DESIGN EVALUATION OF HIGH RELIABILITY LITHIUM BATTERIES

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INTRODUCTION

High reliability batteries are required not only for space applications but also for implantable medical devices as well. In this paper, I will be discussing the techniques used by Medtronic to evaluate high reliability lithium batteries for implantable applications.

Medtronic, Inc., through its Energy Technology division, began manufacturing lithium batteries for implantable device applications in 1977 with the introduction of its lithium-iodine system. Manufacture of lithium-thionylchloride batteries for use in higher current drain applications such as implantable drug pumps and pain control devices began several years later. Because of these applications, the evaluation of each battery design is very important and it is performed with a high reliability goal in mind.

BACKGROUND

Once a new battery design has been established and assembly procedures finalized through prototype test builds, the design must successfully complete a three stage evaluation program. The first stage, design qualification, involves a large battery build intended as the qualification set for the final battery design. Within the next year, production qualification tests begin on actual production batteries. Concurrent with these qualification programs, real time or long term discharge tests are also initiated. The data, along with the qualification program results, are then used to project battery longevity and generate reliability data for each battery design. By utilizing this evaluation sequence, a lithium battery can be verified as capable of meeting the high reliability requirements demanded in applications such as space or implantable medical devices.

TEST METHODS AND RESULTS

The typical design qualification program consists of accelerated discharge tests, calorimetry measurements, environmental exposure, destructive analysis and materials compatibility and corrosion resistance testing. Accelerated discharge is performed at 37°C under various constant current conditions in large walk-in ovens with the batteries positioned in various orientations. Figure 1 shows the voltage behavior of a lithium-iodine battery at current drains of 50-400μA as a function of delivered capacity. The data are then used to construct a mathematical model to project battery longevity at application rates.

During the accelerated discharge tests, several cells from specific tests are periodically monitored for heat output on a Tronac model 315RA calorimeter. The heat output, corrected for polarization effects, for a lithium-iodine battery and a lithium-thionylchloride battery are shown in Figures 2 and 3 respectively. Assuming the heat output is self-discharge related, and after correcting for the entropic heat effect, the capacity loss can be determined and included in the longevity projection calculations.

Environmental exposure tests are performed on all battery designs to simulate worst case conditions the battery might experience during shipping and handling. These tests include subjecting batteries to various combinations of +60 and -40°C temperature extremes combined with mechanical shock and vibration testing, followed by electrical discharge. Abuse tests such as over-discharge, charge, short circuit and shock are also performed on the thionylchloride batteries to determine safety characteristics. Destructive analysis tests are completed to verify the batteries are constructed according to the design engineer's specifications.

The compatibility of all battery components with the reactive electrode and electrolyte materials is best determined by accelerated and actual temperature exposures over the projected battery lifetime. At pre-determined time intervals, several batteries are removed from application rate discharge at 60 and 37°C and the various components shown in Table 1 are examined for signs of corrosion and chemical degradation utilizing scanning electron microscopy, Auger electron spectroscopy, X-ray spectroscopy and other metallurgical and chemical techniques.

Of the indicated phenomena of interest, degradation of the glass in the feedthrough is important, particularly in liquid electrolyte systems. Figure 4 shows a scanning electron micrograph of a typical glass seal from a fresh battery, while Figure 5 shows a glass seal from a liquid electrolyte lithium battery from another manufacturer after approximately 3.6 years exposure. The exposed feedthrough shows extensive glass fragmentation across its entire surface.

This phenomenon has led to premature battery failure in various liquid electrolyte systems. To test for this problem, several of my colleaques have recently developed a technique that examines glass degradation in a matter of weeks instead of years. This technique, detailed at the Fall ECS meeting in New Orleans, involves sputtering nickel onto glass slides, discharging them in the electrolyte of interest and monitoring the current during discharge. SEM/x-ray spectra techniques can then be used to characterize the reaction products.

The last step in the design evaluation involves real time or long term discharge tests. The batteries required for these tests originate from the design qualification build and time samples of production battery builds. Figure 6 compares the real time discharge results for a lithium-iodine battery to the longevity projection. The real time data are tracking the projected curve very well, just as other lithium-iodine battery designs have tracked their projected curves during the past eight years of using this technique. We therefore believe battery lifetime can be reliably forecast after one year of testing instead of the five to ten years typically required to discharge the battery at the application rates.

One method of examining the reliability of batteries at application rate is the calculation of the random failure rate. A summary of random failure rate data for three general lithium-iodine battery designs are indicated in Table 2. Nearly 4400 Type A batteries on laboratory test have accumulated 230 million hours at a random failure rate of 0.0023%/month at a 90% confidence level. With this low rate, this battery design is exhibiting a reliability comparable to silicon transistors and diodes. Type B and C batteries are also accumulating significant device hours with similar low random failure rates.

CONCLUSIONS

Within one year, a lithium battery design can be qualified for device use through the application of accelerated discharge testing, calorimetry measurements, real time tests and other supplemental testing. Materials and corrosion testing verify that the battery components remain functional during expected battery life. By combining these various methods, a high reliability lithium battery can be manufactured for applications which require zero defect battery performance.

Table 1. MATERIALS AND COMPONENTS PERFORMANCE ASSESSMENT.

COMPONENT	PHENOMENA OF INTEREST
METALLIC	• CORROSION — TYPE AND EXTENT (IF ANY)
NON—METALLIC	• CHEMICAL STABILITY AND STRUCTURAL INTEGRITY, INSULATION PROPERTIES
FEEDTHROUGH	• GLASS DEGRADATION • SEAL HERMETICITY
WELD JOINTS	• LOCALIZED CORROSION • INTEGRITY • PENETRATION AND FUSION

Table 2. RANDOM FAILURE RATES FOR LITHIUM IODINE BATTERIES

BATTERY	INITIAL SAMPLE	MAX. YEARS	DEVICE-HOURS	RANDOM FAILURE RATE (%/MO.)
TYPE A	4350	8.9	$230x10^6$	0.0023 *
TYPE B	1887	5.9	$84x10^6$	0.0034
TYPE C	1355	5.4	$37x10^6$	0.0045
SILICON TRANSISTORS				0.0028
SILICON DIODES				0.0011

*LOWEST RFR PRIOR TO NATURAL END-OF-LIFE.

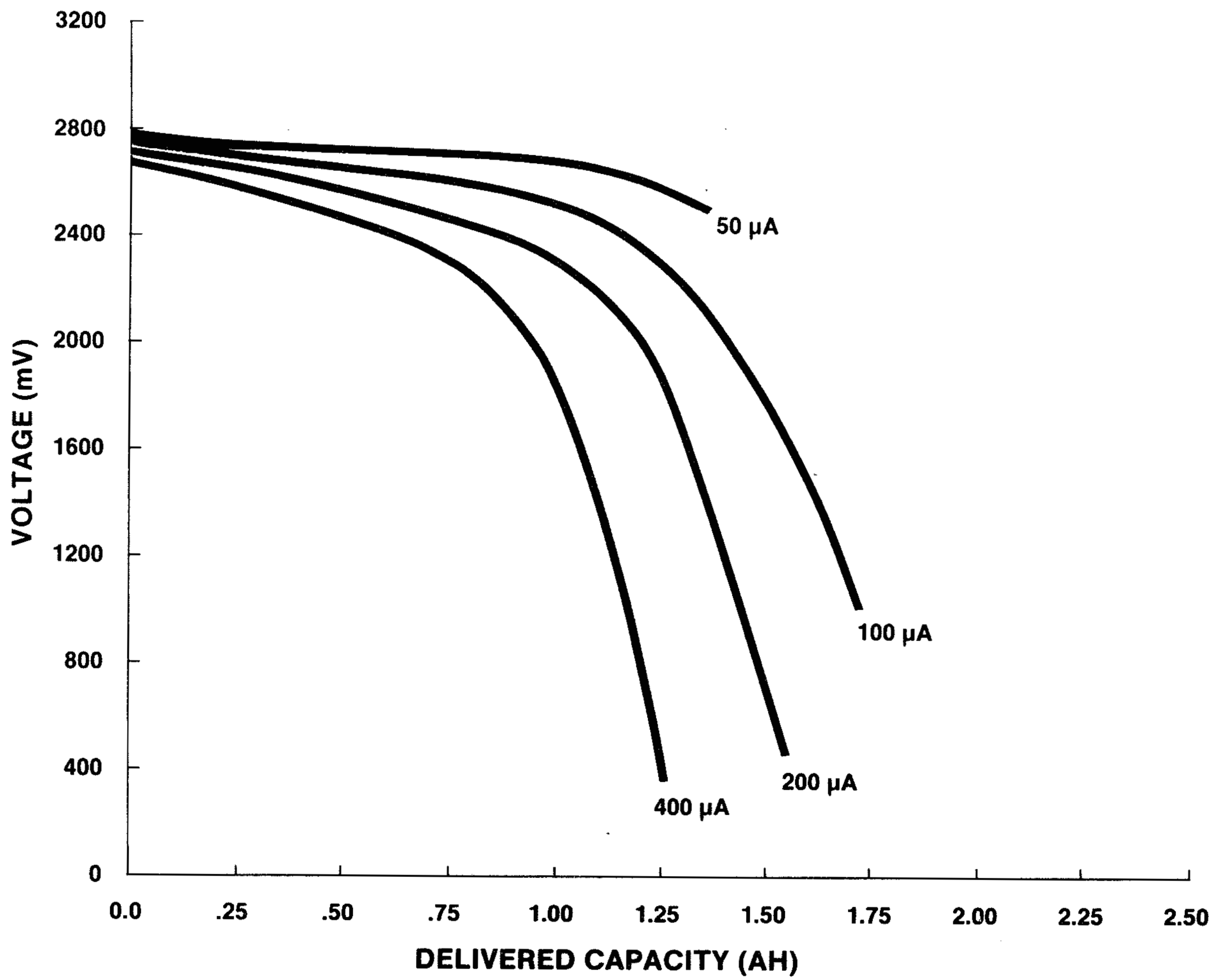

Figure 1 - Accelerated Discharge of a Lithium Iodine Battery.

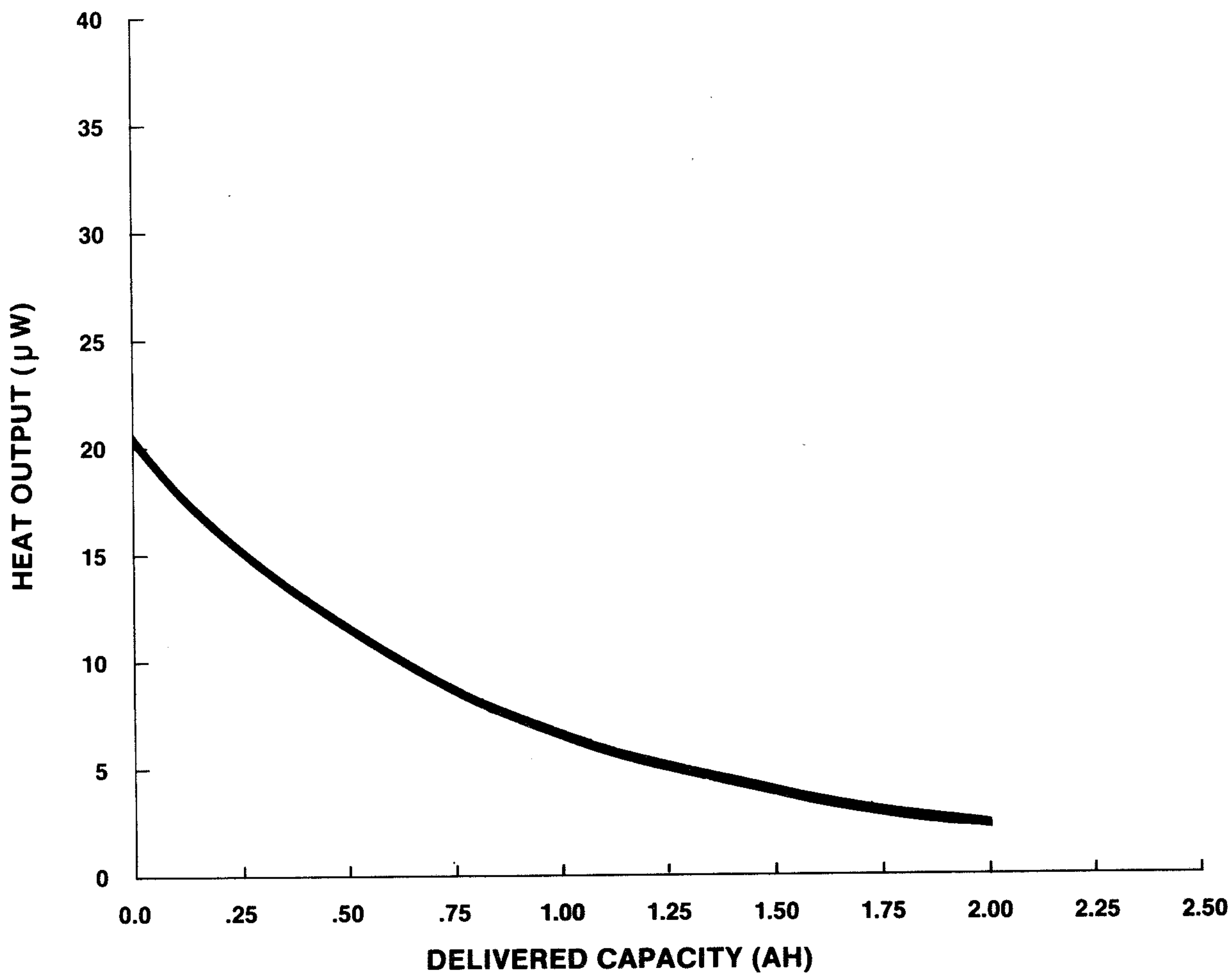

Figure 2 - Heat Output vs. Delivered Capacity-Lithium Iodine Battery.

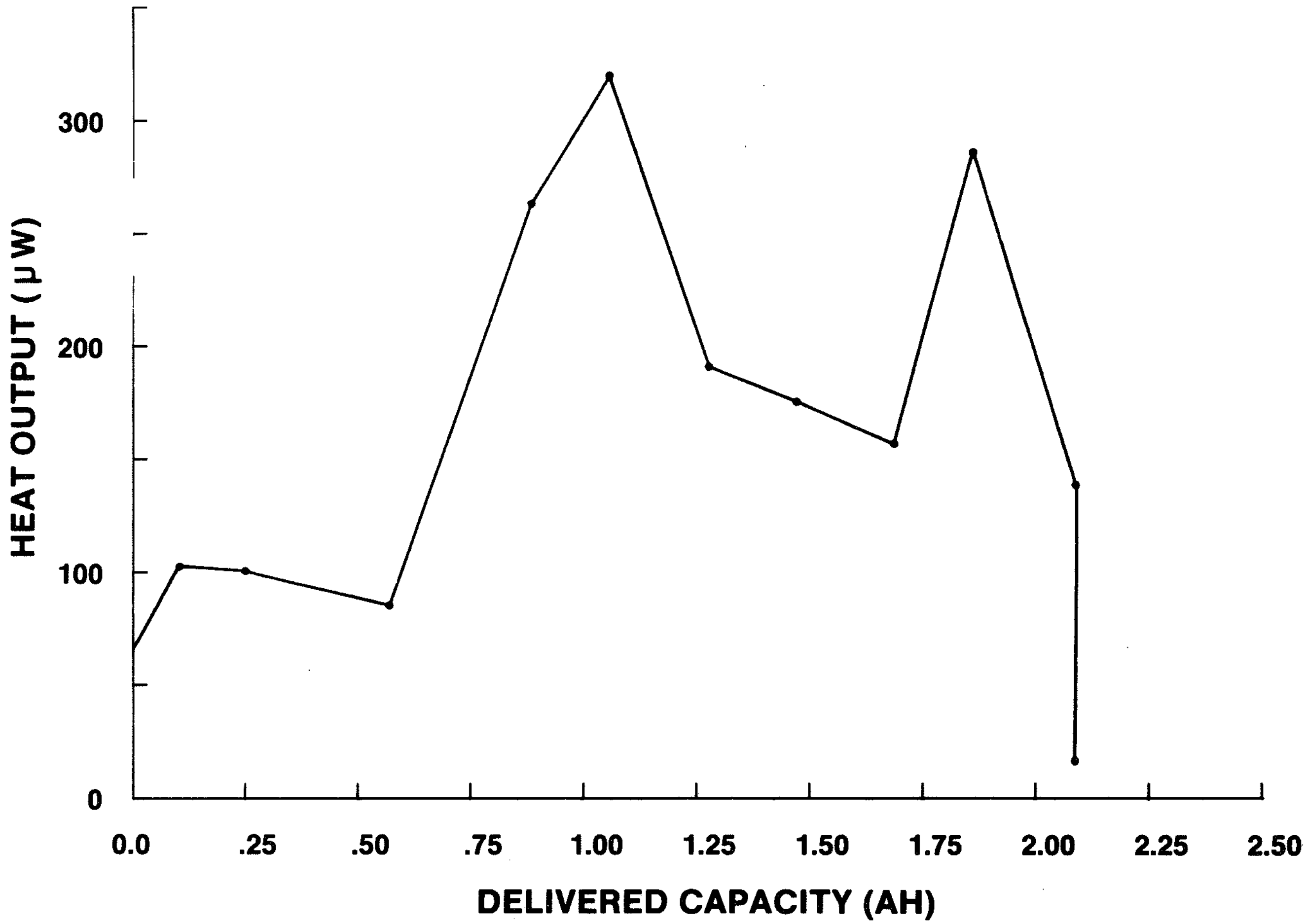

Figure 3 - Heat Output vs. Delivered Capacity-Lithium Thionyl Chloride Battery.

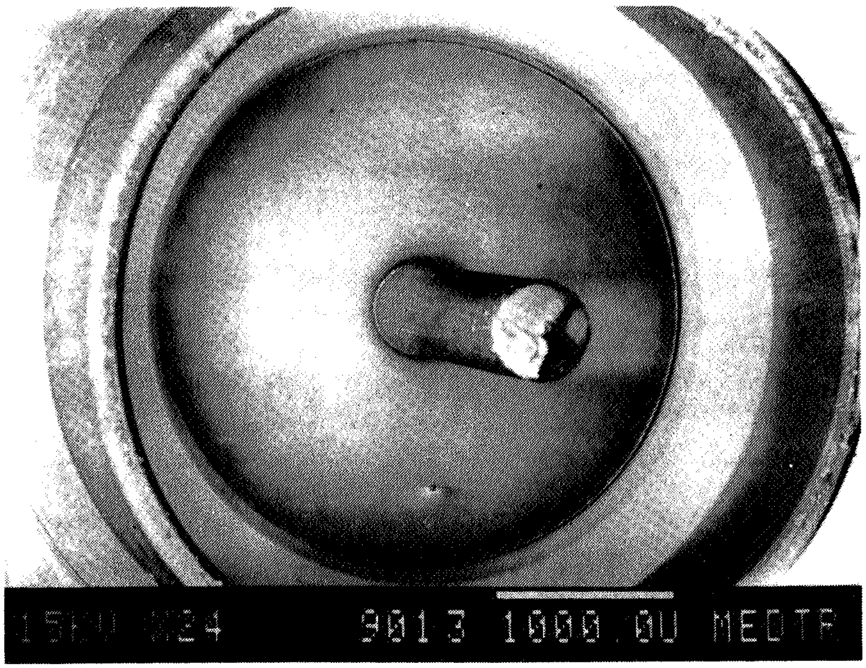

Figure 4. Glass Seal From Fresh Battery

Figure 5. Glass Seal After Exposure to Liquid Electrolyte

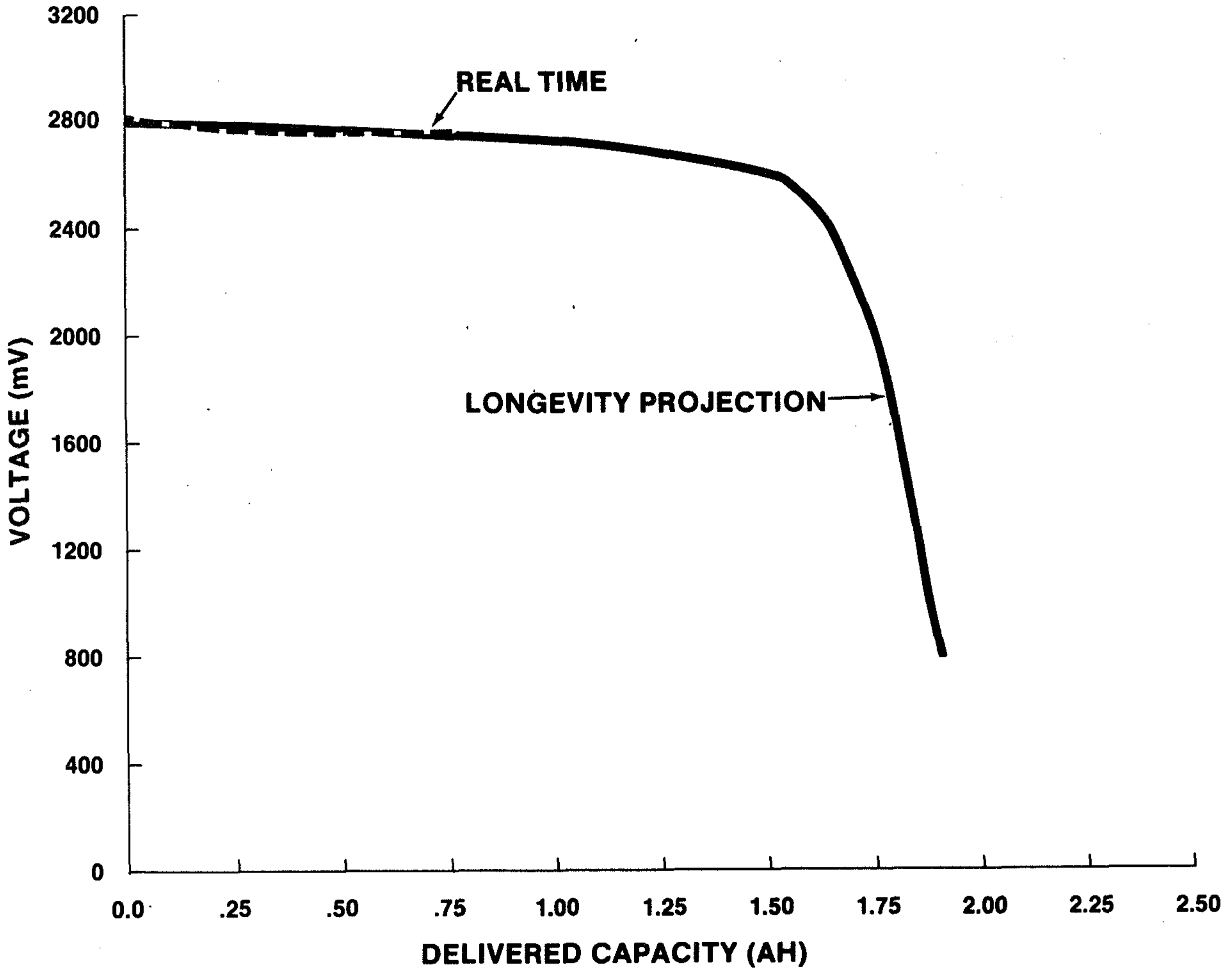

Figure 6 - Realtime Discharge Results For a Lithium Iodine Battery.