PRELIMINARY SILVER-HYDROGEN CELL TEST RESULTS

Charles Lurie
TRW Space and Technology Group

ABSTRACT

Silver-hydrogen cells have been on test at TRW since July, 1982. The objective of the test is to estimate useful life by operation at accelerated, simulated geosynchronous orbit conditions. Ten simulated seasons have been run and are summarized. The results to-date reflect stable, trouble-free performance and indicate that the silver-hydrogen couple shows promise as a lightweight alternative to the nickel systems.

INTRODUCTION

The silver-hydrogen couple is attractive because of its high specific energy and energy density. At the last Battery Workshop SAFT presented test results obtained with silver-hydrogen cells designed and built in their aerospace facility in Romainville, France.(1) The results reported were encouraging and projected a specific energy in the range 65 to 80 Wh/kg and an energy density in the range 50 to 60 kWh/m^3. TRW purchased four of these cells in 1981 and started testing in 1982. This paper presents a summary of the testing to-date including the objectives, the test articles, the test plan and setup, and preliminary test results.

The primary objective of the test is to estimate the useful life of the SAFT silver-hydrogen cells by operating them at accelerated, simulated geosynchronous orbit conditions. Testing is restricted to the geosynchronous orbit application because the limited number of test articles dictate a single set of operating conditions, and it appears that booster limitations will continue to make battery specific energy a more important parameter for high-altitude missions than for low-altitude missions.

A secondary objective is to identify spacecraft integration issues peculiar to the silver-hydrogen couple. These will include discharge voltage characteristics, thermal characteristics, and charge management issues.

TEST ARTICLES

The test articles are type HRA 46S silver-hydrogen cells manufactured by SAFT in Romainville, France. SAFT rates the cell at 46 ampere-hours and indicates that beginning-of-life capacity, for an 11.2-ampere discharge at

23 ±2°C, is 58 ampere-hours following 22 hours of charge at 2.8 amperes. This discharge is terminated at 0.8 volts and the charge voltage limited at 1.65 volts. Testing at TRW, using the same charge-discharge cycle, yielded average capacities of 54.8 ampere-hours at 10 ±2°C and 56.0 ampere-hours at 15 ±2°C. Analysis of these data results in a capacity temperature coefficient of 0.25 Ah/°C.

Maximum cell operating pressure is specified at 40 atmospheres for the HRA 46S cells using Inconel 625 containers. New containers made from Inconel 718 are available and will be rated at 70 atmospheres maximum pressure. Rated specific energy is 75 Wh/kg at 23 ±2°C. During characterization testing at TRW the average specific energy observed was 69 Wh/kg at 15 ±2°C. Following eight charge-discharge cycles, each consisting of 22 hours of charge at 2.8 amperes followed by an 11.2-ampere discharge to 0.8 volts, the observed specific energy was 66 Wh/kg. The cells weigh 880 grams and are filled with 193 ml of 10.3 N potassium hydroxide electrolyte.

With the exception of the silver electrode and the separator the components of the silver-hydrogen cells under test are similar to those of a nickel-hydrogen cell. The chemistry, as indicated in figure 1, is simply that of the silver and hydrogen electrodes. The silver electrode, made by the SAFT continuous rolling process, is 0.57 millimeter thick with a porosity of 60 percent and utilizes an expanded silver grid. The separator consists of multiple layers of nonwoven nylon Pellon material adjacent to the silver electrode and multiple layers of Yardney C19 cellophane.

TEST PLAN

The four silver-hydrogen cells were placed on test in July 1982 and have been operating continuously since. The life test simulates geosynchronous orbit cycling and is preceeded by a series of characterization cycles which will be repeated after completion of the life test. Eclipse seasons during the life test consist of 45 12-hour days with the "stepped" eclipse duration profile shown below. Solstice seasons are shortened to one week during which the cells are discharged at 29.2 amperes to 0.8 volt and recharged.

Day	Eclipse Duration (Minutes)
1-5, 41-45	32
6-10, 36-40	50
11-15, 31-35	62
16-20, 26-30	68
21-25	72

During the course of the test it is anticipated that conditions will be varied to simulate various loads and charge management approaches.

The test cells are mounted in aluminum jackets heat sinked to a thermostatically controlled thermal plate maintained at 5 $\pm$2°C.

Charge management consists of charging the cells at 3.8 amperes until the capacity recharged equals the capacity discharged during the cycle or the cell voltage exceeds 1.67 volts. The cells are then trickle charged until the next eclipse entry. The objective of this approach is to maintain a recharge ratio very close to 1:1. The silver-hydrogen couple's high charge efficiency and low self discharge rate make this feasible. Maximum end-of-charge cell pressures are maintained below 600 psi.

Thus far all eclipse discharges have been at the 29.2-ampere rate. For the maximum duration (72 minutes) eclipse discharges this is equivalent to depths-of-discharge of 76 percent of rated capacity or 63 percent of measured capacity.

RESULTS

Typical voltage, current, temperature, and pressure characteristics observed during low-rate charging are shown in figure 2. The two-plateau voltage curve and the linear pressure rise are characteristic of the system.

Similar characteristics are depicted in figure 3 for a typical C/2 rate discharge performed prior to the life test. The small contribution of the peroxide plateau is typical of results obtained with this type of cycling. The pressure curve is linear.

Inspection of the plot of minimum end-of-discharge voltages versus eclipse season day for Seasons 3, 5, 7, and 10 shown in figure 4 reveals two interesting points:

- The range of end-of-discharge voltages observed during a season is less than observed with a nickel system.
- No season-to-season trend is apparent indicating the absence of degradation through the 10 simulated seasons depicted.

The voltage levels may appear to be a little low but are attributed to an average end-of-discharge temperature of about 8°C.

The cell internal pressure versus eclipse season day relationship shown in figure 5 is typical. Data are presented for both end-of-charge and end-of-discharge pressures. The end-of-charge pressure data plotted represents end-of-trickle charge pressure as this is a more accurate indication of state-of-charge, going into eclipse, then the pressure recorded at switch down from full to trickle charge. The relationships are smooth and suggest a stable configuration.

Despite the smooth and stable end-of-charge and end-of-discharge pressure relationships, analysis of the evolving data base revealed that the minimum end-of-discharge voltage was tracking the previous end-of-charge pressure as can be seen in Figure 6. Although this observation has not yet been investigated, it appears to be related to the fact that it is difficult to return to the same state-of-charge each day when the charge management approach is based on a recharge ratio of 1:1.

It seems probable, as a general observation, that charge management approaches for the silver-hydrogen cell will need to be more sophisticated than for either the nickel-cadmium or nickel-hydrogen system.

CONCLUSION

Results to date indicate that the silver-hydrogen cell shows promise as a lightweight alternative to the nickel systems. Testing at TRW has been restricted to geosynchronous orbit simulation, and this conclusion should be considered in that context. However, the stable, trouble-free performance observed thus far suggests that the system should also be evaluated at low earth orbit conditions.

REFERENCE

1. B. J. Goualard, P. Fougere.: Status of SAFT Silver Hydrogen Cell Development. 1982 Goddard Space Flight Center Battery Workshop, 16-18 November 1982, NASA CP 2263, p. 347.

- **Silver Electrode**

$$2\,Ag + 2\,OH^- \rightleftharpoons Ag_2O + H_2O + 2e$$

$$Ag_2O + 2\,OH^- \rightleftharpoons 2\,AgO + H_2O + 2e$$

- **Hydrogen Electrode**

$$4\,H_2O + 4e \rightleftharpoons 2\,H_2 + 4\,OH^-$$

- **Overall Reaction**

$$Ag + H_2O \rightleftharpoons H_2 + AgO$$

- **During Overcharge**

$$4\,OH^- \longrightarrow 2\,H_2O + O_2 + 4e \qquad \text{(Silver Electrode)}$$

$$2\,H_2 + O_2 \longrightarrow 2\,H_2O \qquad \text{(Hydrogen Electrode)}$$

Figure 1. The Silver-Hydrogen Couple.

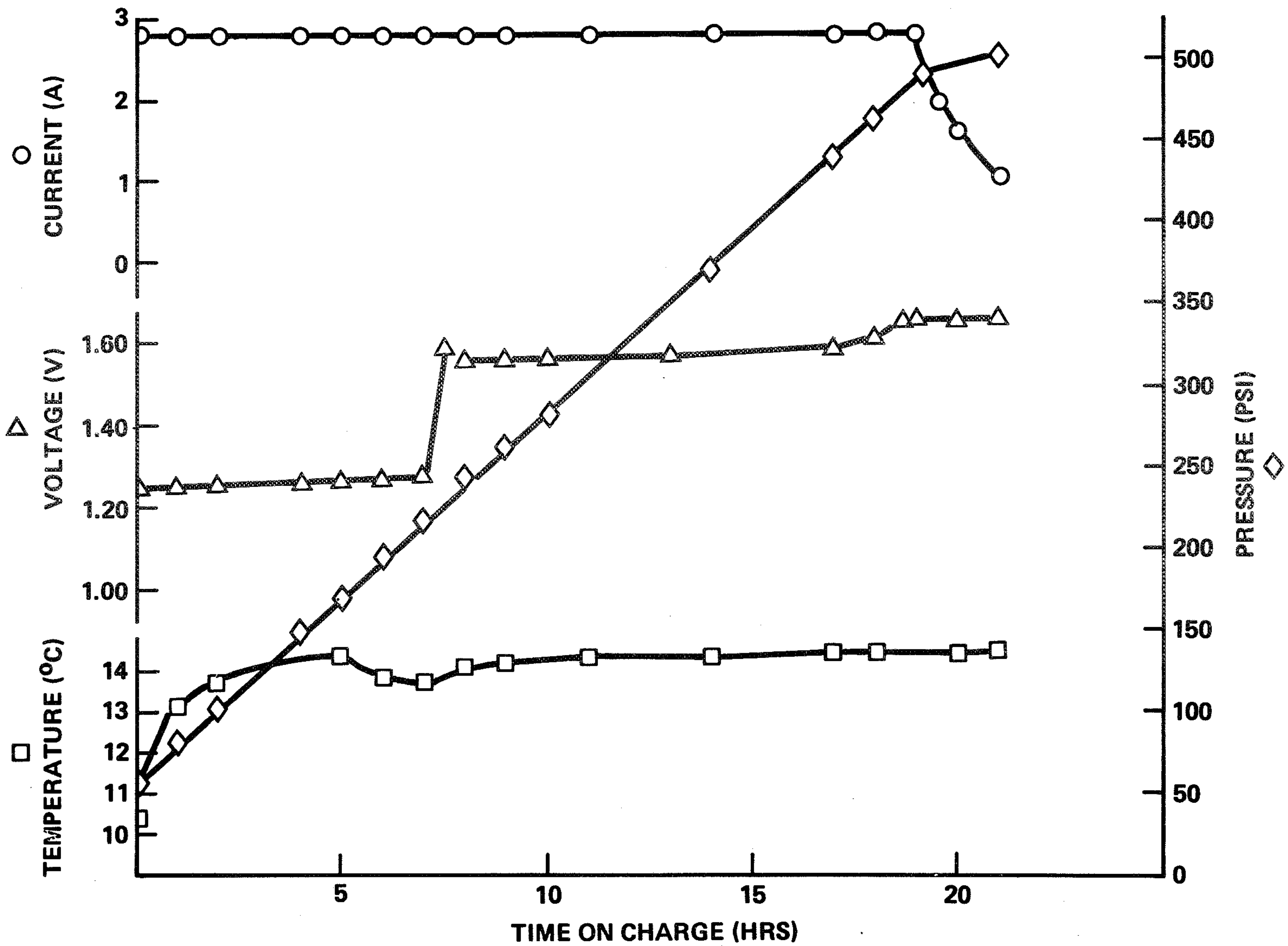

Figure 2. Typical Low-Rate (C/16) Charge Characteristics Prior to Life Test.

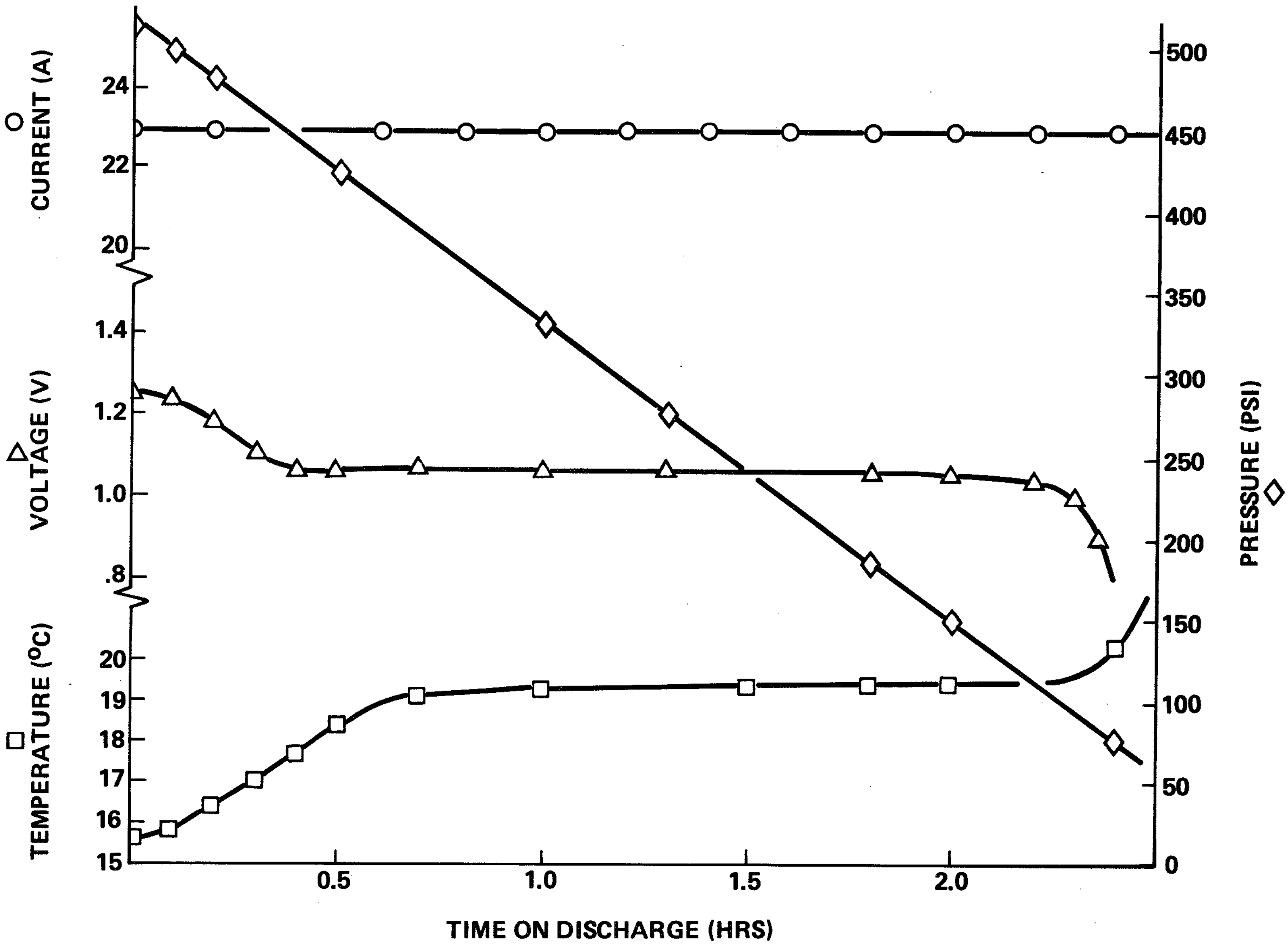

Figure 3. Typical C/2 Discharge Characteristics Prior to Life Test.

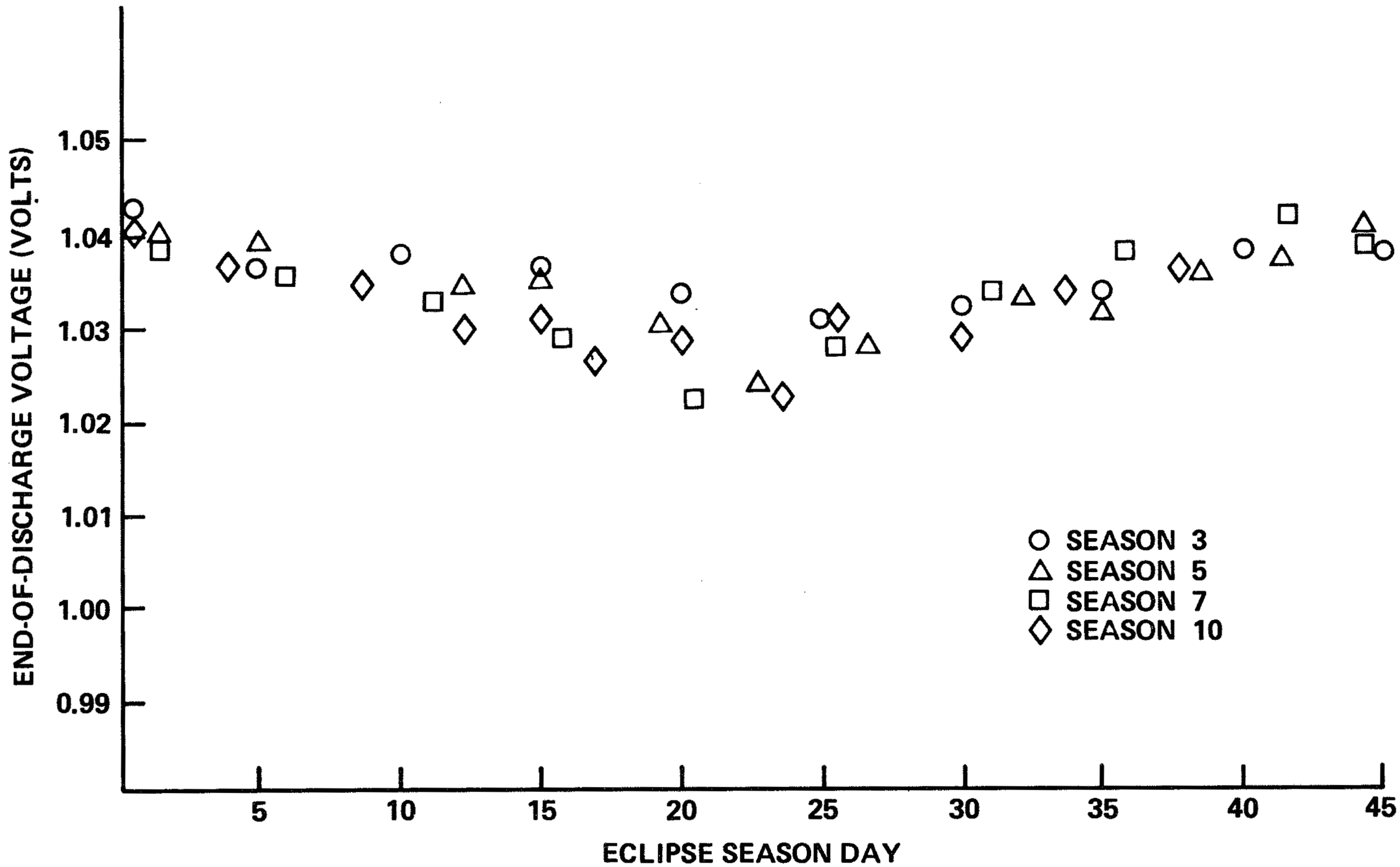

Figure 4. End-of-Discharge Voltage Versus Eclipse Season Day for Seasons 3, 5, 7, 10.

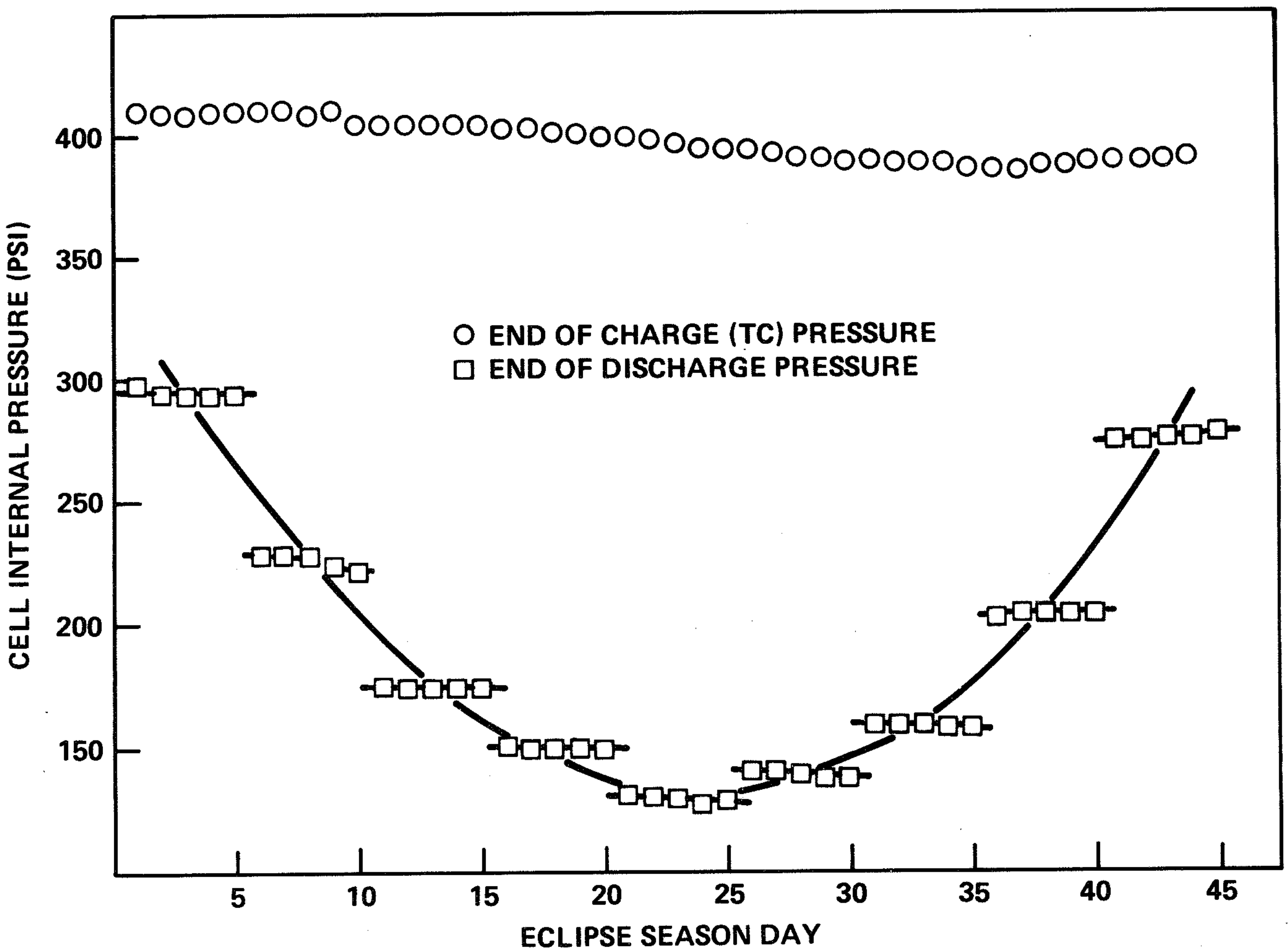

Figure 5. Cell Internal Pressure Versus Eclipse Season Day - Season No. 7.

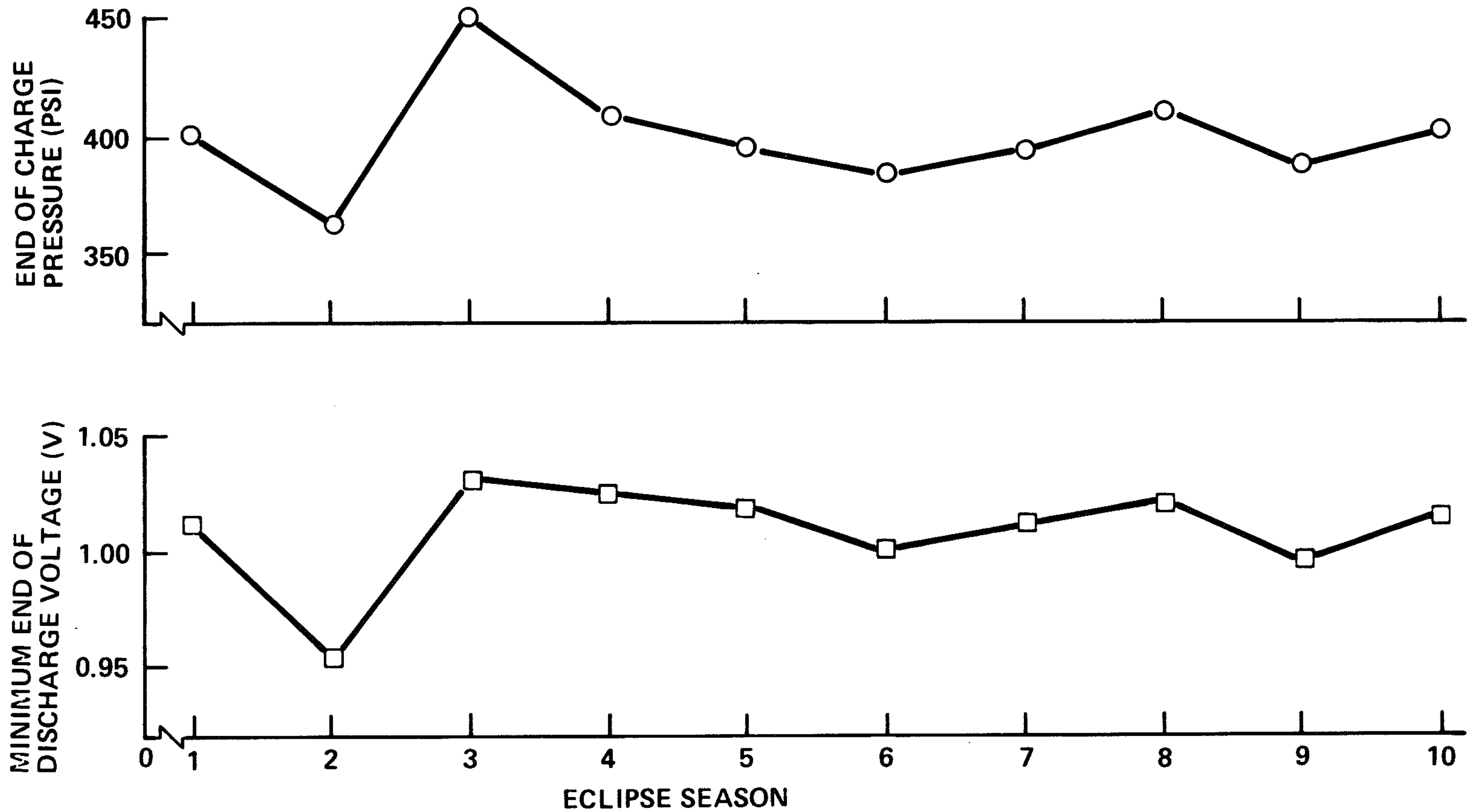

Figure 6. Relationship Between End-of-Charge Pressure and Subsequent End-of-Discharge Voltage.

SESSION V

DISCUSSION

Q. Unidentified, Aerospace Corp.: Have you taken any cells apart yet?

A. Lurie, TRW: No we are going to wait for one to fail.

Q. Dunlop, Comsat: One question when you are estimating 25% energy density or weight savings the only thing I don't understand is you've got about 10% improvement in energy density. Your measured 66 watt hours per pound or one hour per kilogram rather is about the same as the 60 watt hours per kilogram now so you got about a 10% advantage right now.

A. Lurie, TRW: That's .66 we ought to compare apples and apples that 66 was an actually achieved number at a given temperature. If we take the maximum specific energy that we could measure if we were looking for the maximum number I think we would be up near 80. This was a 66 under specific set of conditions at a temperature which gave us less than the max and after eight deep cycles.

Q. Unidentified: What would be the maximum conditions?

A. Lurie, TRW: A higher temperature for one thing.

Q. Unidentified: What temperature you gave a number of 2.5 amp-hours per degree or something. I don't know what the number was.

A. Lurie, TRW: If you look in the region of about 5 degrees Centigrade to 25 degrees. Centigrade and it looked as if the coefficient was minus .25 amp hours per degree centigrade.

Q. Unidentified: Was there a peak, is there some peak?

A. Lurie, TRW: We don't have enough data, it's based on three points. I might say that to clarify that a bit. The actual specific energy that we achieved in the cycling in the GO cycling was around 43 or 44. The useable specific energy at 75% up to discharge.

A. Lurie, TRW: When I say that 25% I'm talking about on a battery basis. Useable specific energy.

Q. Gordon: You indicated that you thermostatically controlled the base plate or heat sink mounting. Did you do any work in monitoring envelope temperature to determine the delta?

A. Lurie, TRW: That was shown on the one of the curves was temperature. Yeah, the battery temperature did go up above that certainly.

Q. Jagielski, GSFC: On one of the features you showed a very very linear relationship between pressure and I was wondering if that is typical of the silver hydrogen cells or is that just typical of your charge control scheme?

A. Lurie, TRW: It's typical of the silver hydrogen cells that we've just tested.

Q. Jagielski, GSFC: Do you foresee maybe pressure sensing as a viable control method then?

A. Lurie, TRW: I don't see why not if someone can figure out how to measure temperature reliability over a ten-year period.

A. Jagiewski, GSFC: I said pressure sensing.

A. Lurie, TRW: Measure pressure reliably over a long period of time. I think the sensor is possible more of a problem than the pressure characteristics of a cell.

Q. Rogers, Hughes Aircraft: You give accelerated orbit and I'm wondering whether there's any data relating the results you get to the accelerated orbit with those you might get in a real orbit. How do we relate this to what one would really expect?

A. Lurie, TRW: You mean because this is silver and not nickel.

A. Rogers, Hughes Aircraft: No.

A. Lurie, TRW: Just in general. That's a question that's always a fair question to ask in fact we don't know.

Q. Ritterman, Comsat: You mentioned that you had a charge/discharge ratio of 1 to 1. You mentioned it again and that you did have some trickle charges now silver hydrogen as you showed by the two slopes on the charge/discharge curves has very low self discharge so when you trickle you are actually putting in some capacity?

A. Lurie, TRW: Yeah. The trickle charge rate was 50 milliamps. It was so low that it amounted to a very very small fraction of an amp-hour. Oh less than that much less than that.

Q. Betz, Naval Research Lab: Chuck, why do you go to such lengths to avoid overcharge at what really doesn't seem to be such a high rate if you look at nickel hydrogen 3.8 amps on a 46 amp hour cell.

A. Lurie, TRW: Okay the 3.8 was dictated by the 12 hour day. That is not a desirable current density for this system. We don't want to overcharge it just based on what we know of the silver electrode. If we are looking for really long life we don't want to overcharge it and because of the efficiency of the system it's not necessary.

Q. Betz, Naval Research Lab: It's not a separator problem it's the positive electrode problem?

A. Lurie, TRW: Yes, that's my understanding. Nothing has failed yet but we are assuming that the silver electrode is the potential problem for long life.