UPDATE OF THE IUE BATTERY IN-FLIGHT PERFORMANCE

S. Tiller
NASA/GSFC

The data that was presented at the workshop last year summarized performance of the IUE spacecraft batteries from the time of launch, January 1978, through the first 10 months of operation.

(Figure 3-22)

During this session I would like to update the data to carry us through 22 months of operation. First, let me point out that the spacecraft has two 17-cell, 6-ampere-hour nickel-cadmium batteries and that operational directives limit the DOD to 80 percent, and the maximum discharge current to 4.5 amperes per battery. It should also be noted that the two batteries have an approximate 8° C temperature delta between them.

Since launch, the spacecraft has passed through four solar eclipse seasons ranging from 24 to 25 days each. Between the eclipse seasons, or during the solstice seasons, the batteries are placed in a low-rate trickle charge mode of operation.

These curves are plotted from the spacecraft telemetry data with a point selected at random over approximately 625 days of operation. The battery current curves, charge current curves, and the third electrode curves indicate that they are being well maintained in the trickle charge mode of operation.

The fluctuations noted in the battery voltage and the battery temperature are caused by the spacecraft being moved throughout a beta range of 0 to 130 degrees. At 0 and 130 degrees, the solar panels start becoming efficient, and at that time the batteries will start producing power, sending power to the spacecraft.

(Figure 3-23)

This data represents the battery discharge voltage during the peak eclipse seasons, one through four. One thing I would like to point out is that during eclipse seasons three and four, the spacecraft power requirements reduced slightly in order to maintain the batteries above an 80-percent DOD and above a 4.5-ampere discharge current. You can notice this on the third and fourth eclipse seasons, as compared to eclipse season number two.

(Figure 3-24)

Here you see the battery voltage observed at the end of the discharge during the daily seasons or daily eclipse periods over the four eclipse seasons.

Here again you can notice the eclipse season number two and number three, that number two actually has a lower voltage than number three, due to the reduction in spacecraft power during the eclipse season three and four.

(Figure 3-25)

The two dashed lines in this graph represent the rate of battery voltage degradation relative to the available power to the spacecraft, over 14 solar eclipse seasons.

The X's represent the spacecraft batteries, the circles represent data performed on a 6-ampere-hour test pack at Crane, and the lower curve represents data acquired from a test flight tested here at the Goddard Space Flight Center.

This pack has been terminated since we ran the tests through seven solar eclipse seasons. I would like to point out a couple of things:

The pack that was tested at Goddard had been in operation for approximately 1 year prior to the first solar eclipse season at about a 50-percent DOD. After we made some calculations, we believe the battery voltage is approximately 1/4 volt high for this particular data.

The trends being established from these three sources indicate that the spacecraft battery will follow the trend that was predicted on the curve. Future data points from the spacecraft battery and from the tests at Crane will be plotted on the future curves to maintain trends through the future eclipse seasons.

DISCUSSION

FORD: I might make a comment that the cell design and the background were provided by you in the workshop 2 years ago. Right? Or 3 years ago?

BAER: We went through it a little bit last year, too, but I think it was originally presented 2 years ago.

IUE SPACECRAFT
BATTERY TRICKLE CHARGE CHARACTERISTICS
DURING THE SOLAR SOLSTICE SEASONS
(BATTERIES SN-05, -06)

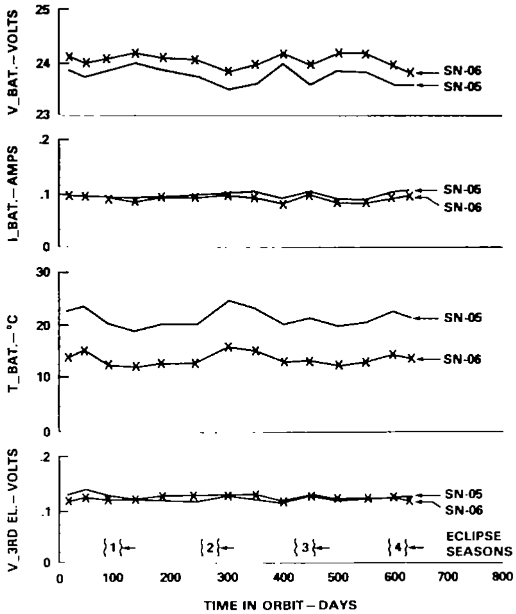


Figure 3-22

END OF DISCHARGE VOLTAGE VS DAY IN ECLIPSE
(IUE SPACECRAFT)

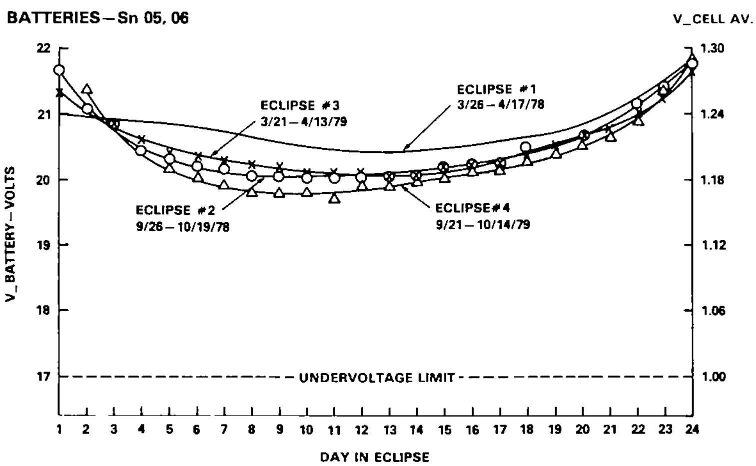
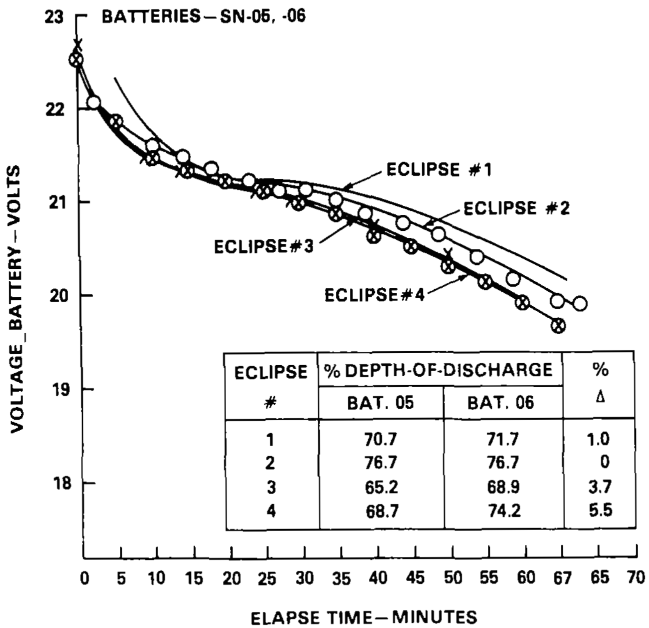


Figure 3-23

IUE SPACECRAFT BATTERY DISCHARGE VOLTAGE AT THE PEAK ECLIPSE PERIOD OF SOLAR ECLIPSE SEASONS 1–4



ECLIPSE #	% DEPTH-OF-DISCHARGE BAT. 05	BAT. 06	% Δ
1	70.7	71.7	1.0
2	76.7	76.7	0
3	65.2	68.9	3.7
4	68.7	74.2	5.5

Figure 3-24

IUE SPACECRAFT BATTERY AVAILABLE POWER AND VOLTAGE VS ECLIPSE SEASONS PREDICTED PERFORMANCE AT 80% D.O.D.

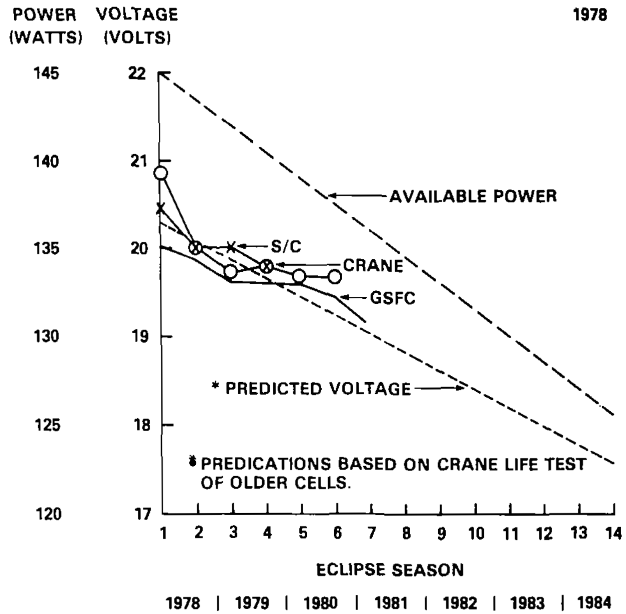


Figure 3-25

RECONDITIONING OF VIKING LANDER BATTERY

A. Britting
Martin Marietta

To summarize the previous report we made last year a little bit gives us, if I can use the word, a data base to work from.

(Figure 3-26)

This is a Martin Marietta-built Viking Lander. We launched two of these in August and September 1975 for a 90-day mission to Mars. We were to perform a search for life on Mars, characterize the weather, and do quite a series of other things.

We had a planetary quarantine requirement imposed upon us, in that we were not allowed to contaminate the surface. We interpreted that as meaning we must bake the lander batteries and everything else in it to 233° F for 54 hours. This imposed some interesting hardships for battery designers.

(Figure 3-27)

This is the Viking lander power system. On top are two series connected 35-watt radioisotope thermal electric generators, redundant power conditioning distribution assembly, redundant shunt regulators, and four 24-cell, 8-ampere hour NiCad batteries. The cells were built by GE.

We regulate the bus at 27 to 36 volts. Our battery charging scheme is such that we have a single battery on the charge bus being charged for 1 hour while the other three batteries are supplying the equivalent bus loads. We alternately cycle batteries A, B, C, and D 24 hours a day.

(Figures 3-28 and 3-29)

As I said, the batteries are 24-cell, 8-ampere hour NiCads. We have two batteries for assembly. In the picture on the right you have one battery in the front, second battery in the back. We have two battery assemblies per spacecraft. Each battery weighs 50 1/2 pounds.

Heat sterilization requirement was the item for which we had no data base to draw from so we chose to use Pellon FT 2140 nonwoven polypropylene separator material.

The voltage temperature control for charge conditions was used. During cruise we received power from the orbiter for battery charging at C/15 as well as trickle charging. And the typical lander charge rate was C/8 for all batteries of 1-ampere charger.

During ground testing before launch, we did have individual cell monitoring. But after launch, all we had was voltage and temperature at the battery level.

(Figure 3-30)

On the right-hand side I am putting up the cell characteristics. I will leave them there for your reference.

(Figure 3-31)

This chart represents the battery cycle life from cruise to the present. It gives the typical depths of discharge and the cycles for those depths of discharge. As I said, this was originally a 90-day mission. We are currently passing our 1200th day for both landers, which are still operating.

(Figure 3-32)

We did condition the batteries during cruise. Now that conditioning was done by charging them, discharging them through a 19.3-ohm fix load, and then recharging them, measuring the ampere-hour capacity and recording it.

This is one of the batteries on Viking Lander 1, battery B. During cruise we measured a capacity of 8.8 ampere-hours. We didn't intend to do subsequent tests after landing because we did plan on a 90-day mission. But there was some opportunity here to get some information as far as degradation on the battery is concerned. So we went ahead and reactivated the discharge sequence after 716 days on the surface. We discharged and compared each one of the batteries. This one is representative of the Lander 1 batteries, having roughly a 10-percent degradation after almost 2 years.

(Figure 3-33)

Lander 2 had some interesting differences. This lander tended to operate at a higher temperature than the other lander. We had some spacecraft hardware anomalies that caused it—part of the contribution to the high temperature was a busier sequence, which tended to heat up the equipment bus.

The second curve here was taken just a little bit less than 2 years after touchdown.

What happened here is that during the Martian winter, this particular vehicle happened to sit right on the edge of the northern polar cap on Mars, and therefore we were afraid that frost was going to build up on the landers. As a result, we shut down much of the external operating hardware, such as soil samplers, etc. As a result, the lander was essentially asleep. With it being asleep, we didn't terminate the charge-discharge sequence. We went ahead on a 1-hour charge cycle, but with no discharging, constantly putting power in for 1-hour cycles for roughly the Martian winter, about 6 months.

I think this was partly contributing to the 4.5-ampere hour, or 50-percent loss in capacity that we see here.

(Figure 3-34)

That last slide was about the point to where we had reported last year.

Slightly after the workshop, we got additional data, which showed us the hardware anomaly that caused us to operate in excess of 80°F for the 137-day period. Coupled with low-discharge rates, low-recharge rates, and because of the high temperatures, there was lower battery terminal voltage.

When we came out of this period, we found that we had lost roughly as much as 75-percent original capacity of the batteries. At this time we decided to embark on a program on Lander 2, to do more than just to discharge to the predetermined 27.3-volt cutoff that we had been normally doing earlier along the curve here, and do a time discharge instead.

We arbitrarily chose a 7-hour time discharge through the 19.3-ohm resistive load bank because it fit nicely into the sequence. We followed that by a 21-hour recharge, C/8, and the 19.3 ohms give us a value of C/5 discharge rate. Some of the gains can be seen in the next chart.

(Figure 3-35)

I picked on one battery in particular. I am planning on doing a lot of this testing on all those batteries. I have completed the second battery. This is battery C, but I have completed the second battery already. I will just talk about battery C here.

The second column from the right is the discharge ampere-hours. In there you can see the cruise. And then an early lander capacity being about 10 percent degraded, as was on Lander 1. Then lo and behold, a little over 2 years after touchdown, we see that 75-percent degradation that I talked about because of the thermal and other powers we had there.

We did a discharge shortly thereafter to 27.3 volts. That's a gain of about 1 ampere-hour you see on Sol H58. After that, I started the 7-hour time discharges. Some of what you see on the line is called Sol—Sol is a Martian day and is 24.6 hours long—but on the Sol H65 line, some of that increase you see to the 5.11 ampere-hours is most probably due to the previous discharge test we do where we got 2.95 ampere-hours.

I took that battery down to 9.88 volts, terminal voltage, in the 7-hour period. About 90 days later, I repeated the test to see what impact we had on that battery, gained another 1 1/2 ampere-hours. The battery terminal voltage at the end of that 7-hour period was 18 volts, which has shown that we have done something to the battery.

(Figure 3-36)

This vugraph is rather a dramatic one. It is a graphical presentation of the previous chart.

This curve summarizes all of what was on the last chart. The highest curve, the long-dashed curve there, happens to be the cruise curve. You can see the subsequent degradations in capacity finding the long-time discharge. The first one is the thin solid line going down, the 9.88 volts. On the final-time discharge we see what may even be an evidence of second plateau. I have marked on that final curve the 27.3-volt power conditioning distributions, where the cutoff level would be.

(Figure 3-37)

Currently, we are on about a once-a-week basis on Lander 1, running a sequence that discharges the batteries about 1 ampere, or at about 12-percent DOD. Peak discharges may reach 15 percent. We are recharging at about a 1-ampere rate.

Currently, on the batteries on Lander 1, we have run approximately 7000 cycles at less than 10-percent DOD. On Lander 1, because we have been running fairly deep discharges before this time, I believe they are semiconditioning the batteries. We have had no evidence of any battery degradation.

The battery open-circuit voltage remains as it was at touchdown, at 32 to 33 volts. We are having equal load sharing to within 1/10 ampere during all heavy or light dishcarges. Sharing very well. And our batteries are reaching charge cutoff on recycle.

(Figure 3-38)

As I said, we had to work with Lander 2 a little bit. It is going through about a once-a-month 1- to 1.3-hour discharge at 12 to 15 percent, at a discharge of 18 percent maximum.

I am going to complete our 7-hour time discharges. I have worked on battery A and battery C so far, and batteries B and D this month and next month. Subsequent to that I will report on them. I do plan on finishing at least one time discharge in every battery.

Since we began the discharge, 7-hour time discharges, we have got a significant increase in battery capacity. The open-circuit voltage recovery on the Lander 2 batteries, which was 32 and 31 volts, is now back up to 32 to 33 volts.

Batteries A and C, which are already exposed to the time discharge, now take more than their share of the load. There is a 4-ampere load on the bus. That's like three-quarters of it. The third battery on the discharge bus hardly supplies any of the load. And we are reaching regular battery charge cutoffs.

(Figure 3-39)

In summation, we have done approximately 4 years of operation on the surface, but I have to say no failures with quotes around it. We did have only 90-day operational requirement. Our polypropylene separator material chosen appears to be still working well. He might want to add a couple of things to that.

One of the things we did learn here was that although we didn't plan on having any reconditioning mechanism on the spacecraft, in this case it was good that we did. We think we have learned something from that. But in future missions of this type, it might be wise to always include something to enable you to do some kind of conditioning.

They might be good, so we don't do time discharges and worry about cell reversals. As you are taking the batteries down, you might want to have some individual cell monitoring. I think that's probably a good idea.

Our current plans now are for Lander 1 and Lander 2: Lander 1 is going to operate until 1990. I am not going to stick around and monitor it that long. Lander 2, as somebody mentioned, doesn't have any TWTA problems. We lost both TWTA's, we lost each of the TWTA's on Lander 2, so we only have relay length capability from Viking Lander to Viking Orbiter which then gets relayed to earth.

When the last remaining two Orbiters go away, they run out of control system gas, that will be the end of the Viking Lander 2 mission. That is why I am working heavily with Lander 2. I feel that's my vehicle that I can play with a little bit. I call it my billion-dollar playtoy and try to gather as much information before we lose that vehicle.

In a recent slide taken on the Martian surface from Lander 2 the temperature was about -154° F during the day and -196° F at night. There is frost on the surface. That's what is called a clathrate. It is composed of six parts carbon dioxide and one part water vapor.

DISCUSSION

MUELLER: How many cycles did you get within one cycle per day?

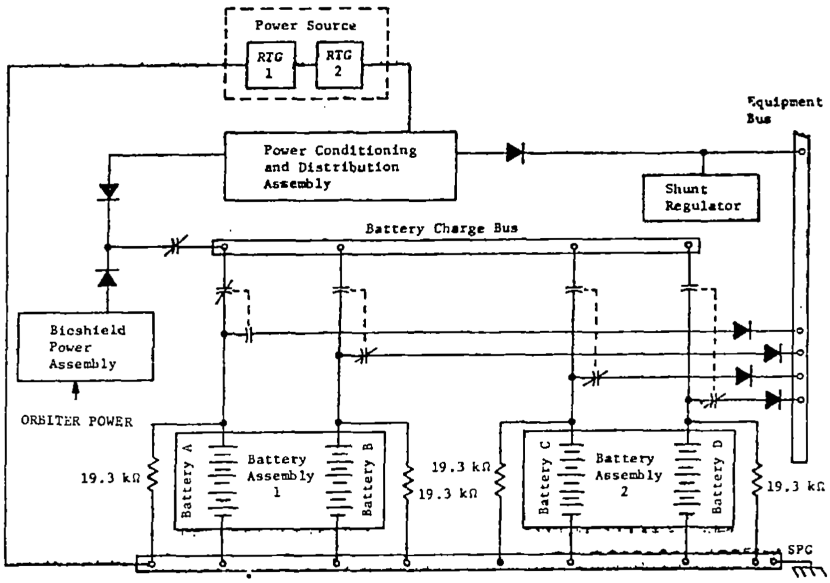
BRITTING: When you say cycles, charge cycles on batteries?

MUELLER: Current discharge cycles.

BRITTING: We charge the batteries on a once-per-hour basis essentially six times a day. Each battery is on the bus 1 hour a day—on the charge bus, 1 hour; then on the discharge or equipment bus, 3 hours. Then back on the charge bus for 1 hour.

MUELLER: Six cycles per day?

BRITTING: Six cycles per day.



Viking Lander Power System Block Diagram

Figure 3-26

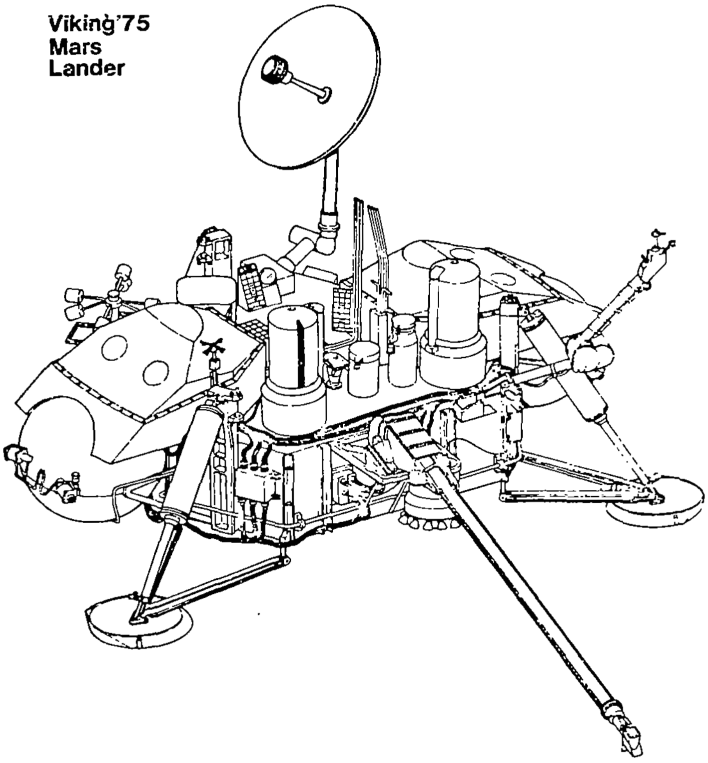


Figure 3-27

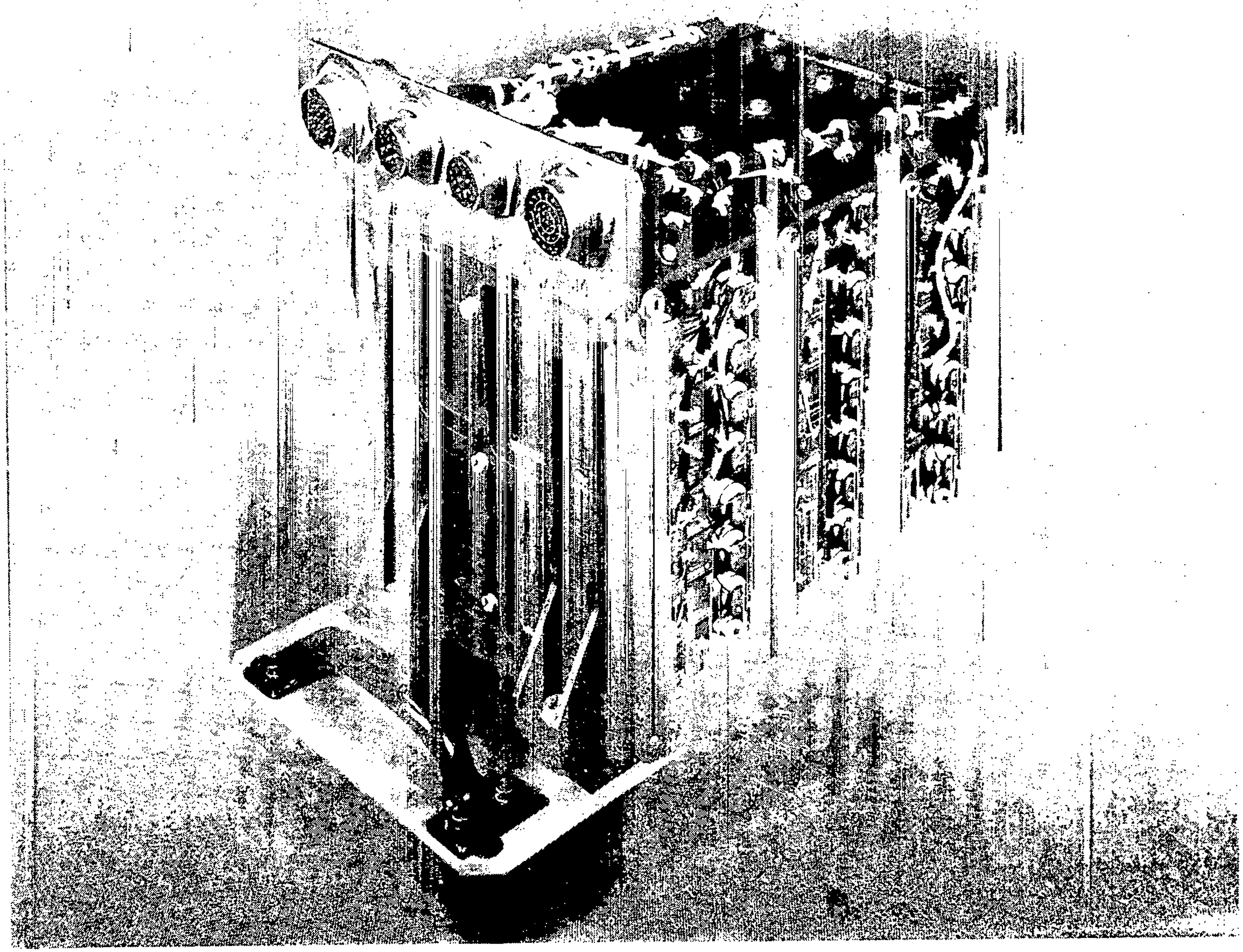


Figure 3-28

BATTERY CHARACTERISTICS

2 - 24-8AH BATTERIES/ASSEMBLY

2 - BATTERY ASSEMBLIES/SPACECRAFT

BATTERY WEIGHT	50.5 LBS
HEAT STERILIZATION	54 HOURS @ 233°F

CHARGE CONDITIONS

- VOLTAGE/TEMPERATURE CONTROL
- C/15 - IN CRUISE FROM VO 75
- C/160 - TRICKLE
- C/8 - TYPICAL LANDED OPERATION

MONITORING

- TEMPERATURE } FLIGHT
- BATTERY VOLTAGE } FLIGHT
- CELL VOLTAGE - GROUND ONLY

Figure 3-29

Cell Capacity	8 A-h (Rated)
Cell Weight	273 gm - Lot Average
Cell Size	7.589 cm x 2.27 cm x 8.651 cm (including terminals)
Case Material	304L Stainless Steel
Case Wall Thickness	0.48 ± 0.05 mm
Insulated Terminals	Positive and Negative
Terminal Type	Nickel Post with Ceramic Insulator CE - all Nickel-Braze
Auxiliary Electrode	None
Separator Material	Pellon FT2140 Nonwoven Polypropylene
Separator Thickness	0.216 mm
Plate Pack Wrap	Pellon FT2140 Nonwoven Polypropylene
Case Liner	0.127 mm Solid Polypropylene Sheet
Electrolyte	KOH
Electrolyte Concentration	34%
Electrolyte Quantity	21.5 to 23.5 cc
Plate Substrate	0.101 mm Perforated Steel Sheet
Sinter Porosity	80% Nominal
Number of Plates	POS 11
	NEG 12
Plate Size	7.0 ± 0.03 x 4.9 ± 0.03 cm
Plate Thickness	POS 0.066 to 0.071 cm
	NEG 0.078 to 0.081 cm

Figure 3-30

BATTERY CYCLE LIFE

Period		VL-1	DOD	VL-2	DOD
Cruise					
Cruise Checkout		1	25%	1	25%
Subsystem Test		6	20%	6	20%
Mars Orbit Insertion					
Preseparation Checkout		1	25%	1	25%
Preseparation					
Preseparation thru Touchdown		1	50%	1	46%
Landed					
Thru end of Primary Mission	Sept 76	43	55% Max 10-20% Typ	61 Nov 76	29% Max 10-20% Typ
Thru Conjunction	Nov 76	65	23% Max 13-20% Typ	8	5% Max 5% Typ
Thru Extended Mission	Jun 78	308	40% Max 10-20% Typ	211	42% Max 10-20% Typ
Thru Nov 78		32	15% Max 5-10% Typ	8	20% Max 10-20% Max
Thru Continuation Mission	Mar 79	32	15% Max 5-10% Typ	2	22% Max 12-20% Typ
Thru Survey Mission	Oct 79	18	15% Max 5-10% Typ	4	20% Max 12-18% Typ
Total		507 Cycles		303 Cycles	

Figure 3-31

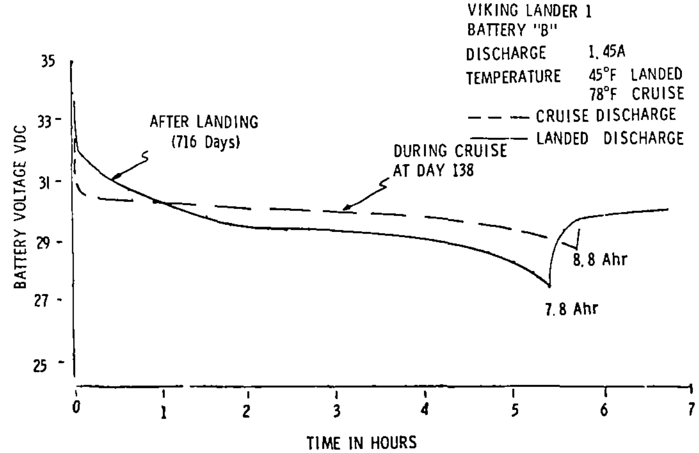


Figure 3-32

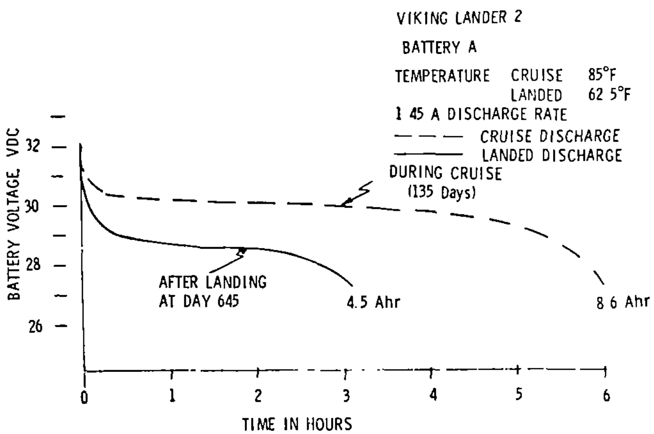


Figure 3-33

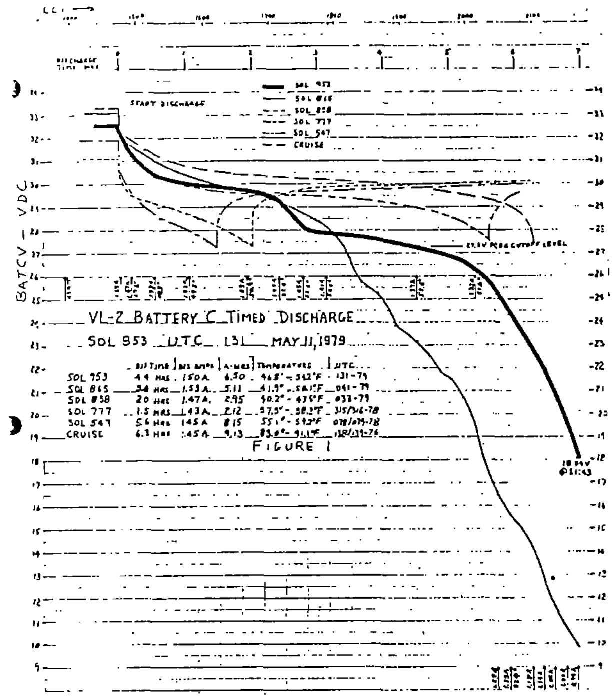


Figure 3-34

PERIOD	UTC DATE	DISCHARGE DURATION (HRS)	AVERAGE DISCHARGE VOLTAGE (VOLTS)	DISCHARGE AMPERE-HOURS (AH)	DISCHARGE TEMPERATURE ($^{\circ}$F)
CRUISE	138/139-76	6.3	30.2	9.13	83.0° - 91.1°
SOL 547	078/079-78	5.6	29.4	8.15	55.1° - 59.2°
SOL 777	315/316-78	1.5	28.7	2.12	57.5° - 58.3°
SOL 858	033 - 79	2.0	28.9	2.95	40.2° - 43.5°
SOL 865	041 - 79	3.42 7.0	29.95* 24.78**	5.11* 8.74**	41.9° - 50.1°
SOL 953	131 - 79	4.35 7.0	29.37* 27.66***	6.50* 9.84***	46.8° - 54.2°

* To 27.3 V nominal PCDA charge control logic cutoff level

**

** To 7 hour timed discharge. Battery terminal voltage at this time was 9.88 volts.

*** To 7 hour timed discharge. Battery terminal voltage at this time was 18.04 volts.

Figure 3-35

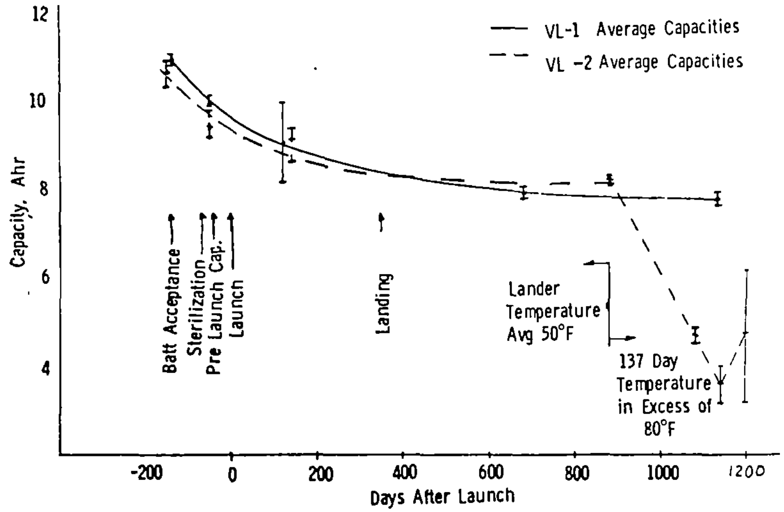


Figure 3-36

PERFORMANCE

VIKING LANDER 1

- o DISCHARGE/RECHARGE
  - – 1 AMPERE DISCHARGE (C/8) FOR 1 HOUR ≈ ONCE/WEEK (12% DOD)
  - – PEAK DISCHARGES TO 15%
  - – RECHARGE @ C/8 RATE
- o RESULTS
  - – NO EVIDENCE OF BATTERY DEGRADATION
  - – BATTERY OCV REMAINS AT 32-33 VDC AFTER 4 YEARS
  - – EQUAL LOAD SHARING EVIDENCED DURING DISCHARGES
  - – BATTERY CHARGE CUTOFFS OCCUR EACH HOUR

Figure 3-37

PERFORMANCE (CONT)

VIKING LANDER 2

- o DISCHARGE/RECHARGE
  - – 1 AMPERE DISCHARGE (C/8) FOR 1-1.3 HOUR APPROXIMATELY ONCE/MONTH (12 - 15% DOD)
  - – PEAK DISCHARGES TO 18%
  - – 7 HOUR TIMED DISCHARGE AT APPROXIMATELY ONCE/YEAR THROUGH 19.3 OHM FIXED LOAD BANK
- o RESULTS
  - – SIGNIFICANT INCREASE IN BATTERY CAPACITY
  - – BATTERY OCV WELL RECOVERED FROM 30-31 VDC LOWS TO MORE CONSISTENT 32-33 VDC
  - – TWO BATTERIES ALREADY EXPOSED TO TIMED DISCHARGE HOG DISCHARGE LOADS FOR LONGER PERIODS OF TIME
  - – REGULAR BATTERY CHARGE CUTOFFS

Figure 3-38

SUMMARY

- o 4 YEAR OPERATION WITH NO FAILURES
  - - 90 DAY OPERATIONAL REQUIREMENT
- o CELL TYPE
  - - POLYPROPYLENE SEPARATOR
  - - STANDARD UNTREATED NEGATIVE PLATES
  - - HEAT TREATMENT OF COMPLETED CELL ASSEMBLY
- o RECONDITIONING/MAINTENANCE VERY SUCCESSFUL
  - - VIKING LANDER-1 WEEKLY DISCHARGE/RECHARGE
  - - VIKING LANDER-2 TIMED DISCHARGE/RECHARGE RECONDITIONING

Figure 3-39