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Results from the Testing and Analysis of LDEF Batteries

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Batteries were used on LDEF to provide power to both the active experiments and the experiment support equipment such as the Experiment Initiate System, Experiment Power and Data System (data acquisition system), and the Environment Exposure Control Canisters.

Three different types of batteries were used: lithium sulfur dioxide (LiSO_2), lithium carbon monofluoride (LiCF), and nickel cadmium (NiCd). A total of 92 LiSO_2 , 10 LiCF , and 1 NiCd batteries were flown on LDEF. In addition, approximately 20 LiSO_2 batteries were kept in cold storage at NASA LaRC. This presentation reviews the various investigations and post-flight analyses of the flight and control batteries.

The primary objective of these studies was to identify degradation modes (if any) of the batteries and to provide information useful to future spacecraft missions. Systems SIG involvement in the post-flight evaluation of LDEF batteries has been two-fold: (1) funding SAFT (original manufacturer of the LiSO_2 batteries) to perform characterization of 13 LiSO_2 batteries (10 flight and 3 control batteries) and (2) integrate investigator results. No testing of LDEF batteries occurred at Boeing.

LiSO₂ Batteries

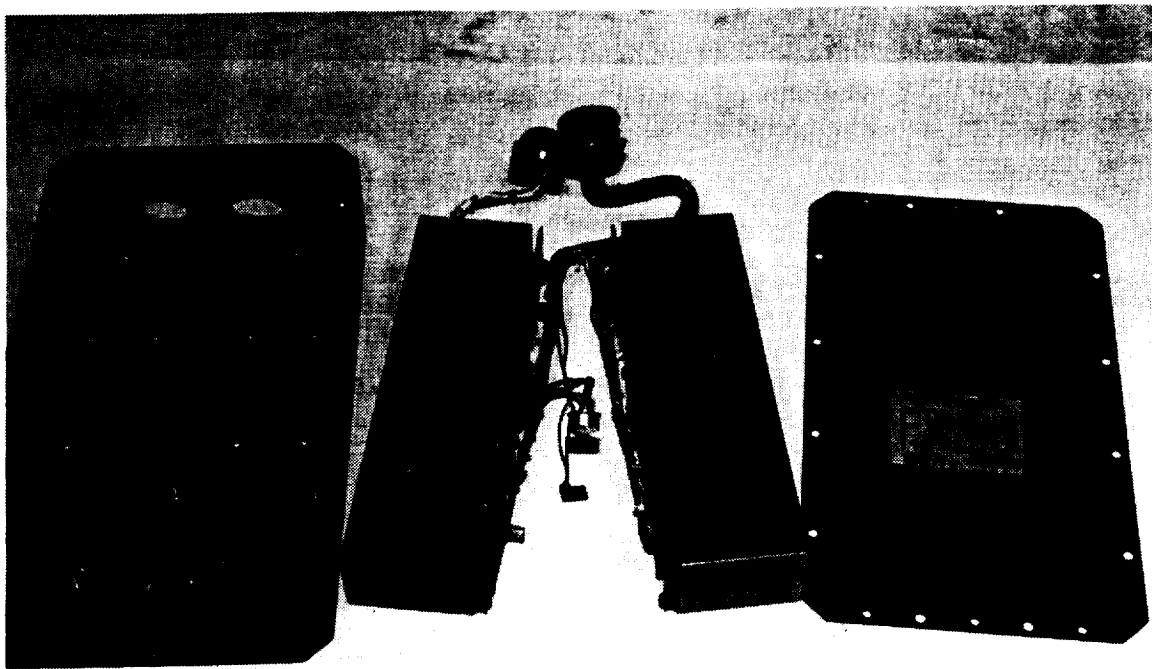
A total of 92 LiSO₂ battery packages (provided by NASA LaRC) were flown on LDEF. These batteries were divided into three voltages: 7.5, 12, and 28 volts. The individual cells were D-size and manufactured by Duracell (the Duracell LiSO₂ division has been purchased by SAFT America). Because many of the active experiments and LDEF support systems experienced cutoff prior to expending the total battery capacity, a large number of batteries had substantial remaining charge when LDEF was retrieved. Several control batteries were kept in cold storage at NASA LaRC throughout LDEF's mission and were then made available to the battery community.

During LDEF de-integration at Kennedy Space Center, all batteries were checked for evidence of leaks and post-flight voltages determined. No remaining capacity measurements were made.

SAFT America received 10 flight batteries and 3 control batteries for comparative evaluation and destructive physical analysis. The results are contained in the footnoted reference. The retained capacity testing of three control batteries showed that the capacity loss over approximately 69 months was around 11%. The one unused battery flown on LDEF suffered an almost 30% capacity loss. The difference in capacity loss is attributed to differences in ambient temperatures. The ground-stored batteries did not see temperatures above 40° F whereas the flight batteries were subjected to temperature ranges from 40° F to over 95° F during the LDEF mission. The LiSO₂ batteries suffered capacity loss due to parasitic reactions.

The following four figures show representative photographs of the LiSO₂ battery disassemblies performed at SAFT. This figure shows both a LiSO₂ battery case disassembled and a close up of a LiSO₂ cell block.

* Raman, "Experimentation and Destructive Physical Analysis for the Space-Exposed LiSO₂ Batteries from the LDEF," SAFT America, Inc., 1991.



LiSO₂ Battery Case Disassembled



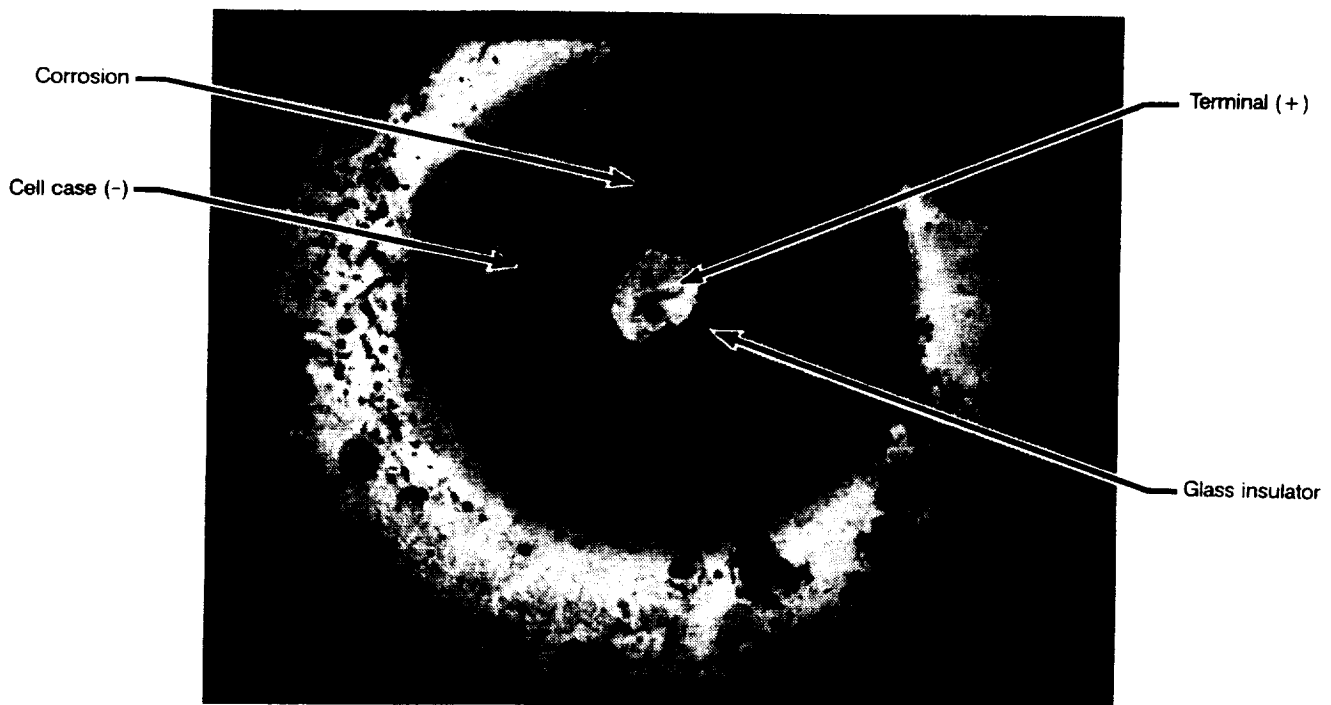
Closeup of LiSO₂ Cell Block

Results of LiSO₂ Investigations Con't

This figure shows a LiSO₂ cell opened and a close up of the corrosion around the glass to metal seal. The corrosion around the seal was expected and was also found on the control batteries.



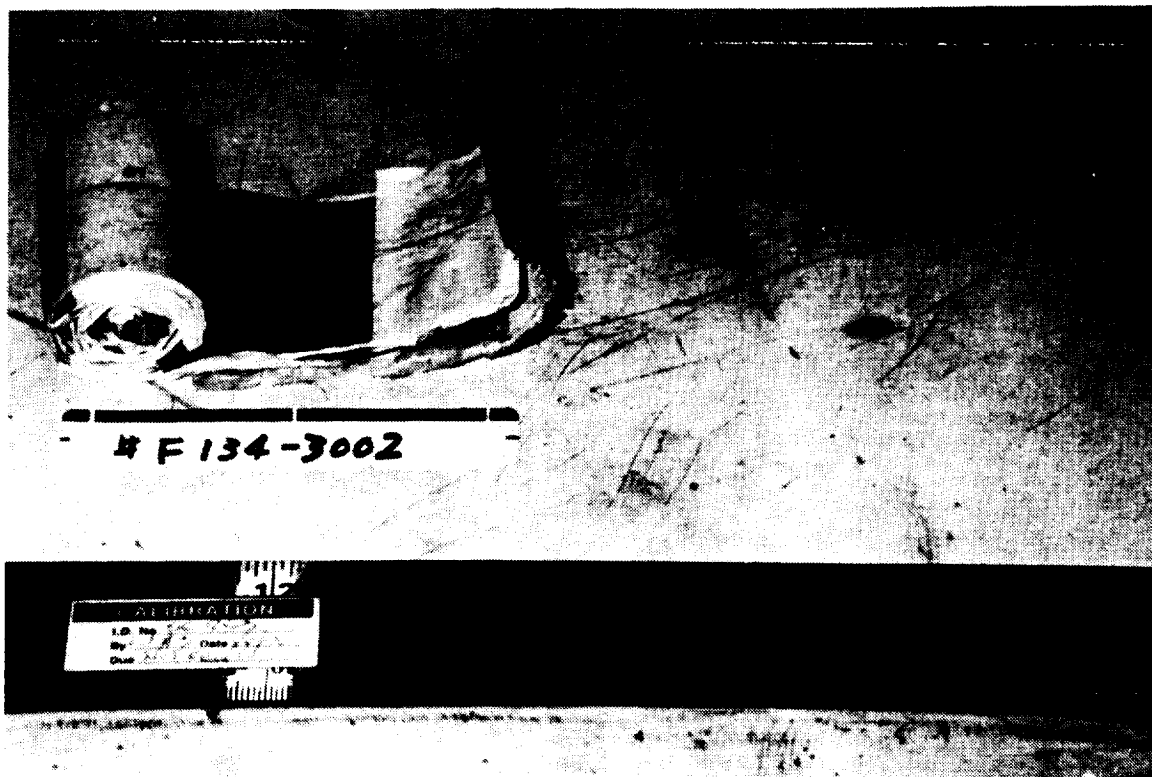
LiSO₂ Cell Opened



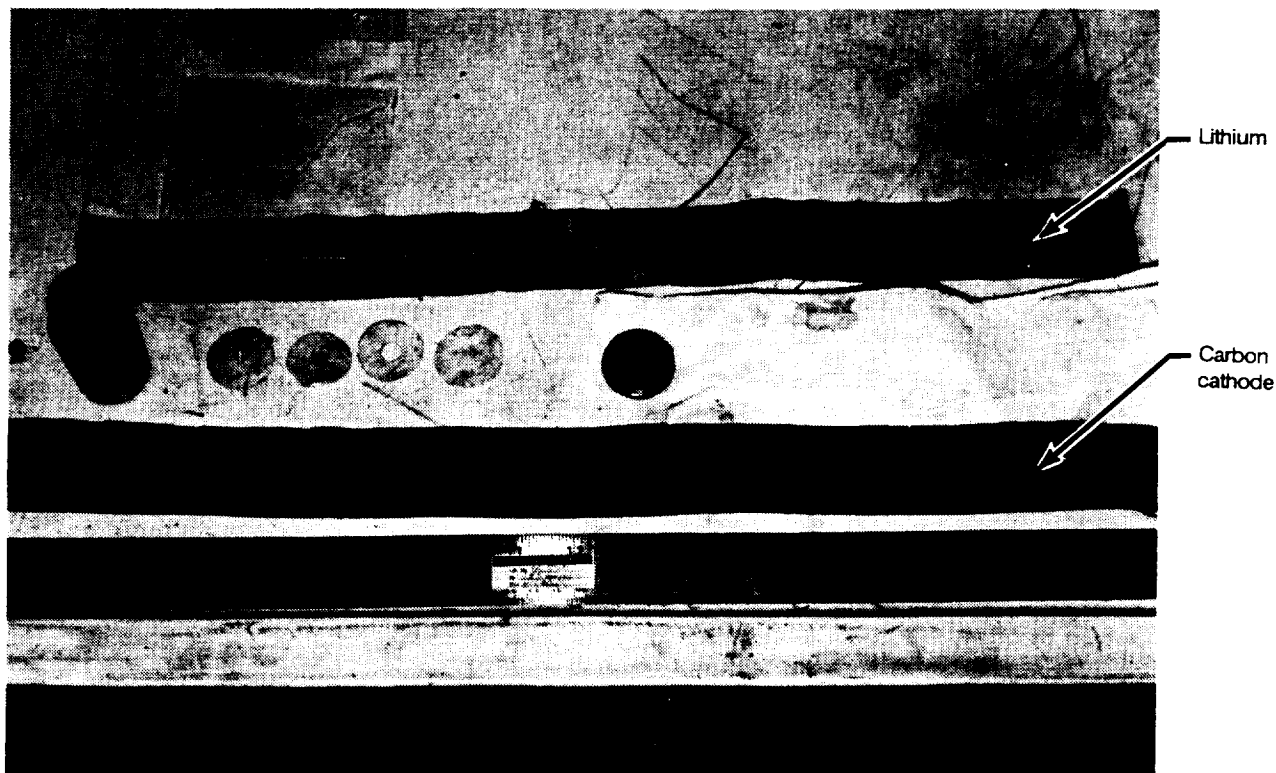
Closeup of Glass to Metal Seal

Results of LiSO₂ Investigations Con't

Shown is the condition of the lithium anode and the carbon cathode from a control battery. Note the good condition of the lithium strip.



LiSO₂ Cell Electrode Materials



LiSO₂ Cell Components - Control Cell

Results of LiSO_2 Investigations Con't

This photo shows the lithium and carbon from a flight battery that was at a 35% state of charge. Note the absence of lithium.



LiSO_2 Cell Components – Flight Battery With a 35% State of Charge

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Investigation of LiCF Batteries

Investigation of the LiCF batteries has been performed by AZ Technology, NASA MSFC, and Naval Weapons Support Center. All ten LiCF batteries were used on the two active MSFC experiments: four batteries were used on the MSFC heat pipe experiment (Experiment S1005) and the other six were used on the Thermal Control Surface Experiment (Experiment S0069). As predicted, all ten batteries were depleted on return of LDEF. The required experiment life was 12 months, with an expected life of 15 to 18 months. All ten batteries met or exceeded life expectations

The cells were roughly double D size having vented construction with a rated capacity of 25 Ah and a nominal voltage of 3 volts. The cells were potted in a plastic block and hermetically sealed with a "can opener" vent for relief of cell over-pressure.

LiCF BATTERIES

- **Used on MSFC experiments**
 - **S0069 & S1005**

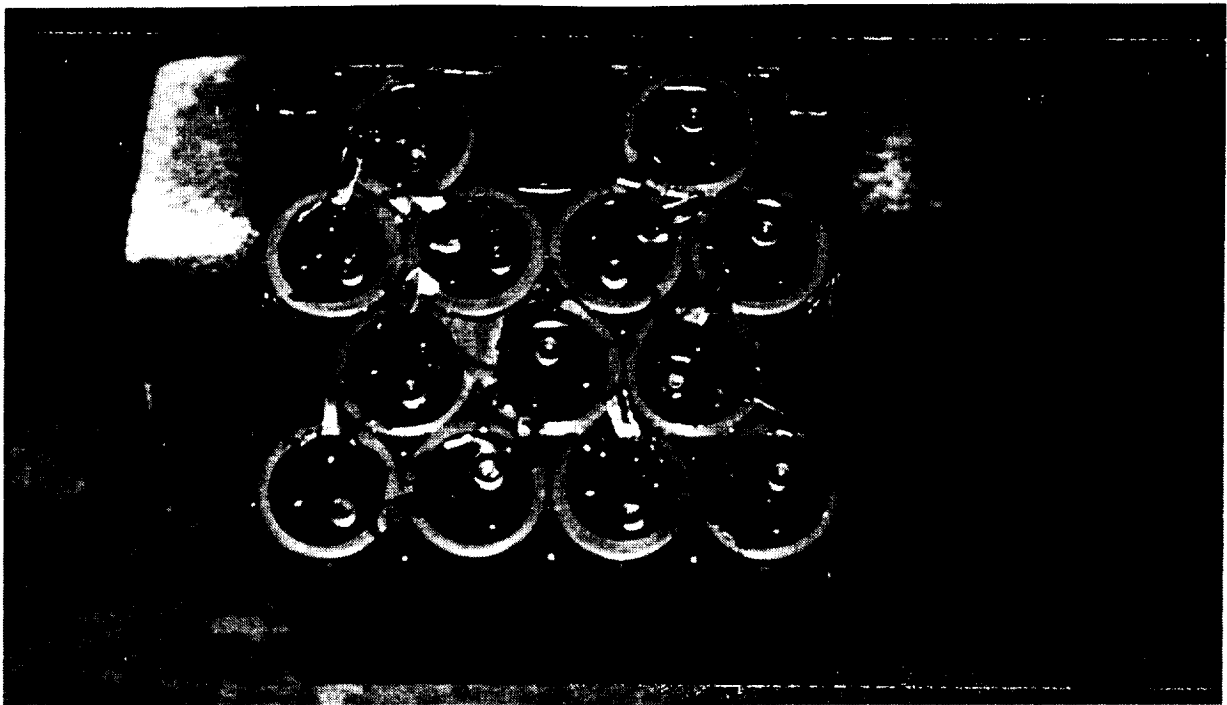
- **All ten batteries returned depleted**

- **S0069 battery life was 19.5 months**
 - **Anticipated lifetime was 15-18 months**

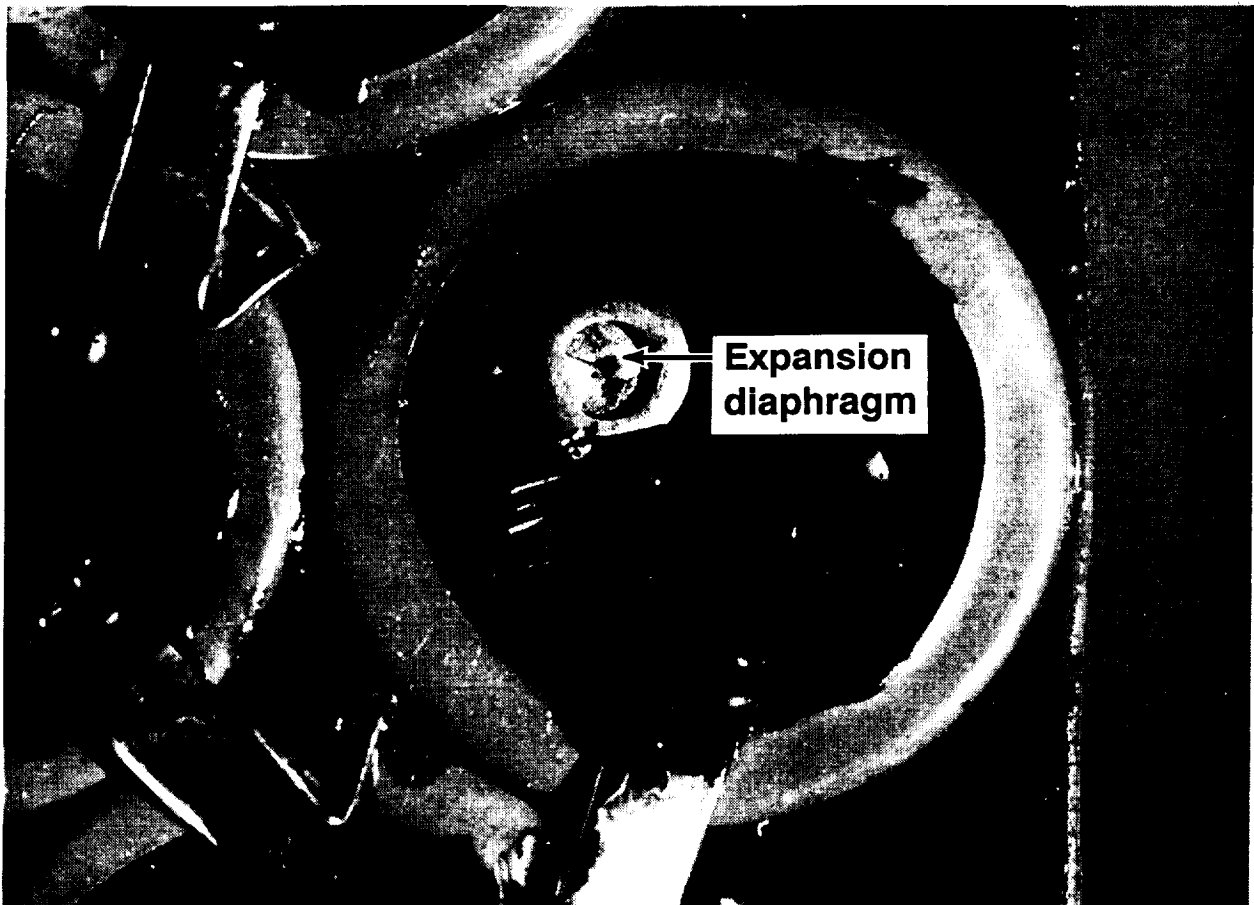
- **Noticeable order evident for all batteries**
 - **Source identified as the electrolyte**
 - **O-ring did not operate as designed**

LiCF Electrolyte Leakage

All ten LiCF batteries possessed a strong odor, first noticed during the deintegration of S0069 and S1005 at MSFC. The electrolyte used in the Eagle-Picher Industries LiCF batteries is dimethyl sulfite, which contains small amounts of other sulfur compounds that can be quite odorous. AZ Technology investigated the cause and effect of the leaked electrolyte vapors from the ethylene propylene battery containment case. The presence of the odor was determined to be the normal byproduct of the discharge process. The LiCF cell is designed with an expansion diaphragm on the top of the cell with a sharp, rigid protrusion adjacent to the diaphragm. This photo shows a LiCF battery (made up of 13 individual cells) removed from the battery case. The diaphragm expanded during the slow discharge process when internal cell pressure increased. Eventually the diaphragm was punctured, releasing the electrolyte vapors. The cells were sealed in battery boxes. The O-ring seal experienced softening and deformation due to the extended exposure to the electrolyte vapors which allowed the vapors to leak from the battery box. However, this created no performance problem for the battery or associated experiment hardware. It is important to note that the ground-stored LiCF batteries experienced the same phenomena.



LiCF Cells Removed From Battery Case



LiCF Cell

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LICF Voltage Versus Time On-orbit

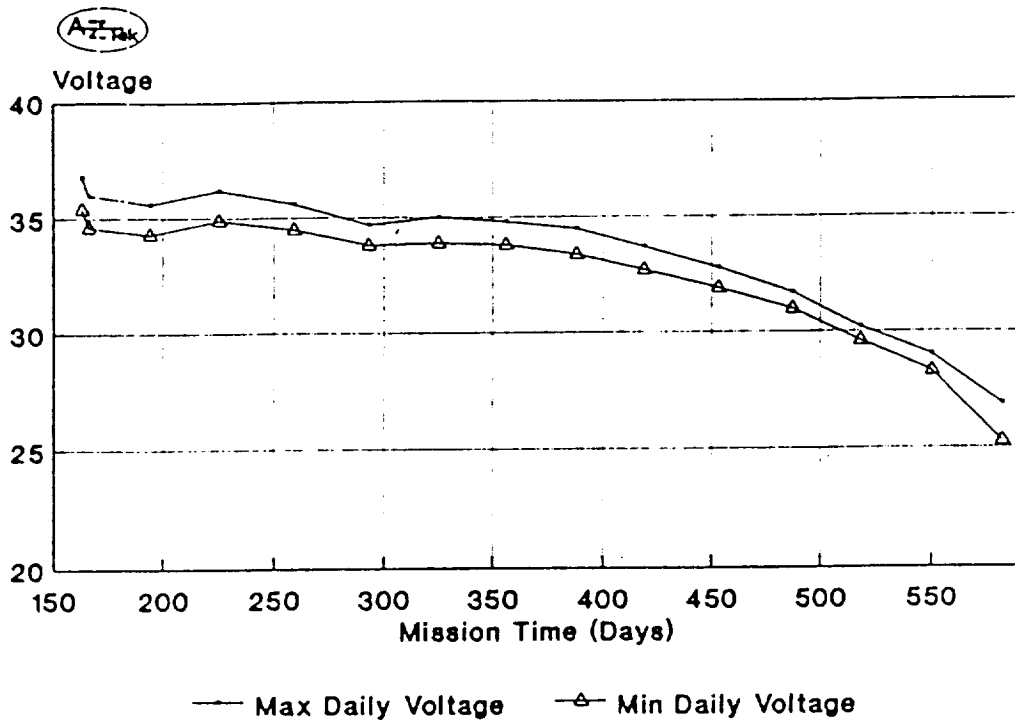
This figure, provided by AZ Technology, shows the gradual degradation of battery voltage versus time for one of the four batteries used on S0069.

Lithium Carbon Monofluoride Batteries - LDEF Flight Data

Gradual Degradation of Voltage with Flight Duration

12 Month Mission - Achieved

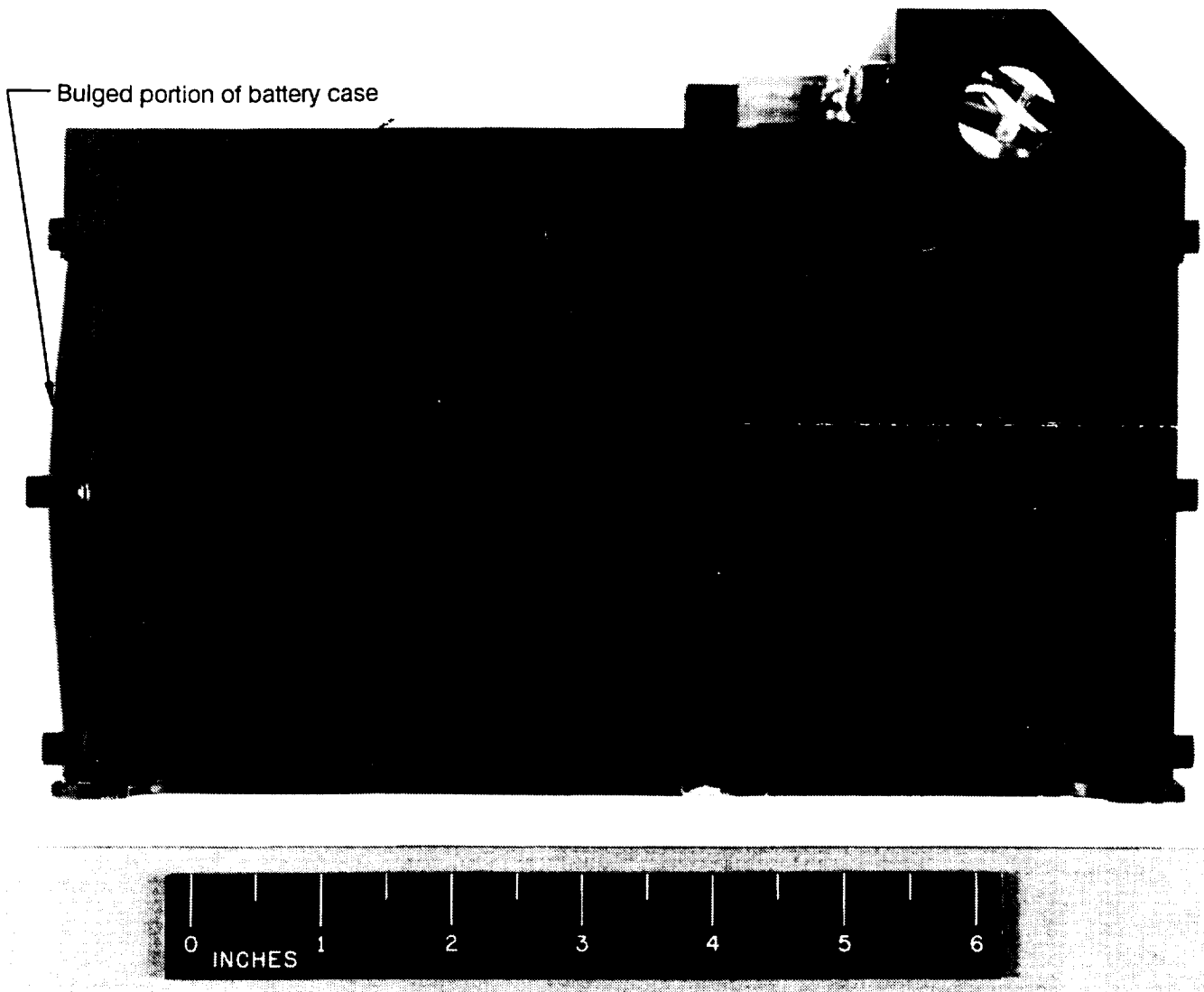
12 to 18 Month Expected Life - Achieved



Investigation of the Nickel Cadmium Battery

One NiCd battery manufactured by General Electric was flown on the Low Temperature Heat Pipe Experiment (Experiment S1001). This battery was continuously charged by a four arrays of solar cells which were located on the space end of LDEF. Analysis and testing of the battery was performed by S. Tiller and D. Sullivan of NASA GSFC. The battery consisted of 18 cells, which were mounted on an aluminum baseplate. Pre-flight power analysis for the 12 Ah NiCd battery indicated a need for 2 to 3 amp discharge. However, reduction in the experiment current requirements during flight resulted in much lower power demand. This led to an overcharging situation that caused the development of internal pressure, resulting in the bulging of the cell case. This bulging is especially noticeable on one end of the cell pack, as shown in this figure.

LDEF/HEPP
POWER SYSTEM BATTERY
(12-AH NiCd)



Bulging of NiCd Battery Case

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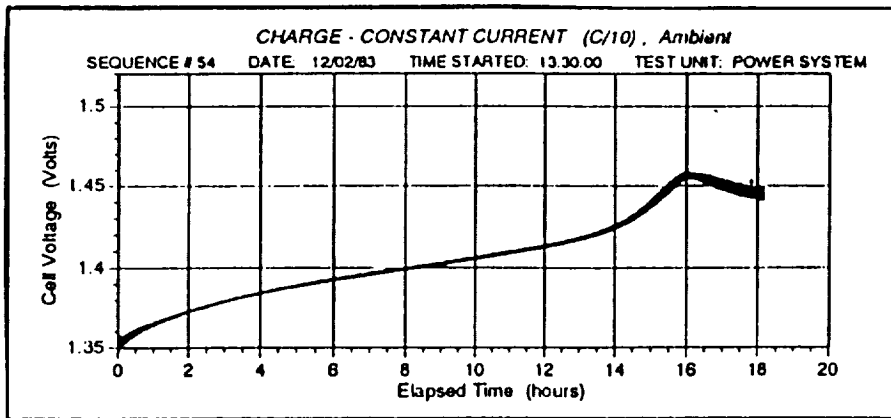
Loss of NiCd Overcharge Protection

The loss of overcharge protection is obvious from the difference in voltage performance shown for the pre-flight and post-flight measurements of cells on constant current, as shown in this figure. Pre-flight charge profile showed all cells were matched and reached full state of charge in 18 hours, while maintaining voltage below 1.46 volts. Post-flight data showed considerable differences between cells with cell #10 (this cell bulged the most during the mission) reaching a high voltage of 1.52 volts which tripped the charge for the battery off at 14 hours of charge. Discharge testing produced similar results.

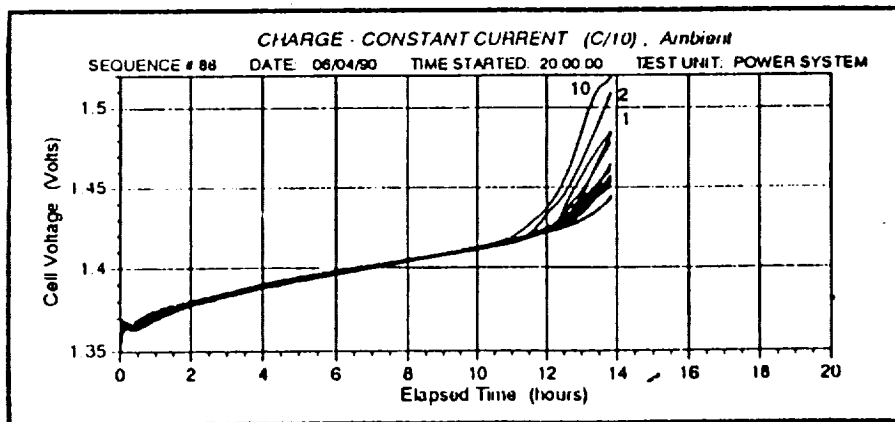
Despite the obvious bulging of some cells, loss of overcharge protection, and failure of cell #10 during the open circuit recovery test, the battery still had the capability to provide output current in excess of the cell manufacturer's rated capacity of 12 Ah.

NiCd Battery

Constant Current Charge Indicates Loss of Overcharge Protection



Pre-flight Capacity Charge



Post-flight Capacity Charge showing loss of overcharge protection

Summary of LDEF Battery Findings

All LDEF batteries were mounted on interior surfaces of LDEF and, therefore, experienced a mild temperature environment. All batteries met or exceeded their predicted post-flight state-of-charge.

The LiSO₂ batteries exhibited good charge retention, with a loss in capacity of an unused flight battery of less than 5% per year. The LDEF LiSO₂ batteries showed charge retention properties commensurate with that expected, based on the temperatures experienced by these batteries. The favorable performance underscores the merit of the selection of LiSO₂ batteries of similar design for the Galileo mission.

Testing completed at the Naval Weapons Support Center investigated the post-flight condition of three LiCF batteries: one flight battery provided by MSFC, one control battery discharged to 0 volts prior to dissection, and one control battery dissected as received. Their findings showed that no significant changes occurred in the chemistry or function of the LiCF cells as a result of operation on LDEF. The differences found in material compositions were either trivial, or when significant, a result of long term degradation of cell electrolyte in storage prior to discharge.

The NiCd battery showed the effect of loss of overcharge protection. However, this did not affect the on-orbit performance.

For additional information, the reader is referred to the Systems SIG report dated February, 1992.

LDEF BATTERY SUMMARY

- **LDEF batteries met and exceeded design requirements and predicted lifetimes.**
- **LiCF flight batteries experienced leakage of electrolyte vapors.**
 - **Similar phenomena occurred for ground stored LiCF batteries.**
- **NiCd battery suffered loss of overcharge protection.**

