# DEEP RECONDITIONING TESTING FOR NEAR EARTH ORBITS

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## INTRODUCTION

During ground testing of nickel cadmium cells, deep reconditioning is accomplished by resistively loading the individual cells until the cell voltage approaches 0.0 volts. This type of reconditioning has been shown to improve discharge voltage performance and the capacity of the cells. RCA has implemented this technique in a synchronous satellite application (Ref. 1) with encouraging results.

Others have adopted a battery reconditioning technique in orbiting spacecraft using a single resistor across the entire battery. The level of discharge is limited to 1.1 or 1.0 volt per cell average to prevent cell reversal and hydrogen evolution within the cell. This method has not met with great success in improving voltage, capacity or life.

TRW has shown data for a deep reconditioning procedure in a synchronous orbit test regime (Ref. 2) that shows substantial improvement in life cycling capability and voltage performance. Their technique is to discharge the entire battery to nearly 0.0 volts at low rates and permit the cells to reverse. Their data shows reduced hydrogen evolution, hydrogen recombination, and no damage to the cells or battery. A possible advantage of the TRW method over the RCA method lies in its simplicity and reduced weight.

No data, however, exists to show the problems or benefit of deep reconditioning to near earth orbit missions with the high cycle life and shallower discharge depth requirements.

## OBJECTIVE

A simple, battery level approach to deep reconditioning of nickel cadmium batteries in near earth orbit would be useful to spacecraft designers. Successful reconditioning would lead to increased reliability, higher utilization, and therefore reduced costs and subsystem mass. All worthy goals. To evaluate the concept of deep reconditioning for near earth orbit missions, a direct comparison with an alternative to reconditioning should be constructed.

## APPROACH

A test plan was developed to perform deep reconditioning in direct comparison with an alternative trickle charge approach. Assuming a near earth orbit with a precession rate that produces periods of 100% sun; battery reconditioning opportunities appear. The option of trickle charge or reconditioning the batteries

occurs when the satellite solar array can support the loads in 100% sun with little or no battery support, (depending on battery redundancy).

Since battery life testing takes so long, in this test some acceleration was applied. For near earth, long term missions (i.e. 5 years) discharge utilization of less than 15% - 20% is appropriate. Acceleration to 40% discharge depth appeared reasonable and not excessively stressful. The orbital analysis for the sample showed 100% sun intervals varying between 50, 100, and 150 days. As discharge depth was accelerated by roughly a factor of two, reconditioning interval was divided by two. Table 1 shows the orbital 100% sun interval, accelerated test interval, and cycle number for the planned test reconditioning intervals. The next column shows the actual cycle numbers of reconditioning. Such deviations do not affect the value of the data. The durations of each reconditioning period are also shown.

Table 2 provides information on the test articles and other specifics of the selected cycling regime. The cells were delivered from December 1975 through February 1976, had been tested for acceptance and selection, and were designated as flight spare cells. They had been stored at room ambient until the start of this test. Reacceptance evaluation began in December, 1979, and life cycling in February 1980. In both voltage and capacity performance, the cells to be used for the reconditioning and trickle charge comparison were virtually identical. The actual charge - discharge cycling was performed with both groups of cells in the same circuit, experiencing the same current, and in the same temperature controlled bath. At the designated time for reconditioning, the circuit was broken, and one group of cells subjected to trickle charge while the other group was reconditioned. The reconditioned group was then charged at 0.60 ampere for 24 hours prior to return to cycling.

## RESULTS AND DISCUSSION

Both the cycling and reconditioning appeared nominal through the sixth reconditioning after 3666 cycles. Both the first and sixth reconditioning (See Figures 1 and 2) show uniform capacity and voltage performance. Maximum reversal voltages approached -0.20 volts and maximum reversal currents fall from initial rates of C/200 (0.030 amps) to C/3000 when the reconditioning was terminated. End of discharge voltage, identical for both groups until the first reconditioning, followed expected patterns. (See Figures 3 and 4) The non-reconditioned, trickle charged cells end of discharge voltage decreased substantially with cycling. Reconditioning provided immediately improved voltage performance at end of discharge, although the effectiveness appears to be decreasing. Immediately following each reconditioning, end of charge voltages tended to increase, and continued to increase with each reconditioning. As cycling continued, the end of charge voltages would decrease and stabilize between reconditioning periods. Also observed in the end of charge voltages was an increasing divergance in only the reconditioned cells.

In the next reconditioning period, a greater divergence in capacity appeared; and the eighth period gave cause for concern. (See Figure 5) We cannot explain the strange behavior of cell number 9's voltage. Cycling and reconditioning continued, with the reconditioned group of cells showing divergence in both cycling

voltage and reconditioning capacity and voltage.

Suddenly, within two cycles after 8321 cycles and the twelfth reconditioning and recharge, cell number eight failed by shorting and was removed. Within 50 cycles after the thirteenth reconditioning at 8921 cycles, cell number six end of discharge voltage was falling below 1.0 volts. Its voltage barely held on between 0.6 and 1.10 volts at end of discharge until the fourteenth reconditioning at cycle 9323. It showed only 3.6 ampere hours of capacity in that reconditioning. (See Figure 6). It operated normally following reconditioning and cycled normally for about 700 cycles before again falling below 1.0 volts at end of discharge. Figures 7 and 8 depict the results of a 4.0 ampere capacity discharge at cycle 10,142. Note the relative uniformity of capacity of the trickle charged cell group compared to the four remaining reconditioned cells. All cells were then reconditioned with 1Ω resistors prior to return to cycling. Cell six failed completely within 20 cycles. Cell number seven also had an end of discharge voltage below 1.0 volt, but continued to perform and degrade until complete failure 150 cycles later at 10,303. By cycle 11,100, cell number ten fell below 1.0 volt at end of discharge, but continued cycling; degrading slowly until ultimate failure on cycle 12,743. After 2000 additional cycles, the test was terminated without additional failures. The cells in the trickle charge group had been showing increasing end of charge voltages since shortly after cycle 9000, but no end of discharge voltage in the trickle group ever fell below 1.0 volt.

## CONCLUSIONS

The results of these tests clearly demonstrate that the deep reconditioning procedure described and reported here for near earth orbit application is inferior to the alternative of trickle charging. Cell failures, seemingly related to the reconditioning itself, begin to occur at almost half the cycle life of the trickle charge group. Certainly end of discharge voltage, at least for most of the cycling duration, was higher for the reconditioned cells; but the trade off in lost reliability does not appear warranted.

Some might reason that the test is not applicable because of the age of the cells, separator material, recharge method, or other reason. We have no argument. Our hope was to demonstrate improved reliability due to the deep reconditioning procedure. Our evidence is opposite. We welcome further explanation and contrary data and encourage those considering deep reconditioning at the battery level for near earth orbit missions to develop their own data and share their results.

## REFERENCES

1. Napoli, J.: "Reconditioning of RCA SATCOM Batteries in Orbit", The 1976 Goddard Space Flight Center Battery Workshop, X-711-77-28, Nov. 1976, pp. 185.

2. Scott, W.R.: "Life Tests and Reconditioning", IBID, pp. 199.

Table 1

Reconditioning Schedule

| TYPICAL ORBITAL 100% SUN INTERVAL -DAYS- | ACCELERATED RECONDITIONING INTERVAL -DAYS- | PLANNED RECONDITIONING -CYCLE- | ACTUAL RECONDITIONING -CYCLE- | RECONDITIONING DURATION -HOURS- |
|---|---|---|---|---|
| 100 | 50 | 650 | 668 | 264 |
| 50 | 25 | 998 | 1025 | 241 |
| 100 | 50 | 1663 | 1681 | 232 |
| 50 | 25 | 1995 | 2012 | 237 |
| 100 | 50 | 2660 | 2747 | 219 |
| 150 | 75 | 3658 | 3666 | 310 |
| 150 | 75 | 4655 | 4677 | 364 |
| 100 | 50 | 5320 | 5331 | 360 |
| 50 | 25 | 5653 | 5667 | 362 |
| 100 | 50 | 6318 | 6318 | 340 |
| 150 | 75 | 7315 | 7331 | 405 |
| 150 | 75 | 8313 | 8321 | 337 |
| 100 | 50 | 8978 | 8959 | 288 |
| 50 | 25 | 9310 | 9323 | 382 |

Table 2

Battery Cell And Cycling Information

| | | |
|---|---|---|
| Test Articles: | | Ten GE 6 Ah nickel cadmium cells, P/N 42B006AB34, polypropylene separator, Ag Treated Negative. |
| Temperature | : | 20°C ±1°C, immersed in controlled bath. |
| Simulated Orbit Period | : | 108 minutes |
| Discharge Parameters | : | 35 + 1, -0 minutes |
| | | 4.00 ±.04 ampere |
| | | 40% nominal depth of discharge |
| Charge Parameters | : | 73 + 0, -1 minutes |
| | | 2.10 ±0.10 amperes adjustable (actual 2.04 ampere) |
| Trickle rate, Group A | : | 100ma, C/60 |
| Reconditioning rate, Group B | : | Resistive, 112 ohms (100 ohms plus line resistance) |
| | | C/100 nominal discharge |
| | | C/130 at 1.0 volt avg. |

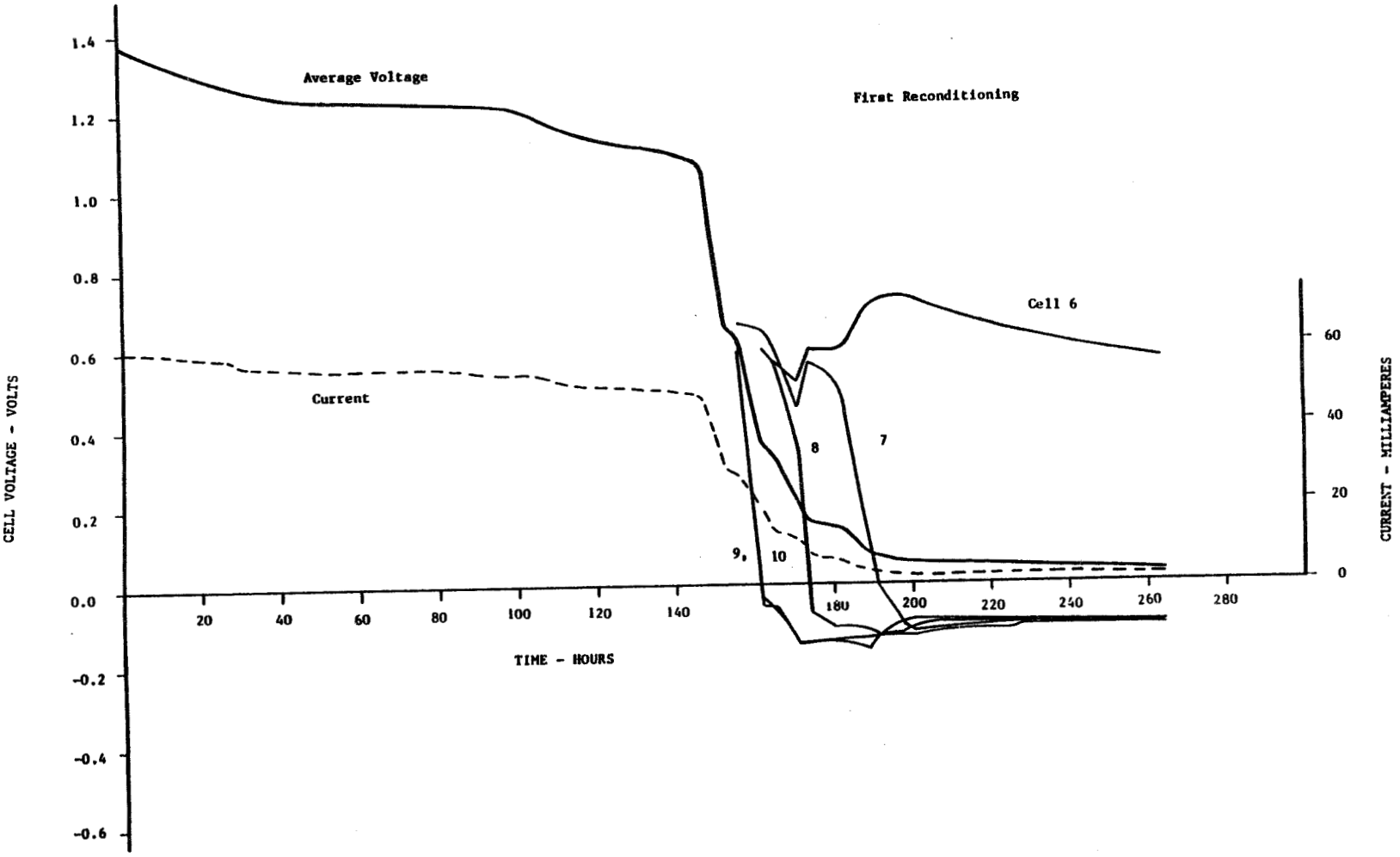


Figure 1. Voltage and current vs. time, 5 cell battery during reconditioning with 100 ohm resistor, after 667 cycles at 40% depth of discharge.

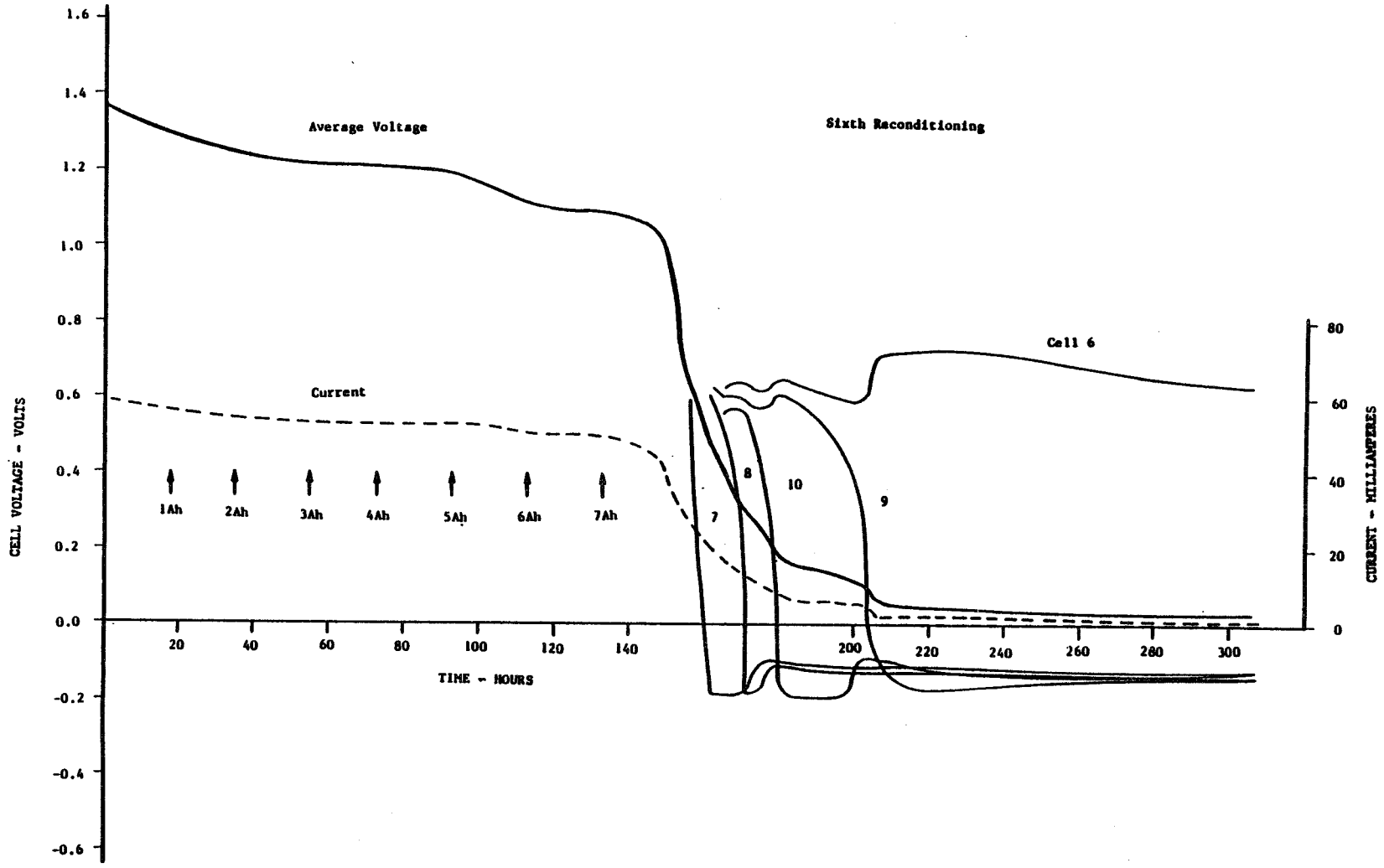


Figure 2. Voltage and current vs. time, 5 cell battery during reconditioning with 100 ohm resistor, after 3666 cycles at 40% depth of discharge.

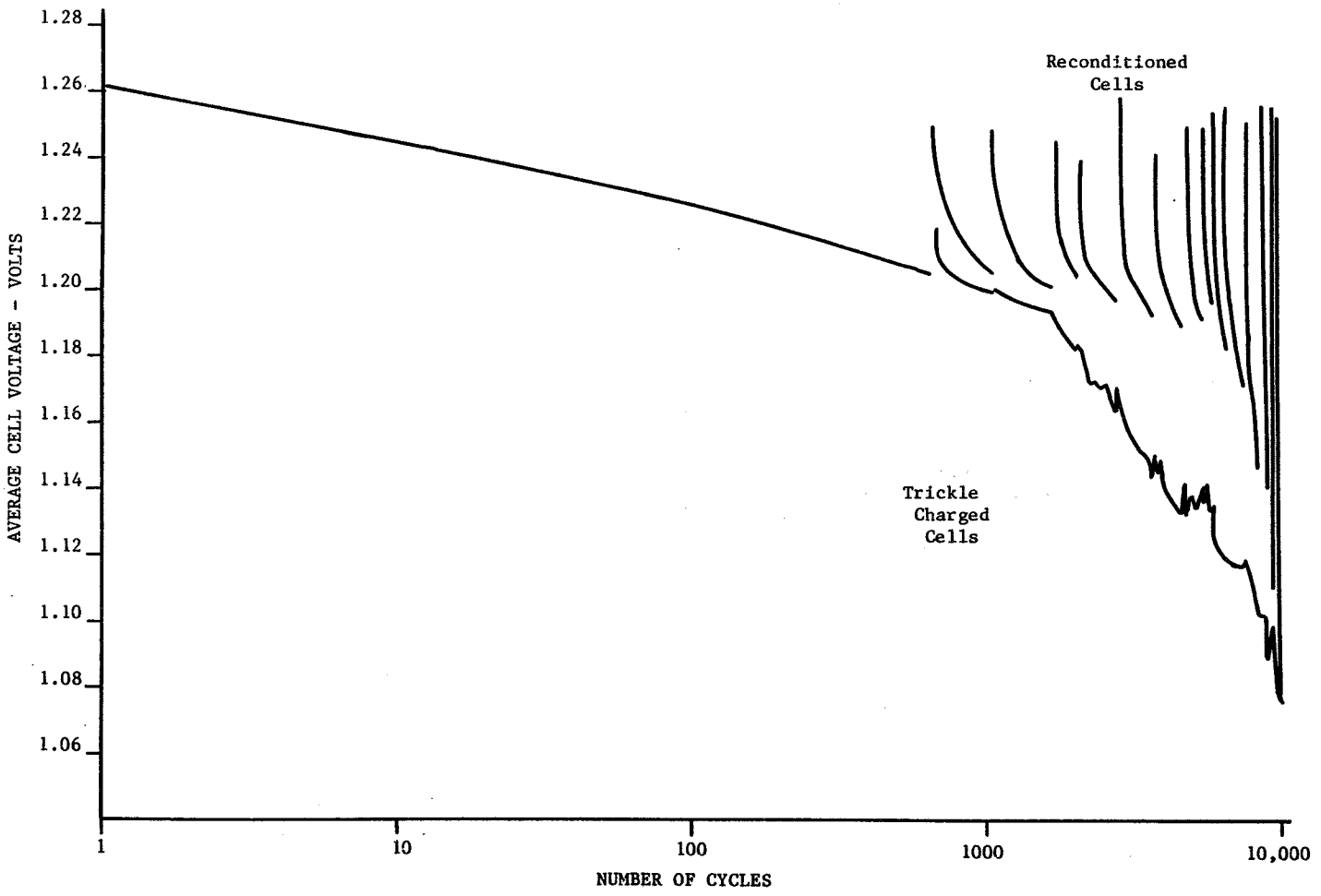


Figure 3. End of discharge voltage vs. number of cycles, reconditioned and trickle charged cells, cycled in 108 minute period, 20°C, 40% depth.

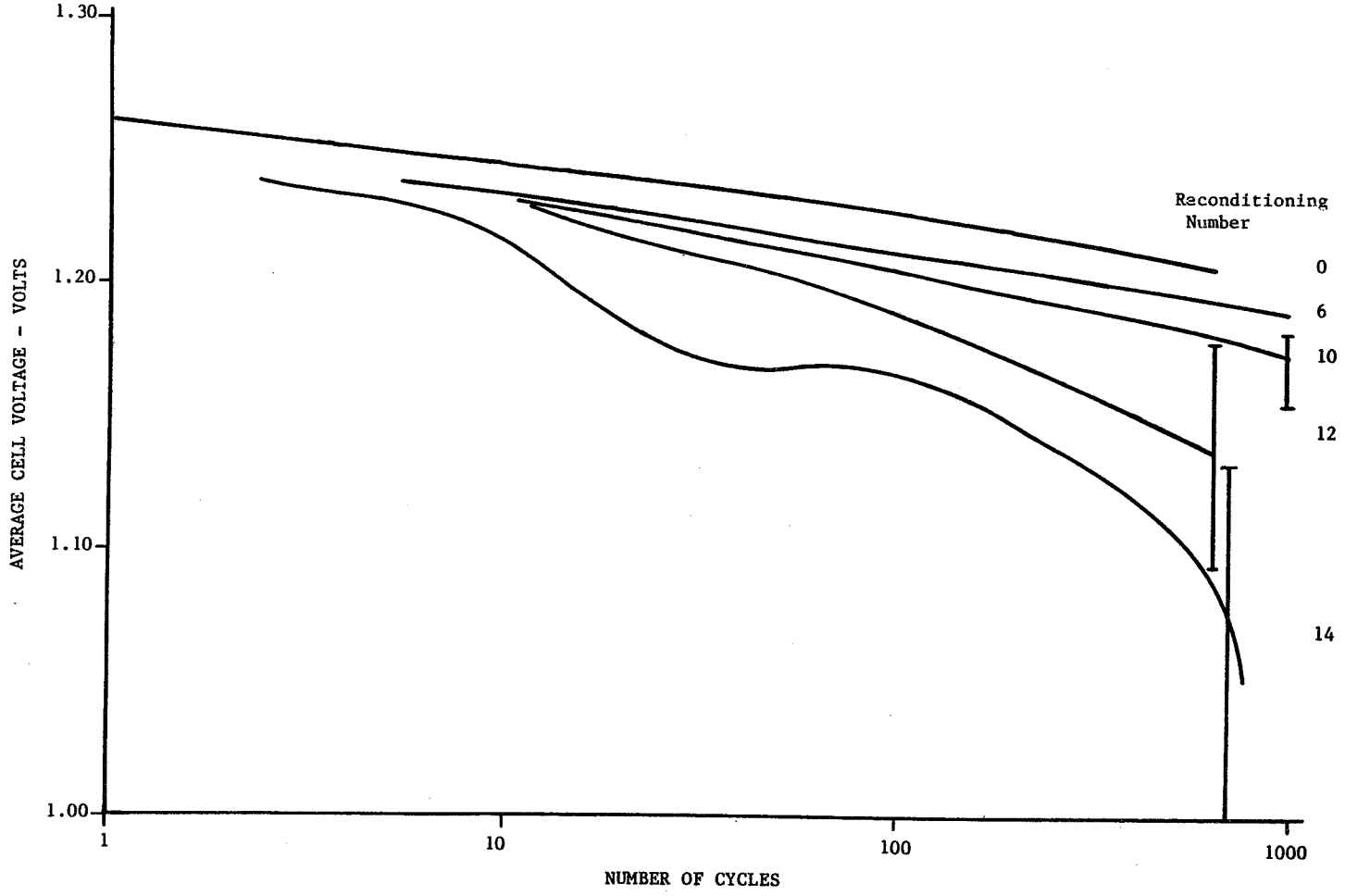


Figure 4. End of discharge voltage vs. number of cycles since reconditioning, data from before reconditioning and after selected reconditionings.

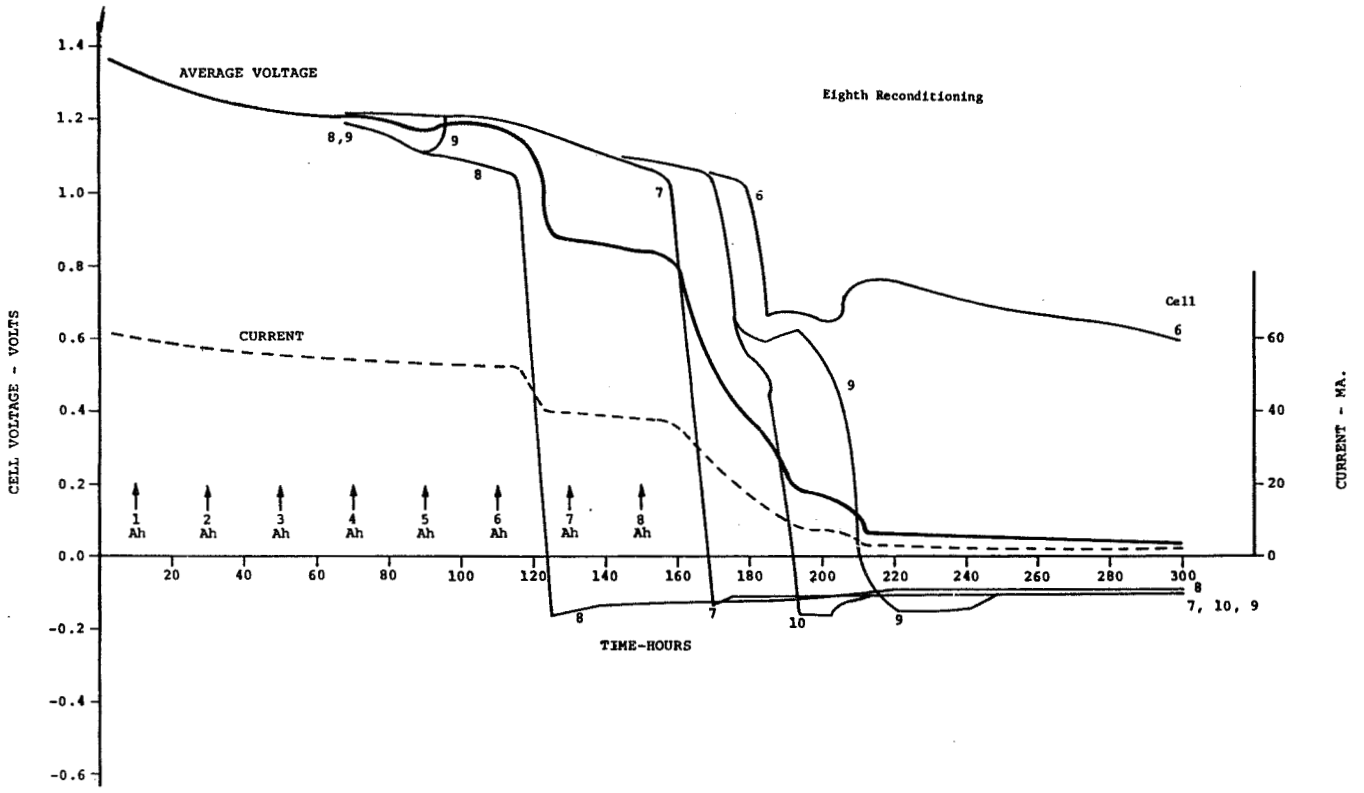


Figure 5. Voltage and current vs. time, 4 cell battery during reconditioning with 100 ohm resistor, after 5331 cycles at 40% depth of discharge.

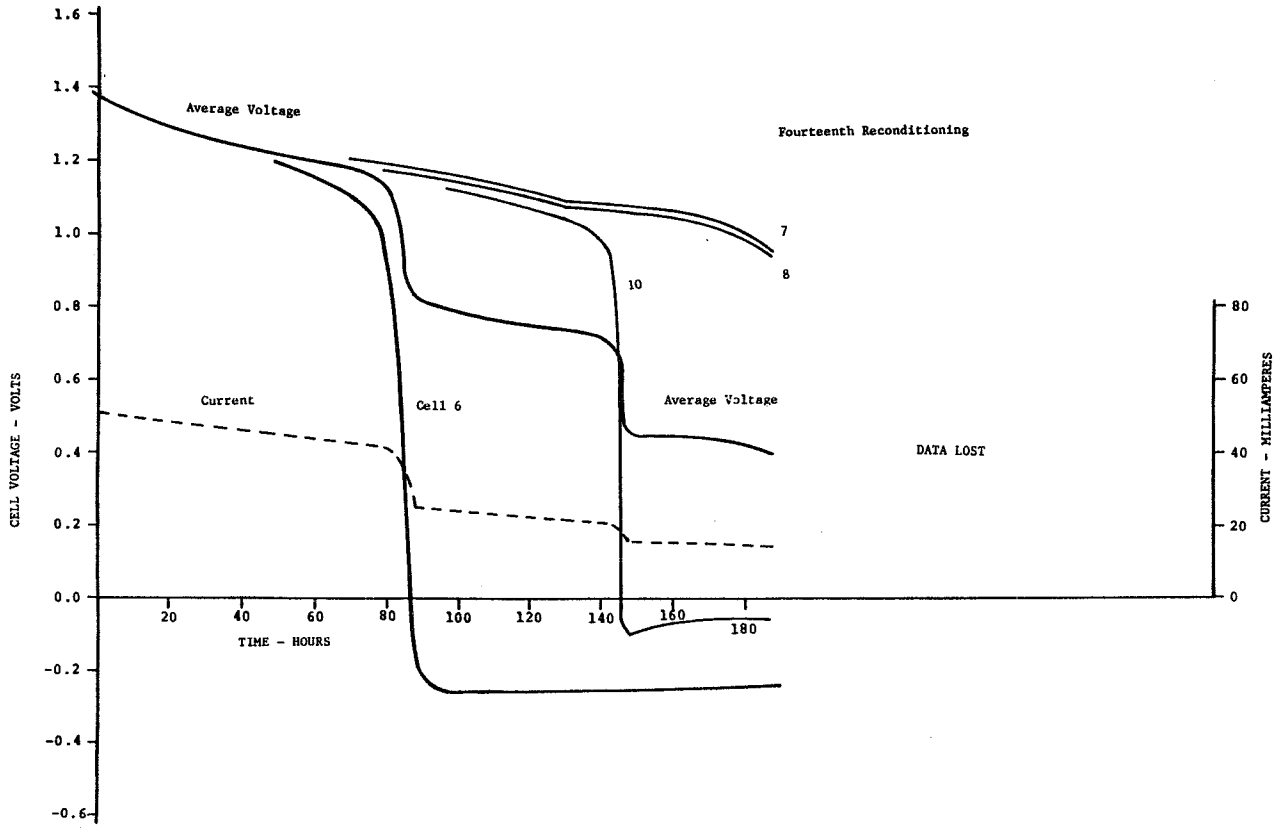


Figure 6. Voltage and current vs. time, 5 cell battery during reconditioning with 100 ohm resistor, after 9323 cycles at 40% depth of discharge.

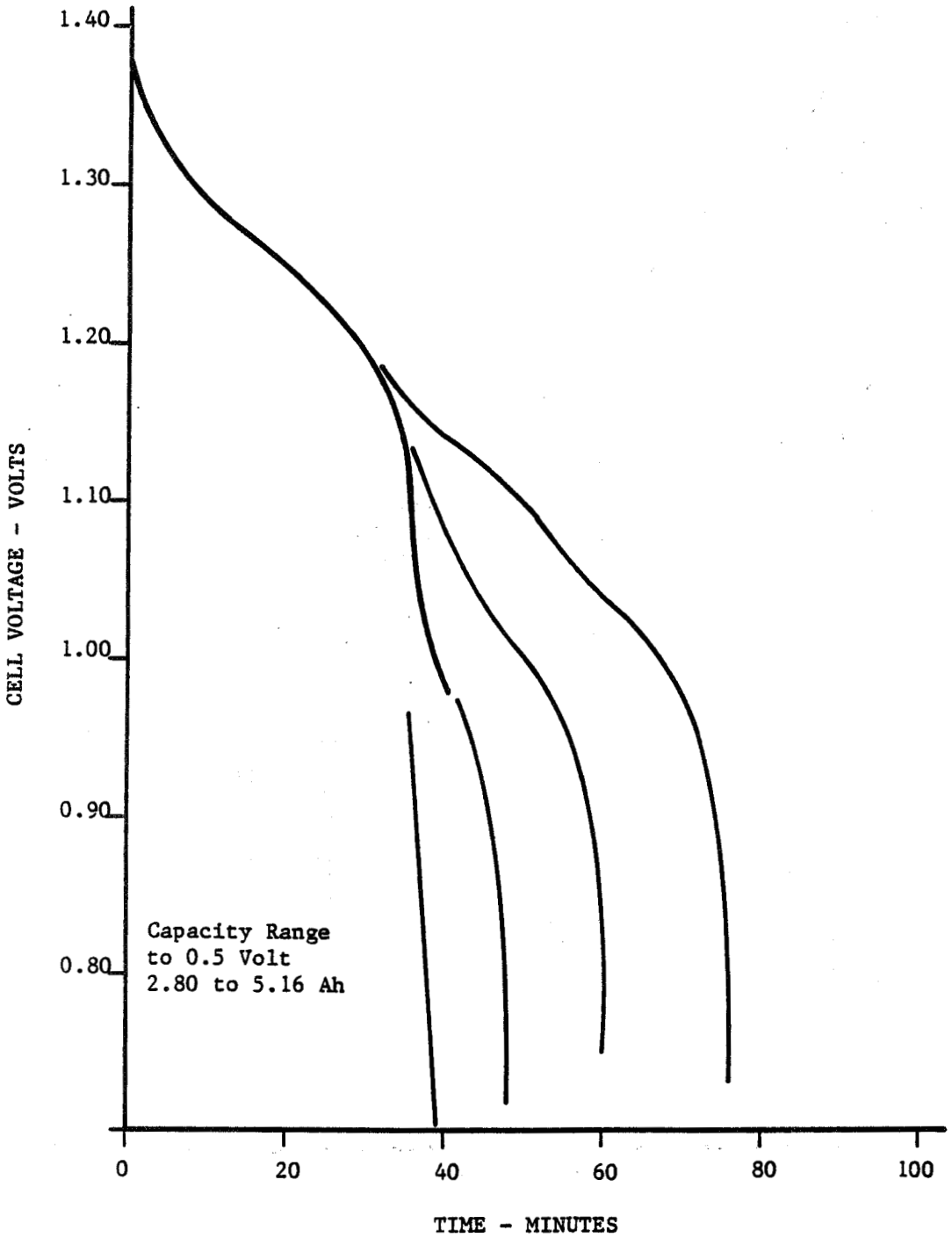


Figure 7. Discharge voltage vs. time, four reconditioned cells, after cycle 10142, 4 ampere rate.

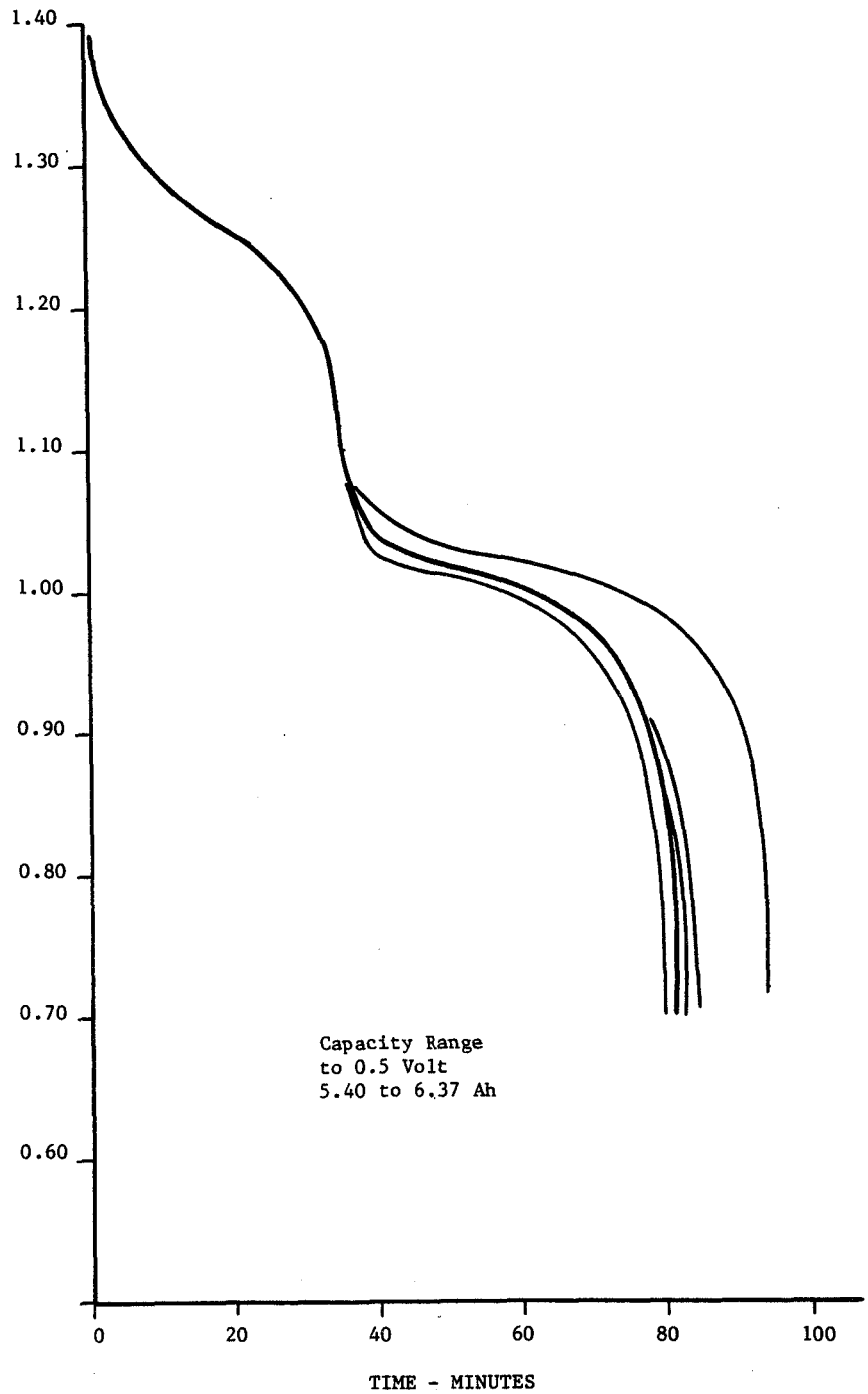


Figure 8. Discharge voltage vs. time, five trickle charged cells, after cycle 10142, 4 ampere rate.

SESSION IV

DISCUSSION

Q. Badcock, Aerospace Corporation: Fred, could it be that you reconditioned it to death. I mean you reconditioned them an awful lot? Was it necessary to do it that often I guess is what I'm really asking?

A. Betz, Naval Research Lab: The idea I guess was to take the opportunities when they were available which were 100%. It's a valid question. I don't know. Someone had said this morning maybe we ought to recondition more often. I guess it does better but my evidence says not so. It was rather frequent but we did accelerate the depth in discharge also. The variability was 25,50 and 75 days.

COMMENT

Ritterman, Comsat: You anticipated my comment. With all my experience in reconditioning which was in test as well as orbit application indicated that deep reconditioning does help the capacity. I think you might be creating a wrong impression about reconditioning even though you stated that you used it. If you had run the same kind of test with cells and gotten the same results I would say you are re-conditioning it to death or it's inappropriate to use it in this application. But I think not necessarily overwhelming but considerable data on reconditioning indicates that it shouldn't be used in every instance but for chosen ones it is very good.

Betz, Naval Research Lab: I agree with you Paul. My problem I guess is that I have many cells working in the exact circuit side by side and the only difference was trickle charge. I certainly should have expected some of those guys to act up somewhere along the way.

Q. Sullivan, APL: Fred, did you do anything special to limit the cell reversal voltage to 2/10th's of a volt?

A. Betz, Naval Research Lab: No, that was the natural reverse potential.

Q. Sullivan, APL: Do you think that had anything to do with the degradation that is if you had not allowed them to reverse would have been better results.

A. Betz, Naval Research Lab: If I had prevented them from reversing then I would have not been reconditioning by the method that we had kind of agreed upon before the test. So the test assumed that I was going to permit cells to reverse. I don't know if there would have been better results.

Q. Question inaudible.

A. McDermott, Martin Marietta: Okay I guess my first question, are you talking about the flight battery or the one where we are doing life cycle test on.

A. Mani, Energy Conversion Devices, Inc.: The life cycle testing one.

A. McDermott, Martin Marietta: We haven't done anything other than doing the life cycle test. We haven't pulled a battery out to do any kind of cell evaluation because it is still on life cycle test. We've achieved over 16,000 cycles right now at a 20% depth discharge. I would say when the battery would fail or we would have a cell failure or something like you know we probably would do a failure analysis on it but we haven't done anything to date.

Q. Mani, Energy Conversion Devices, Inc.: My second question is when you used the L-shaped kind of device inside the battery how that is going to reduce the heat affect which elevates the temperature from 20 degrees to 32 or something like that?

A. McDermott, Martin Marietta: Oh it wasn't just that. We also improved thermal spacecraft design if you want to call it on the spacecraft. But how the L-bracket basically helped is it allowed a direct heat transfer down to the plate we mounted on. See the cells when they are mounted there's an aerospace on the bottom and that aerospace serves as a hard thermal gap for the heat to get out. So by putting the L-bracket on the side and underneath actually up touching the bottom also we provided a direct heat transfer to the plate.

A. Mani, Energy Conversion Devices, Inc.: Thank you.