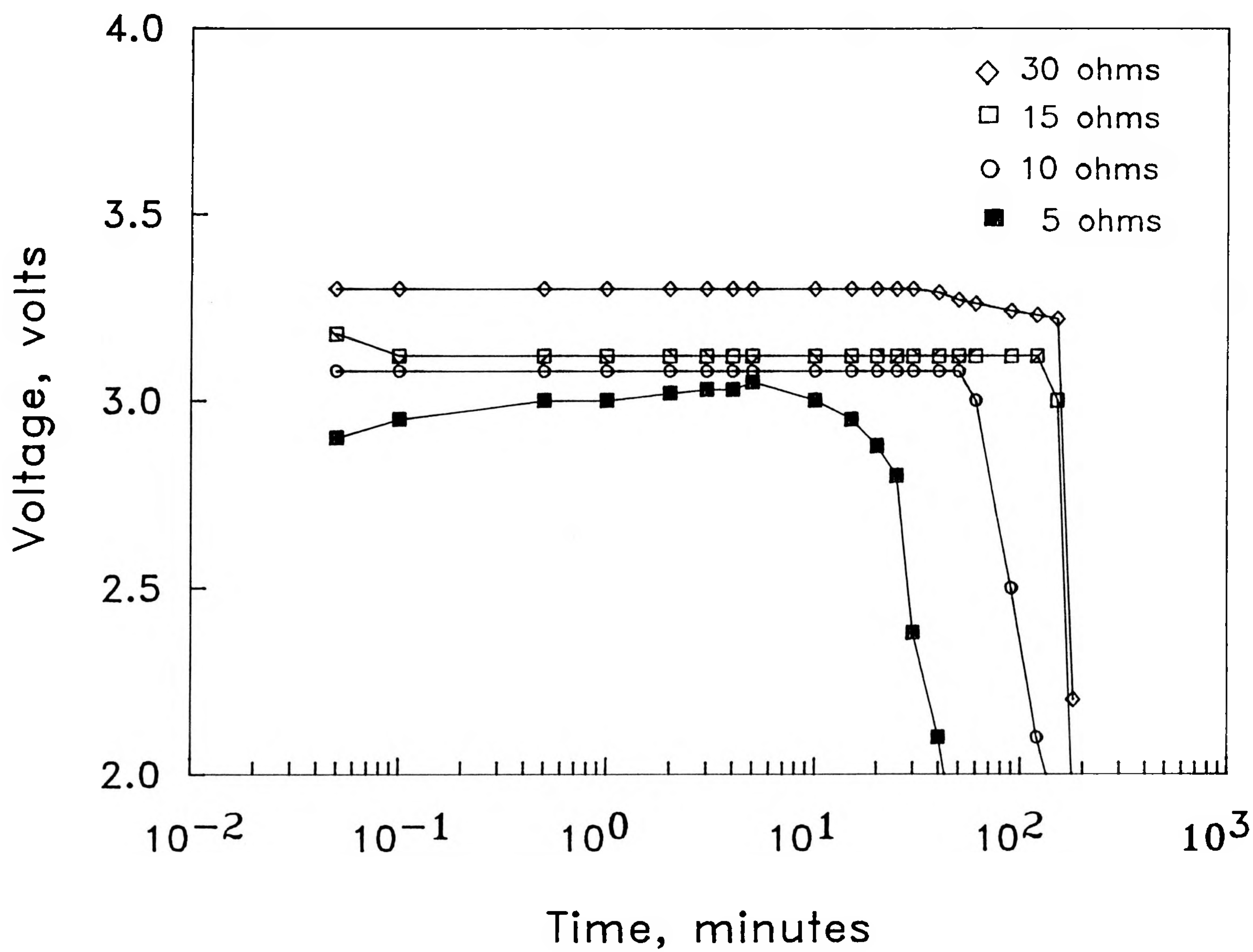
TYPICAL STATIC PERFORMANCE and CHARACTERISTICS

Typical performance for cells of the final design are shown in Figure 3 .

Figure 3: Typical room temperature performance of single cells verses drain rate (anode plate area 46 cm^2, cathode current collector 43 cm^2).

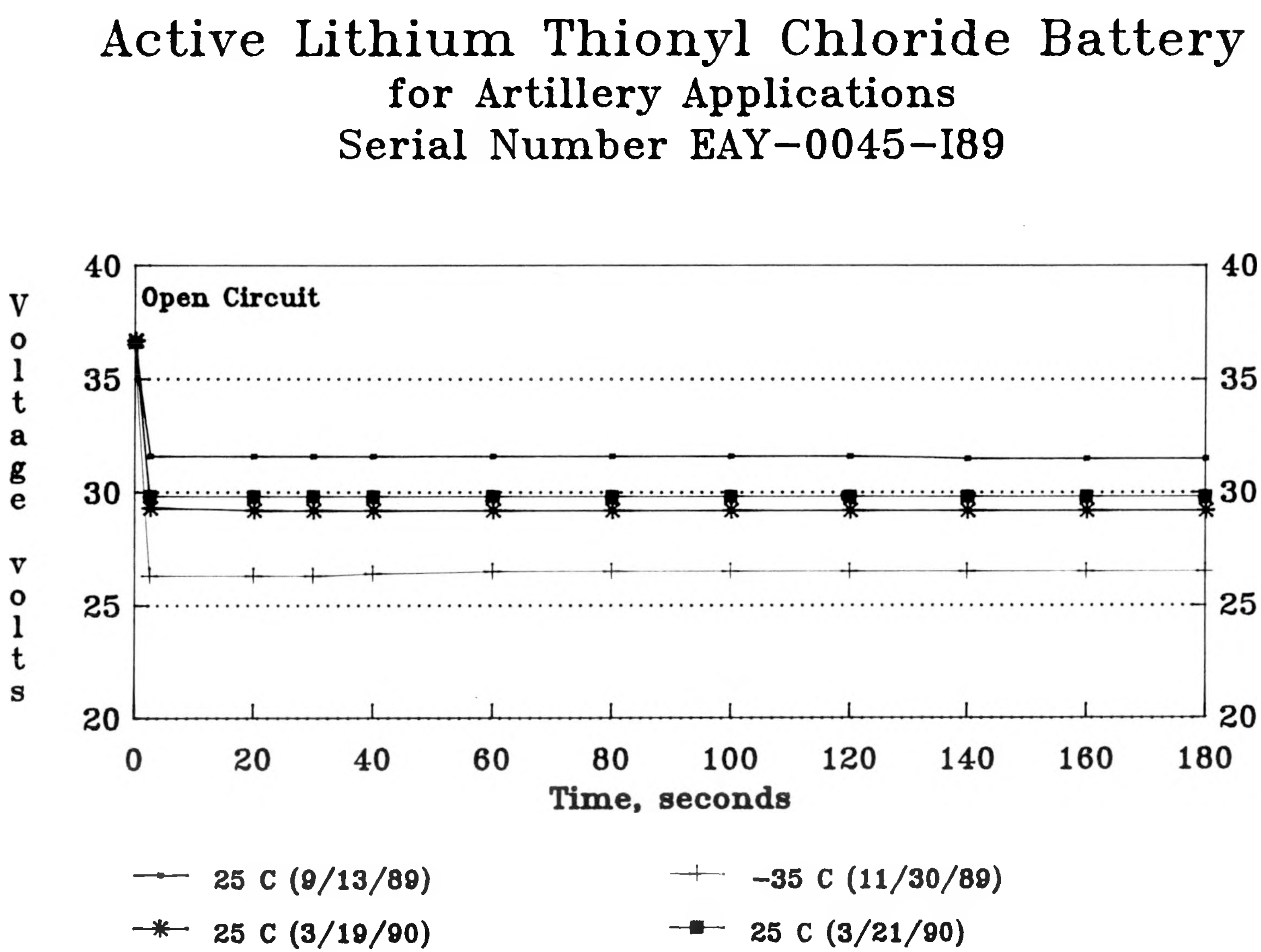
The battery was subjected to maximum thermal stablization and electrical conditions. The battery has much more capacity than required (approximately 30 A-m) versus a system requirement of 1.8 A-m. The challenge was assuring adaquate rate capability at the -35 C test condition. As shown (Figure 4) the battery easily exceeds the required performance goals.

Figure 4: Typical performance verses storage time and discharge temperature, when discharged across a 50 ohm resistor.



4.0
3.5
3.0
2.5
2.0
Voltage, volts
◇ 30 ohms
□ 15 ohms
○ 10 ohms
■ 5 ohms
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Time, minutes

FIGURE 3



Active Lithium Thionyl Chloride Battery
for Artillery Applications
Serial Number EAY-0045-I89
Voltage volts
Open Circuit
40
35
30
25
20
0
20
40
60
80
100
120
140
160
180
Time, seconds
25 C (9/13/89)
-35 C (11/30/89)
25 C (3/19/90)
25 C (3/21/90)

FIGURE 4

Voltage delay effects were also evaluated for batteries stored at -10 C with a one week excursion to room temperature then discharged at -35 C across a 50 ohm resistive load (approximately 11 mA/cm^3). Figure 5 shows the voltage excursion as the load, after several months of -10 C storage with a one week excursion to room temperature. Special handling is required to assure proper operation at 600 mA and -35 C. This special handling consists of storing the batteries at -10 C or lower. Any necessary temperature excursions to room temperature must not occur for greater than four weeks if -35 C operation is required. This minimizes time for formation of the passivation film on the lithium anode. Additional information on the voltage delay associated with this cell will be presented at this meeting, reference 1.

Figure 5: Voltage/Time profile for a battery stored for four months at -10 C with a one month excursion to room temperature.

TEST RESULT SUMMARY

Flight worthiness has been demonstrated through actual artillery projectile usage.

The Artillery Fired Atomic Projectiles (AFAP) have used the ALTC power battery for telemetry systems to transmit various data about the condition of the projectile components, and/or the environments which the projectile is experiencing, during gun launch in the artillery tube and/or in free flight. Table 1 provides a summary of maximum dynamic environments that the ALTC battery has successfully survived and operated in a normal manner.

SETBACK ACCELERATION (g's):	16,800
SETBACK DURATION (ms):	12
VELOCITY (ft/s):	2960
APOGEE (kft):	75.4
TIME to APOGEE (s):	62
SPIN RATE (RPM):	17,500
BREECH PRESSURE (ksi):	60.1
TIME IN THE TUBE (ms):	11.5
ANGULAR ACCELERATION (rad/s^2):	320,000

TABLE 1: Summary of Dynamic environments associated with AFAP artillery programs

The ALTC battery has successfully provided uninterrupted 24 to 32 Vdc at up to 450 milliamperes at -35 C, 25 and 55 C in actual artillery tests at maximum dynamic environments.

CONCLUSIONS

The program goal was to provide a direct replacement power battery for the no-longer produced reserve ammonia battery, capable of extended dynamic environments. This goal was met using the active lithium thionyl chloride flat-plate design. The active battery allows our customers greater flexibility over the "one-shot" reserve battery that was previously used.

The ALTC battery electrical performance is unaffected when subjected to actual artillery tests at 105% of maximum expected dynamic environments produced by the Artillery Fired Atomic Projectiles.

Special handling is required to assure proper operation at -35 C at the maximum current of 600 mA (13 mA/cm^2).

We feel this is a viable battery system for artillery applications with environmental demands even greater than those of todays weaponry.

ACKNOWLEDGMENT

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G. Twombly, and G. Laswell both EPI, for fabrication, product evaluation and finally production of the ALTC battery.

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REFERENCE

1. F. M. Delnick and A. R. Baldwin, Proceedings of the 34th International Power Sources Symposium, June 1990; "Voltage Delay in Li/$SOCl_2$ Cells for Artillery Applications".

Active Lithium Thionyl Chloride Battery

Voltage Delay Characteristics

Serial Number EAY-0045-I89

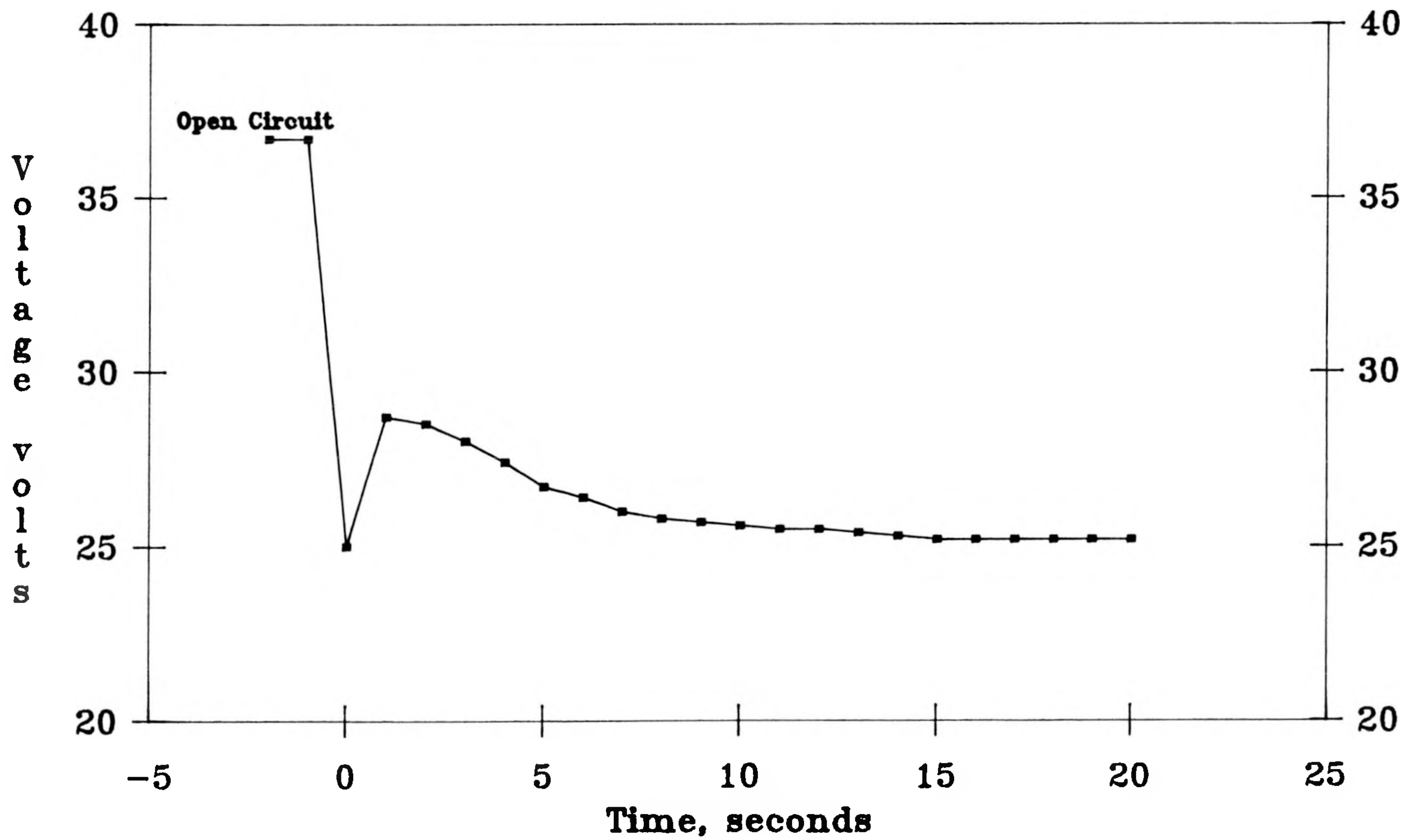

FIGURE 5