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OAO BATTERY DATA ANALYSIS

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Bethpage, New York 11714

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Final Report

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16. Abstract

Summary, consolidation and analysis of specifications, manufacturing process and test controls, and performance results for OAO-2 and OAO-3 lot 20 Amp-Hr sealed nickel cadmium cells and batteries. Correlation of improvements in control requirements with performance a key feature. Updates cell/battery computer model to improve performance prediction capability. Applicability of regression analysis computer techniques to relate process controls to performance checked.

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PREFACE

The material contained in this report summarizes and consolidates pertinent information on specifications, manufacturing process and test controls, and performance results for OAO batteries. The 20 Ampere-hour sealed nickel cadmium cells for these batteries were manufactured and tested under the most stringent quality assurance requirements used to date, closely monitored by Grumman and NASA/GSFC engineering. The report relates changes in cell and battery performance to improvements in these controls. By updating the cell/battery computer model used in the OAO Power Supply Simulation Program, this report also improve battery performance prediction capability significantly.

Applicability of regression analysis techniques to correlate process controls to cell performance proved to be somewhat limited. However, this effort showed several areas where further control imrpovements, especially in documentation and traceability improvements, would not only provide more uniform results, but would also enable more sharply defined correlations.

The cell data analyzed herein is taken from lots manufactured and tested for OAO-2, OAO-B, and OAO-3 flight and flight spare use. While trends and correlations were shown to exist on these data, the reader is cautioned in his interpretation of these results in application to other nickel cadmium cells.

The authors gratefully acknowledge the guidance, assistance, provision of data, patience and understanding of Messrs. Floyd E. Ford and Thomas J. Hennigan, Sr. of NASA/GSFC. Their helpfulness has been invaluable to the sucessful completion of this effort.

Gratitude is also hereby expressed to Messrs. E. E. Miller and F. Burgess of Grumman for their assistance in the preparation of this report, and to Messrs. I. Schulman and E. Kipp of Gulton Battery Corporation, for supplying required information.

TABLE OF CONTENTS

TABLE OF CONTENTS

(Continued)

Note #1. References to AV252CS-25F should read AV252CS-25G

LIST OF FIGURES AND ILLUSTRATIONS

LIST OF FIGURES AND ILLUSTRATIONS
(Cont'd)

LIST OF FIGURES AND ILLUSTRATIONS

(Cont'd)

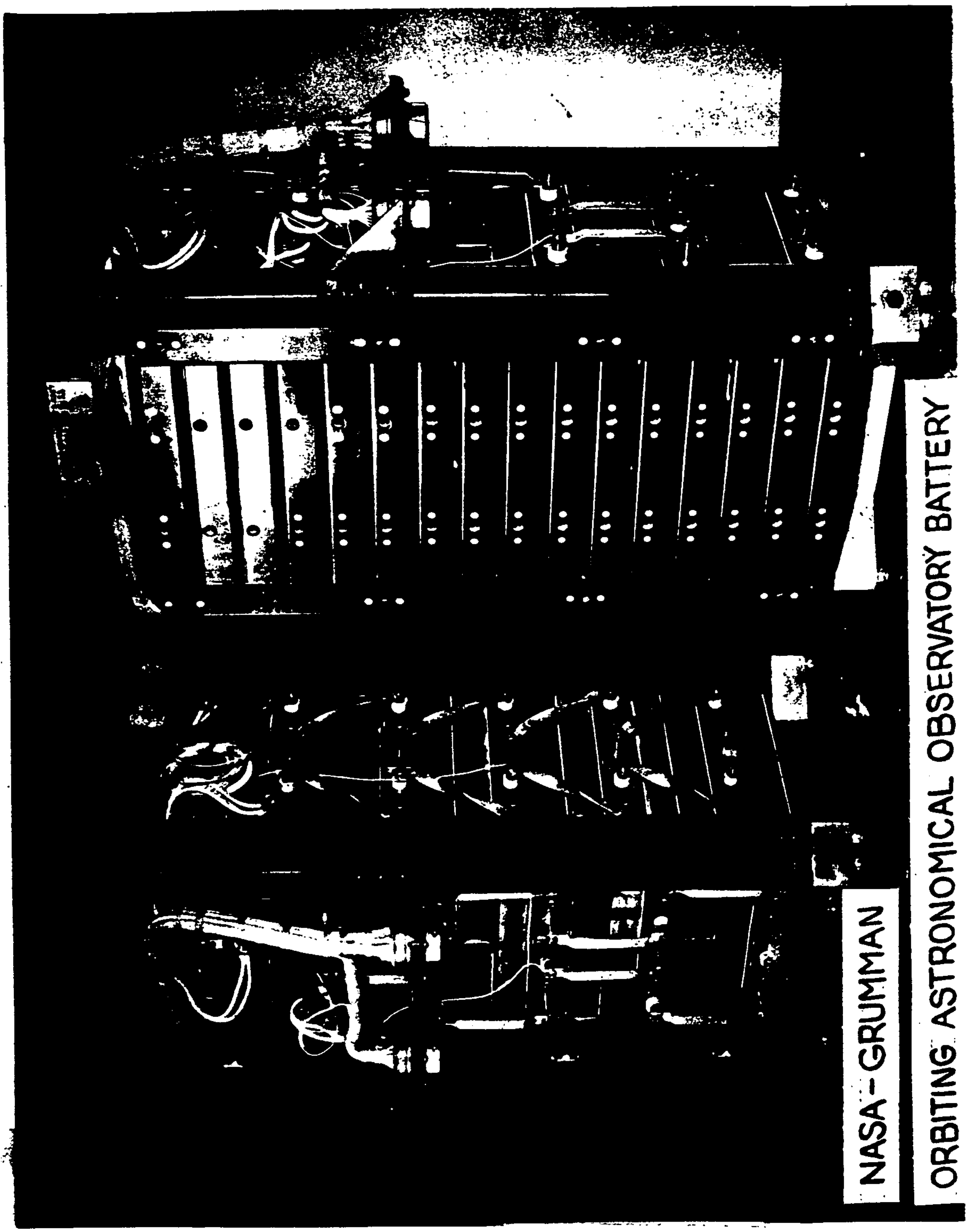
LIST OF FIGURES AND ILLUSTRATIONS
(Cont'd)

LIST OF FIGURES AND ILLUSTRATIONS
(Cont'd)

LIST OF FIGURES AND ILLUSTRATIONS

(Cont'd)

LIST OF TABLES


NASA-GRUMMAN
ORBITING ASTRONOMICAL OBSERVATORY BATTERY

INTRODUCTION

The OAO (Orbiting Astronomical Observatory) spacecraft number 2 has successfully completed over three years and 16,000 orbits, powered by a solar array/nickel cadmium battery power source.

The battery assembly consists of three parallel connected strings of 21 (OAO-2) or 22 (OAO-3 and following) series connected cells, divided into two sub-assemblies (battery stacks) as shown in photograph on page . Each stack has an assigned serial number, the higher of which contains the third electrode cells.

Each cell is insulated with Kapton film and potting compound (Dow-Corning number 325) and faces a 1/8" thick anodized aluminum heat fin. Each heat fin, in turn, is mounted against a thermally louvered heat sink. Quad-redundant temperature sensing resistors and thermostats are mounted directly against the coldest and hottest cell surfaces for thermal control. The total battery weight is about 165 pounds.

The primary charge mode is a voltage versus temperature charge control. Eight voltage/temperature (BVLS) levels are available for charge control. The charge backup mode consists of a preset trip level generated from the oxygen sensing auxiliary electrodes.

Prior to OAO-2 batteries, it was common practice for the user to specify a minimum of quality assurance and control provisions on the cell component level. A considerable amount of testing on flight cells was therefore required to obtain an acceptable reliability level. A different approach was taken here, starting from OAO-2 spacecraft flight units. Each component, material and manufacturing step was carefully and continuously reviewed by an engineering team with representation from NASA/GSFC, Grumman and the manufacturer. The results of these reviews were incorporated in parallel, and interactively, into the OAO cell specification and the NASA/GSFC-Industry interim high reliability cell specification (Reference 1). Total Grumman engineering and/or quality control coverage monitored and enforced the provisions thereby generated, assessed the results thereof in terms of cell and battery performance, life and reliability, and evaluated and analyzed cell test data to update and improve both specifications noted above. As a result, flight hardware for OAO-2 and on appears to represent the highest state-of-the-art to date.

The data presented herein has been taken from the four assemblies of OAO batteries constructed since the OAO-2 flight set (S/N 25A and 26A). The list below shows these batteries, their production dates and vehicle assignments.

Battery Assembly S/N	Date of Mfg. (Filling with Electrolyte)	No. of Cells/Batt.	Vehicle Assignment
25A and 26A	August 28, 1968	21	OAO-2 Flight
30 and 31	October 9-16, 1968	21	OAO Backup, then
		22	OAO-B* Flight
32 and 33	August-September 1969	22	OAO-B Flight
34 and 35	July-August 1970	22	OAO-B Backup, then
			OAO-3 Flight Backup
36 and 37**	April 1972	22	OAO-3 Backup

NOTES:

* S/N 30 and 31 were not flown.
** S/N 36 and 37 were constructed during the writing of this report and limited data is available.

The amount of cell production data on these later assemblies will be enhanced by progressively increased efforts to control cell materials and manufacturing processes.

The report is divided into sections, each of which follows a particular phase of battery assembly from material selection through final battery performance in tests and flight.

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SECTION 1.0

PROCESS CONTROLS

This section documents the controls employed during the manufacture of the OAO batteries. It includes data on physical and chemical analyses of those components intrinsic to the cell (separator, electrolyte and plates) as well as extrinsic factors (effect of plate weight screening).

1.1 CHRONOLOGY OF PROCESS CONTROLS AND CELL SPECIFICATION DEVELOPMENT

During the fabrication of the subject batteries, frequent changes were made to the cell manufacturing process. Many of these changes were the result of increased understanding of the nickel-cadmium state-of-the-art. Others were incorporated to increase reliability of the finished batteries.

Table 1.1 presents a summary of the cell process changes made during the subject battery builds. It is to be used in conjunction with OAO cell Specification No. AV-252CS-25F, Appendix B. The cell changes, the battery first affected, and the specification paragraph changed, are all listed in the table.

1.2 PRE-CELL FABRICATION

Included in this section are the results of many of the analyses performed on the subject battery cell components. These include separator, KOH and plate analyses from the four batteries manufactured, beginning with the batteries currently in the OAO-2 spacecraft (S/N 25A, 26A).

1.2.1 Separator

Effort here included analysis of and improvements to physical parameters (thickness, strength, porosity, wettability, etc.) chemical characteristics (purity), electrical parameters (resistivity, interference with electrochemical reactions, etc.) and handling requirements (lot control, washing and drying, etc.). The following summarizes this work and its results.

Much controversy arose in the latter part of 1968 concerning the value of wetting agents in separator material. At that time, the batteries originally intended for the OAO-2 flight sets showed higher-than-expected cell voltages during spacecraft tests at Goddard Space Flight Center, and it was speculated that the presence of wetting agents in the separators of those batteries could be causing the anomaly.

The addition of wetting agents to the separator was a result of requests by battery manufacturers to suppliers of nylon spearator materials for faster wetting times in commercial cells.

DEVIATIONS INCORPORATED INTO BATTERY MANUFACTURE AS REFLECTED IN OAO CELL SPECIFICATION AV-25203-25F (Affected paragraph referenced)

		- OAO BATTERY SERIAL NUMBER -		
		S/N 25A, 26A, 30, 31	S/N 32, 33	S/N 34, 35
o ELECTRODES		1. did not incorporate para. 3.4.5.2 (b),(i), & (j) 2. in para. 3.4.5.3 (1) crack defined differently 3. para. 3.4.5.3 (d) (9) was absent 4. para. 3.4.5.3 (d) (8) only applicable to positive plate 5. para. 3.4.5.3 (e) & (f) were not applicable	1. para. 3.4.5.3 (d) (8) only applicable to positive plate 2. did not incorporate para. 3.4.5.2 (h), (i) & (j) 3. in para. 3.4.5.3 (1) cracks defined differently 4. para. 3.4.5.3 (e) & (f) were not applicable	1. para. 3.4.5.3 (d) (9) only applica to positive plate
o FORMATION		1. para. 3.4.5.4.2.8.3 (a) end of first sentence was 0.5 ±0.1 volts 2. para. 3.4.5.4.2.8.3 (c) - a 1Ω resistor was used 3. para. 3.4.5.4.2.8.3 (i) - negative capacity cutoff was -0.20 volt, no sub group A & B 4. para. 3.4.5.4.2.8.2 (d) applicable for S/N 30, 31 & sub.	1. para. 3.4.5.4.2.8.3 (b) & (a) changed from 0.5 ±0.1 volt to 0.75 ±0.25 volts 2. para. 3.4.5.4.2.8.3 (c) - a 1 resistor was used 3. para. 3.4.5.4.2.8.3 (i) - negative capacity was - 0.20 volt and there was no sub group A & B	NONE
o SEPARATOR		1. para 3.4.3.1.7 - target specification was less than 0.25% by weight	1. para. 3.4.3.1.7 -target specification was less than 0.25% by weight	NONE
o ELECTROLYTE		1. para. 3.4.6.3.1 (d) - the max. solids content not specified	NONE	NONE
o CELL HARDWARE	- Container	NONE	NONE	NONE
	- Cover	NONE	NONE	NONE
	- Terminals	1. para. 3.4.6 - S/N 25A, 26A had only one insulated terminal	NONE	NONE
o TESTING	- Radiographic	1. para. 3.4.5.4.2.13 - radiographic examination not performed	1. Added rework categories for x-ray rejects (this build only)	NONE
	- Insulation Check	1. para. 3.4.6.1.12.3 (d) sub-categories (1), (2), (3) added for 30, 31 and sub.	NONE	NONE
	- Precharge	1. - PROPRIETARY - 2. para. 3.4.5.4.2.16, last sentence - valves were opened during this step 3. para. 3.4.5.4.2.17.. absent	1. - PROPRIETARY - 2. para. 3.4.5.4.2.16, last sentence - valves were opened during this step 3. para. 3.4.5.4.2.17.1 absent	. Gas collected during precharge as detailed in "precharge" section of this report
	- Electrical Operations	1. para. 6.0, Appendix II (i) & (j) not included 2. para. 6.0, Appendix II (k) 1Ω short was for 16 hrs. minimum	1. para. 6.0, Appendix II (i) & (j) not included 2. para. 6.0, Appendix II (k) 1 short was for 16 hrs. minimum	NONE
o TESTING	- Ratio	1. para. 3.4.5.5.1 sampling rate - only 1 sample minimum from following stages: conclusion of electrical formation, conclusion of neutralization and drying, completion of standard capacity test 2. para. 3.4.5.5.2 (A) was 75°F to 35°F	SAME CONTENTS AS FOR 25A 31	NONE

TABLE 1.1

A high voltage trend was observed by various aerospace cell users in those cells having separators with wetting agents. It was postulated that these wetting agents were interfering with the electrochemical reactions of the cell. Since there is no necessity for "quick-wets" in aerospace-grade sealed Ni-Cd cells, it is generally felt that these agents should be absent from such cells. The NASA interim high-reliability cell specification incorporated this constraint, as did the OAO cell specification, beginning with S/N 25A, 26A battery construction.

Not only wetting agents, but other possible mechanisms which could interfere with the electrochemical reactions of Ni-Cd cells causing abnormal cell performance, became the targets of extensive study and intensive investigation. By the time of the issuance of the NASA interim high-reliability specification, numerous chemical and physical tests had been defined for separator quality assurance alone. Among the quality tests incorporated in the OAO cell spec were the following (see OAO cell spec AV 252-CS-25F, Appendix B - Paragraph 3.4.3):

- o Name of separator material supplier
- o Base material
- o Fiber manufacturer
    - - part number
    - - lot number
    - - date of mfg.
- o Separator suppliers style number
    - - lot number
    - - date of mfg.
- o Material slit by:
- o Absence or presence of wetting agents added by separator supplier?
- o Type of wash and number of times separator washed
- o Nominal, maximum and minimum thickness
- o Weight (gm/m^2) on three samples
- o Dimensions and dimensional changes (width, length and thickness when wet and when dry)
- o Percent thickness change
- o Wet volume
- o Electrolyte absorption
- o Electrolyte retention
- o Porosity

- Separator resistance
- Tensile strength and appearance of break
- Analysis of organic content
- Analysis of inorganic content
- Discoloration in electrolyte

The OAO cell manufacturer uses Pellon style 2505 separator* in the finished cell but uses Dynel and Viscon separator during plate formation. Pellon lot #16015 was used for battery S/N's 25A, 26A through 32, 33 while lot #17160 was used for S/N 34, 35. Neither lot contained wetting agents.

Included in Tables 1.2.1-1 through 1.2.1-3 are the results of the determination of the organic and inorganic content of the various separators.[2] The organic content was obtained by a method defined in paragraph 3.4.3.1.6 of the OAO cell specification (see Appendix B). The determination of the inorganics was accomplished by the following analyses:

NITRATE	The Taylor method with phenoldisulfonic acid
SILICA	The Taylor method using color reagent one and two
CARBONATE	The Barium-Chloride method
NICKEL	Atomic Absorption method
ZINC	Atomic Absorption method
TITANIUM	Sulfuric-Acid Peroxide Colorimetric method
CHLORIDE	The Mohr method

A sample of pellon (lot #17160) was ashed and analyzed for inorganic constituents using a Baird atomic emission spectrograph. This spectrogram is shown in Figure 1.2.1-1.

Shown in Table 1.2.1-1 is the specification target for total organics and inorganics. Although the target for total inorganics is less than 1.0% by weight, it was controlled tighter (less than 0.25% by weight) for OAO battery S/N's 25A, 26A through 32, 33.

Tables 1.2.1-4 through 1.2.1-6 list results of the determination of the physical properties of the pellon separators. Table 1.2.1-7 is a listing of explanatory notes on how the tests were conducted and on which cell batches these separator lots were used.

---

* Formerly designated as 2505 ML

Table 1.2.1-1 OAO Pellon Separator Analysis

	S/N 25A, 26A, 30, 31, 32, 33	S/N 34, 35	Max Value
● Applicable Battery			
● Pellon Style No.	2505	2505	
- Lot No.	16015	17160	
● Organic Content			
- % Residual	1.27 - 2.44	1.35 - 1.50	2.440
- % Wt. Loss:			
Methanol	2.50 - 2.58	1.23 - 1.29	2.580
Ethanol (ESB)	0.60 - 0.80	0.60 - 0.80	0.800
Methylene CL (ESB)	1.20 - 2.00	1.20 - 2.00	2.000
● Inorganic Content			
- % Ash	0.111 - 0.170	0.180 - 0.250	0.250
- % Nitrate	0.00012 - 0.00015	0.032 - 0.038	0.038
- % Silica	N/D (2)	0.044 - 0.045	0.045
- % Carbonate	0.650 - 1.120	< 0.003	1.120
- % Nickel	N/D	0.010 - 0.011	0.011
- % Zinc	N/D	0.160 - 0.200	0.200
- % Titanium	N/D	< 0.008	0.008
- % Chloride	0.062 - 0.130	0.200 - 0.280	0.280

● Specification Target - Less than 2.0% by weight total organics
- Less than 1.0% by weight total inorganics

NOTES:

1. Style 2505 was formerly designated 2505 ML
2. "N/D" indicates "not detected".

Table 1.2.1-3 OAO Cell Formation Separator Analysis - Viscon

	S/N 25A, 26A, 30, 31, 32, 33	S/N 34, 35	Max Value
● Applicable Battery	S/N 25A, 26A, 30, 31, 32, 33	S/N 34, 35	Max Value
● Viscon P/N	8787	8787	
● Organic Content			
- % Residue	0.290 - 2.330	0.510 - 0.700	2.330
- % Weight Loss	1.340 - 1.910	0.570 - 0.670	1.910
● Inorganic Content			
- % Ash	0.049 - 0.204	0.065 - 0.130	0.204
- % Nitrate	0.00010 - 0.00012	0.029 - 0.050	0.050
- % Silica	N/A	≤ 0.018	0.018
- % Carbonate	0.539 - 0.631	0.005 - 0.018	0.631
- % Nickel	N/D (2)	≤ 0.010	0.010
- % Zinc	N/D	≤ 0.003	0.003
- % Titanium	N/D	≤ 0.004	0.004
- % Chloride	0.048 - 0.110	≤ 0.060	0.110

Table 1.2.1-2 OAO Cell Formation Separator Analysis - Dynel

• Applicable Battery	S/N 25A, 26A, 30, 31, 32, 33	S/N 34,35	Max Value
• Dynel P/N	7354	7354	
- R.R. No.			
• Organic Content			
- % Residue	0.270 - 1.520	0.570 - 0.760	1.520
- % Weight Loss	1.000 - 1.400	0.660 - 0.780	1.400
• Inorganic Content			
- % Ash	0.021 - 0.122	0.023 - 0.044	0.122
- % Nitrate	0.00011 - 0.00093	0.019 - 0.026	0.026
- % Silica	N/D (2)	≤ 0.015	0.015
- % Carbonate	0.484 - 1.191	≤ 0.004	1.191
- % Nickel	N/D	< 0.010	0.010
- % Zinc	N/D	≤ 0.003	0.003
- % Titanium	N/D	≤ 0.004	0.004
- % Chloride	0.042 - 0.101	0.110 - 0.130	0.130

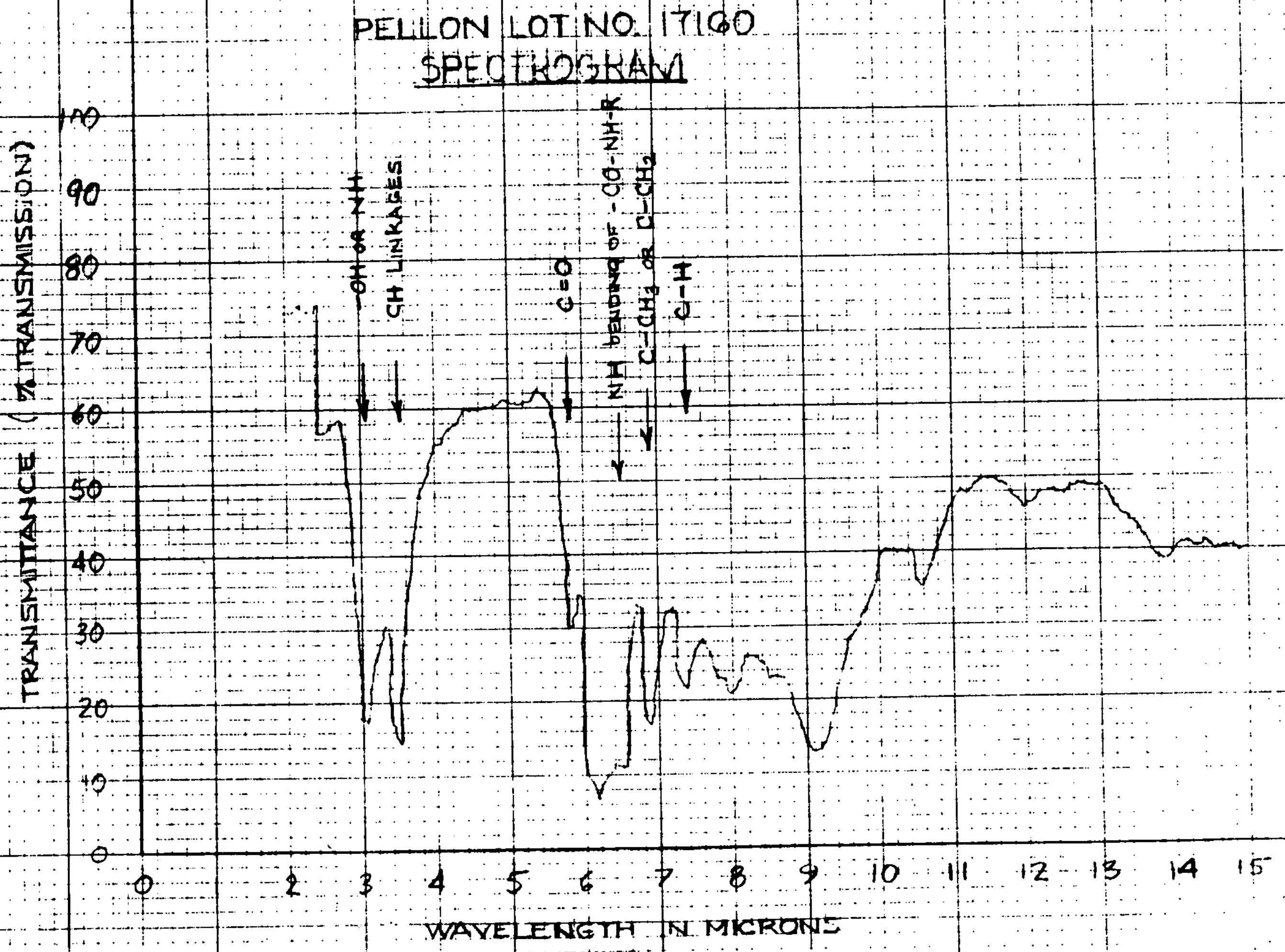

PELLON LOT NO. 17160
SPECTROGRAM
TRANSMITTANCE (% TRANSMISSION)
100
90
80
70
60
50
40
30
20
10
0
-OH or NH
CH LINKAGES
C=O
NH bending of -CO-NH-R
C-CH3 or C-CH2
C-H
0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
WAVELENGTH IN MICRONS

FIGURE 1.2.1-1

Table 1.2.1-4 Pellon Lot #16015

Test	Maximum	Minimum	Mean	# Samples
Dimensional[e]				
Thickness (dry)(cm)	0.042	0.041	0.0458	110
(wet)(cm)	0.095	0.088	0.0915	-
Electrolyte Absorption[e]				
Dry weight (gms)	0.5	0.5	0.5	4
Wet weight (gms)	4.7	4.7	4.7	4
Grams of electrolyte absorbed	4.2	4.2	4.2	-
Porosity	-	-	-	-
Resistance[a]				
Separator resistance (ohm-cm^2)	0.069	0.060	0.065	-
Tensile Strength at Break				
(lbs)	6.0	5.0	5.75	4
Air Permeability[a]				
(seconds to pass 300 cc)	2.5	2.5	2.5	-
Wettability[a]				
(seconds to minimum resistance	80	66	72	-
Wicking - 35% KOH[a]				
Height (mm) @ 5 minutes	0	0	0	-
15 minutes	2.5	2	2.25	-
30 minutes	7.0	5.5	6.25	-

NOTE: See Table 1.2.1-7 for superscript explanations

Table 1.2.1-5 Pellon Lot #17160

Test	Maximum	Minimum	Mean	# Samples
Dimensional[e]				
Length wet (cm)	6.5	6.5	6.5	9
dry (cm)	6.5	6.5	6.5	9
Width wet (cm)	2.5	2.5	2.5	9
dry (cm)	2.5	2.5	2.5	9
Thickness wet (cm)	0.043	0.035	0.0395	9
dry (cm)	0.045	0.037	0.0413	9
% thickness change	9.1%	2.2%	4.3%	9
Electrolyte Absorption[e]				
Dry weight (gms)	0.1076	0.0858	0.0984	9
Wet weight (gms)[2]	1.0250	0.7904	0.9605	9
Grams of electrolyte absorbed	0.9246	0.7046	0.8621	9
Grams of electrolyte retained	0.8359	0.6141	0.7450	9
% electrolyte retained	96%	77%	86.7%	
Porosity[d]				
Percent porosity	125%	104%	115%	9
Resistance[c]				
Separator resistance (ohm-cm^2)	0.0443	0.0081	0.0198	6
Specific resistivity (ohm-cm)	0.969	0.177	0.433	6
Tensile Strength at Break				
(lbs)	6.5	5.0	5.75	4
Discoloration of Sample in Electrolyte		- NONE -		

NOTE: See Table 1.2.1-7 for superscript explanations

Table 1.2.1-6 Pellon Lot #11097
(Third Electrode Separator)

Test	Maximum	Minimum	Mean	# Samples
Dimensional [e]				
Thickness wet (cm)	0.038	0.025	0.0312	18
dry (cm)	0.035	0.025	0.0295	18
Electrolyte Absorption [e]				
Dry weight (gms)	0.1080	0.0770	0.0904	18
Wet weight (gms)[2]	1.0770	0.7460	0.8982	18
Grams of electrolyte absorbed	0.9730	0.6670	0.8079	18
Grams of electrolyte retained	0.8730	0.5940	0.7160	18
% electrolyte retained	93%	85%	88.7%	18
Porosity [d]				
Percent porosity	148%	97%	115.1%	18
Resistance [c]				
Separator resistance (ohm-cm^2)	0.258	0.080	0.185	3
Specific resistivity (ohm-cm)	0.0079	0.0016	0.0047	
Percent Elongation	1.230	0.625	0.928	-

NOTE: See Table 1.2.1-7 for superscript explanation

Table 1.2.1-7 Notes on Separator Tests

Superscript Number	
a.	Data taken from E.S,B. report - "Fifth Quarterly Report on Alkaline Battery Separator Studies (23 June 1968 - 23 September 1968) for Goddard Space Flight Center, Contract NAS 5-10418." (Reference 3).
b.	Wet weight before draining 15 ±5 minutes as defined in OAO cell Specification AV252CS-25F, Para. 3.4.3.1.2 (b).
c.	Resistance measurements described in OAO cell Specification AV252CS-25F, Para. 3.4.3.1.3.
d.	Porosity measured as defined in OAO cell Specification AV252CS-25F, Para. 3.4.3.1.2 (c).
e.	Dimensional measurements, changes and electrolyte absorption, retention techniques are defined in OAO cell Specification AV252CS-25F, Para. 3.4.3.1.2.
1.2.1-4	Used in OAO battery S/N's 25A, 26A, 30, 31, 32 and 33.
1.2.1-5	Used in OAO battery S/N 34 and 35.
1.2.1-6	Used in OAO battery S/N 32, 33 (third electrode wrap only).

1.2.2 Electrodes

The OAO cell contains nine (9) positive and ten (10) negative sintered plaque electrodes. The elctrodes are rectangular, approximately 13 cm x 7 cm and range in thickness from 0.081 cm to 0.095 cm (positive) and 0.079 cm to 0.087 cm (negative). An oxygen sensing electrode is included in some cells as a method of charge control. This electrode is U-shaped, located around the narrow sides and bottom of the cell pack, and measures approximately 36.8 cm x 1.9 cm x 0.07 cm. It is also wrapped in Pellon separator, but one which is thinner than that used in plate separation. The plates are initially tested at the plate manufacturer's facility (Socie'te' des Accumulateurs Fixes et de Traction - S.A.F.T.) for the properties shown in Table 1.2.2-1 and Table 1.2.2-2. Also presented is the calculated plate utilization in ampere-hours per gram of active material, based on the hydrate loading and the results of the SAFT sample capacity test.

No information is available on the nitrate and carbonate content of the plates used in the subject batteries. However, subsequent to OAO battery S/N 34, 35, the cell specification incorporated a requirement for the cell manufacturer to perform a determination of the electrode's nitrate and carbonate content. The results of the tests, as performed by Gulton Industries, are shown in Table 1.2.2-3 for OAO battery S/N 36, 37. Also shown are the results of carbonate analyses performed at SAFT. The nitrate test employed the standard Kjeldahl method of nitrate determination, while the carbonate content was determined by a leaching/titration method. A modification to the carbonate determination is performed on the positive plate, by Gulton, in which acid is added to a pulverized plate sample and the quantity of CO_2 gas evolved is measured. The current OAO cell specification (Appendix B, Paragraph 3.4.5.4.2.8.4.3) defines a nitrate maximum requirement of 330 micrograms per gram of active material, sinter and substrate on the nickel electrode and a maximum of 10 milligrams of carbonate per gram of active material, sinter and substrate, on the cadmium electrode. The design goal for the carbonate content is less than 5 milligrams per gram of electrode.

No additives were reported in the plates. However, at least one source has found cobalt present in the positive plate.[4]

A chemical analysis[5] was performed in April, 1968, on an OAO cell (S/N 221) in which cobalt was also detected in the nickel electrode. Table 1.2.2-4

Table 1.2.2-1 Initial Plate Testing At S.A.F.T. Negative Plate Results

OAO Battery S/N	Saft Lot #	Porosity (%)	Hydrate grams/dm^2	Capacity A-hr./dm^2	Utilization A-hr. /gram*
25A, 26A & 30, 31	33	65.82	16.66	4.20	0.252
	34	65.54	16.97	4.19	0.247
	35	65.18	16.41	4.12	0.251
	36	67.54	16.72	4.16	0.249
32, 33	98	64.50	16.70	4.17	0.250
34,35	103	66.80	16.00	4.00	0.250
	104	66.70	16.30	4.10	0.252
	105	66.90	16.10	4.10	0.255

* Utilization = $\frac{\text{Capacity}}{\text{Hydrate}}$

Table 1.2.2-2 Initial Plate Testing At S.A.F.T. Positive Plate Results

OAO Battery S/N	Saft Lot #	Porosity (%)	Impregnation grams/dm^2	Hydrate grams/dm^2	Nickel Attack grams/dm^2	Capacity A-hr./dm^2	Utilization A-hr./gram*
25A, 26A & 30, 31	34	47.8	13.16	16.20	2.96	4.14	0.256
	35	46.7	13.52	17.06	3.53	4.25	0.249
	36	46.8	13.47	17.03	3.57	4.22	0.248
32, 33	106	45.5	14.32	17.15	3.48	4.27	0.249
	107	45.5	14.32	17.15	3.48	4.34	0.253
34,35	112	45.0	12.70	15.10	2.40	3.90	0.258
	113	45.4	13.20	15.70	2.50	4.00	0.255
	114	45.5	13.40	15.90	2.50	3.90	0.245

* Utilization = $\frac{\text{Capacity}}{\text{Hydrate}}$

Table 1.2.2-3

Results of Carbonate and Nitrate Analyses Performed at SAFT and GULTON for Electrodes from OAO Battery S/N 36, 37

	Performed at GULTON*		Performed at SAFT	
	Nitrate	Carbonate	Nitrate	Carbonate
Positive Plate	55, 45, ppm	13.8, 14.0, mg/g	-	133 mg/dm^2
	35, 35 ppm	16.5, 19.0 mg/g		
Negative Plate	125, 15, 15 ppm	5, 8, 7, 5, 5 mg/g	-	69 mg/dm^2

* Positive plate melange #127
Negative plate melange #117

Table 1.2.2-4

Results of Chemical Analyses on Electrodes from OAO Cell S/N 221 as Taken from U. S. Government Memorandum #3403

Cell Sample	Combined Spectrographic, X-Ray Diffraction and X-Ray Flourescence Results
Nickel Plate Active Material	Ni, Fe, Co, Cd, Pb, Mg, Na, K, Ca, Cr (trace), Ni $(OH)_2$, $KHCO_3$
Nickel Plate Grid	Ni, Fe, Co, Ca, Mn, K, Cd, Na
Cadmium Plate Active Material	Cd, Ni, K, Pb, Na, Ca, Si, Cr, Fe, Ni $(OH)_2$, Cd $(OH)_2$
Cadmium Plate Grid	Cd, Ni, Mn, K, Na, Fe, Co (small), Cr (trace), Ag (trace)
Third Electrode Active Material	Ni, Si, Mg, Na, K (large), Cd, Pb, B, Ag, Mn (trace), Ca (trace), Cu (trace)
Third Electrode Grid	Ni, Co, Fe, Mn, K, Na, Mg, Ag, Si, B, Pb, Cd, Cr (trace), Zn (trace), Ca (trace)

shows the results of the combined analyses on the negative and positive electrodes, as well as the third (adhydrode) electrode. It should be noted that silicon is present in significant amounts. However, the plates in this analysis were from an earlier assembly than S/N 25A, 26A, and at this time the silica content in the water used for rinsing plates was not controlled. Beginning with S/N 25A, 26A, the OAO cell specification required a maximum silica content in the water of 1 ppm.

1.2.3 Electrolyte

The OAO cell specification requires complete traceability of the electrolyte back to the manufacturers batch number, grade and analysis. The date the electrolyte is purchased as well as the date that the container is first opened is also recorded.

Potassium hydroxide "mercury cell" grade electrolyte is mixed with distilled water to the required concentration. The following specification requirements ensure a contamination-free electrolyte:

ITEM	SPECIFICATION	TEST PROCEDURE USED
Distilled Water	- silica content less than 1 ppm - solids content less than 50 ppm	
Electrolyte	- carbonate content less than 0.01 gm/liter - hydroxyl ion concentration held to ±20 mg/cc - nitrate content of 1 mg/liter or less - content of silver, cobalt, copper, iron, sulfur, zinc and any other impurities present in concentrations greater than 100 ppm shall be noted and reported	double titration with phenolphthalein and & methyl orange analytical methods - colorimetric analysis spectrochemical analysis

The spectrographic results for the electrolyte used in OAO battery S/N's 32, 33, 34, 35, 36, and 37 are shown in Table 1.2.3-1.

1.2.4 Cell Terminals

All standard OAO cells for batteries up to and including battery serial number 32 had one insulated (ceramic) terminal. The other terminal (negative) was welded directly to the case cover. All auxiliary electrode cells had two insulated terminals. The auxiliary electrode tab was welded to the underside of the cover.

The decision to use one insulated terminal on OAO standard cell was made several years back when insulated terminal seal leakage was the predominant mechanism in cell failure.

Early in 1967, Grumman funded a study for a ceramic seal improvement for the OAO cell. This study resulted in the addition of a "stress relief collar"; the use of the silver-copper eutectic braze alloy to replace silver braze; and the addition of nickel plating over the braze material to the underside of the cover assembly. As a result of these terminal modifications, seal failures became rare as cell life determining factors. However, some terminal corrosion (plating) problems were observed whereby the braze material formed a "bridge" across the ceramic sleeve causing an internal cell short. Also occasionally, during cell testing, when a voltage probe, or any other metal object touched both terminal stud and cover, the accident caused permanent damage to the seal.

To further improve cell performance reliability it was decided, in 1969, to change from one to two insulated terminals. This decision was mainly based on the following[6]:

- Higher reliability for the insulated terminal was achieved by addition of the "stress relief member (collar)" and change to the silver-copper braze alloy plus nickel plating.
- A slower plating (corrosion) rate of braze material across the ceramic was observed when two, rather than one, insulated terminals are present. Now a total of two shorts (one across each ceramic) need to be present for a cell to fail electrically.
- Accidentally induced external shorts between a terminal and the container will not support sufficient current to permanently damage the seal.

In November 1968 it was discovered that cells, constructed 9-12 months earlier had developed leaks through the lower nickel-iron cup of the terminal.[7] It was determined that the acidic tinning flux used for the soldering operation was trapped in the terminal cavity causing stress corrosion. This problem was eliminated when the terminal cavity was blocked, using a silicone potting material (E.C. 1663) prior to the fluxing operation. This potting material was removed after completion of tinning, and assuring that all flux traces were removed. In addition, precautionary instructions were added to the cell specification (see Appendix B, Paragraphs 3.4.6.2 and 4.5.15) and to all

Table 1.2.3-1 KOH Analysis

Element	S/N 32, 33	S/N 34, 35	S/N 36, 37
Aluminum	vft	vft	vft
Arsenic	ND	ND	ND
Antimony	ND	ND	ND
Barium	ND	ND	ND
Boron	ND	ND	ND
Bismuth	ND	ND	ND
Cadmium	ND	ND	ND
Calcium	ND	ND	ND
Carbon	X	X	X
Chromium	ND	ND	ND
Cobalt	ND	ND	ND
Copper	vft	ND	ND
Iron	vft	ND	ND
Lead	ND	ND	ND
Lithium	ND	ND	ND
Magnesium	vft	ND	ND
Manganese	vft	ND	ND
Mercury	X	X	X
Molybdenum	ND	ND	ND
Niobium	ND	ND	ND
Nickel	ND	ND	ND
Phosphorus	X	X	X
Potassium	P	PH	P
Sodium	ND	ft	ND
Sulfur	X	X	X
Silicon	vft	ND	ND
Silver	vft	ND	ND
Tantalum	ND	ND	ND
Tellurium	X	X	X
Tin	ND	ND	ND
Titanium	ND	ND	ND
Tungsten	ND	ND	ND
Uranium	X	X	X
Vanadium	ND	ND	ND
Zinc	ND	ND	ND
Zirconium	ND	ND	ND

P - 10 to 100%
ND - Not Detected
X - Not tested
H - Upper half of range shown
ft - Less than 0.01%
vft - Very faint trace

cell/battery operational instructions. These require a thorough cleaning and drying of the cavity after each phenolphthalein leak check.

1.3 CELL FABRICATION

Once the plates have been inspected and approved, they are screened according to plate weight. This procedure was incorporated beginning with the assembly of battery S/N 34, 35 and consists of first determining the average weight of all the positive or negative electrodes and then rejecting any plates which fall outside ±3.5% of the average. The effect of plate weight screening is to improve capacity uniformity among the cells in the battery. This was shown in an analysis performed at Goddard Space Flight Center by G. Halpert.[8]

Table 1.3 shows how plate weight screening reduced the spread in capacity among cells in battery S/N 34, 35. The standard deviation of capacity in these cells ($\sigma = 0.33$) is approximately half of that observed in cells without screening. Since the cells are designed to be positive limiting both on charge and discharge, the distributions reflect the correlation of positive plate weight with capacity and cannot reveal whether the negative capacity distribution is also tightened by weight screening.

Battery S/N	Plate Weight Screened?	Mean Capacity (A-hr.)	Capacity Std. Deviation (A-hr.)	Range (A-hr.)
S/N 25A, 26A	no	25.46	0.62	2.83
30,31	no	25.63	0.69	3.66
32, 33	no	26.22	0.51	3.68
34, 35	yes	23.27	0.33	1.50

TABLE 1.3

Effect of Plate Weight Screening (Plate Average Weight ±3.5%)
On Cell Capacity

SECTION 2.0

INITIAL CELL PERFORMANCE AT SELLER'S (CELL MANUFACTURER'S) FACILITY

2.1 ELECTRICAL TESTING

This section summarizes the results of the initial testing performed at the seller's facility on both the electrode packs and finished cells. Included are (in the order of the cell fabrication):

- Formation
- Precharge
- Manufacturer's electrical testing
- GAC cell selection tests
- Ratio tests

2.1.1 Formation

The formation (electrochemical cleaning operation) is performed at Gulton on individual packs of nine positive and ten negative electrodes using a combination of Viscon and Dynel separator material and placed in open nylon containers. The packs are flooded to a minimum of 1/4 inch above the separator with 34% potassium hydroxide solution. The packs soak at room temperature for a minimum of four hours and a maximum of twenty-four hours prior to the first electrical operation. All electrical connections to the pack or between the electrodes in the pack which are susceptible to attack by electrolyte are either of stainless steel or nickel plated materials. Electrolyte level is maintained throughout the operation at 1/4 inch above the separator by adding 34% KOH when necessary.

The electrical regime consists of a series of charge-discharge cycles (Gulton proprietary) followed by a C/2 discharge to 0.70 ±0.1 volt to determine the positive electrode capacity. After a 0.1Ω drain on individual cells to 0.1 ±0.1 volts, the total negative electrode capacity is determined by an additional 2.0 amp discharge to -0.25 volts.

Following the formation cycling and electrode capacity determination, the packs are disassembled, the positive and negative electrodes are separated and immediately submerged in separate de-ionized water baths. This rinsing operation is completed when the last drippings from the sample electrodes display a Ph reading of 6 to 8. The plates are then air dried at 50 ±5°C for a 16-24 hour period. The deionized water used to wash the plates must exhibit a resistivity greater than 1.0 megohm-cm, a silica content less than 1.0 ppm, and a solids content less than 50 ppm.

Figures 2.1.1-1 and 2.1.1-2 show the distribution of the positive and negative electrode capacities during the formation discharge. The effect of the plate weight screening shows as a tighter distribution for the positive plates on S/N 34, 35, although the negative capacity spread did not appreciably change. This suggests that the weight screening of the negative electrodes did not improve the spread of negative plate capacity. The point may be erroneous, however, since during the formation discharge the cell reverses to only -0.25 volts. Perhaps if the cell were discharged down to -1.0 volts, the true value of the negative electrode capacity would be realized. The -0.25 volt intercept occurs at the beginning of the negative electrode discharge curve "knee" and hence is not completely representative of the total negative capacity (see Figure 2.1.1-3). It has been determined, in fact, that a 10 amp discharge down to -1.0 volt consistently reveals an additional 10% negative capacity than is shown by a 2 amp discharge to -0.25 volts. Based on results from NASA/GSFC,[8] showing a strong correlation between negative plate weight and capacity, it is expected that, if the discharges had been made down to -1.0 volts, the distribution of negative capacity would be tighter for the S/N 34, 35 cells than for the cells built previous to battery S/N 34, 35.

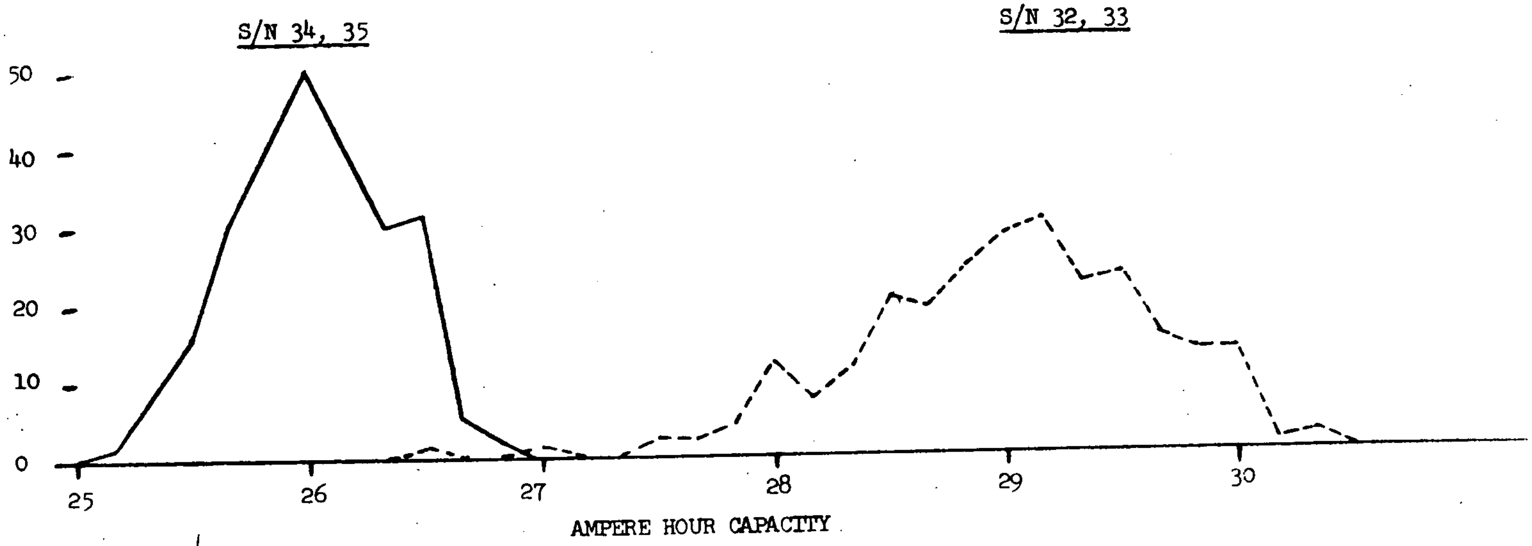
2.1.2 Precharge

Precharging the negative electrode is desirable in sealed Ni-Cd cells to have a charged cadmium reserve to prevent a negative electrode capacity limiting condition during discharge in cycling.[9,10] It is desirable that a certain amount of precharge (usually a proportion of the total negative) exists, and that this amount be known and controllable. In reviewing the literature one can find a wide diversity of precharging techniques, each with its own degree of uncertainty as to the amount of precharging which the cadmium electrode receives.

To resolve some of these uncertainties, NASA/GSFC and Grumman undertook steps during the construction of battery S/N 34, 35 to measure and set the precharge on the negative electrode. Figure 2.1.2-1 shows, in diagram form, the Gulton precharge operation. Cells are charged in a rate/time method where most of the oxygen gas evolving from the fully charged nickel electrodes can escape, thereby minimizing the recombination at the negative electrode. Hence, the negatives will receive an additional charge over the positives. Upon discharge

FINAL CAPACITY DISCHARGE DURING FORMATION -

POSITIVE PLATE DISTRIBUTION



MEAN = 26.03 A-hr.

σ = .335 A-hr.

CUTOFF VOLTAGE = 0.70 ±0.10 V

MEAN = 29.00 A-hr.

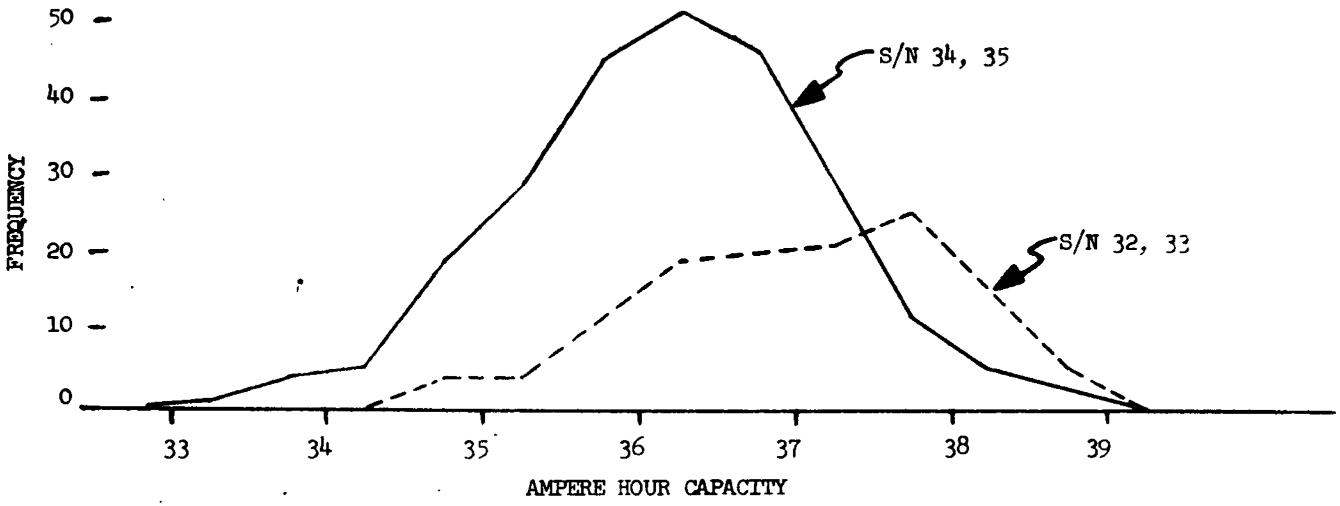
σ = .616 A-hr.

CUTOFF VOLTAGE = 0.75 ±0.25 V

FIGURE 2.1.1-1

FINAL CAPACITY DISCHARGE DURING FORMATION - NEGATIVE

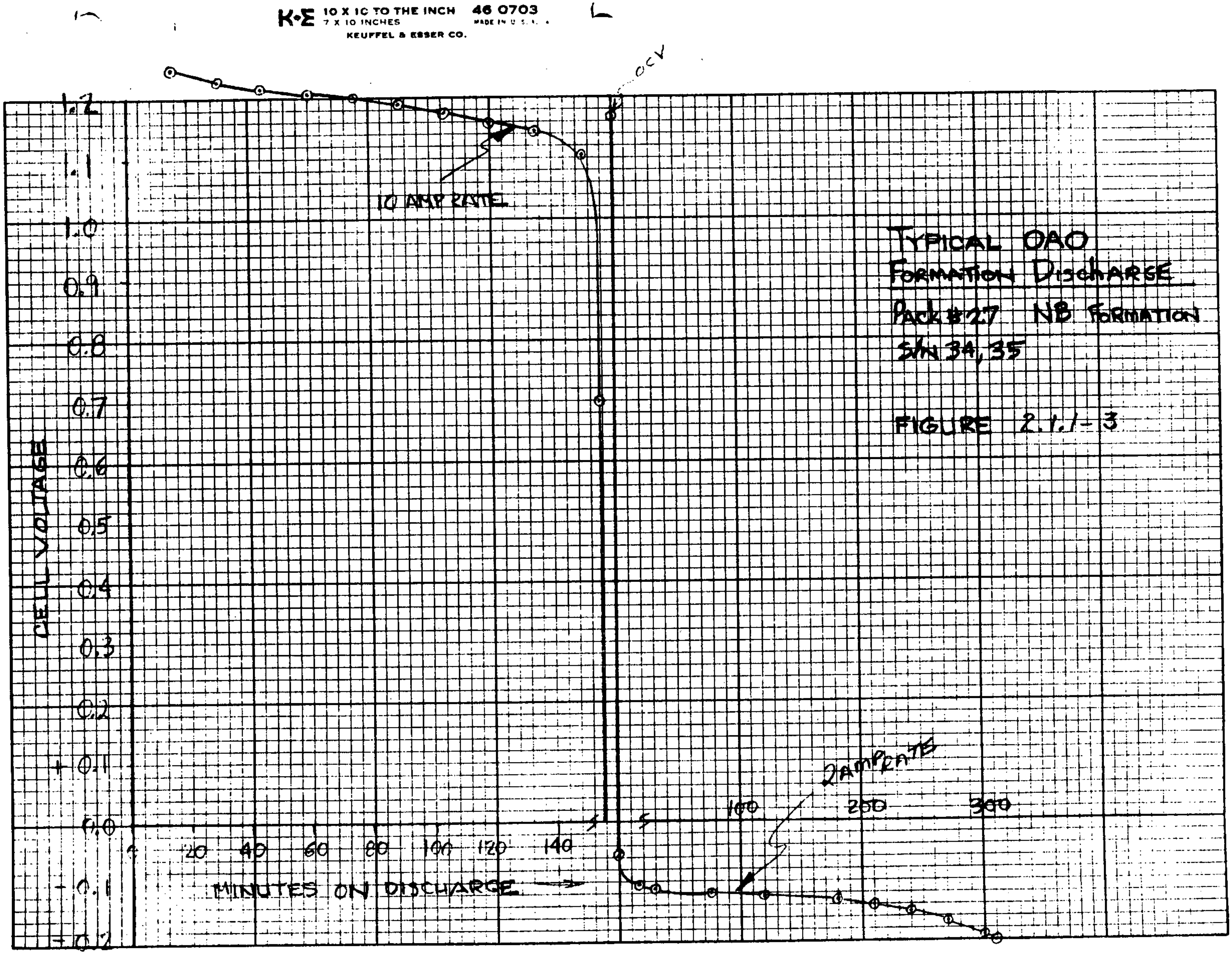
PLATE DISTRIBUTION 10 AMP TO -0.25 V



S/N 34, 35 MEAN = 36.19 A-hr.
σ = 0.985 A-hr.

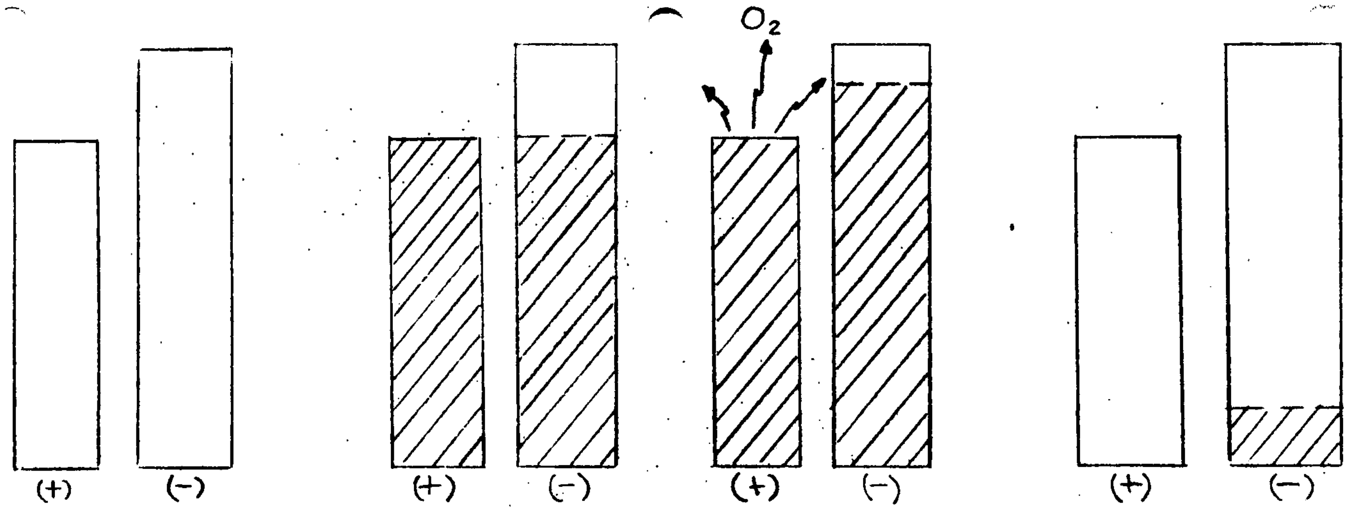
S/N 32, 33 MEAN = 37.00 A-hr.
σ = 0.970 A-hr.

FIGURE 2.1.1-2



TYPICAL OAO
FORMATION DISCHARGE
PACK #27 NB FORMATION
S/N 34, 35

FIGURE 2.1.1-3



- Following formation wash and dry it is assumed that each electrode is fully discharged. Electrodes assembled in cell case in this condition.

- Cells placed on charge for specific time and rate.
- Cell valves are open.

- When the positive plate is fully charged, oxygen escapes.
- Although a partial discharge of the negative plate group occurs due to some recombination, the negative group is now charged to a higher level than the positive group.

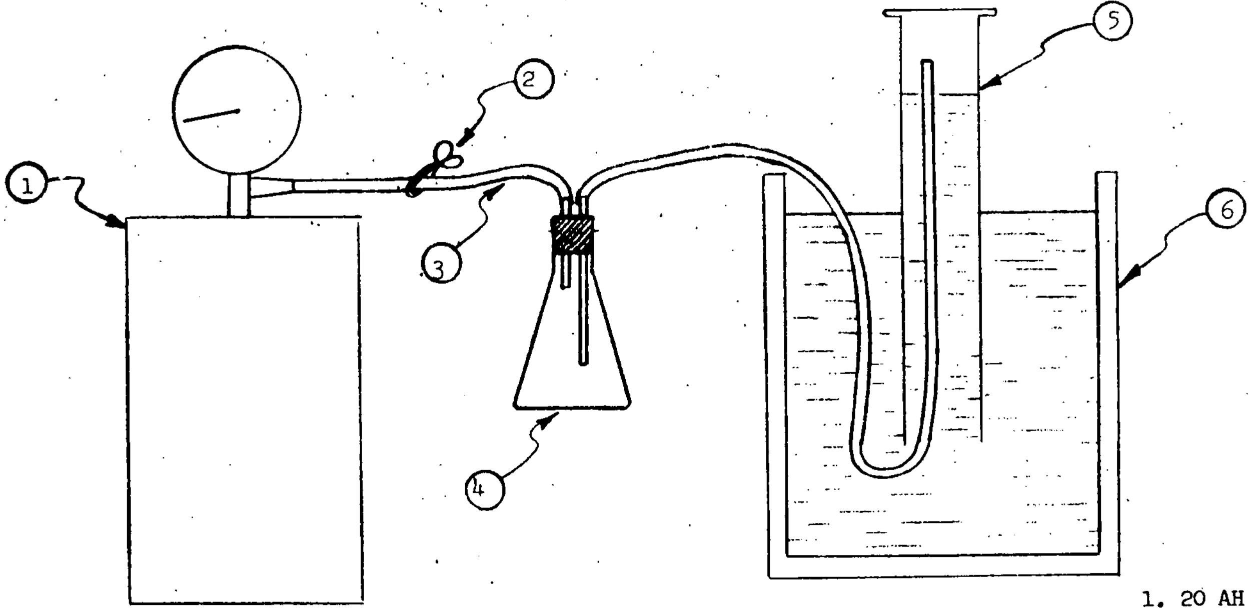
- Cell valves closed.
- When cell is discharged some residual negative capacity (precharge) remains.

▨ = charged
☐ = discharged

FIGURE 2.1.2-1

PRECHARGE SETTING ON OAO CELLS AT GULTON

BLOCK DIAGRAM



PRECHARGE APPARATUS USED TO MEASURE QUANTITY OF GAS EVOLVED DURING OAO BATTERY SERIAL NUMBER 34, 35 ASSEMBLY

APPARATUS

1. 20 AH NI-CD CELL
2. PINCH-COCK
3. TYGON TUBING
4. FLASK USED TO PREVENT BACK-FLOW OF WATER INTO CELL
5. INVERTED GRADUATED CYLINDER
6. TROUGH FILLED WITH WATER

FIGURE 2.1.2-2

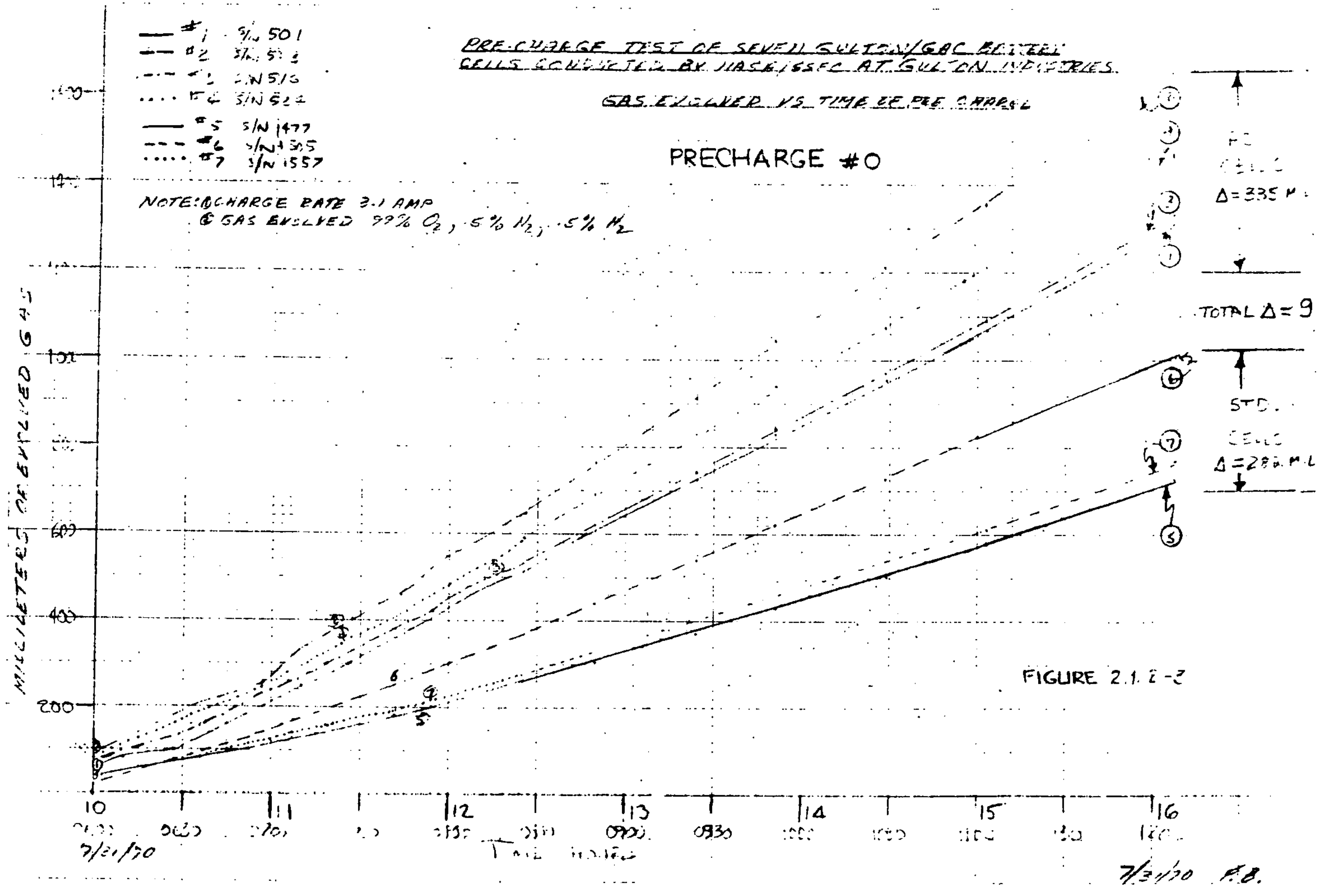
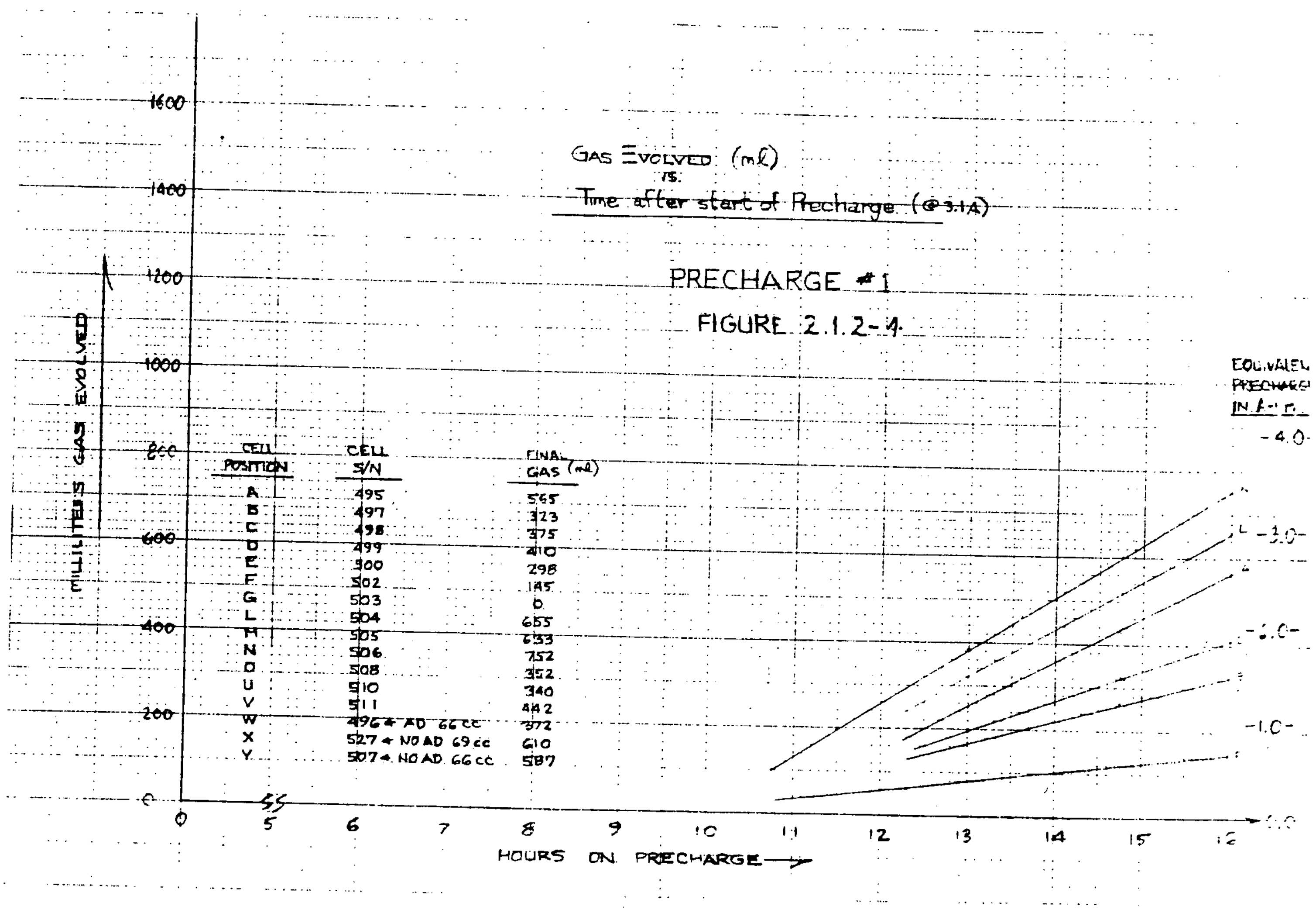

PRE-CHARGE TEST OF SEVEN GULTON/GAC BATTERY CELLS CONDUCTED BY NASA/GSFC AT GULTON INDUSTRIES.
GAS EVOLVED VS TIME OF PRE CHARGE
PRECHARGE #0
#1 S/N 501
#2 S/N 512
#3 S/N 513
#4 S/N 522
#5 S/N 1477
#6 S/N 1505
#7 S/N 1557
NOTE: ① CHARGE RATE 3.1 AMP
② GAS EVOLVED 99% O₂, .5% H₂, .5% H₂
MILLILITERS OF EVOLVED GAS
200
400
600
1000
1400
10
11
12
13
14
15
16
0930
7/21/70
TIME HOURS
F.C. CELLS
Δ=335 ML
TOTAL Δ=9
STD. CELLS
Δ=286 ML
7/31/70 F.B.

FIGURE 2.1.2-2

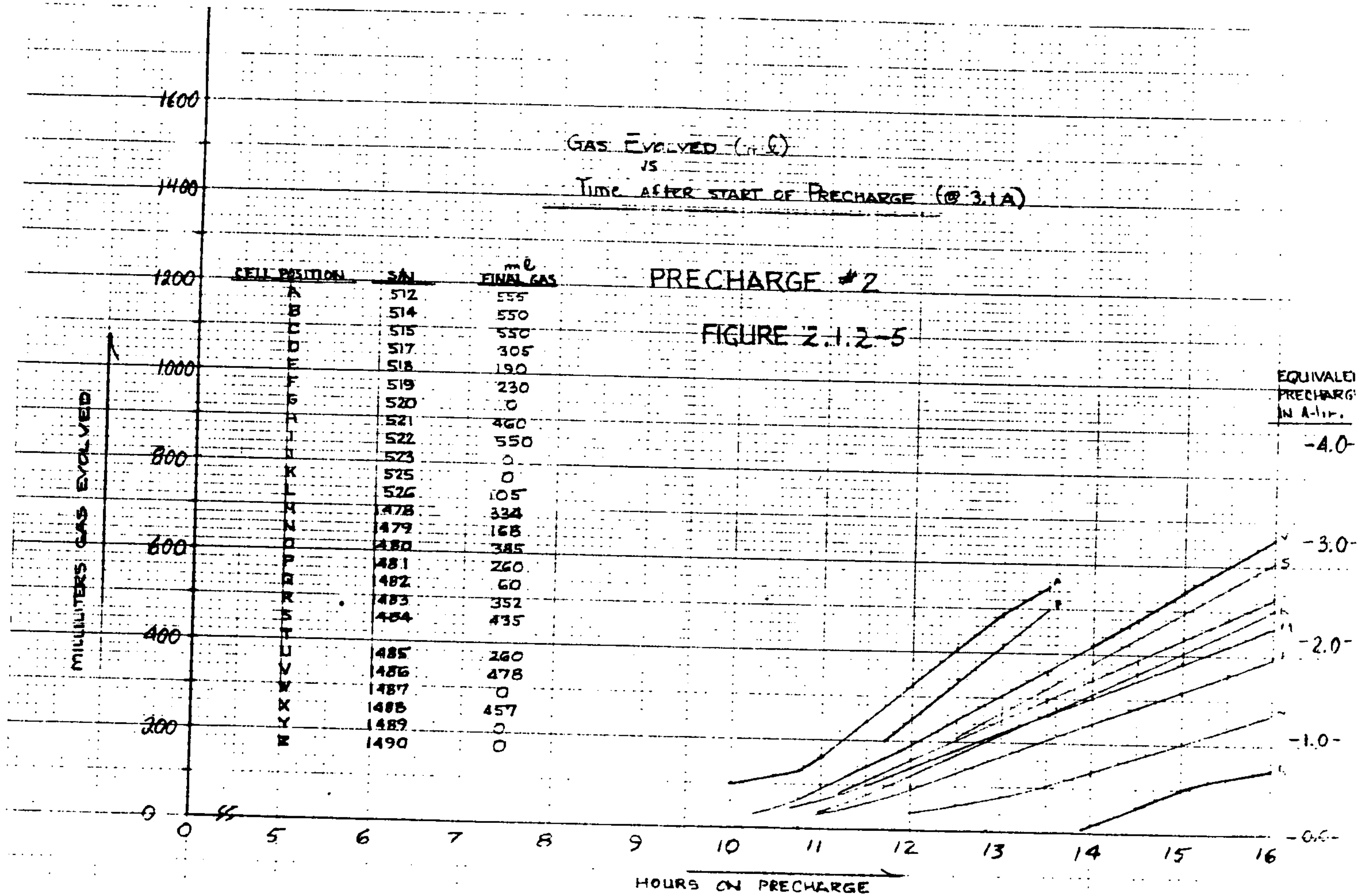
Gas Evolved (ml)
vs.
Time after start of Precharge (@3.1A)

PRECHARGE #1

FIGURE 2.1.2-4



CELL POSITION	CELL S/N	FINAL GAS (ml)
A	495	565
B	497	323
C	498	375
D	499	410
E	500	298
F	502	145
G	503	0
L	504	655
M	505	633
N	506	752
O	508	352
U	510	340
V	511	442
W	496 ← AD 66 cc	372
X	527 ← NO AD 69 cc	610
Y	507 ← NO AD 66 cc	587

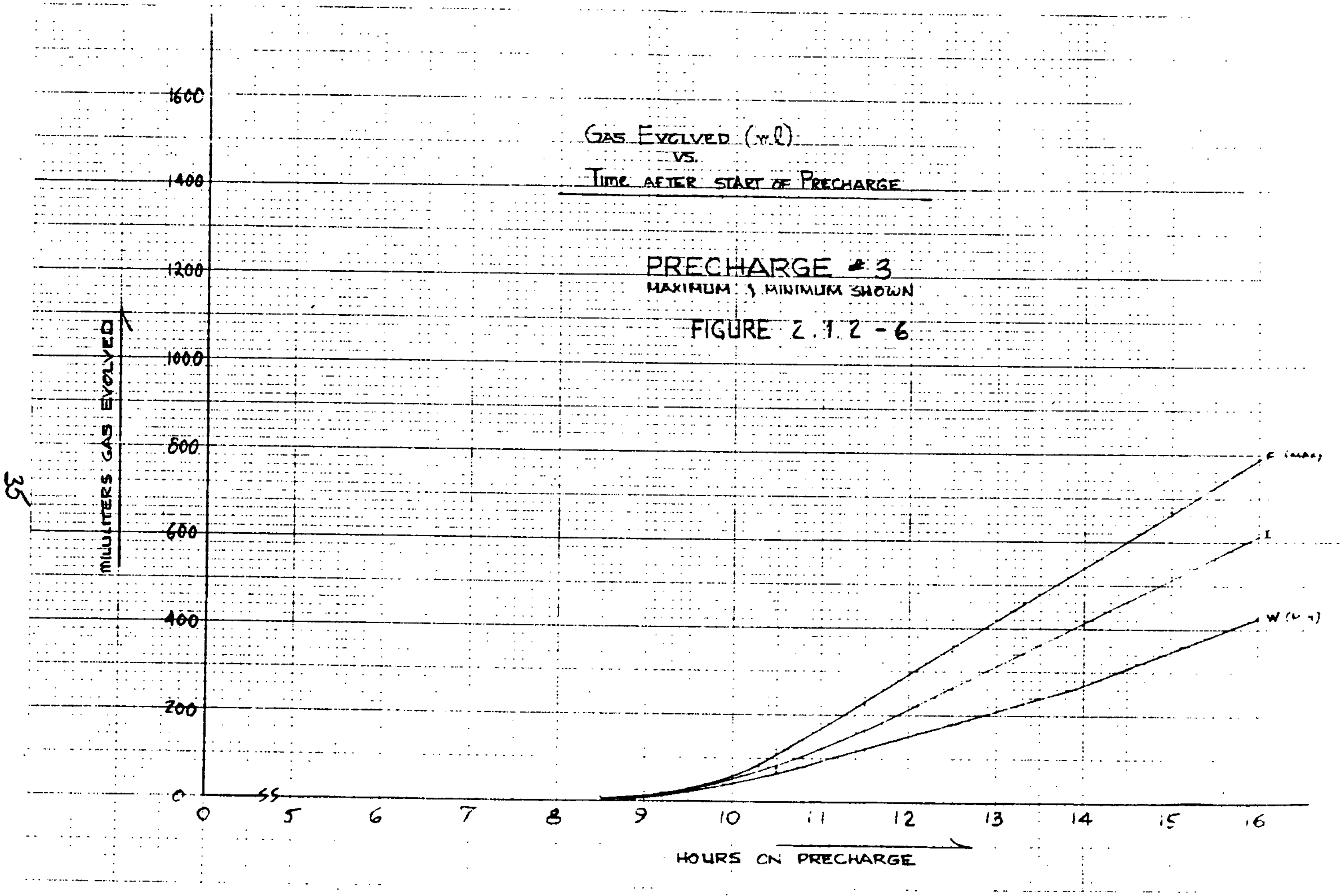


GAS EVOLVED (ml)
vs
TIME AFTER START OF PRECHARGE (@ 3.1A)

PRECHARGE #2

FIGURE Z.1.2-5

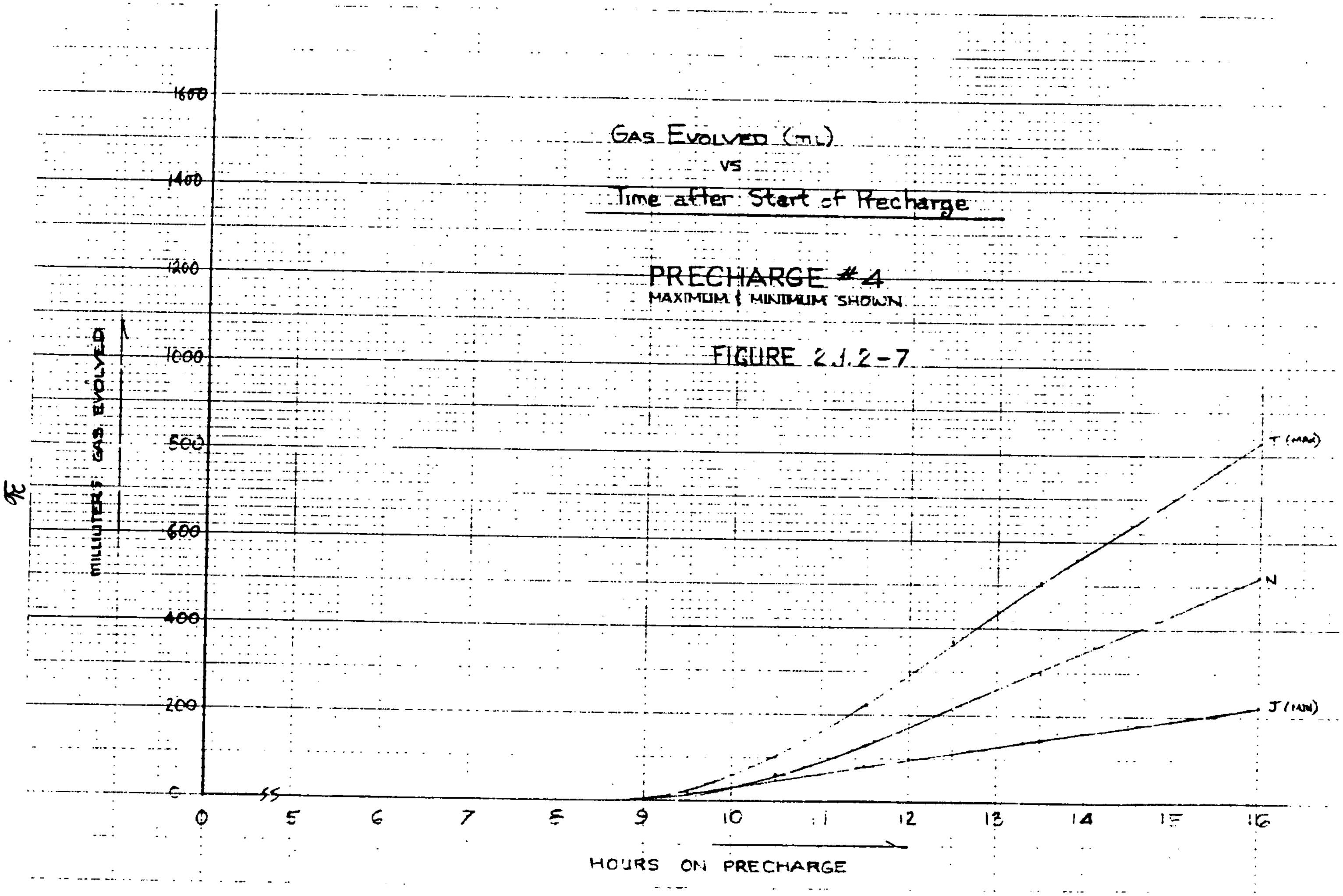
CELL POSITION	S/N	ml FINAL GAS
A	512	555
B	514	550
C	515	550
D	517	305
E	518	190
F	519	230
G	520	0
H	521	460
I	522	550
J	523	0
K	525	0
L	526	105
M	1478	334
N	1479	168
O	1480	385
P	1481	260
Q	1482	60
R	1483	352
S	1484	435
T		
U	1485	260
V	1486	478
W	1487	0
X	1488	457
Y	1489	0
Z	1490	0



GAS EVOLVED (ml)
VS.
TIME AFTER START OF PRECHARGE

PRECHARGE #3
MAXIMUM & MINIMUM SHOWN

FIGURE 2.1.2-6



Gas Evolved (mL)
vs
Time after Start of Precharge

PRECHARGE #4
MAXIMUM & MINIMUM SHOWN

FIGURE 2.1.2-7

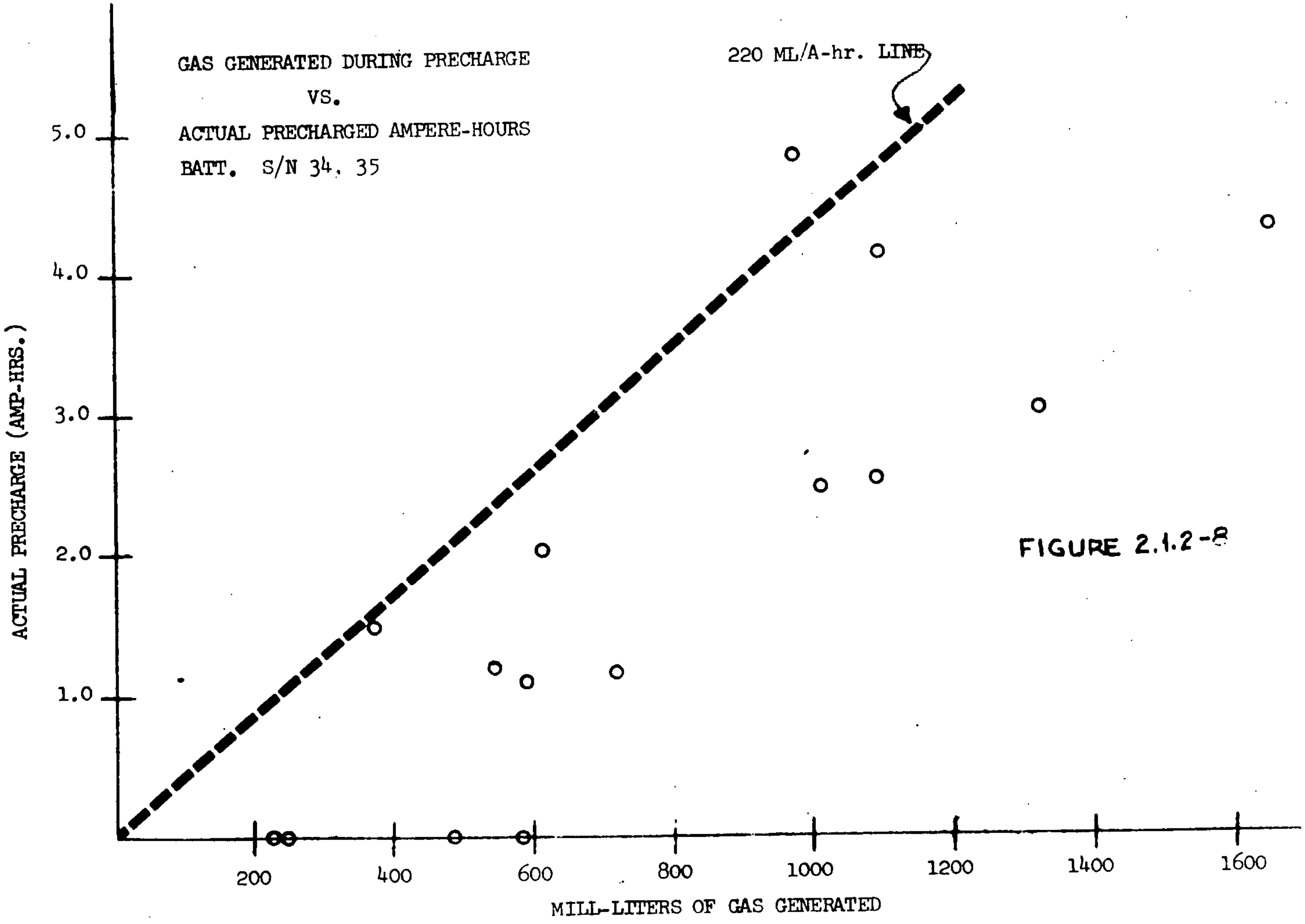

GAS GENERATED DURING PRECHARGE
VS.
ACTUAL PRECHARGED AMPERE-HOURS
BATT. S/N 34, 35

FIGURE 2.1.2-8

this will show up as a reserve supply of charged negative and thus ensure the cell to be positive limiting. Of course it is undesirable for the negatives to become fully charged at the end of charge as this could make the cell negative-limiting on charge where hydrogen gas evolution would occur. It can be appreciated that this technique is valuable but can present difficulty if the negatives are charged too much or too little. To control this precharge setting it is essential to determine the negative electrode residual charge content (Cd) after the washing and drying operation. Figure 2.1.2-2 shows the apparatus used by GAC and NASA/GSFC to measure the precharge more reliably. It consists essentially of apparatus to collect the gas which evolves from the cell while it is on charge. The gas was analyzed and found to be essentially oxygen. The quantity of oxygen gas evolved can be considered as the equivalent amount of negative capacity stored in excess of the positive capacity when both electrodes were started on charge from the fully discharged state.

Figures 2.1.2-3 through 2.1.2-7 show plots of the gas evolution on charge as a function of time. A few items to be noted are that there is quite a spread in the final amount of gas generated during the period on charge and that each cell begins gassing slightly below nine hours. The cells appear to gas when the positive electrodes reach full charge which, for a positive plate capacity of about 27 A-hrs., should be around 8.7 hours at the 3.1 amp rate. Thus the onset of gassing is consistent with the expected. In this test the cells were found to evolve between 60 ml and 1600 ml of oxygen during the period, representing precharges ranging from 0.25 A-hr. to 7.2 A-hr., based on 1 A-hr. of precharge being equivalent to 220 ml of oxygen gas.

Some of the cells were later subjected to ratio tests where the actual precharge was measured. As Figure 2.1.2-8 shows,[14] a strong correlation exists between the amount of gas collected and the measured precharge. The theoretical 220 ml/A-hr. line is also shown. It appears that the theoretical line has the correct slope but should be shifted to the right of the origin. In other words, the cells seem to exhibit a threshold (of about 300 ml) of gas which must evolve before any precharge is measurable on the cadmium plates. Shifting the theoretical line to the right by 300 ml fits the data nicely. Thus, the equation for determining precharge, based on gas measurements, can be written as:

$$Y_{\text{A-hr.}} = \frac{X_{\text{ml}} - 300}{220}$$

where

X_{ml} = ml of O_2 evolved

$Y_{\text{A-hr.}}$ = precharge negative

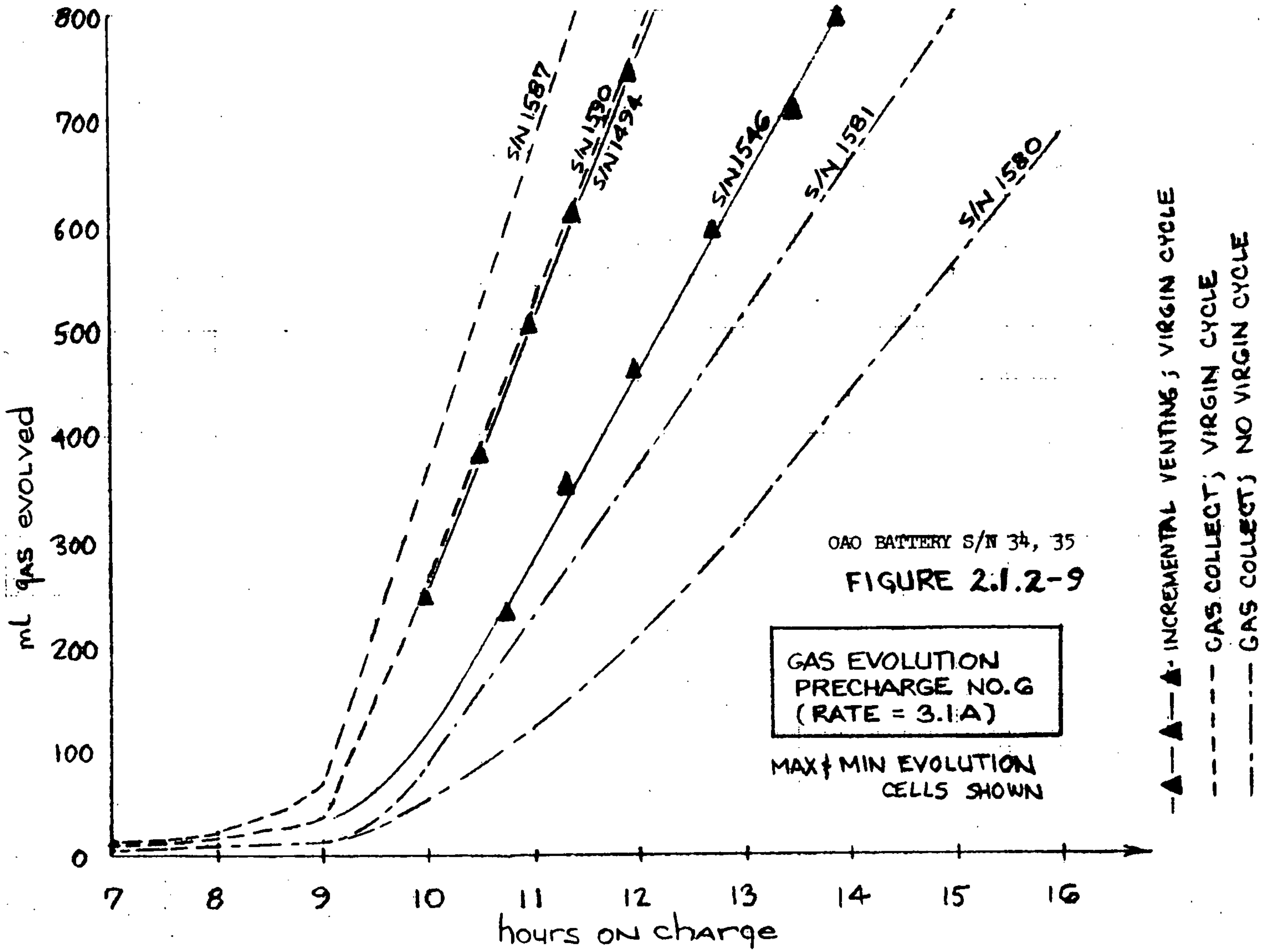
Some sources have indicated that more reliable precharge results may be obtained when an electrical cycle is executed first, before the precharge operation. This was done on an experimental basis for a few cells in the OAO battery S/N 34, 35 manufacture and the results are shown in Figure 2.1.2-9. Also tried was an incremental venting technique whereby the pressure was allowed to build up in cells to a pre-determined level and then the cell was partially evacuated, leaving a residual positive pressure. This was performed sequentially for the duration of the charge and the precharge calculated as a function of the cell case volume and pressure relationship. Figure 2.1.2-9 shows that, not only did the cells which had received one electrical cycle prior to the precharge operation evolve gas earlier, but also there was a tighter range of gas quantity evolved as a function of time.

Another result of the precharge studies indicated that the cells were receiving inadequate soaking before being placed on charge. Figures 2.1.2-10 and 2.1.2-11 show the effect of this inadequate soaking. In both curves, those cells which soaked for under ten hours showed both increased variability and increased precharge over those with longer soaks. It is postulated that the separator was not sufficiently wetted yielding non-uniform electrode charge current densities. This results in poor charge acceptance and premature gassing on the positive electodes, and uncertain precharge on the negative electrodes.

As a result of these precharge studies, changes have been incorporated into the OAO cell specification. A minimum soaking time of twenty-four hours is now specified and the precharge is being controlled to a specific ampere-hour input based on the results of gas measurement. The charge rate remains at 3.1 amps as before but the termination time is dependent on evolving sufficient oxygen to achieve the required precharge.

2.1.3 Manufacturer's Electrical Testing

After the pre-charge is adjusted, the cells undergo Gulton's standard electrical cycling. These tests are shown in Table 2.1.3. They

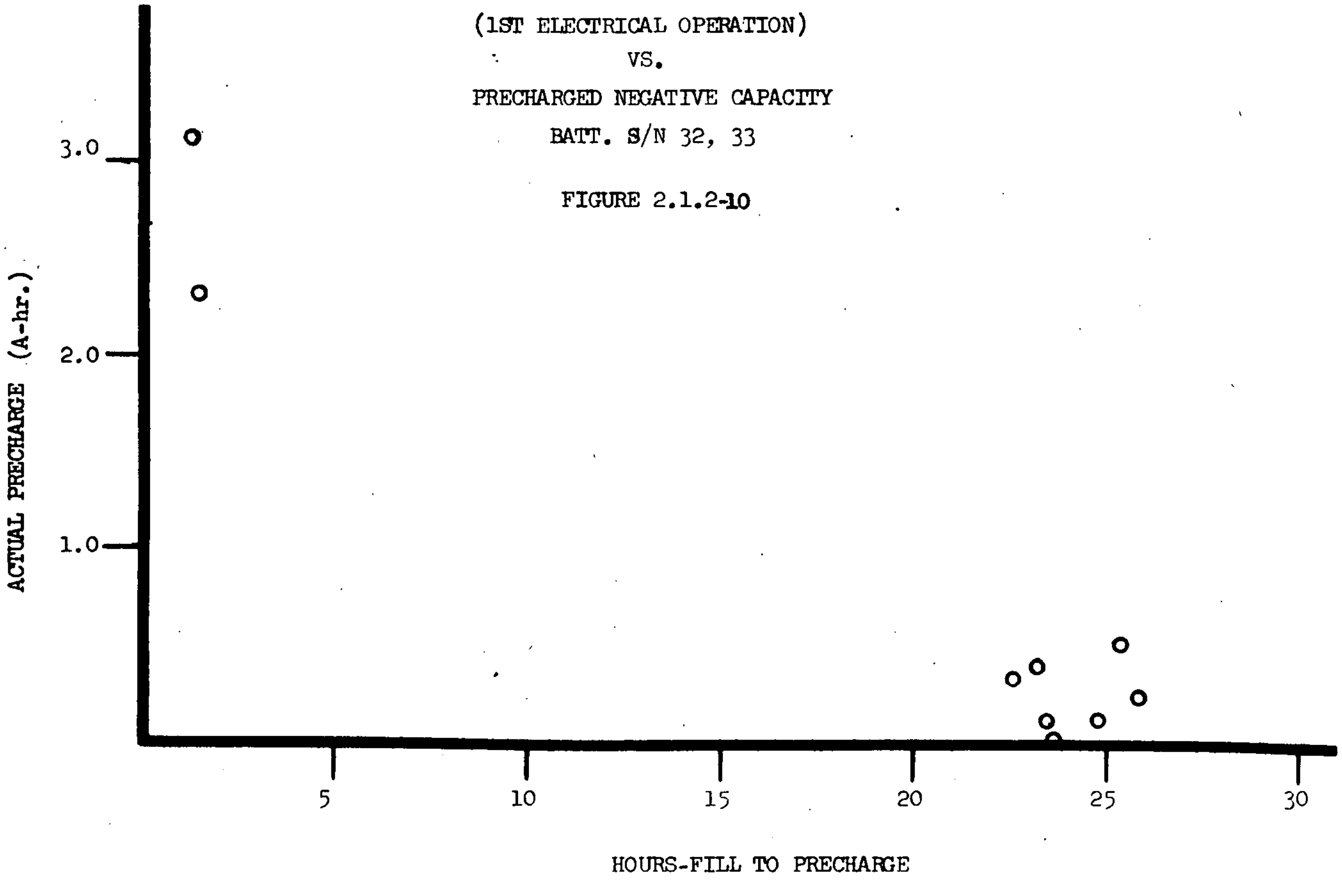


OAO BATTERY S/N 34, 35

FIGURE 2.1.2-9

TIME-ELECTROLYTE ADDITION TO START OF PRECHARGE
(1ST ELECTRICAL OPERATION)
VS.
PRECHARGED NEGATIVE CAPACITY
BATT. S/N 32, 33

FIGURE 2.1.2-10



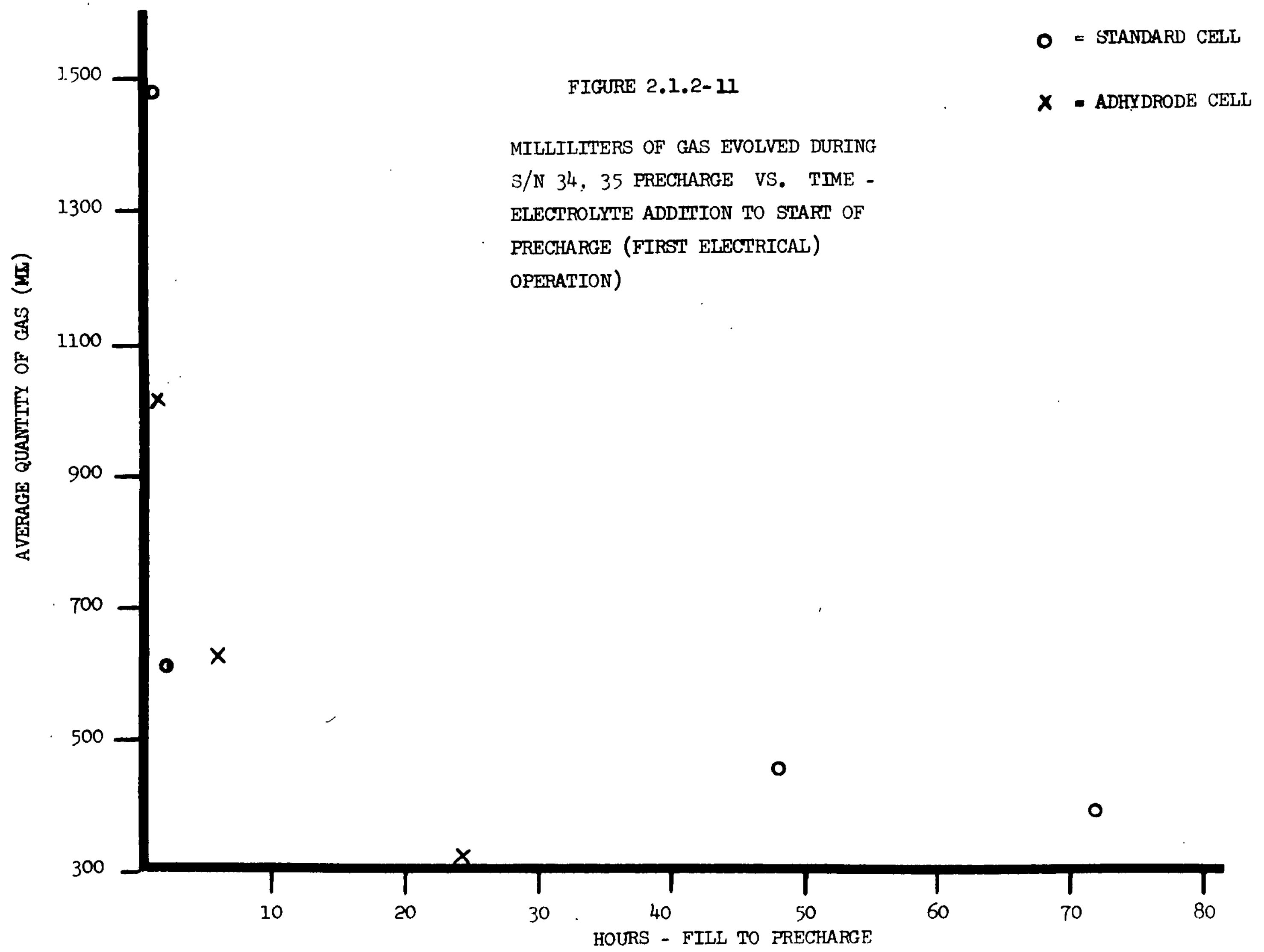


FIGURE 2.1.2-11

MILLILITERS OF GAS EVOLVED DURING S/N 34, 35 PRECHARGE VS. TIME - ELECTROLYTE ADDITION TO START OF PRECHARGE (FIRST ELECTRICAL OPERATION)

ELECTRICAL TESTS PERFORMED AT GULTON

ON OAO 20 A-hr. CELLS*

Sequence	Operation	Measure
1	Charge C/10, 24 hours	Voltage, pressure, pheno ck.
2	Automatic (10) cycles: - Discharge C/2, 30 min. - Charge C/5, 90 min.	Low pressure during last cycle
3	Overcharge C/10, 24 hours	Voltage, pressure, pheno ck.
4	Discharge C/2 to 1.0 volts	Capacity, pressure
5	Short 1Ω, 16 hours	
6	Dead short one hour	
7	Charge C/10, 24 hours	Voltage, pressure, pheno ck.
8	Discharge C/2 to 1.0 volts	Capacity, pressure
9	Short 1Ω, 16 hours	
10	Dead short one hour	

TABLE 2.1.3

* Manufacturers standard tests. Room temperature.

are designed to show that the cells are capable of meeting the specified capacity at acceptable voltages and pressures and to screen out any cells which may have internal shorts, and/or leaks.

2.1.4 Ratio Testing

During cell manufacture, some cells are selected for destructive ratio tests after each of the following steps: formation cycles, drying operation, and completion of all selection testing.[9] Ratio tests determine total negative and positive electrode capacities, as well as the distribution of excess negative capacity on charge and discharge.

The first step is the determination of the amount of precharged negative capacity. After normal discharge to 1.0 volt, cells are flooded with a 34% KOH solution and drained using a 1 Ω resistor for 16 hours. They are then discharged at C/2 rate to -1.0 volt. This discharges that portion of negative capacity set during precharge, and represents surplus ensuring positive limiting on discharge. In this way, the precharge is permanently removed.

The cells are then charged at a 2.0 ampere (C/10) rate for a period of not less than 40 hours, and not more than 64 hours, to 1.51 volts. This assures both electrodes are fully charged, since no significant recombination can occur with the cells flooded. In the past it has often been necessary to utilize the full 64 hours to reach 1.51 volts. The cells are next discharged at a 10 ampere rate to -1.0 volt. Times to +1.0V, +0.5V, 0.0V, -0.5V, and -1.0 volt are recorded. Calculations may now be made of: total positive capacity, total negative capacity, excess discharged negative capacity, and excess charged negative capacity. These figures may then be used to compute precharge and negative to positive capacity ratios. Positive electrode capacity is defined as the discharge to +0.5 volts, and negative electrode capacity as the discharge to -1.0V. A reference electrode is used to determine which electrode is the limiting factor during any rapid change of cell voltage.

Earlier OAO specifications required minimum negative to positive capacity ratio to be 1.30 to 1.00. Recently this was increased to a minimum of 1.40:1.00 to assure large enough reserve to correct for negative electrode inefficiencies (fading) during prolonged cycling.

Tables 2.1.4-1 through 2.1.4-3 show ratio test results for the various battery builds. Positive plate capacity appears to decrease steadily by about ten percent from post-formation to final cell. Negative plate capacity, however, shows a much smaller decrease -- approximately five percent -- from post-formation to final cell but shows an increase in the post-neutralization (drying operation) ratio. Thus, although ratios appeared low following formation, final ratios (finished cells) showed higher results and met specified requirements.

Table 2.1.4-1 Ratio Tests - Post Formation

OAO Battery Serial Number	Parameter	(A-hr.) Amount of Precharge	Capacity to the Following Voltages				
			-1.0 V	-0.5 V	-0.0 V	+0.5 V	+1.0 V
25A, 26A	Maximum						
	Minimum						
	Mean						
	Range						
	# Samples						
30, 31	Maximum						
	Minimum						
	Mean						
	Range						
	# Samples						
32, 33	Maximum	0.70	43.33	42.67	34.83	34.00	30.50
	Minimum	0	41.50	40.83	30.50	29.83	27.50
	Mean	-	42.42	41.67	33.04	32.27	29.25
	Range	-	1.83	1.84	4.33	4.17	3.00
	# Samples	15	19	16	16	19	16
34, 35	Maximum	2.32	43.67	42.83	31.50	30.33	28.17
	Minimum	1.10	41.50	40.67	29.67	28.67	26.83
	Mean	1.52	42.70	41.87	30.67	29.40	27.48
	Range	1.22	2.17	2.16	1.83	1.66	1.34
	# Samples	10	10	10	10	10	10

Table 2.1.4-2 Ratio Tests - Post Wash and Dry

OAO Battery Serial Number	Parameter	(A-hr.) Amount of Precharge	Capacity to the Following Voltages				
			-1.0 V	-0.5 V	-0.0 V	+0.5 V	+1.0 V
25A, 26A	Maximum						
	Minimum						
	Mean						
	Range						
	# Samples						
30, 31	Maximum		44.83			28.83	
	Minimum		42.67			28.16	
	Mean		43.00			28.60	
	Range		2.16			0.67	
	# Samples		6			6	
32, 33	Maximum						
	Minimum						
	Mean		42.50	42.33	32.17	31.54	28.17
	# Samples						
34, 35	Maximum	0.230	44.50	44.00	30.67	28.83	27.00
	Minimum	0.005	43.00	42.67	29.17	26.67	25.50
	Mean	0.024	43.83	43.35	29.95	27.97	26.57
	Range	0.225	1.50	1.33	1.50	2.16	1.50
	# Samples	10	10	10	10	10	10

Table 2.1.4-3 Ratio Tests - Final Ratio Cells

OAO Battery Serial Number	Parameter	(A-hr.) Amount of Precharge	Capacity to the Following Voltages				
			-1.0 V	-0.5 V	-0.0 V	+0.5 V	+1.0 V
25A, 26A	Maximum	5.4*					
	Minimum	3.5*					
	Mean	4.45					
	Range	1.9					
	# Samples	2					
30, 31	Maximum	0.030	35.17	34.83	32.00	31.67	30.83
	Minimum	0.025	31.33	31.00	27.67	27.50	27.33
	Mean	0.028	33.83	33.33	29.35	29.12	28.70
	Range	0.005	3.84	3.83	4.33	4.17	3.50
	# Samples	2	4	4	4	4	4
32, 33	Maximum	3.16	41.33	41.17	32.16	31.33	31.00
	Minimum	0	39.00	38.67	28.33	28.00	27.83
	Mean	0.54	40.22	39.79	29.52	29.14	28.93
	Range	3.16	2.33	2.50	3.83	3.33	3.17
	# Samples	30	30	30	30	30	30
34, 35	Maximum	4.87	41.83	41.50	28.83	28.17	28.00
	Minimum	0	38.83	38.33	26.00	25.83	25.67
	Mean	1.40	40.28	39.70	27.58	26.81	26.55
	Range	4.87	3.00	3.17	2.83	2.34	2.33
	# Samples	19	19	19	19	19	19

* Measured after cell had completed 529 cycles

Apparent changes of electrode capacities through each processing step are seen more clearly in Tables 2.1.4-4 and 2.1.4-5. The SAFT figures are projected plate capacity based on results taken on a sample 1 dm^2 plate. This is taken as a baseline value. The percentage change from baseline occurring in each operation is shown in parentheses. It can be readily seen that the final cell ratios are significantly higher than those from the formation step. These tables allow one to predict either final cell ratio or electrode capacities at intermediate steps in processing, based on initial SAFT sample capacity results for identical plate lots.

Table 2.1.4-6 shows the measured precharged negative distributions on the subject battery builds. Although the amount of data for early builds is slight, that from two later builds indicate the majority of cells have low measurable precharges of less than one ampere-hour.[12]

Table 2.1.4-7 is a summary of the ratios obtained for the various battery assemblies. Battery S/N 34, 35 had the highest values because positive plates contained much less active material than previous builds (see Table 1.2.2-1 and 1.2.2-2). The range of S/N 34, 35 ratios is narrowed, due to effects of plate weight screening.

2.1.5 Cell Selection

All cells selected for flight batteries must come from an identical plate and separator lot and be constructed within a short time interval. Then, in addition to the standard seller's (Gulton) electrical tests, Grumman requires the cells to undergo a series of tests for thorough characterization of each cell's performance for selection purposes. The flight batteries require matching of cells with nearly identical electrical characteristics.

Table 2.1.5 lists the tests required during cell selection. The regime consists of electrical tests designed to match cells with similar capacity, cycling performance and voltage/pressure response during overcharge. A low temperature (4.4°C/40°F) overcharge is also performed to screen out potential negative-limiting cells. The cells are grouped based on the results of the third capacity cycle. A histogram of the capacity distribution is drawn and cells are chosen for each battery such that the total ampere-hour spread in any single battery does not exceed one (1) ampere-hour. Traditionally the cells within the low third of the total capacity distribution

	S/N 25A, 26A	32, 33	34, 35	A.T.S.
I. SAFT CAPACITY IN AMPERE-HOURS	(100%)	(100%)	(100%)	(100%)
(A-hr./dm^2 x .91 dm^2/plate x 9 plates/cell)	34.40	35.25	31.94	35.00
II. FORMATION IN AMPERE-HOURS	(82.99%)	(82.52%)	(81.75%)	(80.71%)
(Final Discharge Capacity)	28.55	29.09	26.11	28.25
III. CAPACITY OBTAIN DURING RATIO TESTS IN AMPERE-HOURS	(90.12%)	(91.63%)	(92.05%)	--
A. Post Formation	31.00	32.30	29.40	
B. Post Rinse	--	(88.51%)	(87.66%)	--
		31.20	28.00	
C. Final Cell	--	(82.78%)	(83.90%)	(88.00%)
		29.18	26.80	30.82

TABLE 2.1.4-4

Projected Positive Plate Capacity Compared To

Results of SAFT Sample Capacity

	S/N 25A, 26A	32, 33	34, 35	A.T.S.
I. SAFT CAPACITY IN AMPERE-HOURS	(100%)	(100%)	(100%)	(100%)
(A-hr./dm^2 x .91 dm^2/plate x 10 plates/cell)	37.95	37.95	37.31	41.95
II. FORMATION IN AMPERE-HOURS	--	(97.25%)	(97.07%)	(98.18%)
(Final Discharge Capacity)		36.91	36.22	41.19
III. CAPACITY OBTAINED DURING RATIO TESTS IN AMPERE-HOURS	(113.83%)	(111.98%)	(114.44%)	--
A. Post Formation	43.20	42.50	42.70	
B. Post Rinse	--	(112.25%)	(117.39%)	--
		42.60	43.80	
C. Final Cell	--	(106.06%)	(107.96%)	(105.00%)
		40.25	40.28	44.05 AH

TABLE 2.1.4-5

Projected Negative Plate Capacity Compared To

Results of SAFT Sample Capacity

Table 2.1.4-6 Distribution of Measured Precharge on Various Battery Assemblies During Final Cell Ratio Tests

Range in Ampere-Hours	S/N 25A, 26A	S/N 30, 31	S/N 32, 33	S/N 34, 35
0.00 - 0.40		2	20	9
0.41 - 0.80			4	
0.81 - 1.20				1
1.21 - 1.60			2	2
1.61 - 2.00			2	2
2.01 - 2.40			1	1
2.41 - 2.80				1
2.81 - 3.20			1	
3.21 - 3.60	1	1		
3.61 - 4.00		1		1
4.01 - 4.40				1
4.41 - 4.80				
4.81 - 5.20				1
5.21 - 5.60	1			
5.61 - 6.00				
6.01 - 6.40		1		
Total Number of Precharge Samples	2	5	30	19

Post Rinse Ratios

	S/N 25A, 26A	30, 31	32, 33	34, 35	36, 37
Maximum		1.591	1.367	1.631	
Minimum		1.445	1.351	1.491	
Mean		1.503	1.360	1.568	
Range		0.146	0.016	0.140	
# Samples		6	5	10	

Post-Formation Ratios

	S/N 25A, 26A	30, 31	32, 33	34, 35	36, 37
Maximum			1.397	1.500	
Minimum			1.239	1.407	
Mean			1.307	1.453	
Range			0.158	0.093	
# Samples			19	10	

Final Cell Ratios

	S/N 25A, 26A	30, 31	32, 33	34, 35	36, 37
Maximum	1.39	1.279	1.476	1.559	
Minimum	1.22	1.074	1.287	1.414	
Mean	--	1.160	1.381	1.503	
Range	--	0.205	0.189	0.145	
# Samples	--	4	30	19	

Summary of Ratios Obtained for

Various Battery Assemblies

Table 2.1.4-7

TABLE 2.1.5

Tests Required by Grumman During

Cell Selection Testing

Test Name	
o Capacity Cycle #1	- C/2 charge to 1.5 volts; C/4 charge to 1.5 volts, C/10 charge for 1 hour or 1.5 volts. C/2 discharge to 1.00 volts each cell.
o Capacity Cycle #2	
o Capacity Cycle #3	
o Drain	- short each cell with 1Ω for 10 hours
o Dead Short	- dead short each cell for one (1) hour
o 15% Depth Cycling	
- Precharge	- C/2 charge to 1.5 volts or 37.0 volts for the series string. C/4 charge to 1.5 volts or 37.0 volts for the series string. C/10 charge for 1 hour or 1.5 volts/cell.
- Cycle #1	- 36 minute (15%) discharge at appropriate rate. C/2 charge to 1.50 volts; 1.6A for remainder of 65 minute charge
- Cycle #2	
- Cycle #3	
o Overcharge	
- Room Temperature	- At end of 65 minutes of cycle #3 of the 15% depth cycling continue overcharging at 1.6A for four hours.
- 40°F	- Stabilize chamber at 40°F ±3°F while charging cells at 0.5 amperes. - Charge cells at 1.0 amps for four (4) additional hours after temperature stabilization.
- 90°F	- Stabilize chamber at 90°F ±3°F while continuing 1.0 ampere charge - Increase rate to 2.3 amperes after temperature stabilization and continue charge for four (4) hours.
o Final Discharge	- Discharge C/2 to 1.0 volts/cell
o Drain	- Short each cell 1Ω for 16 $^{+1}_{-0}$ hours
o Retention of Charge	- Restrain cells to forces similar to those experienced in battery assembly - Remove 1Ω resistor and allow cells to remain open-circuited for 24 $\pm\frac{1}{4}$ hour - Immediately upon completion of 24 hour stand take open-circuit voltage - Voltage must be 1.15 volts or higher to be acceptable
o Final Drain & Short	- Drain each cell with a 1Ω resistor and then dead short each cell individually

are designated as battery 1, the middle third as battery 2 and the cells in the upper capacity distribution one-third are selected as battery 3. Ensuring that the total capacity spread in any single battery is within one ampere-hour reduces the chance of cell reversals during capacity run-down conditions and assures that all the cells will reach a full state-of-charge at approximately the same time. The third-electrode cell in each battery is chosen from this same capacity distribution. Third electrode cells are usually chosen to be the lowest capacity cell in each battery. This allows these cells to begin overcharge slightly before the rest of the cells in the battery, avoiding excessive overcharge in the battery as a whole. The cell specification also imposes a provision that the three batteries in the assembly must be within ±1.0 ampere-hours of each other on the average.

2.2 MULTIPLE REGRESSION ANALYSIS

Knowledge of which processes and components have the greatest effect(s) on reliability (life) and performance is necessary to meet today's high standards for complex products for aerospace. While the sealed Ni-Cd cells used in OAO are produced under, perhaps, the tightest quality control in the industry, finished cells prior to the study and selection efforts reported herein displayed sufficient parametric variations to necessitate some compromises in specification limits. For such cells, key factors include the electrodes, separators, electrolyte and process time/temperature.

Another technique, useful to support and verify the type of result already obtained, for relating these factors to performance and reliability variables is that of multiple regression analysis, done on a computer. Such analysis has been successfully used on the Lunar Module (LM) program to predict primary (silver-zinc) battery capacity from manufacturing data, and in a NASA/GSFC sponsored study of the effects of various electrode process variables for nickel cadmium.[11]

Normally regression analyses are based on data in which the parameters thought to have effects are deliberately varied over relatively wide ranges. The effects are called "response variables" or, simply, "variables". The analyses covered herein, however, were limited to data derived from routine manufacturing, and so are narrower in range than ideally desirable. Further, some parametric information was not available (e.g.: plate thickness, post-formation drying times and temperatures, etc.) Some parameters were constant for all cells (e.g.: separator, electrode and KOH analyses), and could not be used. The manufacturing parameters available are only those found subsequent to assembly into cell stacks -- i.e.: traceability starts at this point, and the plates maintain their identity through to the finished cell. It was thus necessary to rely heavily on electrical data taken at the seller's facility during early performance tests. The major value of these analyses, then, are in the tightening of electrical limits, and the ability to identify potentially poor risk cells without extensive and expensive tests.

2.2.1 Description of Parametric Variables

The parameters studied herein may be divided into two classes:

- Manufacturing/Processing variables
- Test data variables (early tests)

The former may be considered as independent quantities in that each may be altered more or less without regard to any of the others. Test data generally consists of effects, or response variables.

The variables listed in Tables 2.2.2-2 and 2.2.3-1 as used in the two analyses conducted for this program falls in the above noted categories as follows:

Manufacturing Processing

- Dry Cell Weight
- Wet Cell Weight
- Cell Pack Weight (Total weight of plates and separator)
- Positive Group Weight
- Negative Group Weight
- Time -- activation (filling) to start of precharge

Test Data

- Pressure at end of cycle 1 of cell selection
- Pressure at end of 90°F overcharge
- Voltage at end of cell selection, 40°F overcharge
- Electrical operation: 3rd cycle capacity in A-hr.
- Cell selection: 3rd cycle capacity in A-hr.
- Pressure at end of 40°F overcharge
- Pressure at end of room temp overcharge
- Pressure at end of cycle 3 of cell selection
- Pressure at end of cycle 3 of electrical operations
- Gas evolved during precharge
- Pressures at ends of cycles 1 and 2 of cell selection
- Pressures at ends of cycles 1 and 2 of electrical operation

Each variable listed above was used in the analyses. Gas evolved during precharge was treated as input data in the voltage divergence analysis, and as the output (dependent variable) quantity in the precharge analysis. The purpose of the analyses is to demonstrate one or more of the following:

1. The particular way in which an "input" (independently treated) quantity affects the "output" (dependent) quantity
2. The relative weight with which each input quantity affects the output quantity
3. Whether, in fact, a particular input has any relation to the output.

The results are shown in "Beta" coefficients of each input quantity with respect to the output. These coefficients are normalized values. The higher a Beta coefficient in numerical (absolute) value, the more significant the correlation to the output. Positive and negative values only signify the sense in which the effect occurs (e.g.: output increases with increasing input shows as a positive value). Anomalous results (see 2.2.2.1) either means that insufficient data is available, or the particular parameters chosen have little or no effect on the output. Very small numerical results lead to essentially the same conclusion.

2.2.2 Cell Voltage Divergence Analysis

An attempt was made to correlate divergence among the end-of-overcharge voltages found in the spare cells of battery S/N 34, 35 to initial electrical tests. Table 2.2.2-1 is a summary of these diverged quantities after several thousand 100-minute cycles; showing a range of 143 mV (Pack 23B Group I) to 29 mV (Pack 35B).

The cycling was done using 15% depth of discharge, and no constraining voltage limit during charge and overcharge. The latter feature allowed each cell to reach its natural potential for the rate and time of overcharge, independent of the pack and/or any other cell. Weighted values -- from 1 to 9 -- were assigned to each cell, for the analysis, based on relative end-of-overcharge voltage. Weightings are described at the bottom of Table 2.2.2-2, which lists all the variables assigned.

Results (details in Appendix A) show relatively low overall correlation between divergence and the chosen parameters. Following are the five highest correlation factors (Beta coefficients) listed in descending order:

Rank	Parameter Number		Beta
1	V2	Wet Cell Weight	-7.5153
2	V1	Dry Cell Weight	+5.8596
3	V13	Room Temp. Overchg. Pres.	-2.6627
4	V9	Time-Fill to Precharge	+2.1577
5	V12	40°F Overchg. Pres.	+1.9176

2.2.2.1 Discussion of Results

It is of interest to note that the cell weights show significantly higher correlation to divergence than any other parameters. At the same time the two coefficients involved are opposite in sign, and nearly equal in value.

To understand the significance of the above, it must be noted that Wet Cell Weight consists of Dry Cell Weight plus electrolyte weight. Electrolyte weight is held very nearly constant by controlling the volume (cm^3) of 34% KOH solution used to fill the cells. The fact that opposite signs exist indicates opposite effects on cell divergence. It makes little sense to conclude that Dry Weight has one type effect, and Dry Weight plus a constant has the opposite effect. Some other cause for the opposite signs must be found.

A similar analysis of the other variables used in this regression shows similar results. Two possibilities exist:

- None of the variables chosen has any real effect on cell divergence
- The amount of divergence is too small to show any really significant effect from any source.

The smallness of divergence is somewhat overcome by use of weighted values (see Table 2.2.2-2) since these would tend to exaggerate effects rather than hide them. The first, then, seems the most reasonable. The regression analysis would also tend to show no correlation between cell divergence and the data taken in the early tests. In other words, use of any early test data to predict later divergence would be nearly impossible.

2.2.3 Precharge Analysis

Essentially the same data as above, plus some additional pressure information was used to attempt correlation with gas evolved during precharge -- see Table 2.2.3-1. A summary of the results -- printed in full in Appendix A -- is shown in Table 2.2.3-2 which lists the five largest correlations.

2.2.3.1 Discussion of Results

The results show little basic difference in principle from those found for cell divergence. What differences exist are in degree in that the correlations here are even less significant than before.

Perhaps the only variable showing even moderate strength is V9, as expected (see Section 2.1.2). It has been found that soak times less than 10 hours cause not only excess gas evolution, but large variability of actual precharge. Accordingly, current OAO specifications require soaks of 24 hours minimum prior to first electrical operation.

Spare Cells from OAO Battery

S/N 34, 35 on Cycling Tests

Pack Number	Location	Cell S/N	Overcharge Volts	Coded Value
5	GSFC	1514	1.442	5
		518A	1.453	7
		1526	1.425	3
		526A	1.455	7
		1531	1.456	7
6	GSFC	1542	1.420	5
		495A	1.401	2
		1554	1.424	5
		497A	1.381	1
		1575	1.422	5
23B Group I	NAD, Crane	1494	1.510	4
		1517	1.380	1
		1546	1.516	5
		1588	1.520	5
		1591	1.523	5
23B Group II	NAD, Crane	1499	1.518	5
		1537	1.396	1
		1587	1.515	5
		1589	1.531	7
		1590	1.514	5
35B	NAD, Crane	1573	1.454	5
		512A	1.452	5
		1578	1.448	5
		515A	1.474	8
		1492	1.445	4

TABLE 2.2.2-1

TABLE 2.2.2-2

Variables in (Voltage-Divergence) Regression

Variable Number	Description
V1	Dry cell weight
V2	Wet cell weight
V3	Pressure at end of cycle 1 of cell selection
V4	Pressure at end of 90°F overcharge at Gulton
V5	Cell pack weight
V6	Positive group weight
V7	Negative group weight
V8	Voltage at end of cell selection 40°F overcharge
V9	Time-activation to start of precharge
V10	Electrical operations: 3rd cycle capacity in A-hr.
V11	Cell selection: 3rd cycle capacity in A-hr.
V12	Pressure at end of 40°F overcharge at Gulton
V13	Pressure at end of R.T. overcharge at Gulton
V14	Pressure at end of cycle #3 of cell selection
V15	Pressure at end of cycle #3 of electrical operation
V16	Gas evolved during precharge
V17 (dependent VAR)*	Voltage during recent overcharge at test facility (see Table 2.2.2-1)

* this variable coded as follows:

"1" = Very low voltage relative to rest of pack
"2" = Low voltage relative to rest of pack
"3" = Nominally low voltage relative to rest of pack
"4" = Slightly low voltage relative to rest of pack
"5" = Nominal voltage relative to rest of pack
"6" = Slightly high voltage relative to rest of pack
"7" = Nominally high voltage relative to rest of pack
"8" = High voltage relative to rest of pack
"9" = Very high voltage relative to rest of pack

TABLE 2.23-1

Variables in Precharge Gas Evolution Regression

Variable Number	Description	
V1	Dry cell weight	
V2	Wet cell weight	
V3	End of precharge voltage	
V4	90°F overcharge pressure	
V5	Cell pack weight	
V6	Positive plate group weight	
V7	Negative plate group weight	
V8	Voltage at end of 40°F overcharge	
V9	Time-filling to start of precharge	
V10	Capacity - 3rd cycle elec. op. in A-hr.	
V11	Capacity - 3rd cycle cell selection in A-hr.	
V12	40°F overcharge pressure	
V13	Cycle 1	Pressures at end of each cycle of Gulton's electrical operations
V14	Cycle 2	
V15	Cycle 3	
V16	Cycle 1	Pressures at end of each cycle of cell selection.
V17	Cycle 2	
V18	Cycle 3	
V19	Room temperature overcharge pressure	
V20 (dependent variable)	Gas (ml) evolved during precharge	

Variables Selected as Having the Largest Correlation With the Amount of Gas Generated During the Precharge of OAO Battery S/N 34, 35

Rank		Description	Beta Coefficient
1	V9	Time-fill to precharge	-0.944
2	V12	Pressure, end of 40°F overcharge	+0.849
3	V4	Pressure, end of 90°F overcharge	-0.709
4	V2	Wet cell weight	+0.583
5	V1	Dry cell weight	+0.416

TABLE 2.2.3-2

SECTION 3.0

BATTERY PERFORMANCE EVALUATION

3.1 OAO BATTERY MODEL

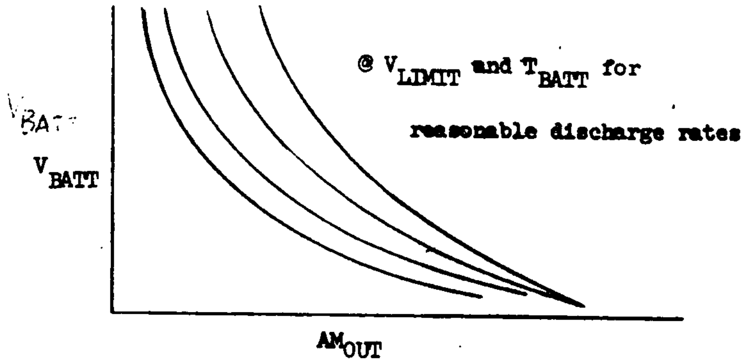
A computer program has been developed to predict the performance of OAO batteries during acceptance tests and flight conditions. This program is written in Fortran IV language and has been modified for use on a 360/67 time-sharing system. It is capable of predicting instantaneous battery voltage and current at each orbital minute, with various charge-mode data inputted. Percent capacity returned, watt-minutes input and output and efficiency are calculated and displayed at the end of each orbit. The model was based on 15% depth-of-discharge during the orbit. It does not presently update battery temperature at each orbit although the amount of heat generated in the battery is predicted. Minor modification is necessary to enable utilization of predicted heat generation to update temperature. The voltage limit to which the battery is charged is a function of battery temperature. Since temperature remains constant in the program, the BVLS curves become single point values, initially established by inputting the constant temperature. The operator establishes battery rating (nameplate capacity) and specifies the number of cells in the battery, enabling the program to convert from cell voltage to battery voltage levels.

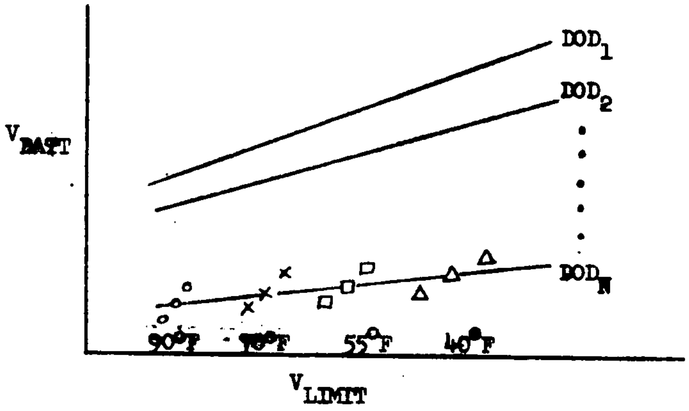
3.2 LOGICAL OPERATION

The model basically consists of five discrete sections, all appearing in subroutine BTR. These are the discharge model section, the charge model section, an overcharge model section an efficiency section and a thermal section.

3.2.1 The Discharge Model

The discharge model was developed from a series of parametric tests which characterized the discharge profile of a Ni-Cd cell as functions of depth-of-discharge, battery voltage, current and temperature. These tests yielded the following type curves:





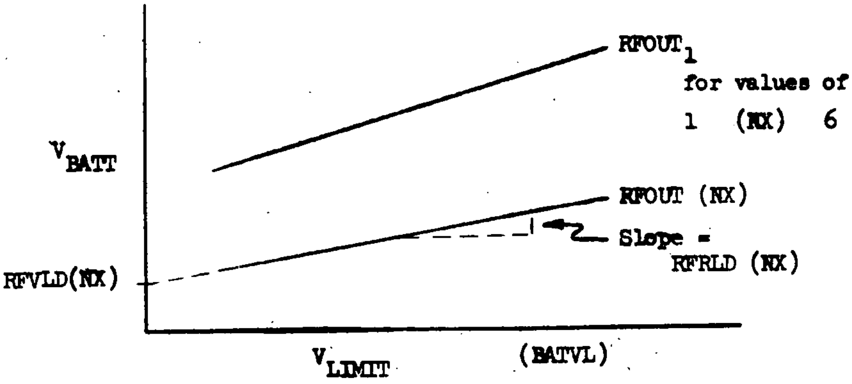
The curves were developed for reasonable discharge currents at various temperatures and preceding charge cycle voltage limits. Shapes were determined by a least-squares fit of data for various temperatures and depths-of-discharge (DOD). Hence, the battery voltage can be characterized as a function of depth-of-discharge and the voltage limit of the preceding charge cycle. Notice that the curves are independent of temperature (normalized over the temperature range from 40°F through 90°F). These V_{BATT} vs. V_{LIMIT} curves are assumed linear of the form $y = mx + b$ where:

y = BTVL = Battery Voltage
m = RFRLD = Slope of Curve

x = BATVL = Battery Voltage Limit

b = RFVLD = Voltage Intercept

The input data set consists of a set of six such curves, each at a particular depth-of-discharge. The indicator for the depth-of-discharge is a variable labelled RFOUT. Thus, the input data set takes the form:



The test data was obtained under the condition AMINT = AM100, or, when the battery started into the discharge phase at 100% state-of-charge. In practice this is not always true so an adjustment must be made relating the input data to the actual state-of-charge of the cell. This is done by the function RBOUT where:

$$\text{RBOUT} = .045\left[\frac{\text{AMINT}}{\text{AM100}} - 1\right] + \left[1 + \left(\frac{\text{AM100 - AMINT}}{\text{Max. of }(9.*\text{BPCAP})\text{or CTHR}}\right)\right] * \left(\frac{\text{CTHR}}{60 * \text{BPCAP}}\right)$$

This equation takes the form of y = mx + b where:

y = RBOUT = Adjustment Factor

m = Scale Factor

x = CTHR/60 * BPCAP

b = Offset Factor

Notice that if AMINT = AM100 then both the scale factor (m) and the offset factor (b) equal zero. When we begin an orbit (if we assume the initial S.O.C. = 100%) then:

CTOT = BSOC * AM100 = 1.0 x AM100 = AM100

AMINT = CTOT

AMINT = AM100

The value of RBOUT then reduces to:

$$\text{RBOUT} = \frac{\text{CTHR}}{60 * \text{BPCAP}} = 0 \text{ since CTHR} = 0$$

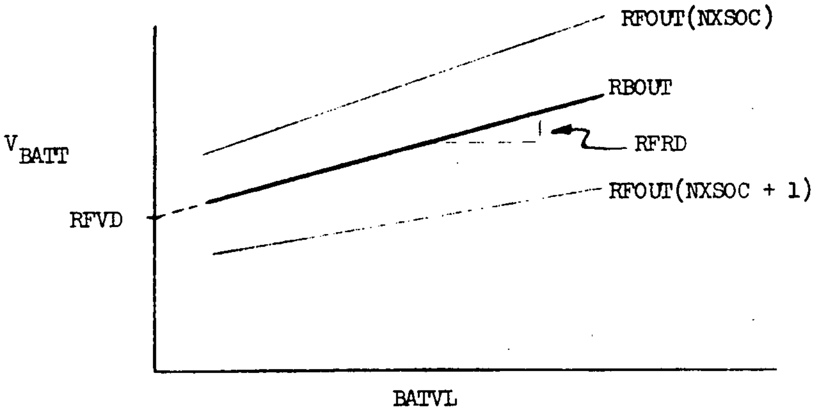
The calculated RBOUT is compared to the values of RFOUT that were entered as input data. The relative position of RBOUT amongst the RFOUT curves is established by the DO loop (statement #310-3). When the value of statement #310-1 becomes zero or positive then the true value of the line is found by interpolation between the RFOUT curves. This is accomplished by statement 320:

$$\text{(320)} \quad \text{RDSOC} = \frac{-\ \text{RBOUT} - \text{RFOUT (NXSOC)}}{\text{RFOUT (NXSOC + 1)} - \text{RFOUT (NXSOC)}}$$

Having determined the location of the point between two input data curves a slope and intercept of a line through the point and equidistant from the input data curves can be determined:

RFVD (Voltage Intercept) = (1 - RDSOC) * RFVLD (NXSOC) + RDSOC * RFVLD (NXSOC + 1)

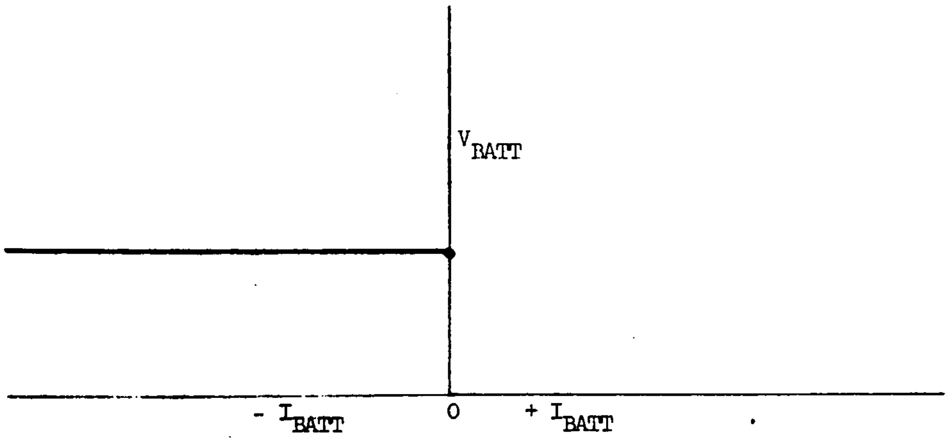
RFRD (Slope) = (1 = RDSOC) * RFRLD (NXSOC) + RDSOC * RFRLD (NXSOC + 1)



From this curve, the battery voltage can be determined for a particular V_L (Voltage Limit from preceding cycle). The voltage intercept (CFK) is adjusted for the number of cells in the battery and modified by the tolerance of the input data set:

$$\text{CFK} = \underbrace{(1 + .003 * \text{BTOL})}_{\text{Tolerance Factor}} * \ (\underbrace{\text{BCEL} * \text{RFVD}}_{\substack{\text{Adjustment for}\\ \text{number of series}\\ \text{connected cells in}\\ \text{battery}}} \quad + \quad - \quad \underbrace{\text{BATVL} * \text{RFRD}}_{\substack{\text{voltage from}\\ \text{intercept to actual}\\ \text{voltage limit.}}})$$

CFCR (Slope) = 0 since we assume a constant discharge current



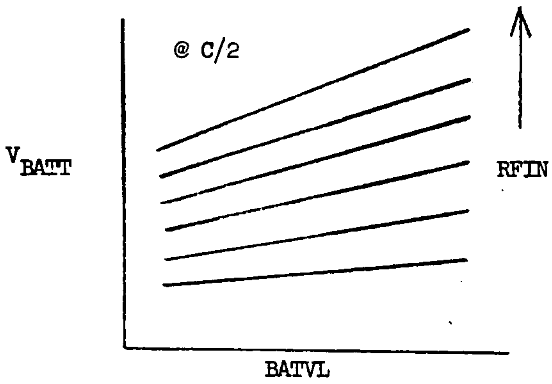
The calculated instantaneous battery voltage and current are therefore:

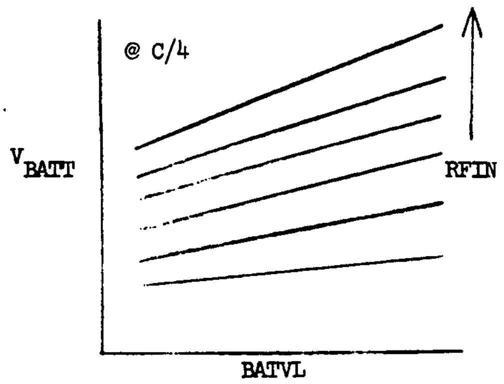
BTVL = CFK = Voltage

BTCR = CNEG = Current

3.2.2 The Charge Model

The input data set for the charge model is developed in a similar manner to that for the discharge model data set; i.e.: as a function of depth of discharge and battery voltage limit from the preceding orbit. One important difference, however, is that whereas the discharge data is defined for "reasonable current rates", the charge model data is particular to two discrete rates, namely, a C/2 and a C/4 charge. In similar manner to the discharge section, a set of curves were developed relating battery voltage to the voltage limit of the preceding orbit, at the two current rates:





These curves, again a linear, least-squares interpolation over the temperature range $40^{\circ}F \leq x \leq 90^{\circ}F$, are each characterized by a state-of-charge indicator RFIN; a slope RFRLC; and a voltage intercept, RFVLC. They are inputted in this form for the two charge rates.

The input data set was derived from data on cells which were cycled to 15% D.O.D. In any particular orbital regime the discharge depth may exceed or be less than 15% of rated capacity. Therefore a scale and offset factor adjusts the input data set to comply with particular usage restraints. Statement 400 is the offset factor:

$$(400) \quad \mathrm{RBSDL} = .300 * \mathrm{Log}_{10}\left[\text{Max. of}\left(\frac{\mathrm{AM100} - \mathrm{AMDL}}{9 * \mathrm{BPCAP}}\right)\text{or}\left(10\text{-}9\left(\frac{\mathrm{AMDL}}{\mathrm{AM100} - 9 * \mathrm{BPCAP}}\right)\right)\right]$$

where the factor (9 * BPCAP) is the number of ampere-minutes corresponding to a 15% D.O.D. relative to the nameplate capacity at 100% S.O.C. Therefore this equation, in effect, compares the number of ampere-minutes out of the battery at the end of the discharge (eclipse) period to the actual (AM100) capacity the cell can contain, and determines whether it is less than or greater than a 15% depth-of-discharge (9 * BPCAP). It then adjusts the data accordingly.

The scale factor is given by:

$$\mathrm{RBIN} = \frac{\mathrm{CTHR}}{(\mathrm{AM100} - \mathrm{AMDL}) - .5\,(\mathrm{AMINT} - (\text{Minimum of AM100 or } \frac{\mathrm{AMINT}}{.95}))}$$

If the cell is not in the overcharge region, the next step is to locate the position of the instantaneous data point amongst the input data curves. This is done by a "do loop". (as it was in the discharge model) and the exact location calculated by:

(520) $$RCSOC = \frac{(RBIN - (RFIN\ (NXSOC) + RBSDL))}{RFIN\ (NXSOC + 1) - RFIN\ (NXSOC)}$$

This statement is simply a linear interpolation between the lines RFIN (NXSOC) and RFIN (NXSOC + 1).

Having defined the locus of the point between two input data curves, a slope and intercept of a line through this point and equidistant from each input data line is found by:

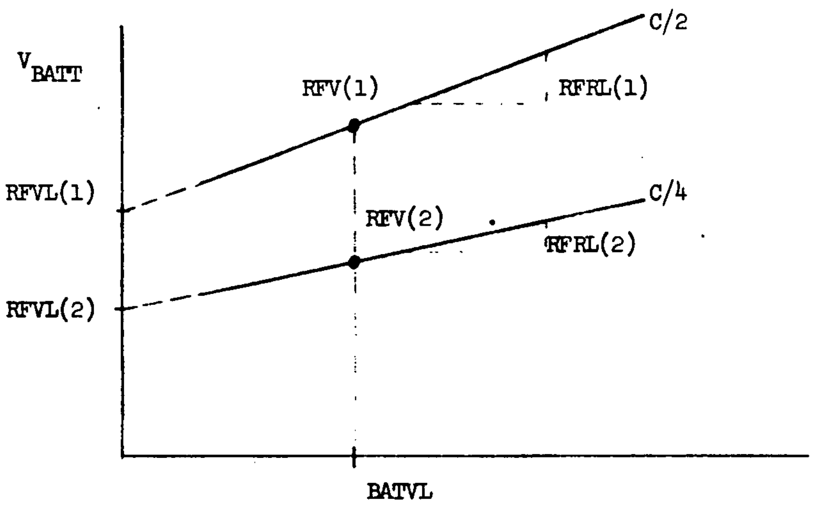
RFVL (NCR) = (1 - RCSOC) * RFVLC (NXSOC, NCR) + RCSOC * RFVLC (NXSOC + 1, NCR)

RFRL (NCR) = (1 - RCSOC) * RFRLC (NXSOC, NCR) + RCSOC * RFRLC (NXSOC + 1, NCR)

where RFVL = Voltage Intercept

RFRL = Slope of Line

These factors are detemined for the two values of current (C/2 and C/4) where NCR = 1 to 2 giving:

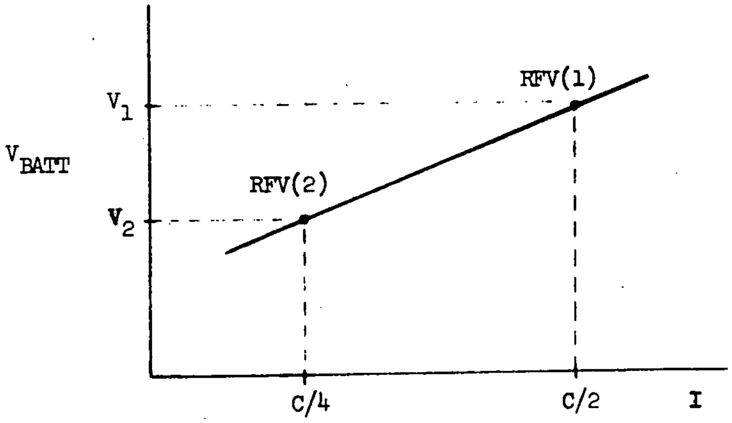


Using this curve, two points can be determined for a given voltage limit (of the preceding orbit), shown here as RFV (1) and RFV (2) and defined mathematically as:

(530-1) RFV (NCR) = BCEL * RFVL (NCR) + BATVL * RFRL (NCR)

Again, the "BCEL" factor adjusts the value of RFV to account for the number of series-connected cells in the battery while BATVL adjusts the voltage limit intercept.

Replotting the points on a general V-I curve gives the following relationship:



The slope of this curve can be defined mathematically as:

$$\text{CFCR} = \frac{\text{RFV (1) - RFV (2)}}{\text{BPCAP/4}} \qquad (\text{C} = \text{BPCAP})$$

The voltage intercept can be defined by:

$$\text{CFK} = (1 - .003 * \text{BTOL}) \left(\text{RFV (2)} - \frac{\text{BPCAP * CFCR}}{4}\right)$$

where the factor (1 - .003 * BTOL) accounts for the tolerance of the input data curves.

At this point the program returns to EPBAT (the main) and the calculation of the instantaneous battery voltage and current proceeds:

$BTCR = (.50^{XSYS})\ CPOS$ (Current)

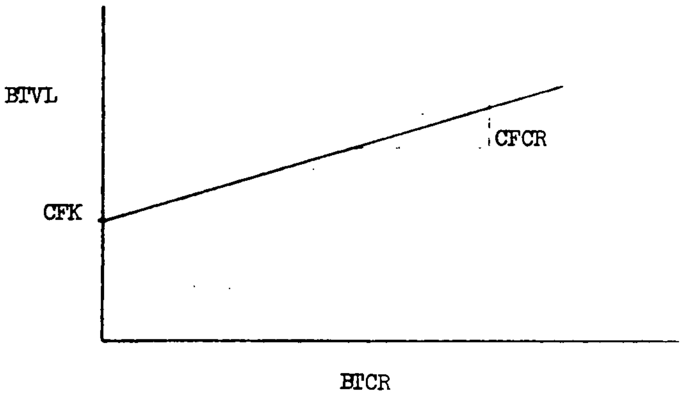
Note that since the cell is not in overcharge then:

$NXSYS = 2$

$XSYS = NXSYS - 2 = 2 - 2 = 0$

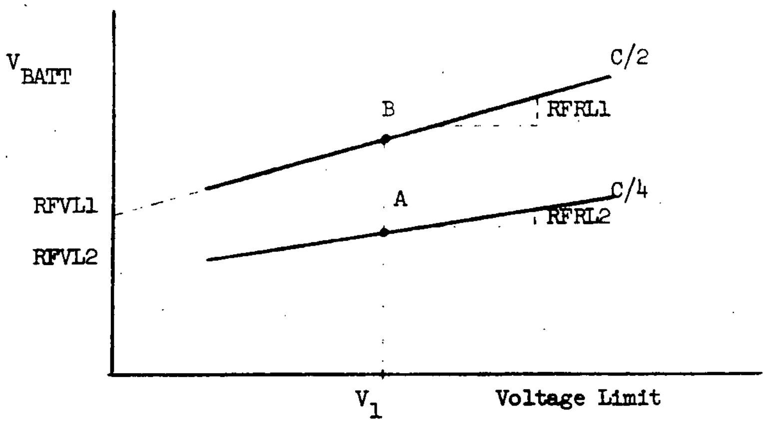
$BTCR = (.50^{0})\ CPOS = CPOS$

$BTVL = CFK + CTCR\ (CFCR)$ (Voltage)



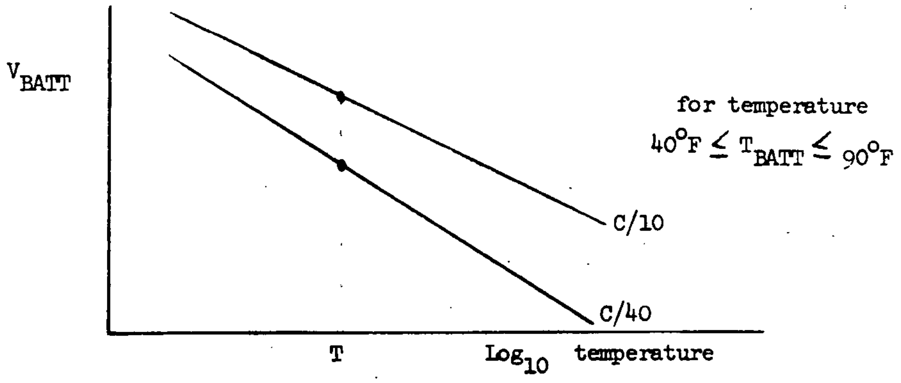
3.2.3 The Overcharge Model

Overcharge, in subroutine BTR, begins at statement label number 600, with NXSYS now at a value of 3 or greater. At statement number 520 (in the "DO" loop or the charge model) the value of NXSOC will become equal to 5 on overcharge, implying that interpolation will begin from the topmost curve in the input (charge) data set. The two curves defined with NXSOC = 5 are obtained identically to the method described for the charge model:



Again two points, here labelled A and B, can be defined for any voltage limit of the preceding orbit.

Another set of curves can be derived as a function of charging temperature, the data having been derived at two overcharge rates: C/10 and C/40. The curves assume the form:



For a given T, therefore, two points (voltages) can be derived; VEOCL and VEOCH, defined by:

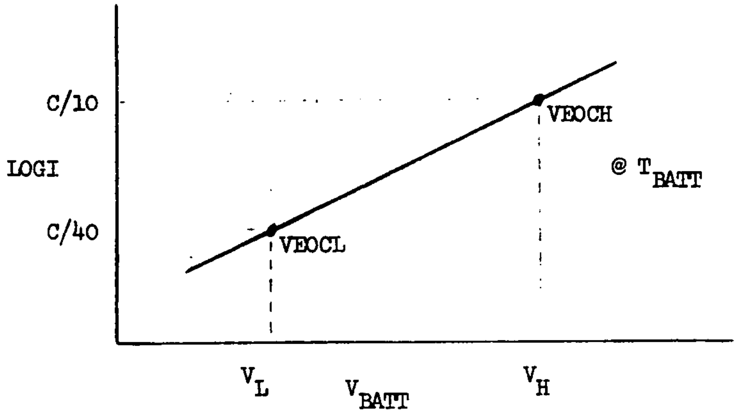
@ C/40 rate: VEOCL = BCEL * (8.060872 - .43429 * LOG (BTEMP))/4.471236

@ C/10 rate: VEOCH = BCEL * (7.397980 - .43429 * LOG (BTEMP))/3.842047 where: BCEL is the factor relating the voltage of single cell to the number of series-connected cells in this battery

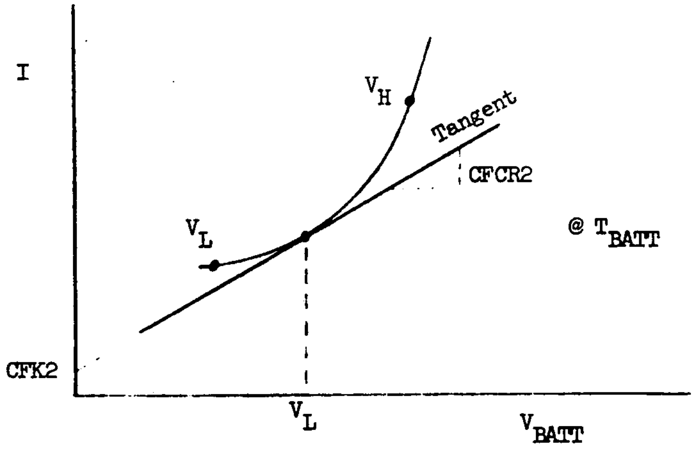
BTEMP is the battery temperature and

the coefficients are least-squares fits of test data in linear (y = mx + b) form.

Re-plotting on semi-logarithmic paper gives:



On linear graph paper this looks like:

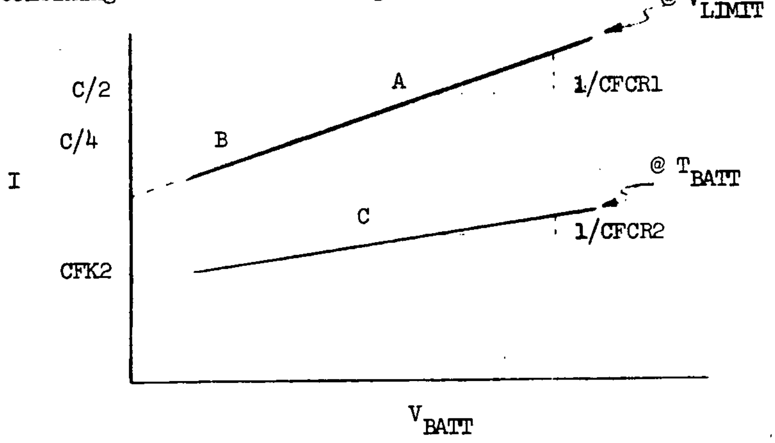


For a given voltage limit, V_L, a tangent to the curve can be constructed, the equation of which is:

$$\mathrm{CFCR2} = \left(\frac{10}{\mathrm{BPCAP}}\right) * \left(\frac{\mathrm{VEOCH - VEOCL}}{.43429 \ \mathrm{lN}(4)}\right) * \left(\frac{\mathrm{VEOCH - BATVL}}{\mathrm{VEOCH - VEOCL}}\right) \quad \text{(Slope)}$$

$$\mathrm{CFK2} = (1. - (.015381 * .43429 \ \mathrm{lN}\ (\mathrm{BTEMP}) - .023575) * \mathrm{BTOL}) * \left(\mathrm{BATVL} - \left(\frac{\mathrm{VEOCH - VEOCL}}{.43429 \ \mathrm{lN}\ (4)}\right)\right) \quad \text{(Current Intercept)}$$

Combining the two relationships:



Using the values of CFK2 and CFCR2, the % return can be calculated as a function of the voltage limit:

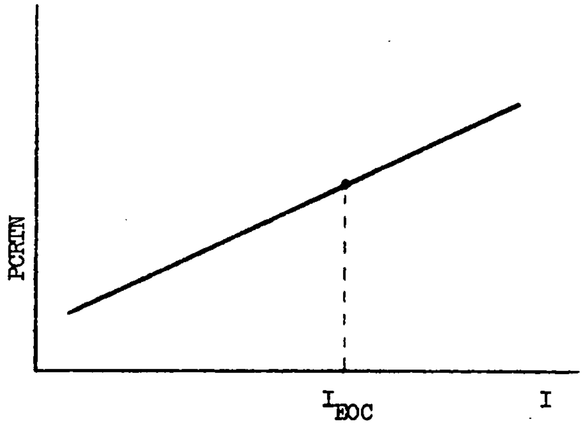
$$\mathrm{PCRTN} = (1 + .013 \ \mathrm{BTOL}) \left(.923263 + .222928 \left(\frac{20}{\mathrm{BPCAP}}\right)\right) * \left(\frac{\mathrm{BATVL - CFK2}}{\mathrm{CFCR2}}\right)$$

Notice that the factor $\frac{\mathrm{BATVL - CFK2}}{\mathrm{CFCR2}}$ is a current,

the factor (.923263 + .222928 (20/BPCAP) normalize the data to a 20 A.H. cell and

the factor (1 + .013 BTOL) is a tolerance on the input data curve.

Since this data was for continuous overcharge, it can be expressed in the following graphical form:



Next, an interpolation factor has to be calculated to determine the locus of the line between the two V-I curves (the one temperature-based; the other voltage-limit-based). This is accomplished by the factor RSO:

$$\text{RSO} = \left(\frac{\text{CTOT}}{\text{AM100}}\right)^4 \left(\frac{\text{RBIN} - \text{RFIN}(5) + \text{RBSDL}}{\text{PCRN} - \text{RFIN}(5) + \text{RBSDL}}\right)$$

Notice that if AM100 = 100% and CTOT = 95% S.O.C. then

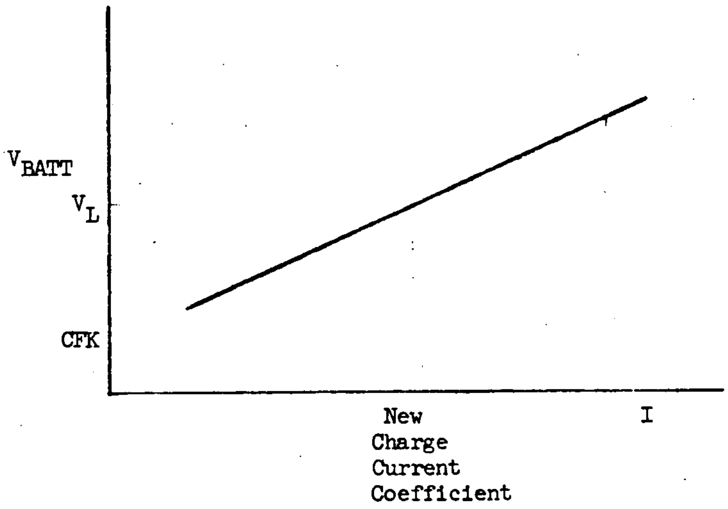
$$\left(\frac{\text{CTOT}}{\text{AM100}}\right)^4 = (.95)^4 = .6$$

if AM100 = 100% and CTOT = 97% S.O.C. then

$$\left(\frac{\text{CTOT}}{\text{AM100}}\right)^4 = (.97)^4 = .88$$

Thus, for a 2% increase in the state-of-charge, the interpolation factor is increased by 28%, resulting in unequal increments for ampere-minutes returned.

By combining the scaling factors, we can derive the equation of the current line as a function of charging voltage:



Expressed mathematically:

$$\mathrm{CFCR} = (1 - \mathrm{RSO})(\mathrm{CFCR1}) + \mathrm{RSO}(\mathrm{CFCR2})$$

$$\mathrm{CFK} = (1 - \mathrm{RSO})(\mathrm{CFK1}) + \mathrm{RSO}(\mathrm{CFK2})$$

At this point control is passed back to the main program. The new charging current and voltage is defined by:

(1) $\mathrm{BTVL} = \mathrm{VREG}$ Taper Charge (Mode 1)

$\mathrm{BTCR} = (\mathrm{BTVL} - \mathrm{CFK})/\mathrm{CFCR}$

(2) $\mathrm{BTCR} = (.50^{\mathrm{XSYS}}) * \mathrm{CPOS}$ Step Charge (Mode 0)

$\mathrm{BTVL} = \mathrm{CFK} + \mathrm{BTCR} * \mathrm{CFCR}$

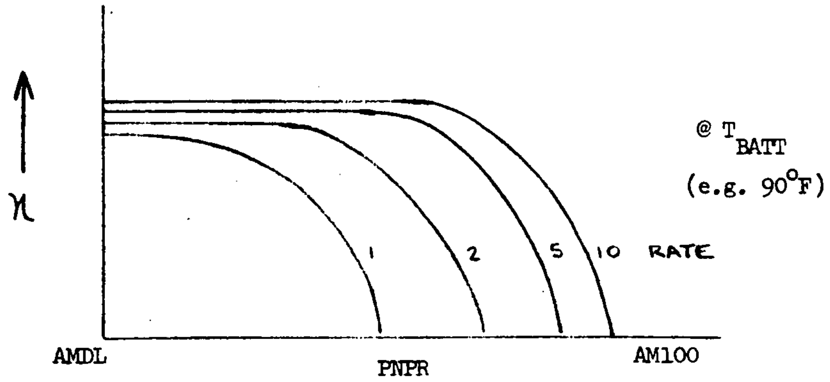
In (1), the taper charge, the battery voltage is locked at the voltage limit and a new, reduced, current value is calculated.

In (2), the step charge, the battery current is reduced by 50% each time the voltage of the battery hits the limiting voltage. The new, reduced, voltage is then calculated accordingly.

3.2.4 The Efficiency Model

The discharge efficiency is set at a constant = 1.0 by definition. When on charge or overcharge, efficiency is a function of temperature, charge rate and state-of-charge.

From empirical (test) data, a family of curves was generated relating efficiency to state-of-charge, for various rates and temperatures. The curves were reduced mathematically to equation form and then coefficients read in as input data. Temperature ranges of 40°, 55°, 70° and 90°F were employed and at each temperature, four charge currents were utilized; 1, 2, 5 and 10 amps. The input data looks thus, in graphical form:



$$\text{where PNPR} = 100. \times \frac{\text{CTOT} - \text{AMDL}}{\text{AM100} - \text{AMDL}} = \text{CADD}$$

PNPR determines the relative number of ampere-minutes from the start of the light period to the end of the light period.

By knowing the battery temperature, a certain family of input data curves is selected by the factor KT.

$$\text{KT} = 1 + 4 * \left(\frac{\text{ITP}}{551}\right) + 4 * \left(\frac{\text{ITP}}{701}\right)$$

and ITP = 10. * BTEMP

Thus, if the battery temperature is less than 55°F, KT will have the integer value of 1; if the temperature is greater than 55° yet less than 70°, KT will have the integer value of 5; etc.. An extrapolation between two temperature sets of data (values of KT) is then performed to determine the exact temperature locus relative to the discrete input levels. This factor is calculated to be:

$$RTE = \frac{BTEMP - RFSE\ (KT)}{RFSE\ (KT + 4) - RFSE\ (KT)} \quad \text{for BTEMP} < 110^{\circ}F$$

where RFSE is the input data indicator (= Rate x Temperature)

A current extrapolation is performed next to determine the relative location of a given point between the various efficiency curves.

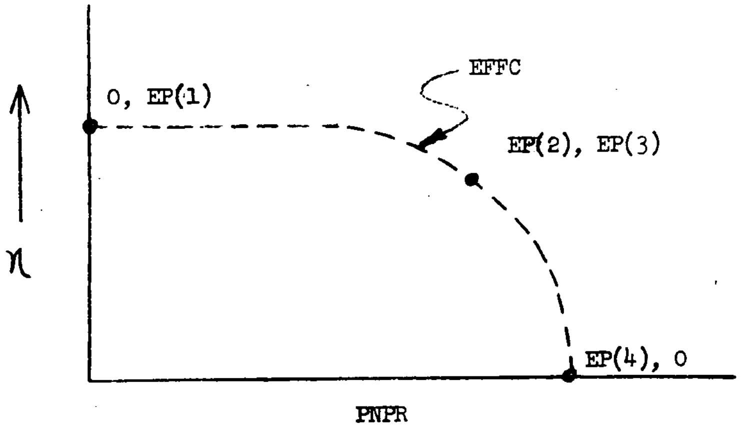
$$KTC = KT + \frac{IBTCR}{201} - \frac{IBTCR - 201}{201} + \frac{IBTCR}{501} - \frac{IBTCR - 501}{501}$$

where $IBTCR = 100. * \left(\frac{20.}{BPCAP}\right)(BTCR)$

This establishes the relative position of the point between two charge curves. The exact locus can be found via extrapolation by:

$$RCE = \frac{((20./BPCAP) * BTCR * RFSE\ (KT) - RFSE\ (KTC))}{(RFSE\ (KTC + 1) - RFSE\ (KTC))}$$

Now knowing the relative location of the curves relating to temperature and current, the exact locus of the curve can be found by extrapolation. This will yield three points on the efficiency vs. S.O.C. curve:



Where:

EP (IEP) = (1. - RTE) * ((1. - RCE) * RFEP (KTC, IEP) + RCE * RFEP (KTC + 1, IEP)) + RTE * ((1. - RCE) * RFEP (KTC + 4, IEP) + RCE * RFEP (KTC + 5, IEP)

The equation of the exponential fit through these three points is given by

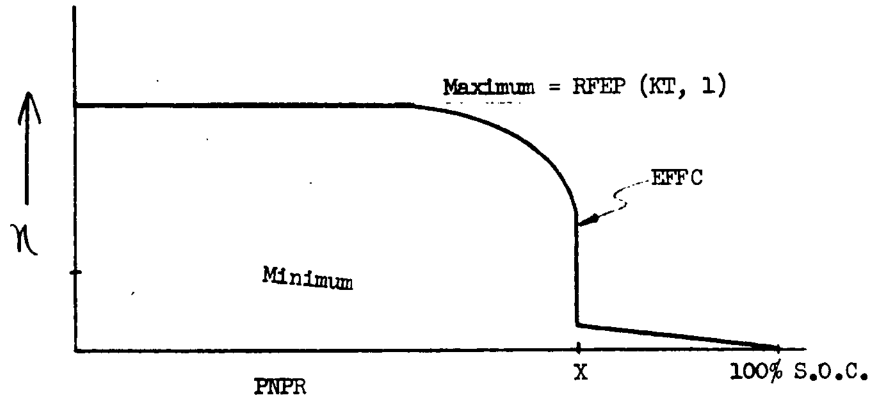
$$\mathrm{EFFC} = \mathrm{EP}\ (1) * 1.0 - \left[\mathrm{C1} \in^{\left(\frac{\mathrm{PNPR}}{\mathrm{C2} * \mathrm{EP}(4)} \right)} - 1.0 \right]$$

where:

$$\mathrm{C1} = \left(1. - \frac{\mathrm{EP}(2)}{\mathrm{EP}(1)} \right) * \in^{\frac{-\ \mathrm{EP}(3)}{\mathrm{C2} * \mathrm{EP}(4)}}$$

$$\mathrm{C2} = \left(\frac{\mathrm{EP}(3)}{\mathrm{EP}(4)} - 1. \right) \Big/ \mathrm{ALOG} \left(1. - \frac{\mathrm{EP}(2)}{\mathrm{EP}(1)} \right)$$

Limits are now set on the curve; a maximum efficiency value given by EFMAX - RFEP (KT + 3, 1) and a minimum value given by EFMIN = .01 - .0001 * CADD. Graphically this can be shown as:



Thus the efficiency at a given state of charge is defined by the locus of the line EFFC up to point where it is then defined as (.01 - .0001 * CADD).

3.2.5 Thermal Section

The present OAO battery model has shown close correlation with actual data although it does not incrementally update the battery temperature at the end of each orbital minute. However, the heat generation is calculated and updated at each minute interval. Essentially two thermal models are employed and the average of these two used for the heat generation rate.

BHGM1 (Model 1) is defined as:

$$\text{BHGM1} = \frac{(\text{WMIN} - \text{WMOUT}) + (\text{AMINT} - \text{AMFIN})(\text{BCEL})(1.48)}{\text{TORB}}$$

BHGM2 (Model 2) is given as:

$$\text{BHGM2} = \frac{(.13)(\text{WMOUT}) + \text{WDCHG}}{\text{TORB}}$$

They are then averaged to give

$$\text{BHGM} = \frac{\text{BHGM1} + \text{BHGM2}}{2}$$

3.2.6 Listing of Variable Names (Label Table)

- A -

AMAX1	Function for Determining the Maximum of Two Variables
AMOL	Ampere Minute Capacity at E.O.D./S.O.L.
AMFIN	Ampere Minute Capacity at E.O.L
AMIN1	Function for Determining the Minimum Value of Two Variables
AMINT	Ampere Minute Capacity at S.O.D.
AM100	Theoretical Capacity in Ampere Minutes

- B -

BATVL	Battery Voltage Limit on Charge
BCEL	Number of Series-Connected Cells in Battery
BCRTN	Capacity Returned at End of Orbit
BHGM	Battery Average Heat Generated in Watts
BHGM1	Heat Generation Model #1 for Battery
BHGM2	Heat Generation Model #2 for Battery
BSOC	Initial Battery State-of-Charge (x 100%)
BTCR	Battery Current Rate
BTEMP	Battery Temperature
BTOL	Tolerance of Input Data Curves (Usually taken as zero)
BTR	Subroutine for Calculation of Instantaneous Battery Parameters
BTVL	Battery Voltage Limit on Charge
BVLS	Charging Voltage Limit Based on Temperature

- C -

CADD	Relative Charge Indication
CAP-RTN	Capacity Returned at End of Orbit
CFCR	Slope of General V-I Curve
CFK	Voltage Intercept of General V-I Curve
CNEG	Discharge Rate in Amperes
CPOS	Charge Rate in Amperes
CTHR	Instantaneous Summation of Ampere-Minutes to a Particular Time
CTOT	Actual Energy Content in Amp-Minutes (Theoretical x State-of-Charge)
C1 C2	Coefficients of Determined Efficiency Curve

- D -

- E -

EDBV	Battery Voltage at E.O.D.
EFFC	Efficiency Coefficient (x 100%)
EFMAX	Line Defining Maximum Theoretical Efficiency
EFMIN	Minimum Realizable Efficiency
EOD-VOL	Battery Voltage at E.O.D.
EOL-CUR	Battery Current at E.O.L.
EOL-EFF	Battery Efficiency at E.O.L.
EOL-VOL	Battery Voltage at E.O.L
	Defines a Point on the Efficiency Curve
EPBAT	Main Program

- F -

- G -

- H -

- I -

IBTCR	Battery charge rate normalized from 20 AH NiCd data
IDAY	Records day of month of user run
IGOTO	Decides to stop program or read in new orbit parameters
IONTH	Records month of user run
IREG	Is zero if regulator is off; is one if regulator is on
ISERT	Argument of BTR; allows program to read in model coefficients only when it is the first minute of discharge, otherwise it skips the reading section and begins processing
ITIME	Integer count for each minute of orbit
ITP	10. x battery temperature
IYEAR	Year of user run

- J -

- K -

KT	Temperature index to locate battery temperature relative to input data set
KTC	Index relating charge rate to temperature

- L -

LT	Becomes positive only when not in eclipse portion of orbit
LTORB	Total orbit time in minutes

- M -

MODE	Method of charge control ("0" = step, "1" = taper)

- N -

NORB	Integer value of orbit number
NRITE	"0" means no printout at end of orbit "1" means print parameters at end of orbit
NSTD	Number of minutes into the eclipse (discharge) region
NSUNT	Number of minutes into the light region
NTO	Integer value of orbit number
NTORB	Total number of orbits
NXSYS	Has the value "1" when system is on discharge Has the value "2" when system is on charge Has the value "3" or greater when the system is in overcharge

- O -

- P -

PCRTN	Per-cent capacity returned
PNPR	Relative charge indication

- Q -

QBAY	"Q" value of battery heat sink

- R -

RAD	Capacity returned at end of orbit
RBIN	Scale factor for charge model curves
RBOI	Scale and offset factor for discharge model curves
RBOUT	Scale and offset factor for discharge model curves
RBSDL	Offset factor for charge model curves
RCE	Relates rate difference between data set and actual battery current
RCSOC	Location of instantaneous charge curve between input data curves
RDSOC	Location of instantaneous discharge curve between input data curves
RFEP	Coefficients for efficiency model on input data set
RFIN	Indicator for input charge model data set
RFOUT	Indicator for input discharge mode data set
RFRD	Slope of voltage vs. voltage limit curve for discharge model
RFRL	Slope of voltage vs. voltage limit curve for charge model
RFRLC	Slope of charge model on input data set
RFRLD	Slope of discharge model on input data set
RFSE	Rate/temperature index for input efficiency model curves
RFV	Point on charge curve relating battery voltage to voltage limit for two charge rates
RFVL	Voltage intercept on charge model curve
RFVLC	Voltage intercept on charge model input data set
RFVLD	Voltage intercept on discharge model input data set
RSO	Relative location of overcharge curve on I-V plot
RTE	Relative temperature difference between battery and input data

- S -

- T -

TSUN	Dummy variable, not presently used in program

- U -

- V -

VEOCH	End of charge voltage for C/40 rate at specific temperature
VEOCL	End of charge voltage for C/10 rate at specific temperature
VREG	Maximum allowable voltage on charge

- W -

WATOT	Summation of watt-minutes
WDCHG	Updates watt-minutes on charge

WMIN	Summation of watt-minutes
WMOUT	Summation of watt-minutes out of battery during discharge

- X -

XSYS	Becomes positive when system is in overcharge

- Y -

- Z -

3.3 PROGRAM MECHANICS

3.3.1 Operating Procedure

The execution begins with raw data being printed out. The program asks the operator if the data is correct. If the answer is no, the program returns to the step in which the charge time (NSUNT), etc. are entered. In so doing, incorrect data is erased and the new input parameters are accepted. The operator selects the number of orbits next and tells the program to print the output on a minute-by-minute basis by the command NRITE = 1. If a minute-by-minute output is not desired NRITE is set equal to zero. NTORB is the number of orbits through which the batteries cycle. If the operator wishes to print the output onto a disk the program has the capability to do so. The output is printed onto the disk in 4F10.3 format, the data consisting of the efficiency, battery state-of-charge, battery voltage and current at a time interval specified by the next statement. The output is also printed onto the console (see sample output) at a time interval specified by the final statement, e.g. - every "I" minutes.

The example given herein was executed for 4 orbits with the printed output appearing at 1 minute intervals. Summaries are given for the first three orbits consisting of the following:

EODV - the battery voltage at the end of the discharge
EOLV - the battery voltage at the end of the charge period
EOLF - the efficiency at the end of light
CRTN - % capacity returned
AMINT - A.MIN capacity at start of the dark period
AMOL - A.MIN capacity at E.O.D./S.O.L.
AMFIN - A.MIN capacity at end of the light period
WMO - watt-minutes out this discharge
WMIN - watt-minutes in this charge.

Below this output are three numbers representing the thermal coefficients. The first two are heat generation rates for the orbit; the third is an average of these two. The fourth (0.0) is a constant, not presently used.

Upon execution of the final (4th) orbit, the data is printed at the specified interval, in this case each minute. Reading from left to right, the output data consists of the following: TIME (orbital minute), REGULATOR STATUS ("0" = OFF, "1" = ON), RBOI, CFK, CFCR, CTHR, WATOT, EFFC, CTOT, BSOC, BTVL and BTCR. The interpretation of each of these variable names is listed in the Label Table (Section 3.2.6).

The program terminates by asking the operator if he wishes to stop (program execution), loop or start again. By looping, the operator returns to the statement asking him to specify the number of orbits and if a print-out is desired. By starting again the operator returns to the beginning of the program and may read in new battery input parameters (state-of-charge, BVLS, temperature, etc.).

3.3.2 Sample Output

The OAO battery model was used to predict the performance of the spacecraft A-2 batteries during orbit 14,427. The parameters were inputted into the model in the following order:

- Date of program execution in month, day, year
  - inputted as 012172 (21 January 1972)
- Time in sun (charge time) of 65 minutes
  Total orbital time of 101 minutes
  Nameplate capacity equal to 20.0 AH
  Number of cells in battery (21)
  Mode (of charge), in this case "1" which means taper charge after voltage limit.
- Initial state of charge inputted as 1.0, or, 100%
  BVLS = 2
  Battery temperature (a constant) of 50.0°F
  BTOL, the curve tolerance, usually set at zero
  CNEG, the discharge rate, equal to -4.6 amps
  CPOS, the charge rate, equal to +4.8 amps.

A copy of the computer output is shown in Appendix F, and Figure 3.4-1

3.4 PREDICTION CAPABILITY

A comparison of the predicted and actual flight data is given in Figures 3.4-1, 3.4-2, and 3.4-3. As can be seen the computer model satisfactorily predicts the battery charge and discharge response at each BVLS level. Predictions comply best with actual data in the end-of-dark battery voltages, time in shunt mode and end-of-light battery currents. The largest difference between actual and predicted data appears in the shape of the charge voltage curve during the unregulated portion. In each case the model predicts a lower voltage than is realized in flight. Some difference also appears in the regulated battery voltage parameter. This difference is probably caused by the inability of the model to relate thermal changes in the battery back to changes in the charging voltage limit. Nevertheless, the model does predict battery operation, when operating in a power system having known characteristics, quite well despite the thermal inflexibility.

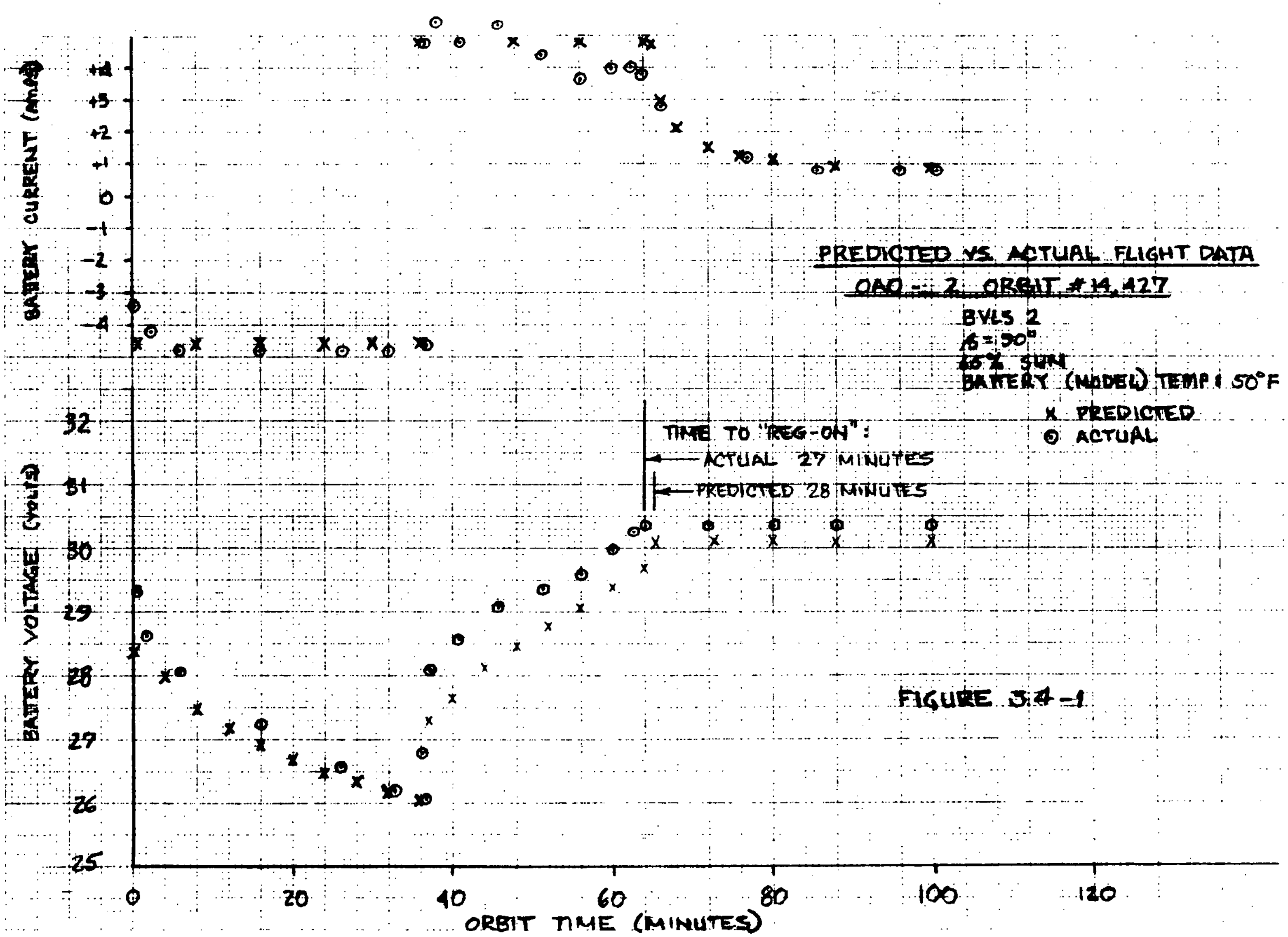

PREDICTED VS. ACTUAL FLIGHT DATA
OAO - 2 ORBIT #14,427
BVLS 2
β = 90°
65% SUN
BATTERY (MODEL) TEMP: 50°F
X PREDICTED
⊙ ACTUAL
TIME TO "REG-ON":
ACTUAL 27 MINUTES
PREDICTED 28 MINUTES
BATTERY CURRENT (AMPS)
+4
+3
+2
+1
0
-1
-2
-3
-4
BATTERY VOLTAGE (VOLTS)
32
31
30
29
28
27
26
25
0
20
40
60
80
100
120
ORBIT TIME (MINUTES)

FIGURE 3.4-1

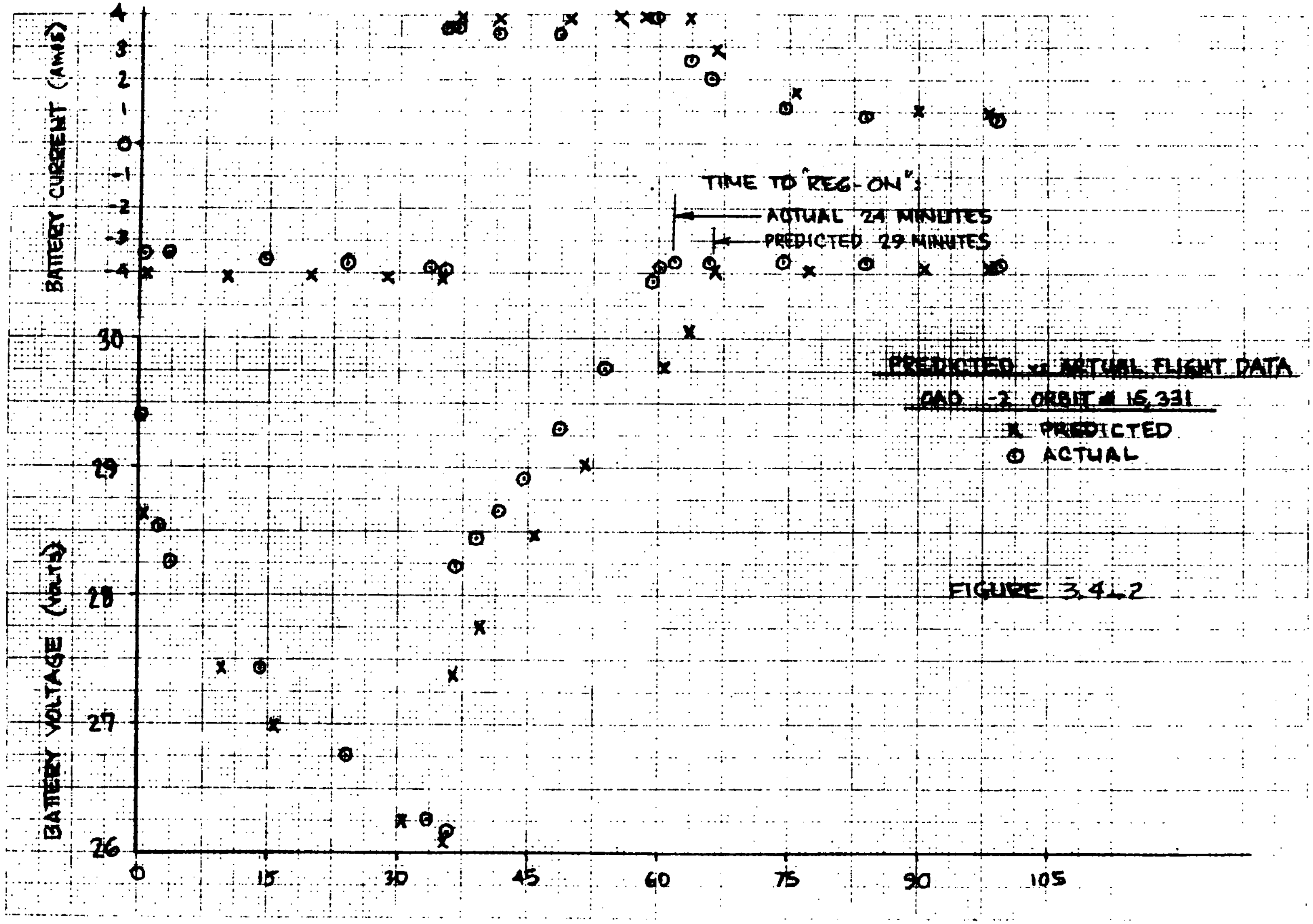

BATTERY CURRENT (AMPS)
4
3
2
1
0
-1
-2
-3
-4
BATTERY VOLTAGE (VOLTS)
30
29
28
27
26
0
15
30
45
60
75
90
105
TIME TO "REG-ON":
ACTUAL 24 MINUTES
PREDICTED 29 MINUTES
PREDICTED vs ACTUAL FLIGHT DATA
OAO -2 ORBIT # 15,331
X PREDICTED
⊙ ACTUAL

FIGURE 3.4.1.2

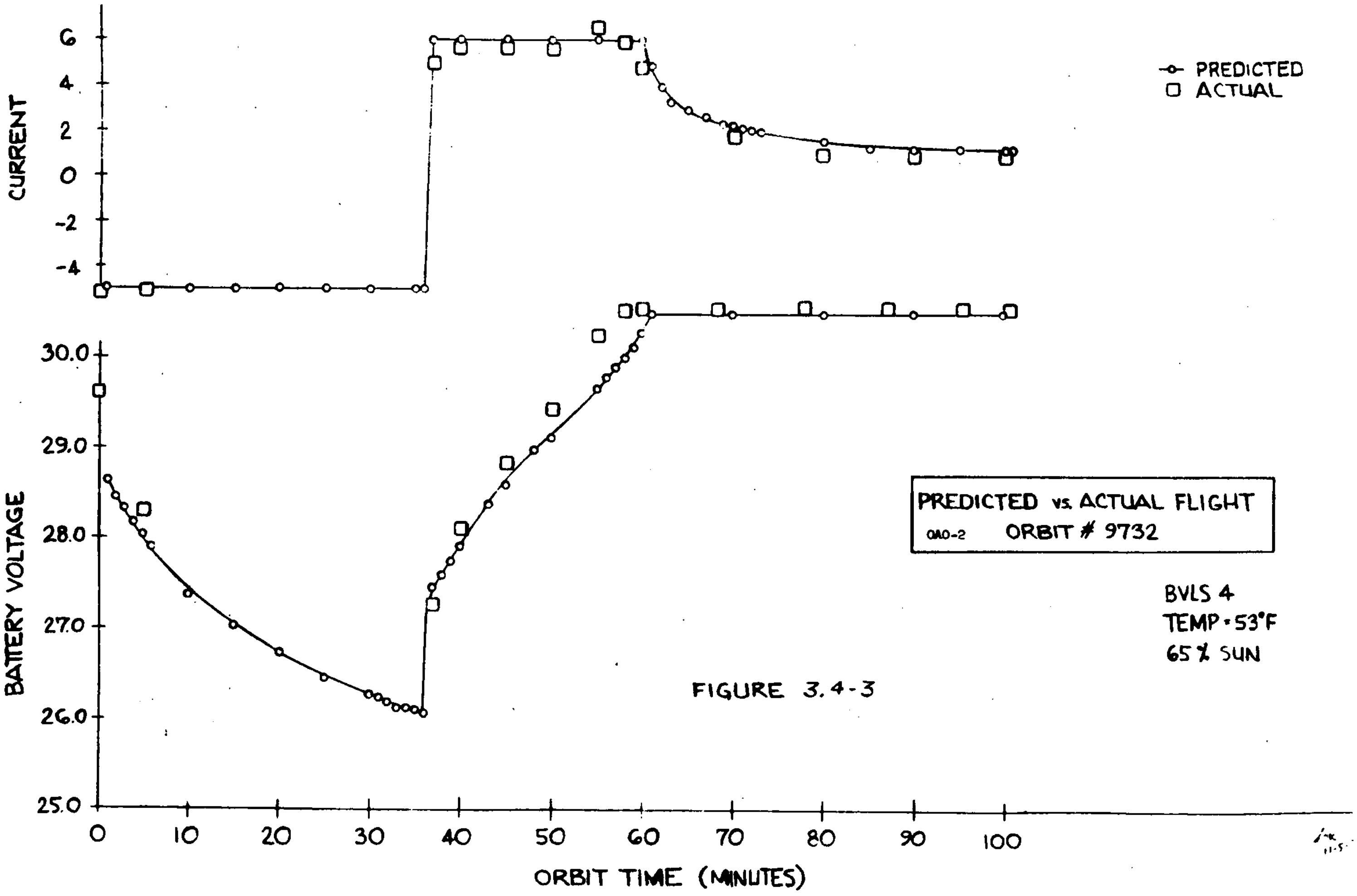

-o- PREDICTED
□ ACTUAL
CURRENT
6
4
2
0
-2
-4
BATTERY VOLTAGE
30.0
29.0
28.0
27.0
26.0
25.0
0
10
20
30
40
50
60
70
80
90
100
ORBIT TIME (MINUTES)
PREDICTED vs ACTUAL FLIGHT
OAO-2 ORBIT # 9732
BVLS 4
TEMP • 53°F
65% SUN

FIGURE 3.4-3

SECTION 4.0

OAO-2 FLIGHT DATA SUMMARY

4.1 OAO-2 FLIGHT PERFORMANCE - FIRST TWO-WEEK SUMMARY

Batteries

Battery operation has proceeded under the Power Charge Controller (PCU) BVLS control (levels shown in Figure 4.1-1) for the entire mission. Battery cool-down following separation was as expected. (see Figure 4.1-2). The batteries have been in a high state of charge for the entire mission, as evidenced by the high adhydrode voltages at the end of light.

Thus far there have been three BVLS levels used:

1. Launch to QTO-5: BVLS 4 - Under this level of control the adhydrodes were reaching into the 450-500 millivolt range at end of light. While this is not dangerous, it was considered to be desirable to lower the level.
2. QTO-5 to MAD-146: BVLS 3 - Under this level of control the adhydrodes were reaching 350 to 425 millivolts at end of light. This was comfortable but still on the high side.
3. MAD-146 to present: BVLS 3 - This change in BVLS level was made in order to establish a new battery operational regime. Under this operation, the battery temperature has lowered to about 50°F, from the more or less typical value of 54-55°F above. In addition end of light adhydrode voltages are now in the 315 to 385 mv region.

Overall battery performance is excellent.

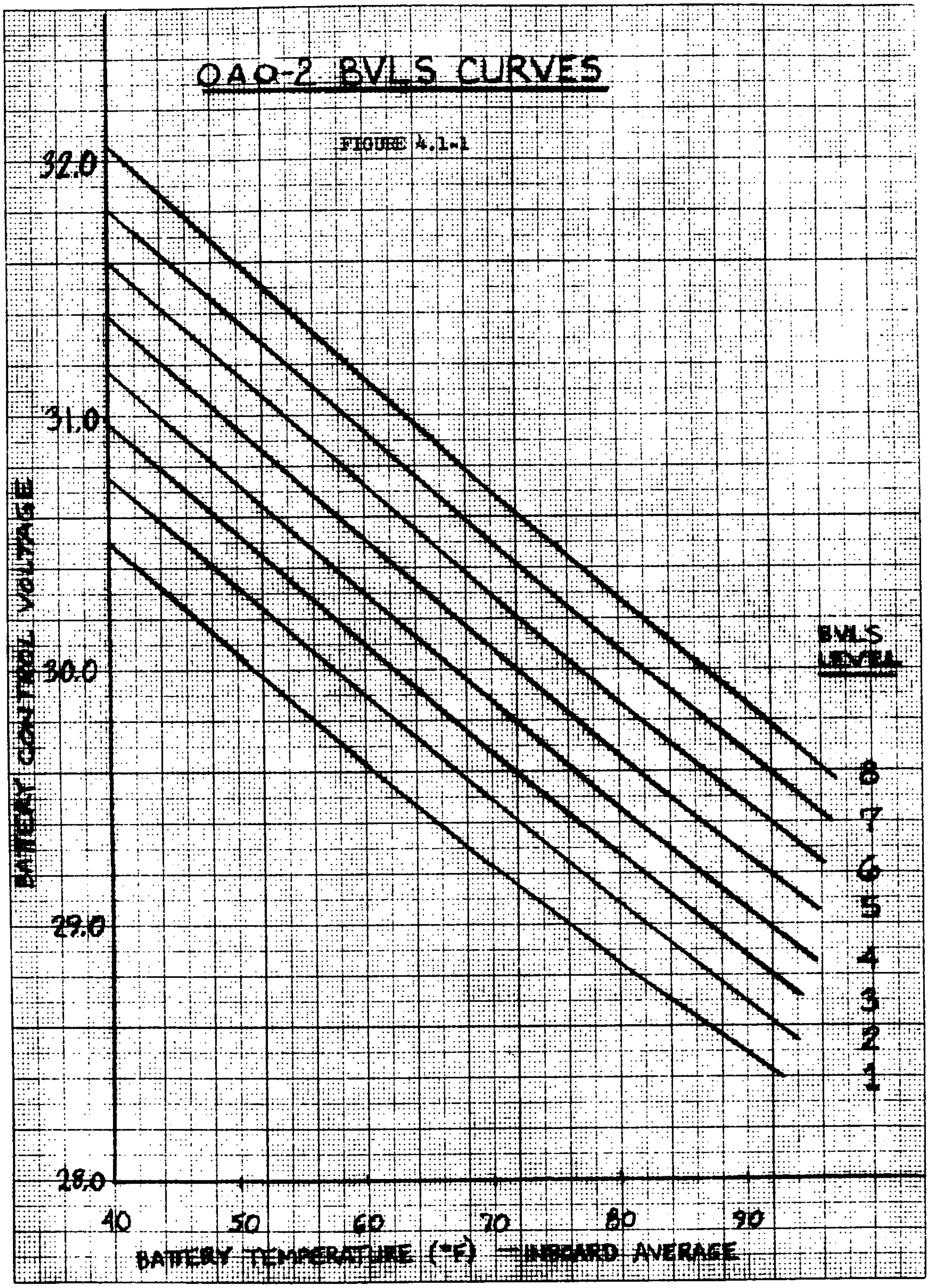
Major Indicators of System Performance

Specific comments are as follows:

1. Battery temperature - presently holding steady in low 50's for past 100 orbits.
2. End of light adhydrode voltages - consistently high indicating overcharge in every light period, except for flip maneuver.
3. End of light charge currents - holding steady at reasonable values, no evidence of rising.
4. End of dark battery voltages - holding steady in the area of 26 to 26.5 volts. (Under-Voltage Regulation-Generator (URG) activates at 25.2 volts).
5. Minutes of shunt charge - spacecraft orientation (beta angle) dependent to a large degree, but for a given attitude it holds steady in 10-20 minute region.

OAO-2 BVLS CURVES

FIGURE 4.1-1



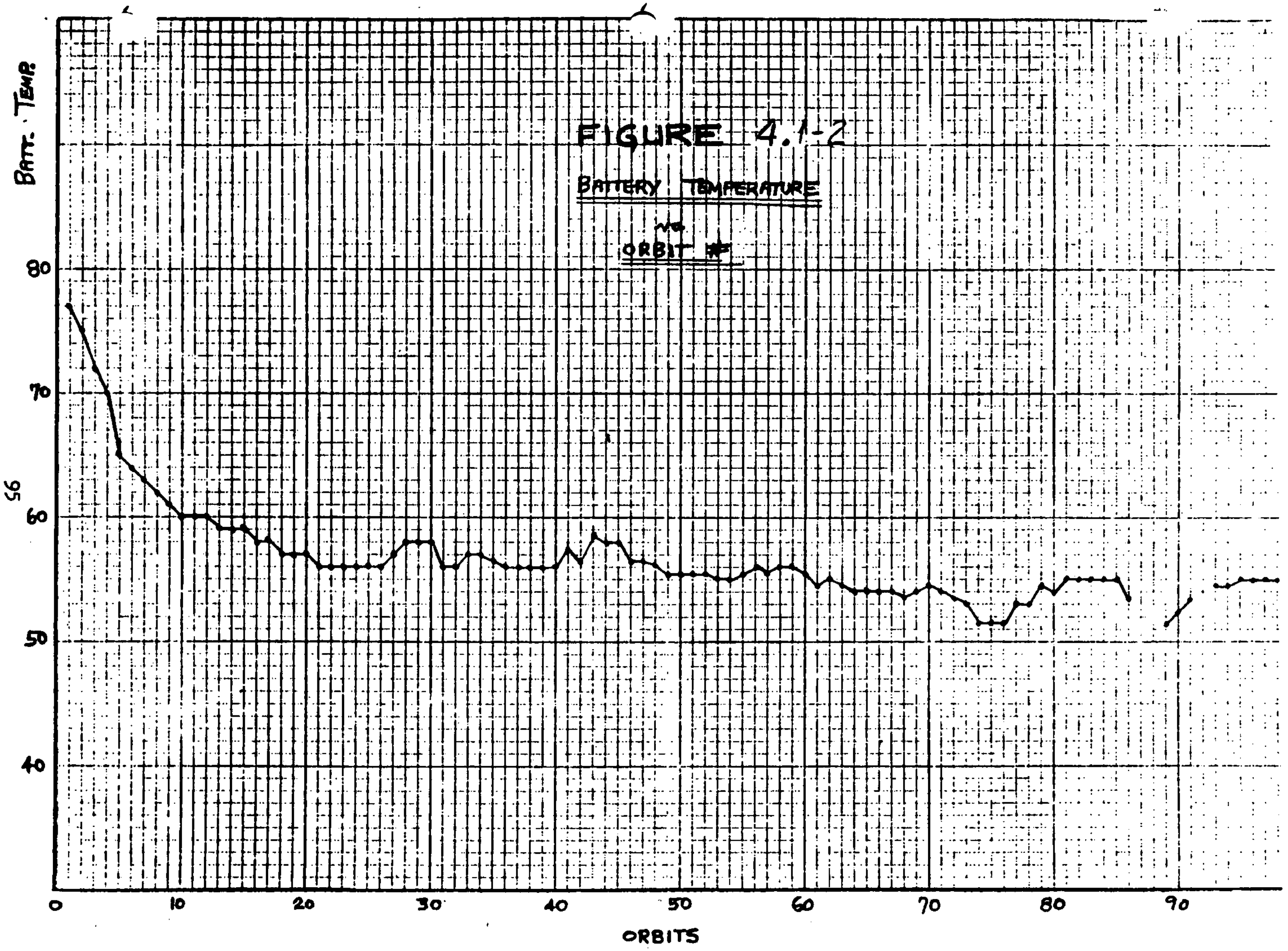


FIGURE 4.1-2

BATTERY TEMPERATURE vs ORBIT #

4.2 30-DAY OAO-2 FLIGHT SUMMARY

Battery performance was excellent with no problems of any sort. Specifically there was no evidence of the problem observed during the vehicle acceptance thermal vacuum test.

NOTE:: The batteries on board during the test had become negative limited, causing potential gassing problems, and reducing effective power utilization. For this reason, they were deemed unworthy for flight, and a new set of batteries was built, tested and flown.

Battery overcharge characteristics appeared satisfactory. In general, end-of-charge currents were in the anticipated range, (see Figure 4.2-1), and were high enough to verify that the battery was not negative limited. (It should be noted that, if the batteries were negative limiting, battery voltage would normally tend to rise sharply, and hydrogen evolution would ensue. In a voltage-regulated charge, as used on OAO, the effect would be that of a relatively sharp reduction in end-of-charge trickle current due to the batteries' higher back EMF. Hence, the preceding statement). Lack of telemetry resolution presented a problem in a detailed analysis.

Battery temperature decreased from the launch level of 78°, as expected. After the initial cool-down, the temperature remained in the range of 50-60°F (see Figure 4.1-2).

Battery internal impedance was as anticipated, with voltage decreasing to 26-26.5V by the end of the dark period (see Figure 4.2-2). Matching of the batteries was adequate, evidenced by typical current sharing as follows: Dark - 33, 34, 35%, shunt charge - 32, 34, 34%. Comparisons of flight data points with pre-flight predictions of charge and discharge performance are shown in Figure 4.2-3 and 4.2-4. Comparisons are quite good, considering errors and uncertainties in telemetry interpretation.

Adhydrode performance was consistent, and, as anticipated, the actual operating range immediately after launch confirmed that batteries were receiving the high degree of overcharge demonstrated in the thermal vacuum acceptance test.

Battery Recharge and Load Support

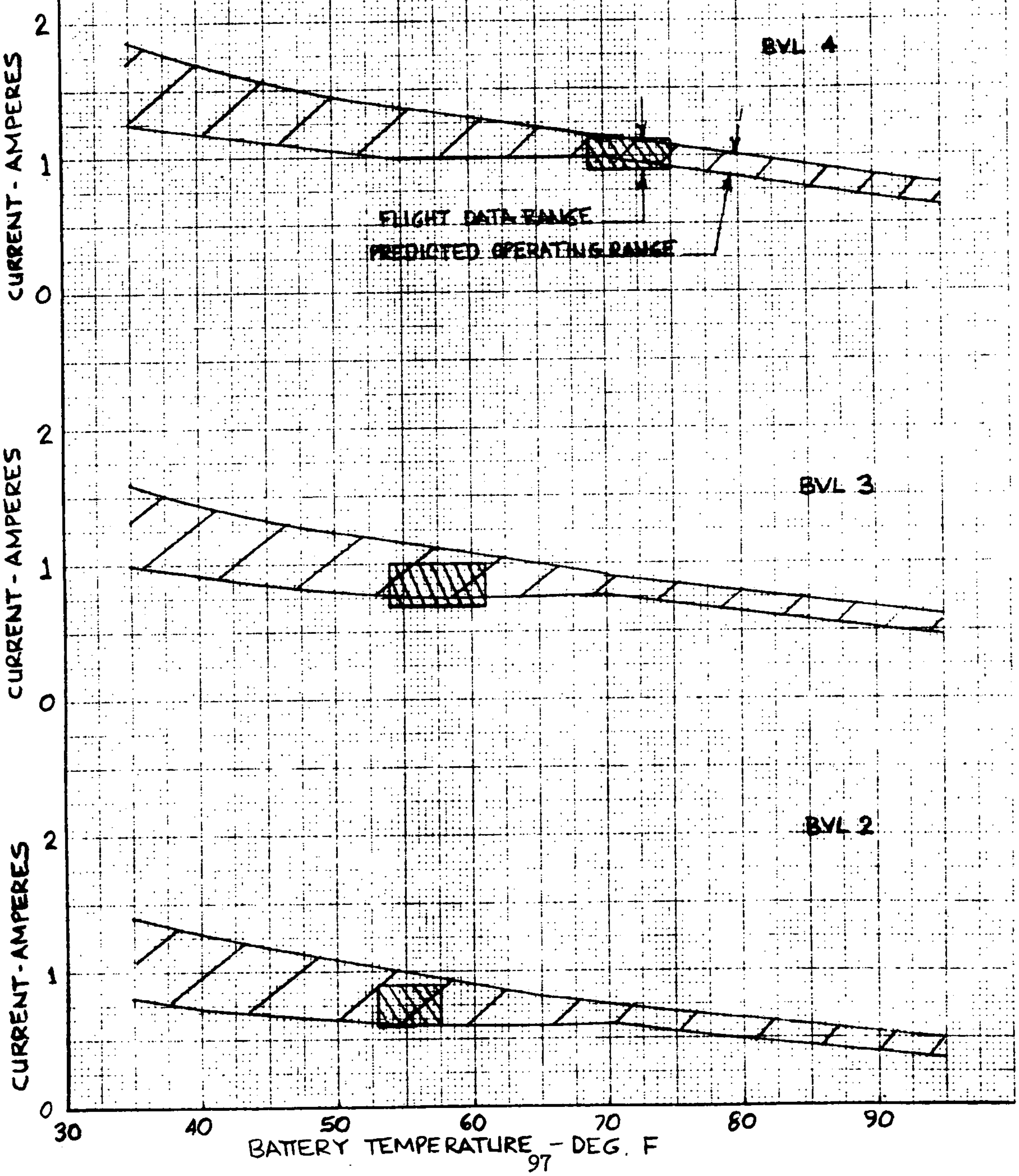
The solar array output was entirely adequate to provide sufficient battery recharge and support the vehicle load requirements. Since there is no known way of directly monitoring battery state-of-charge, the inference that the battery was consistently fully recharged was drawn from the performance of the following parameters:

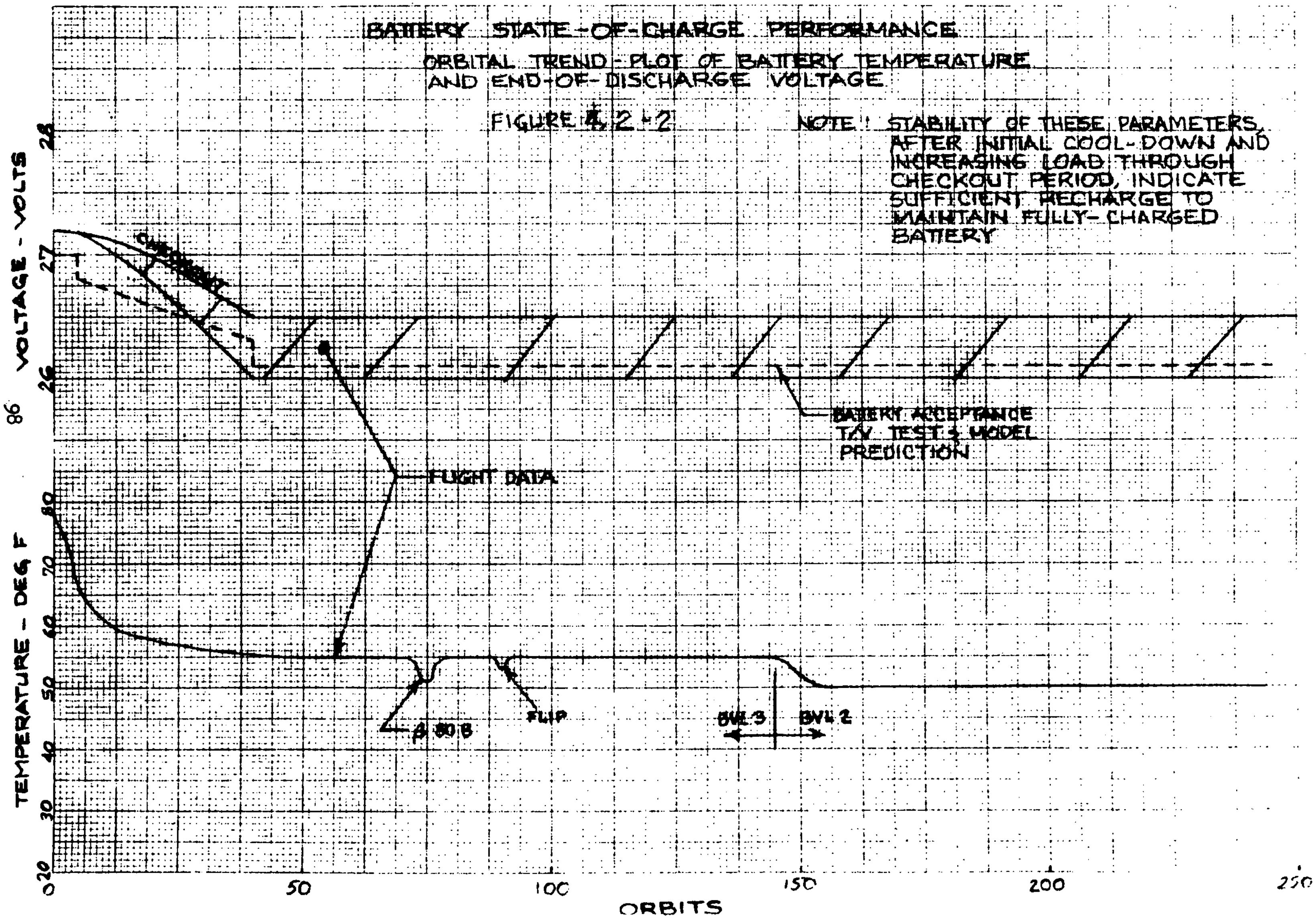
a. Adhydrode voltages at the end-of-light
b. Battery charge currents at the end-of-light
c. Battery discharge voltages at the end-of-dark
d. Battery temperature
e. Duration of short charge (battery charging until regulator turn-on)

BATTERY OVERCHARGE CURRENT

COMPARISON OF FLIGHT DATA WITH PREDICTIONS

FIGURE 4.2-1



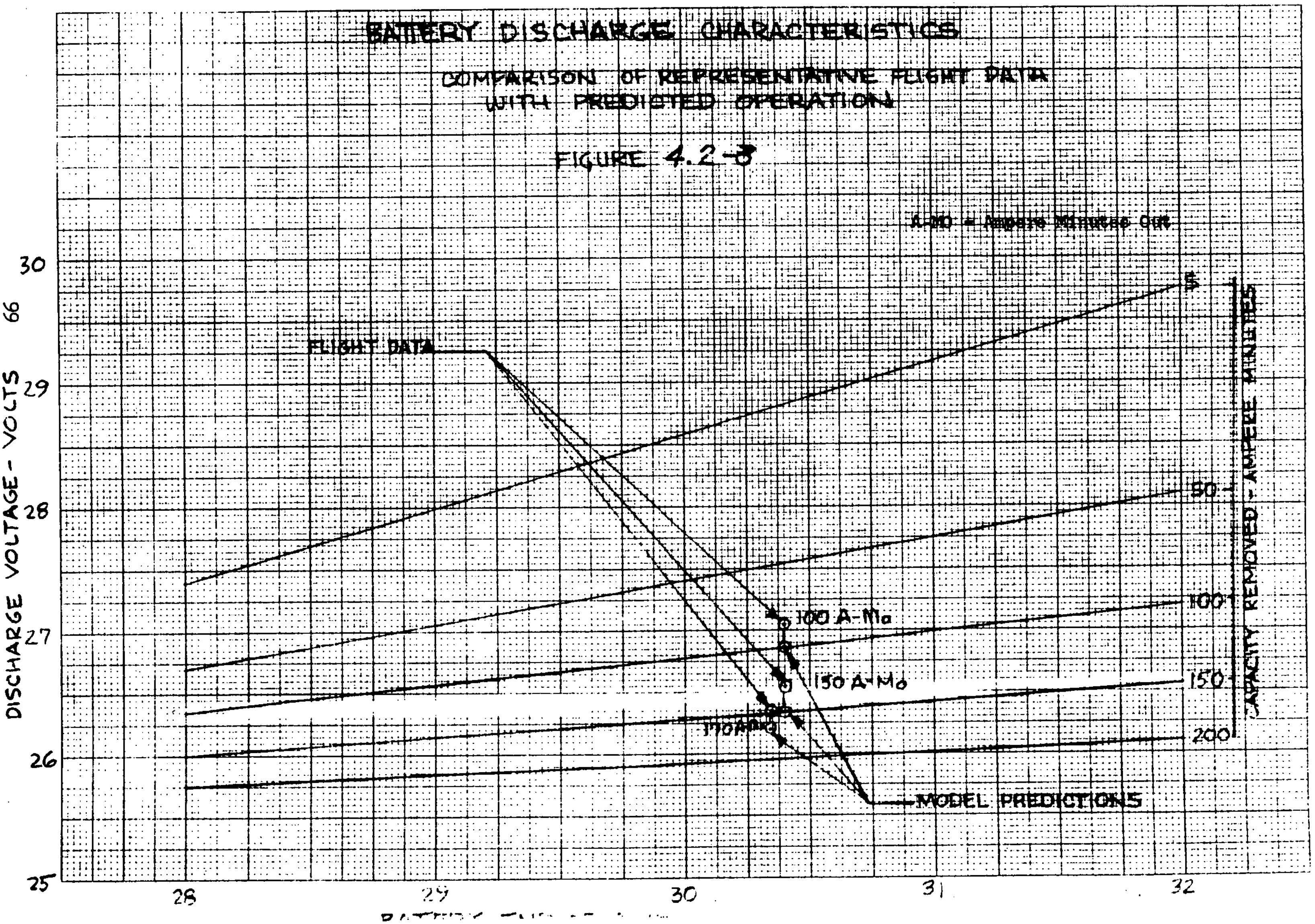


BATTERY STATE-OF-CHARGE PERFORMANCE

ORBITAL TREND-PLOT OF BATTERY TEMPERATURE AND END-OF-DISCHARGE VOLTAGE

FIGURE 4.2-2

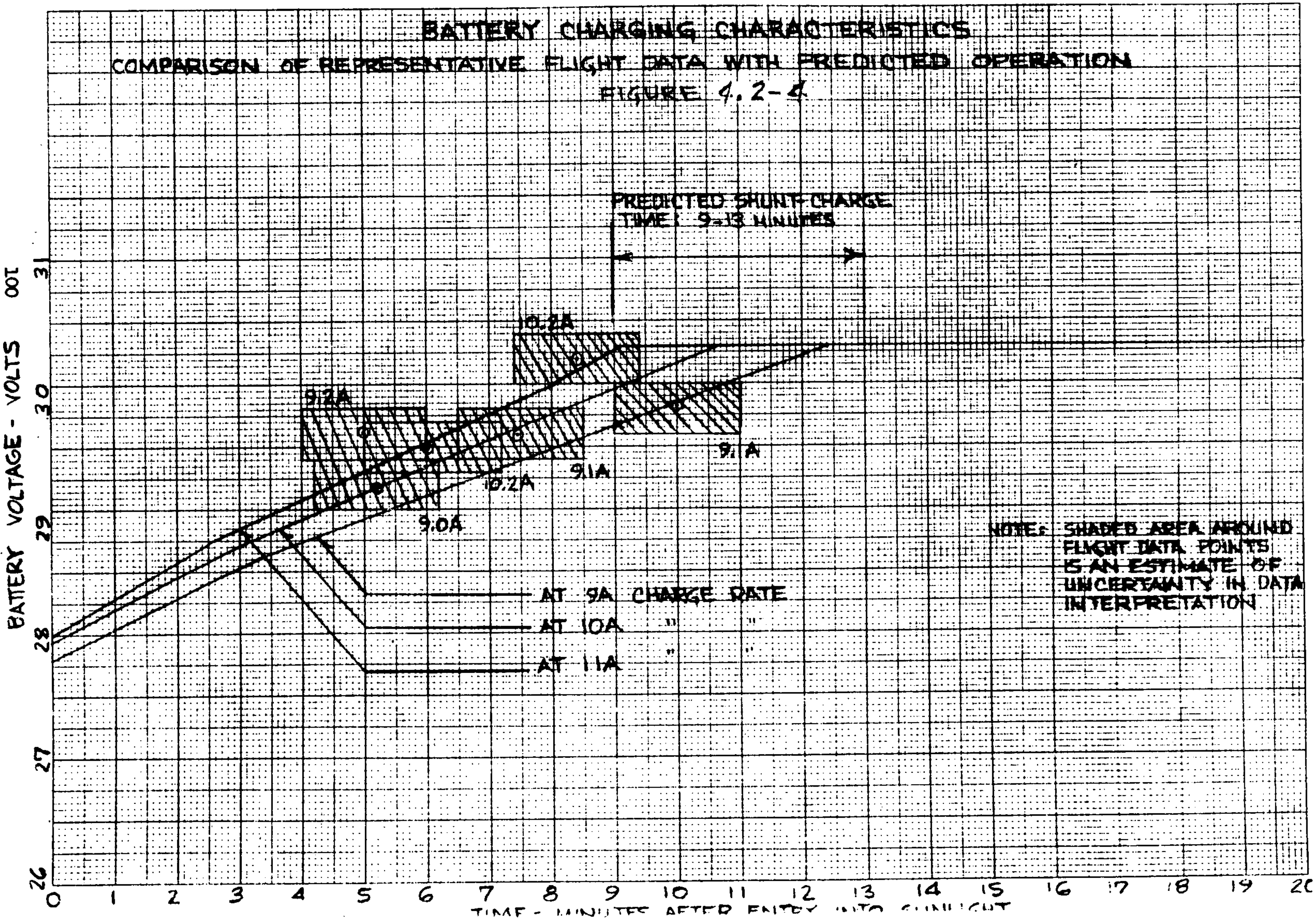
NOTE: STABILITY OF THESE PARAMETERS, AFTER INITIAL COOL-DOWN AND INCREASING LOAD THROUGH CHECKOUT PERIOD, INDICATE SUFFICIENT RECHARGE TO MAINTAIN FULLY-CHARGED BATTERY



BATTERY DISCHARGE CHARACTERISTICS

COMPARISON OF REPRESENTATIVE FLIGHT DATA
WITH PREDICTED OPERATION

FIGURE 4.2-8



BATTERY CHARGING CHARACTERISTICS
COMPARISON OF REPRESENTATIVE FLIGHT DATA WITH PREDICTED OPERATION
FIGURE 4.2-4

Stability of the above parameters over many orbits is the characteristic performance which indicates full battery recharge. Conversely, if the batteries were not being fully recharged, the resultant orbit-to-orbit loss of capacity would be evident from orbital trends showing the parameters to be unstable in the following manner*:

a. End-of-light adhydrode voltages, end-of-dark battery voltages, and battery temperature would gradually decrease;

b. End-of-light charging currents, and shunt-charge duration would gradually increase.

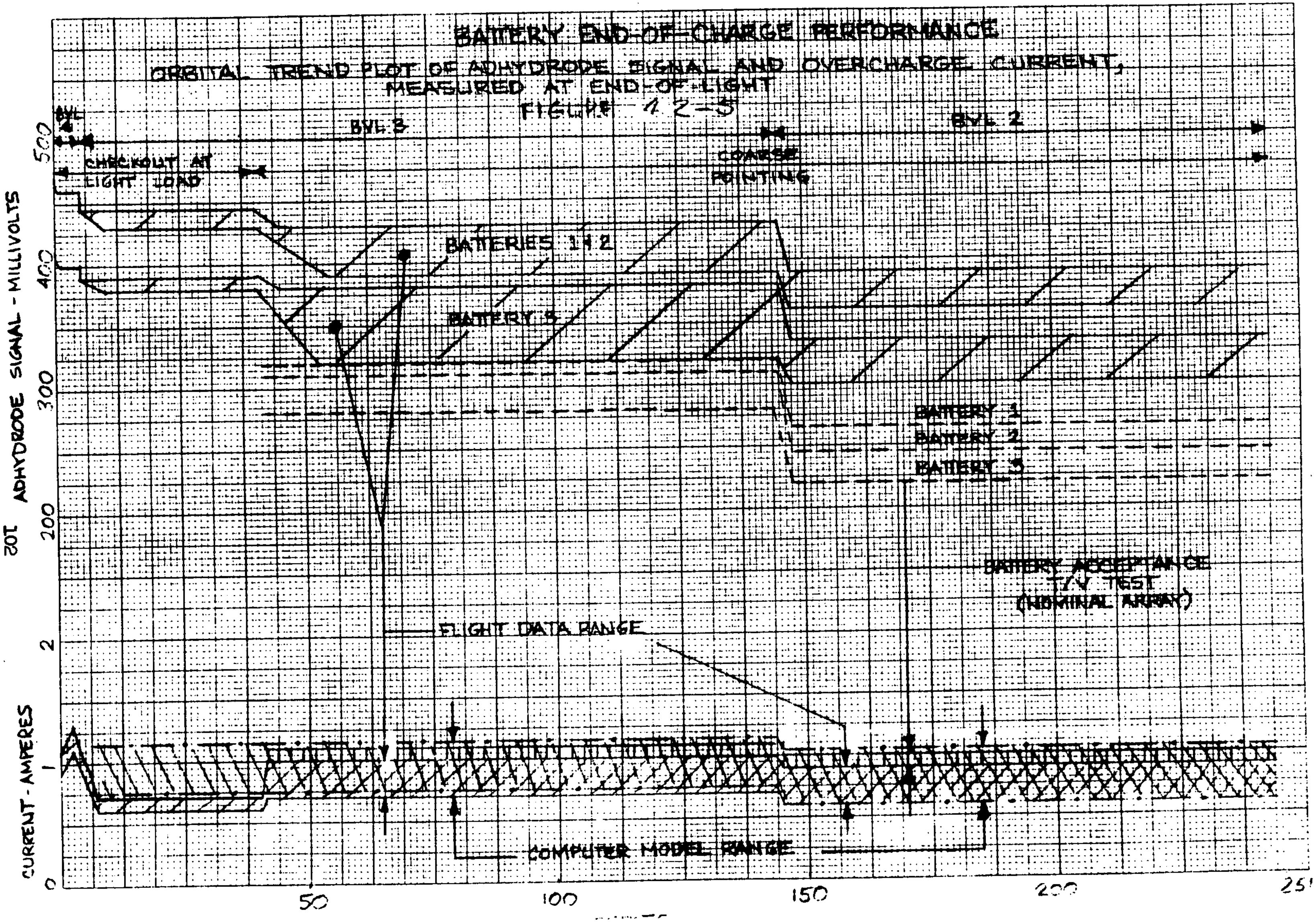
As can be seen from Figures 4.2-2, 4.2-5 and 4.2-6, the parameters were very stable (except for the predictable effects of BVL, load, and/or attitude changes - see discussion below). Over many orbits, there is no tendency toward the stability trends discussed above. On this basis it was concluded that the battery was consistently fully recharged. The correlation among flight data, prediction, and pre-flight tests will be discussed below in this report.

* NOTE: The characteristic relationship of stability of these parameters with sufficient battery recharge and instability with insufficient recharge had been demonstrated and verified in pre-flight subsystem tests.

Effects of Changes in BVL, Load, Attitude

Twice during the early orbital life of the spacecraft, the BVL was deliberately lowered by command. In both cases it was done because end-of-light adhydrode voltages showed that the battery was receiving a higher degree of overcharge than was necessary. In neither case was there any immediate danger to battery operation, but it was felt that a reduced amount of overcharge would be more conducive to battery longevity.

Prior to launch, the BVL had been pre-set to level 4 (nominal) as the optimum level for safe battery recharge considering the uncertainly range in Solar Array performance predictions. Pre-flight battery and subsystem tests had demonstrated that an end-of-light adhydrode voltage of 300 mV, if stable from orbit to orbit, was indicative of full recharge, and also that values well above 300 mV - indicative of a high degree of overcharge - could be expected if Solar Array performance should be substantially above the worst-case minimum performance prediction.



BATTERY END-OF-CHARGE PERFORMANCE

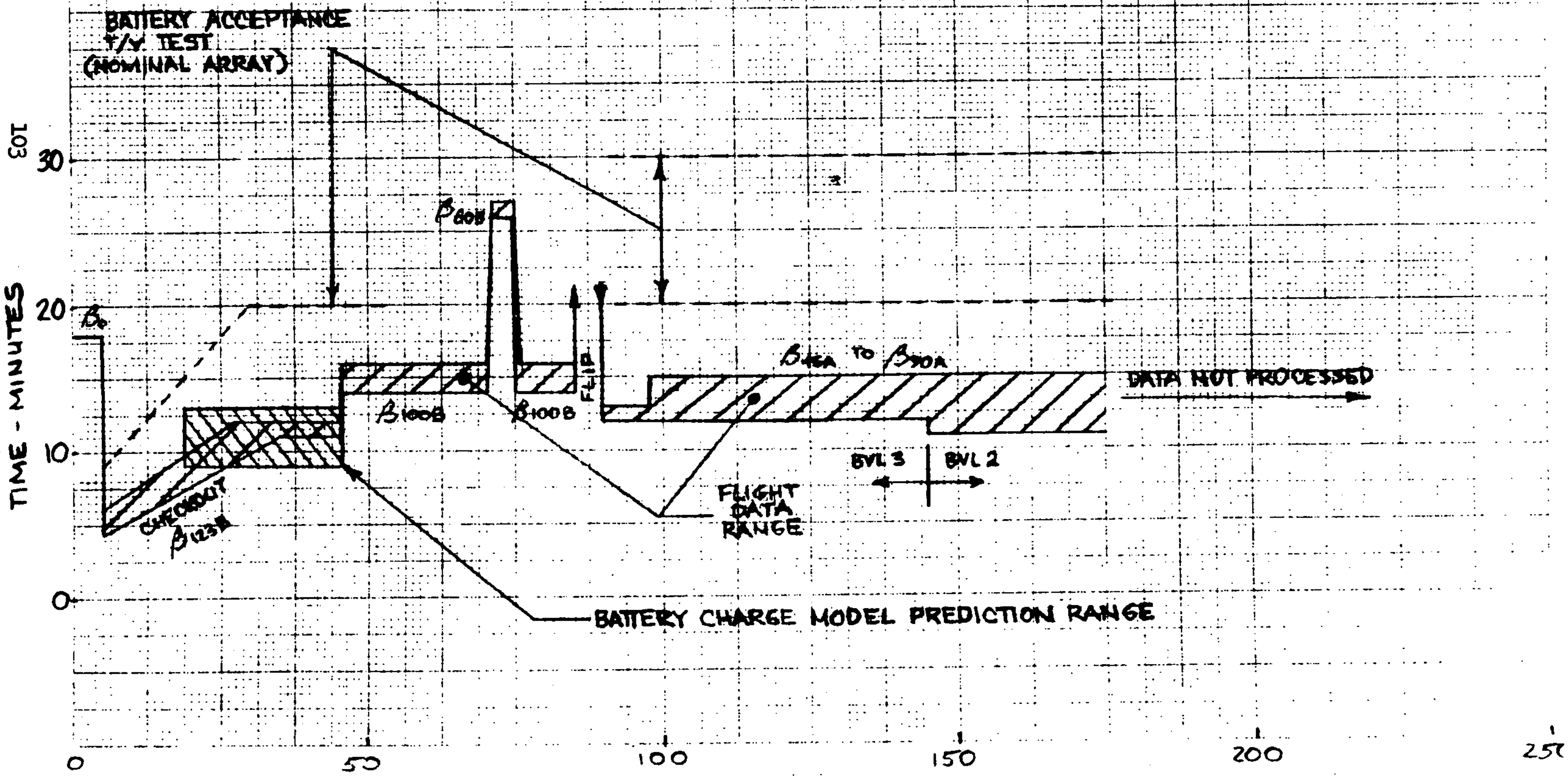
ORBITAL TREND PLOT OF ADHYDRODE SIGNAL AND OVERCHARGE CURRENT, MEASURED AT END-OF-LIGHT

FIGURE 12-5

BATTERY SHUNT-CHARGE PERFORMANCE

ORBITAL TREND-PLOT OF DURATION OF SHUNT-CHARGE PERIOD

FIGURE 4.2-6



During the first five orbits after launch, it was observed that:

a. Overall subsystem performance was good;

b. Solar array performance was within predicted limits and well above the worst-case minimum prediction;

c. End-of-light adhydrode voltages were consistently in the range of 400-460 mV, verifying the high degree of overcharge expected from b..

Based on the above observations, and the decision to reduce the amount of battery overcharge, the BVL was commanded from level 4 to level 3. The command was executed properly and, as expected, had the following effects (see Figure 4.2-5):

a. Adhydrode voltages decreased by 20-40 mV,

b. Battery overcharge currents decreased to 0.6-1.0 A.

Vehicle loads were gradually increased during the checkout period and into Coarse Pointing and Experimenting, with resultant increased battery depth-of-discharge and reduced charge current availability. As expected, the following effects were observed (see Figures 4.2-2, 4.2-5 and 4.2-6):

a. Further decrease of end-of-light adhydrode voltages into the range of 320-430 mV;

b. Slightly higher overcharge currents (still stable over many orbits) in the range of 0.7-1.0 A;

c. Increased shunt-charge duration to the range of 11-16 minutes (stable, except for the few orbits at 80 B-side with its poor solar array attitude);

d. Decreased end-of-dark battery voltages in the range of 26.0-26.5V.

In addition (see Figure 4.1-2), battery temperature decreased as predicted during this period to a stable level of approximately 55°F. As shown in Figures 4.2-2, 4.2-5 and 4.2-6, the flight data corresponded well with pre-flight predictions.

Observation of end-of-light adhydrode voltages through orbit 145 indicated that the batteries were still being overcharged more than was necessary, and the BVL was therefore commanded from level 3 to level 2. As expected, the following effects were observed (see Figures 4.2-5 and 4.2-2):

a. end-of-light adhydrode voltages decreased into the range of 305-390 mV;

b. overcharge currents decreased into the range of 0.6-0.9 A;

c. battery temperature decreased to approximately 50°F.

Continued monitoring demonstrated stability over many orbits and verified optimization of subsystem performance.

Comparison with Predictions

Subsystem and component performance correlated very well with pre-flight predictions and tests, as shown in the figures throughout the previous sections of this report. The flight battery T/V test, which was the final and most representative pre-flight demonstration of subsystem performance, has been emphasized in the comparisons of Figures 4.2-5, 4.2-2, and 4.2-6. It must be especially noted that the obvious differences in performance of adhydrode signals, overcharge currents, and shunt-charge duration are entirely explicable and anticipated, in that the T/V test was conducted with simulation of nominal solar Array performance, while actual flight performance was above nominal.

4.3 FLIGHT SUMMARY - FIRST 15,000 ORBITS

The battery assemblies aboard the OAO-2 spacecraft (S/N 25A and 26A) have successfully delivered power to the vehicle for over three years so far, with no indications of major degradation. Battery end-of-light currents, end-of-dark voltages and charge time in shunt (unregulated) mode have changed little since orbit #2000. No thermal problems have been encountered although there has been some indicated rise in end-of-light battery temperatures recently. Operation has been largely confined to low recharges (BVL 2 or 3) to minimize overcharging the cells and, thus, to lengthen useful life.[12]

Table 4.3-1 gives the summary statistics for representative orbits at a 90° beta angle orientation, 65 minute charge time and BVLS 3 for orbits 2,143 through 15,126. Temperatures varied between 45-55°F, consistent with acceptance test data. End-of-light charging currents remained uniform at about 0.7-0.9 amps. End-of-dark voltages ranged between 25.6-26.5 volts, slightly lower than early orbital data indicated. However, the voltages appear uniform and any differences appear to be correlated to temperature which causes the charging voltage limit (BVL) to shift accordingly (see Figure 4.3-1, top and middle curves). The time in unregulated

SUMMARY STATISTICS - OAO-2 FLIGHT DATA

BVLS 3 $\beta = 90^\circ$ 65% Suntime 101 Minute Orbit

ORBIT #	TIME TO REG. ON	END OF LITE CURRENT	END OF DARK VOLTAGE	TEMPERATURE
2, 143	17 min.	0.8A	26.26-26.32 V	50.3°-54.6°F
3, 676	23 min.	0.8A	25.93 V	46.6°-50.9°F
4, 922	21 min.	0.8A	25.86-25.99 V	45.4°-50.3°F
6, 402	20 min.	0.7A	25.86-25.93 V	46.0°-50.9°F
6, 781	20 min.	0.7A-0.8A	25.66-25.80 V	49.0°-53.4°F
7, 579	26 min.	0.7A	25.86-25.93 V	42.4°-47.8°F
8, 814	21 min.	0.6A-0.7A	25.93 V	44.8°-50.3°F
9, 266	21 min.	0.6A-0.7A	25.53 V	45.4°-50.9°F
11, 625	21 min.	0.6A-0.7A	25.80-25.86 V	47.2°-52.7°F
12, 741	26 min.	0.6A-0.9A	25.80 V	46.0°-51.5°F
12, 745	27 min.	0.7A-0.9A	25.60-25.86 V	45.4°-50.9°F
15, 126	20 min.	0.7A-0.9A	26.32-26.45 V	51.5°-56.5°F

BVLS 2 $\beta = 90^\circ$ 65% Suntime 101 Minute Orbit

ORBIT #	TIME TO REG. ON	END OF LITE CURRENT	END OF DARK VOLTAGE	TEMPERATURE
259	14 min.	0.7A-0.8A	25.93-26.06 V	49.7°-52.1°F
6, 377	25 min.	0.6A	25.73-25.80 V	43.0°-48.4°F
14, 427	27 min.	0.6A-0.8A	26.06-26.12 V	46.0°-52.1°F

NOTE: Telemetry data (battery voltages and currents) accurate to ±2%

TABLE 4.3-1

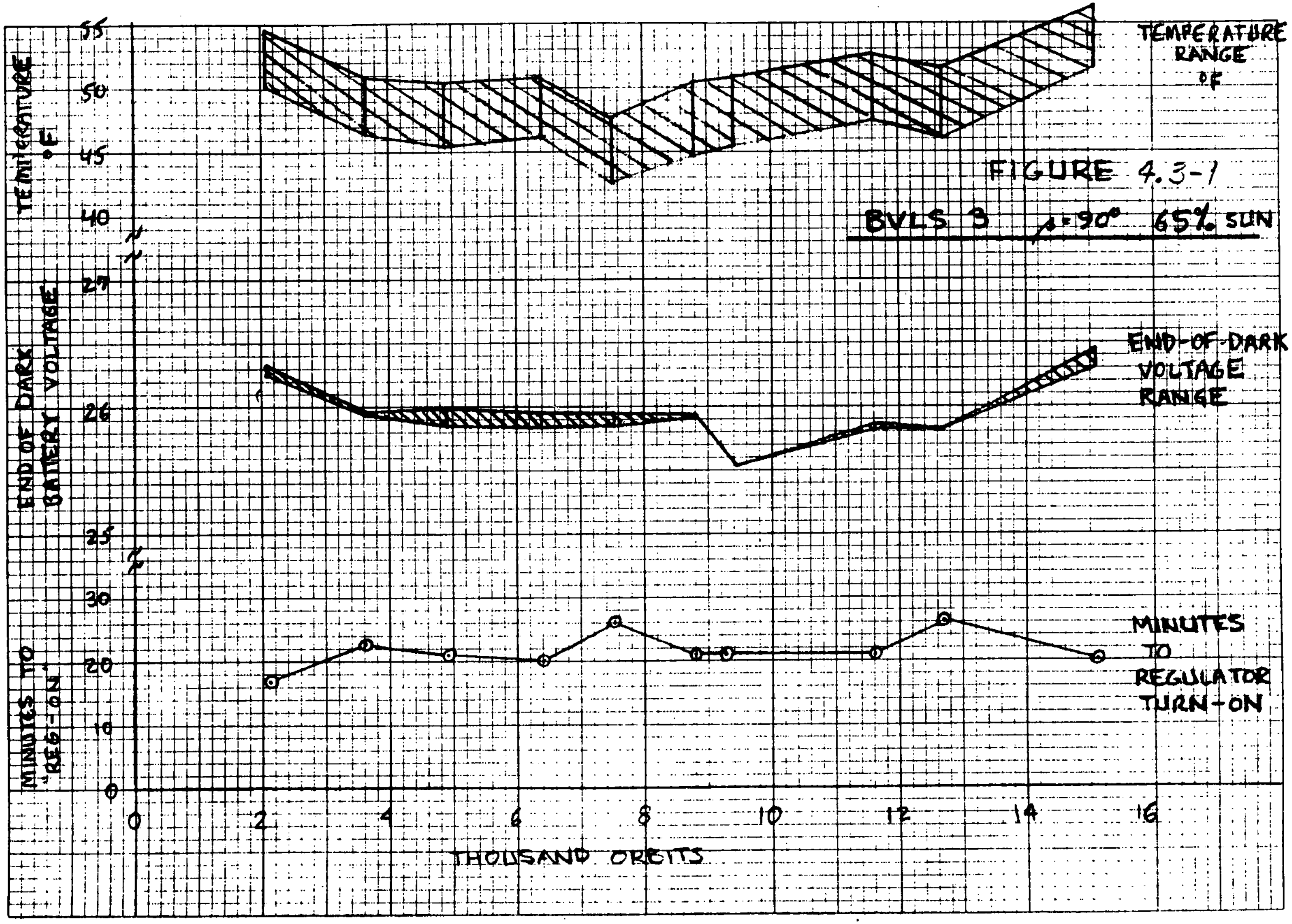


FIGURE 4.3-1

BVLS 3 β=90° 65% SUN

(shunt) charge mode held steady at 20-27 minutes, this value being somehwat higher than early flight data but close to the T/V test data (see Figure 4.2-6). Early data (orbits 0 to 3000) showed lower duration snunt charges of 10-20 minutes. Over 3000 orbits the time to regulator turn-on has been consistently staying about 20-27 minutes. Equivalent data at BVLS 2 are shown in the lower tabulation of Table 4.3-1. Again the time to regulator turn-on shows a significant increase over early orbital data. End-of-light charge currents and end-of-dark battery voltages remained consistent throughout. Table 4.3-2 shows a summary of orbital characteristics for BVLS 2 and 3 at 30 days and after three years of flight. As can be seen, the only appreciable change is in the time to regulator turn-on. All other parameters indicate little or no battery degradation.

No data is available on percent return for each orbit. However, the parameters studied are indicative of a battery receiving a full charge with each orbit. Figures 4.3-2 and 4.3-3 show the number of ampere minutes being put into the battery during the unregulated (shunt) charge portion. An average value of 120 A-min. (2 A-hr.) appears to be returned at BLVS 2 and slightly lower values for BVLS 3.

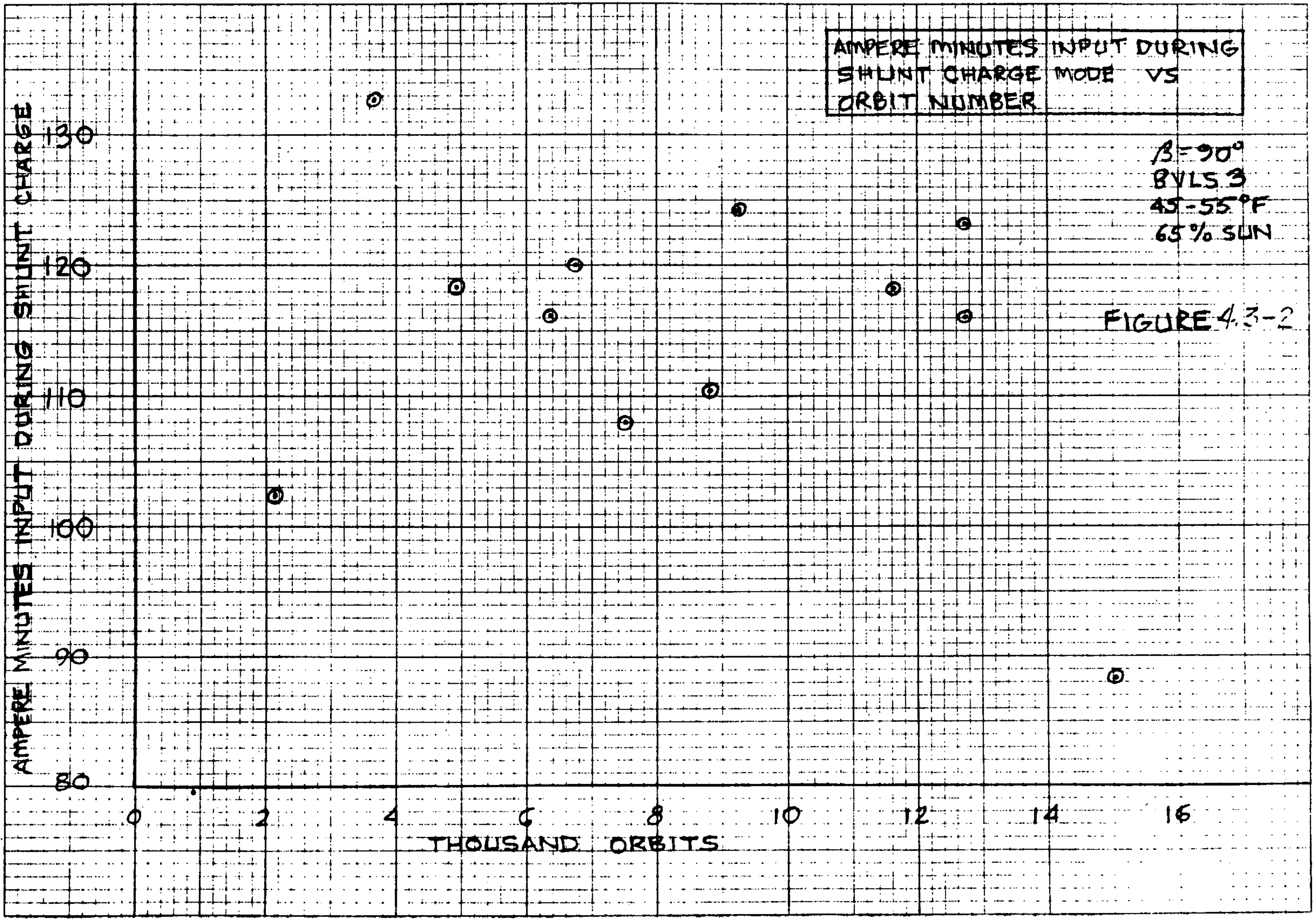
The plot of battery voltage as a function of orbital time is given in Figures 4.3-4 and 4.3-5. The curves show good consistency between early and recent orbits except for differences in shunt charge time. The uniformity in battery charging response is seen clearly in Table 4.3-3 where the average battery voltage during the first fifteen minutes on charge is given for orbits 2,143 through 15,126.

OAO-2 FLIGHT BATTERY PERFORMANCE

Comparison of Recent (3 year) and Initial (30 day) Data

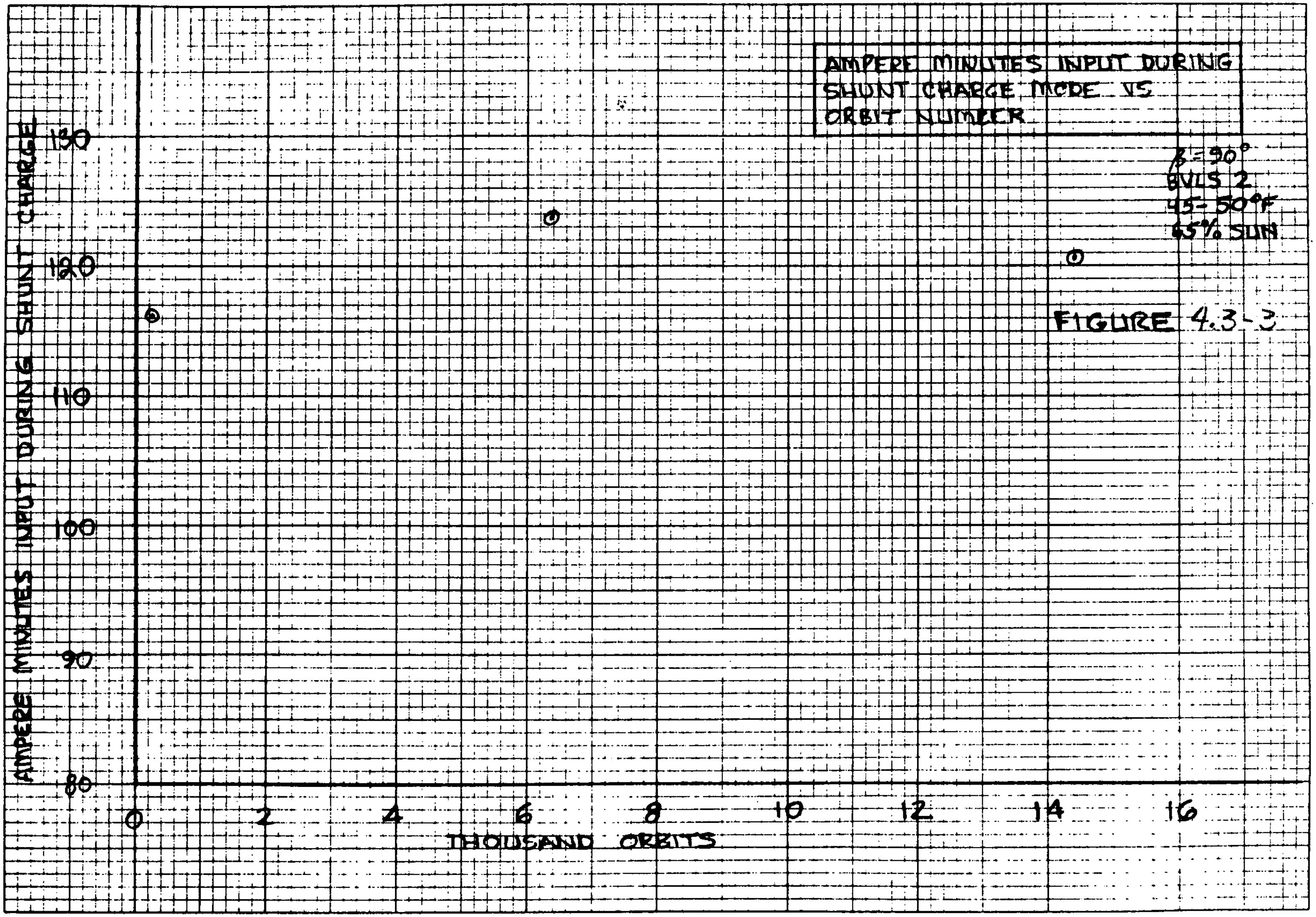
	30 Day Data	3 Year Data
BVLS Level	3	3
Orbit Number	100-150	15, 126
Beta Angle	90°	90°
% Sun	65%	68%
Total Orbit Time	101 min.	101 min.
Battery Temperature	$55^{\circ}F$	$51.5^{\circ}-56.5^{\circ}F$
End-of-Dark Battery Voltage	26.0-26.5 V	26.32-26.45 V
End-of-Light Battery Current	0.7A-1.0A	0.7A-0.9A
Time in Shunt Mode	12-15 min.	20 min.
BVLS Level	2	2
Orbit Number	175-200	14, 427
Beta Angle	90°	90°
% Sun	65%	65%
Total Orbit Time	101 min.	101 min.
Battery Temperature	$55^{\circ}F$	$46.0^{\circ}-52.1^{\circ}F$
End-of-Dark Battery Voltage	26.0-26.5 V	26.06-26.12 V
End-of-Light Battery Current	0.6A-0.9A	0.6A-0.8A
Time in Shunt Mode	11-15 min.	27 min.

TABLE 4.3-2



AMPERE MINUTES INPUT DURING SHUNT CHARGE MODE VS ORBIT NUMBER

FIGURE 4.3-2



AMPERE MINUTES INPUT DURING
SHUNT CHARGE MODE VS
ORBIT NUMBER

FIGURE 4.3-3

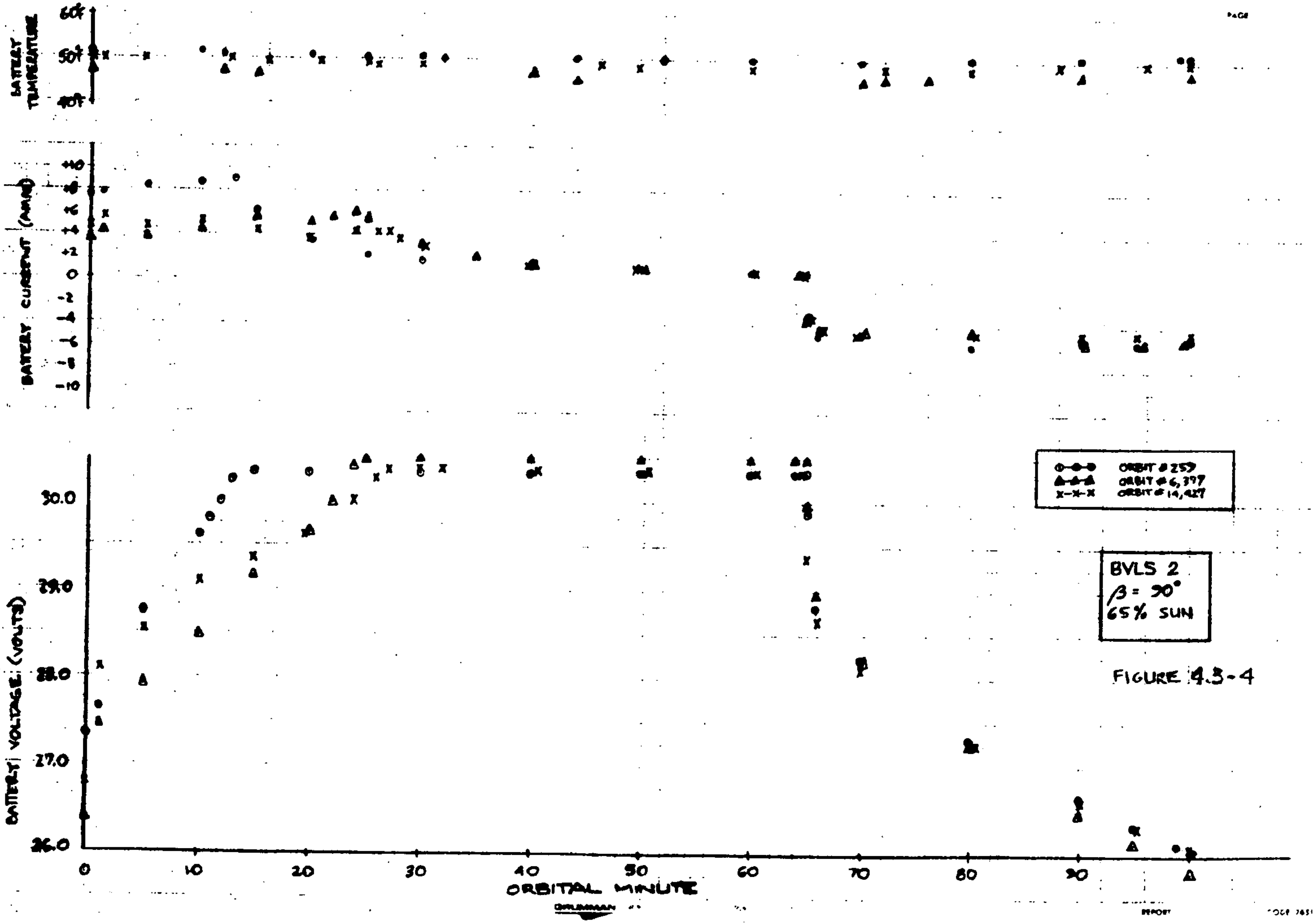

BATTERY TEMPERATURE
60F
50F
40F
BATTERY CURRENT (AMPS)
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
BATTERY VOLTAGE (VOLTS)
30.0
29.0
28.0
27.0
26.0
0
10
20
30
40
50
60
70
80
90
ORBITAL MINUTE
ORBIT # 253
ORBIT # 6,397
ORBIT # 14,427
BVLS 2
β = 90°
65% SUN

FIGURE 4.3-4

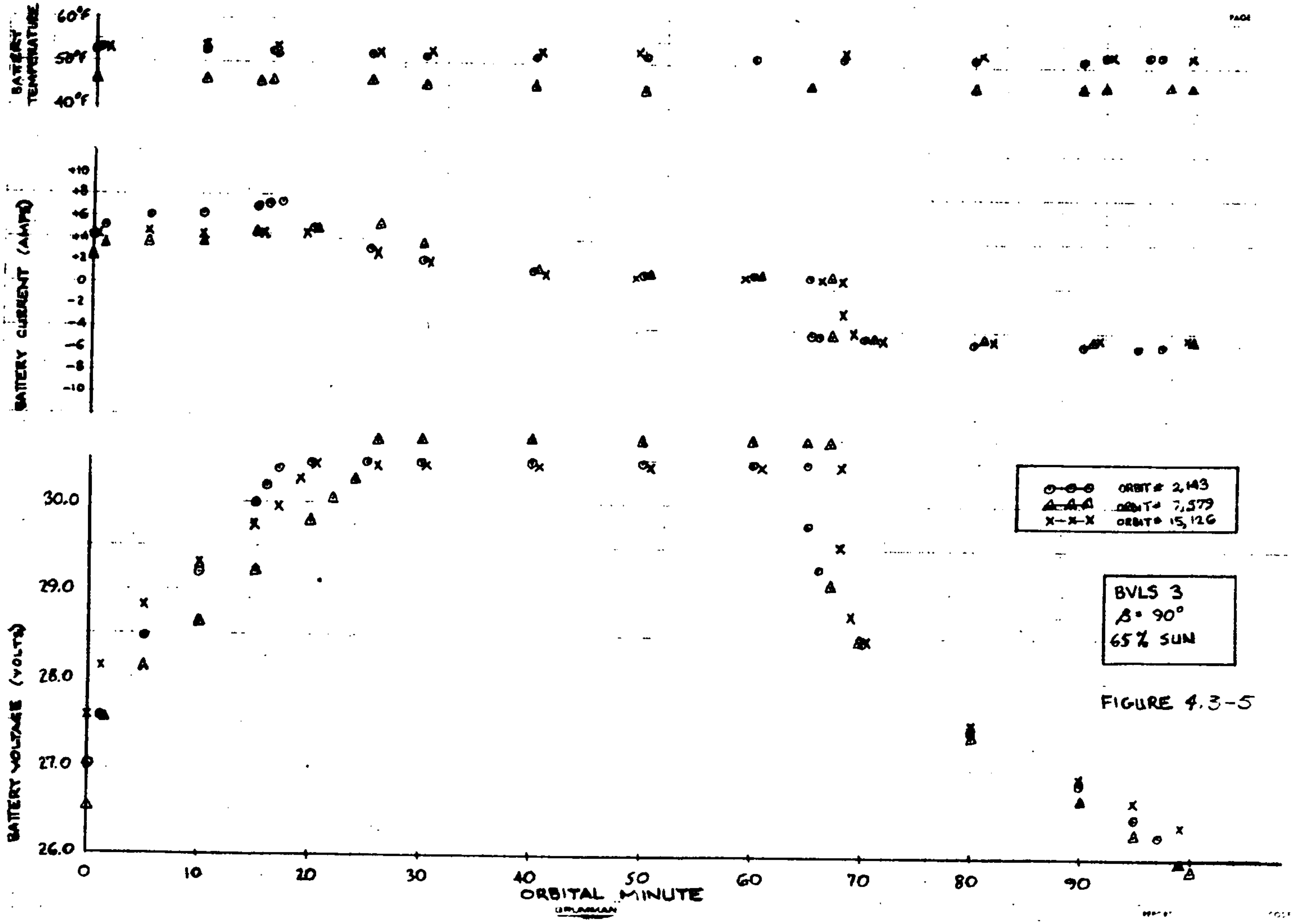

BATTERY TEMPERATURE
60°F
50°F
40°F
BATTERY CURRENT (AMPS)
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
BATTERY VOLTAGE (VOLTS)
30.0
29.0
28.0
27.0
26.0
0
10
20
30
40
50
60
70
80
90
ORBITAL MINUTE
GRUMMAN
⊖-⊖-⊖ ORBIT # 2,143
Δ-Δ-Δ ORBIT # 7,579
X-X-X ORBIT # 15,126
BVLS 3
β = 90°
65% SUN

FIGURE 4.3-5

BATTERY AVERAGE VOLTAGE DURING START OF LIGHT (S.O.L) FOR FIRST FIFTEEN MINUTES OF CHARGE

Orbit #	Avg. Temp.	Start of Light (S.O.L)	S.O.L. + 3 Min.	S.O.L + 6 Min.	S.O.L. + 15 Min.
2,143	53°F	27.50	28.12	28.62	29.98
3,676	49°F	27.18	28.03	28.34	29.54
4,922	48°F	27.24	27.70	28.03	29.50
6,402	49°F	27.18	27.90	28.47	29.61
7,579	46°F	27.11	27.90	28.16	29.17
8,814	48°F	27.20	28.20	28.58	29.67
9,266	49°F	27.18	27.95	28.36	29.59
11,625	51°F	27.35	28.08	28.56	29.48
12,741	49°F	27.18	27.80	28.20	29.12
15,126	54°F	27.60	28.60	28.85	29.76

NOTE:

1. All data at BVLS 3, $\beta = 90^{\circ}$, 65% suntime
2. Telemetry data accurate to ±2% (battery woltages and currents)

TABLE 4.3-3

SECTION 5.0

SPECIAL CELL TESTS

5.1 SUMMARY OF TEST REGIME FOR PACK 23B

- No. of series connected cells in pack: 10
- Cells from OAO battery S/N 34, 35 spare lot
- Cell serial nos.:

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1494	1517	1546	1588	1591	1499	1537	1587	1589	1590

- On test at:

  NAD, Crane ⊗ Goddard Space Flight Center ○

- Depth of discharge: 15%
- Temperature: 10°C
- Cycle Period: 90 minutes
- Charge Rate: 8 amp
- Discharge Rate: 6 amp
- Date Test Began: 1/26/71
- Type of Charge Control: BVLS 4 with periodic switches to BVLS 8 and BVLS 1 for 100 cycle periods.

TEST DETAILS -

- This pack received a controlled precharge (3.5 A-hr.) based on gas measuring techniques.
- Periodic capacity discharges on two cells at a time are made every 88 days.
- Cell S/N 1494 failed at 7800 cycles.

PACK 23B

5.1.1 Pack Description and Test Regime

Pack 23B consists of two 5-cell groups of series-connected cells from OAO battery S/N 34, 35 assembly. These cells received a modified Gulton precharge adjustment wherein the gas generated during the precharge operation was collected and recorded. The cells from group A were charged with their vent valves closed, being opened to evacuate the accumulated oxygen only when a pre-determined pressure had built up in the cells. The group B cells were charged with their valves opened and the gas which evolved was collected into the gas-measuring apparatus described in Figure 2.1.2-2. Both groups had the precharge terminated when each cell received an equivalent 3.5 A-hr. of precharge. Following the precharge and routine electrical characterization cycles at the seller facility, the cells were sent to NAD, Crane for additional testing in January 1971.

Upon arrival at Crane the cells first received a C/20, 48-hour conditioning cycle (see Figure 5.1.1-1). From 1/26/71 to 2/4/71 they underwent various tests including capacity checks, low temperature overcharges (0°C) and open-circuit recovery tests. On 2/4/71 the pack was placed on 10°C life cycling, the 100-minute cycle consisting of an 8.0 amp charge to 1.457 volts/cell (BVLS 4) followed by a 6.0 amp, 15% depth discharge. Every twelve-hundred cycles a capacity check is performed on two cells. Prior to the capacity check the pack receives a significant overcharge by charging to a higher voltage limit (1.505 volts/cell or BVLS 8) for 100 cycles, followed by a reduced charge to 1.420 volts/cell (BVLS 1) for an additional hundred cycles. Finally the pack is returned to BVLS 4 for another hundred cycles after which the capacity check is run.

Since only two cells at a time receive a capacity check (to +0.5 volts), the remaining cells in the pack will continue to accumulate additional cycles, uninterrupted by a low discharge. It has been demonstrated (see "Summary of Test Results on Spare Nickel-Cadmium Cells from OAO-2 Flight Batteries," in Appendix E) that cells which accumulate large numbers of uninterrupted cycles without a low discharge (below 1.00 volts) show a "double-plateau" voltage profile on discharge. The higher, stable plateau occurs in the vicinity of 1.18-1.19 volts while a second, lower, plateau occurs at an average level of approximately 1.05 volts. By staggering the capacity checks on pack 23B by two cells every 1200 cycles, a family of curves is generated showing the discharge voltage profile at 1200 cycle intervals. Thus the rate at which the double-plateau inflection point moves along the x-axis can be defined as a function of cycle life. As of completion of this report, four cells have received capacity checks. Cells C1 and C2 received a check after 3,900 cycles and cells C5 and C6 received a capacity check after 5,600 cycles. Cells C7 and C8 also received capacity checks at around 5,600 cycles during a special test on these two cells in February, 1972. Full details of this test are given herein.

5.1.2 Test Results

A summary of the test events for pack 23B is shown in Table 5.1.2-1. Initial capacity to +0.5 volts is given in Table 5.1.2-2. During the first two taper charges* on 1/30/71, high pressures developed during the 5 amp charge and the taper charges had to be terminated prematurely (see Figure 5.1.2-1). The cells hit a maximum voltage about 20 minutes into the C/4 charge. Cell voltage thereafter steadily decreased, showing overcharge, and charge was terminated due to the high pressure after about 1 hour, 10 minutes at C/4. After each taper charge the pack was discharged at C/2 until the first cell reached +0.500 volts. In each case the pressures dropped to zero or a vacuum resulted. On the third taper charge, cells C9 and C10 reached the limiting voltage after 18 minutes at C/4. The rate was then changed to 1.6 amps for five hours and the end-of-charge pressures ranged from +19 to +36 psig. The pack was overcharged at 0°C on 2/2/71; a profile of the charge voltage is shown in Figures 5.1.2-2 and 5.1.2-3. Pressures at the end of the overcharge ranged from a low of +22 psig for cell C5 to a high of +38 psig for cells C7 and C8. The maximum voltage reached was 1.559 volts on cell C9 after 45 minutes on charge. At that time the voltage spread was about 10 millivolts. Following another capacity discharge, the pack received two 10°C taper charges during which no abnormal voltages or pressures developed.

The pack began active cycling at 10°C to BVLS 4 (voltage limit = 1.457 V/cell) on 2/4/71. Percent recharge throughout the first thousand cycles was about 108%. When the voltage limit was lowered to BVLS 1 (1.420 V/cell) the percent recharge fell to about 102%; when raised to BVLS 8 (1.505 V/cell) the recharge increased to 130-140% (see Figure 5.1.2-4). End-of-charge voltages were very uniform amongst the ten cells; the average divergence was less than 25 mV (see Figure 5.1.2-5).

After 1,509 cycles the entire pack was given a capacity check (6 amp rate until first cell reached +0.500 volts). Cell C8 was the low capacity cell, delivering 22.1 A-hrs. This represents a slight decrease from its initial capacity of 23.8-24.3 A-hr. A plot of its discharge curve is shown in Figure 5.1.2-6. No double plateau is evident from this curve.

After approximately 2700 cycles cell C2 began to show a decrease in end-of-charge voltage. Table 5.1.2-3 shows typical end-of-charge voltages for the BVLS 4 cycling between cycles 2,289 and 5,600. Cell C2 (S/N 1517) remained, on the

* Taper charge is defined as follows: C/2 (10 Amp.) until first cell reaches 1.496V; then C/4 (5 Amp) until first cell reaches 1.496V; then 1.6 Amp for 4 hours.

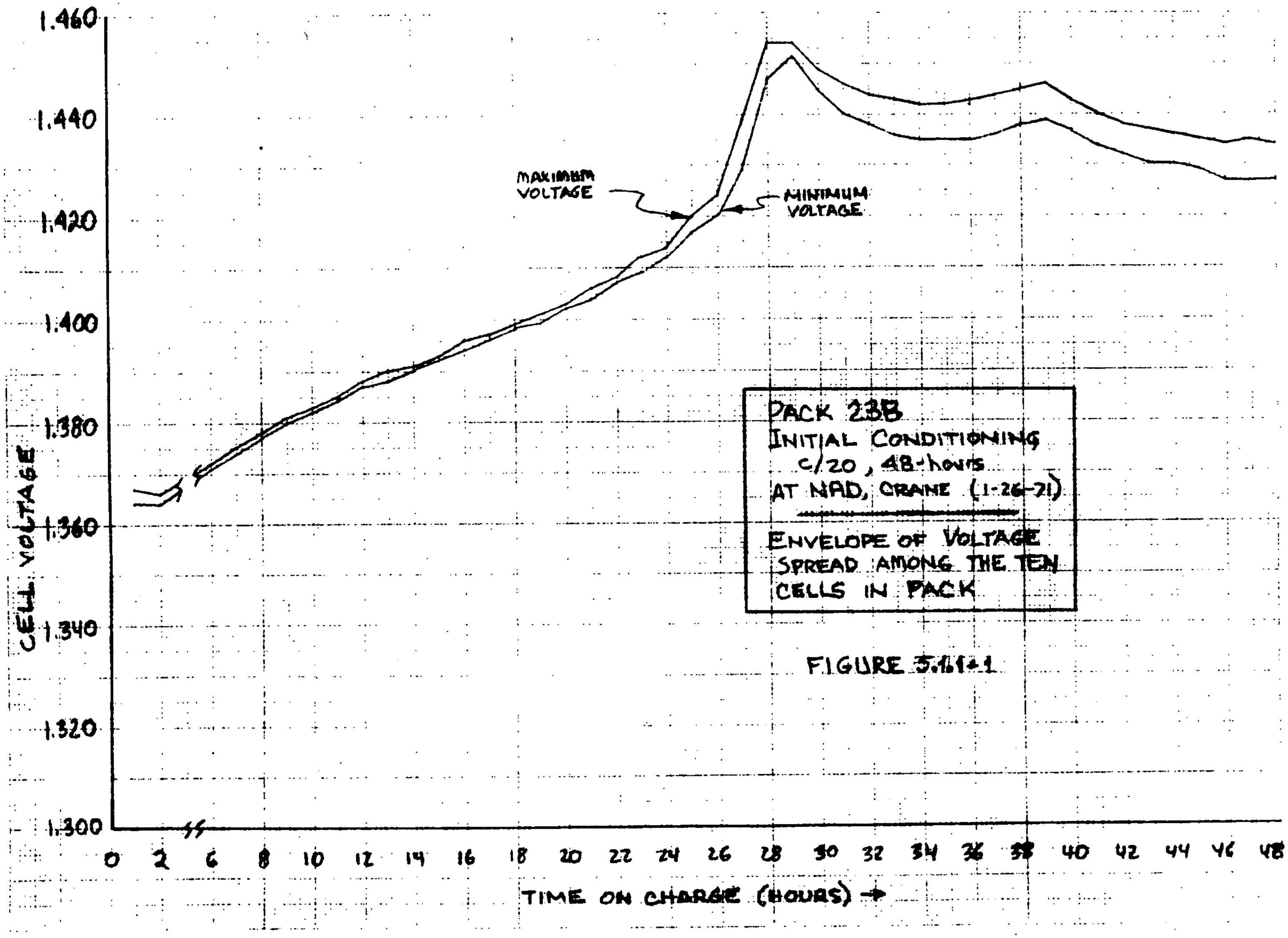

1.460
1.440
1.420
1.400
1.380
1.360
1.340
1.320
1.300
CELL VOLTAGE
0
2
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
TIME ON CHARGE (HOURS) →
MAXIMUM VOLTAGE
MINIMUM VOLTAGE
PACK 23B
INITIAL CONDITIONING
C/20, 48-hours
AT NAD, CRANE (1-26-71)
ENVELOPE OF VOLTAGE SPREAD AMONG THE TEN CELLS IN PACK

FIGURE 5.1.1-1

PACK 23B Log

Date	Event	
1/26/71	Cells received at NAD, Crane	
1/26 to 2/4/71	Initial characterization tests	
2/4/71	Start cycling @ BVLS 4	
2/10/71	Change from BVLS 4 to BVLS 8	NOTE: This type of switching from BVLS 4 to BVLS 8 to BVLS 1 was performed every 100 cycles although it is not shown.
2/17/71	Change from BVLS 8 to BVLS 1	
2/23/71	Change from BVLS 1 to BVLS 4	
5/10/71	Capacity check - entire pack o Discharge entire pack until first cell reaches 0.5 volts o Taper charge entire pack o Resume cycling @ BVLS 4	
10/4/71	Capacity check - C1 and C2 only o Discharge C1 and C2 each to 0.5 volt o Taper charge C1 and C2 o Resume cycling @ BVLS 4	
10/24/71	Overcharge test ($0^{\circ}C$) - entire pack o Discharge 6 amp for 5 min. o Charge 1.0 amp for 5 hours @ $0^{\circ}C$ o Resume cycling @ BVLS 4	
2/1/72	Special test on C7 and C8 (See Table 5.1.2-5)	
2/23/72	Capacity check - C5 and C6 only o Discharge C5 and C6 each to 0.5 volt o Taper charge C5 and C6 o Resume cycling	

TABLE 5.1.2-1

CAPACITY DATA - GROUP I

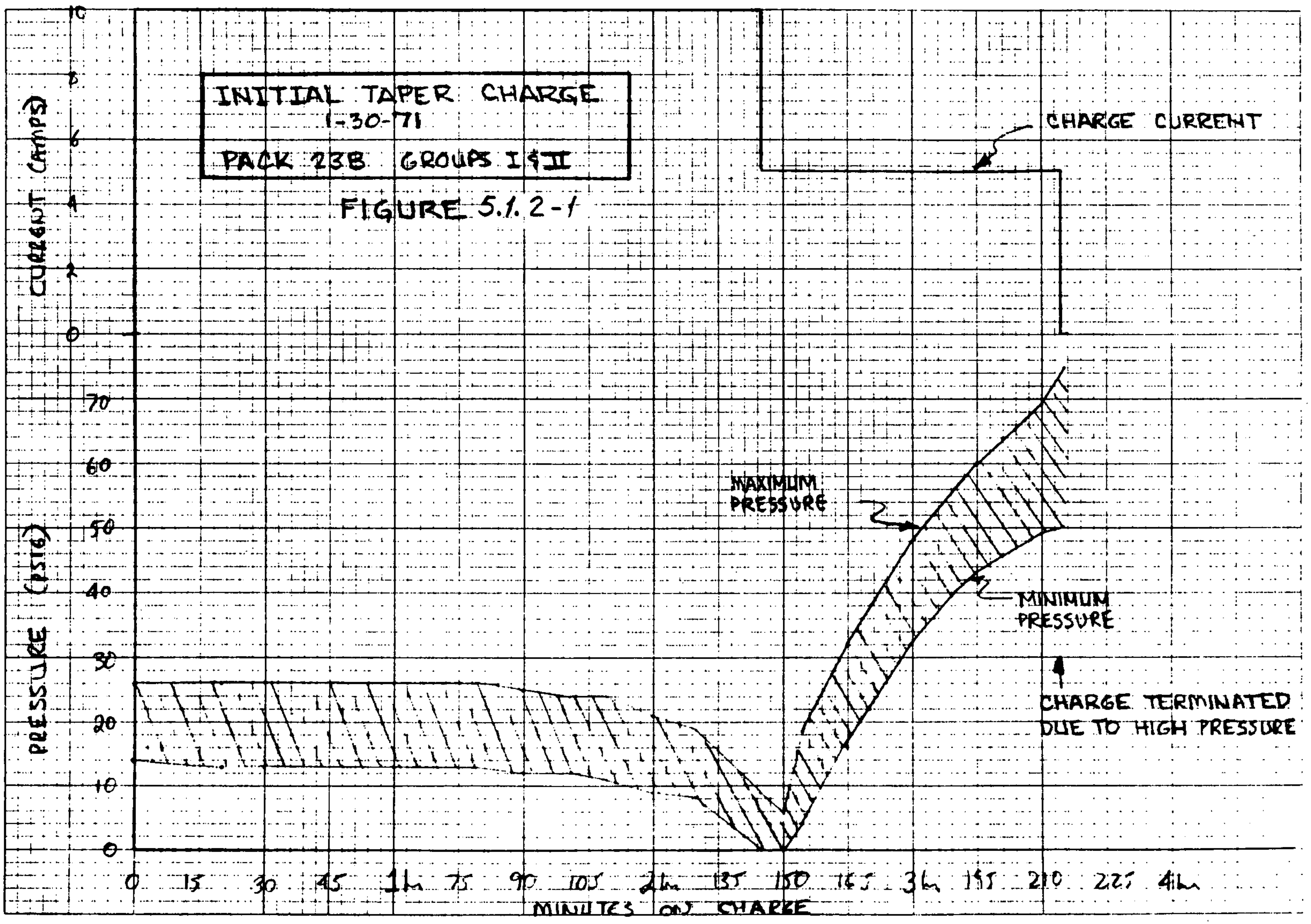
CAPACITY DATA

Test Date	A-hr.$_{In}$. Previous Charge	Type of Previous Chg.	A-hr.$_{Out}$ This Discharge
1/28/71	48 AH	C/20 for 48 hours	23.8, 24.1, 24.3, 24.3, 24.1
1/30/71	28.8, 29.2, 29.5, 29.8, 29.7	C/2 to +20 psig	23.3, 23.6, 23.8, 24.0, 23.8

CAPACITY DATA - GROUP II

Test Date	A-hr.$_{In}$ Previous Charge	Type of Previous Charge	A-hr.$_{Out}$ This Discharge
1/28/71	48 AH	C/20 for 48 hours	24.3, 24.1, 23.8, 24.3, 25.0
1/30/71	29.7, 29.3, 29.0, 29.8, 30.2	C/2 to +20 psig	23.8, 23.6, 23.3, 23.8, 24.3

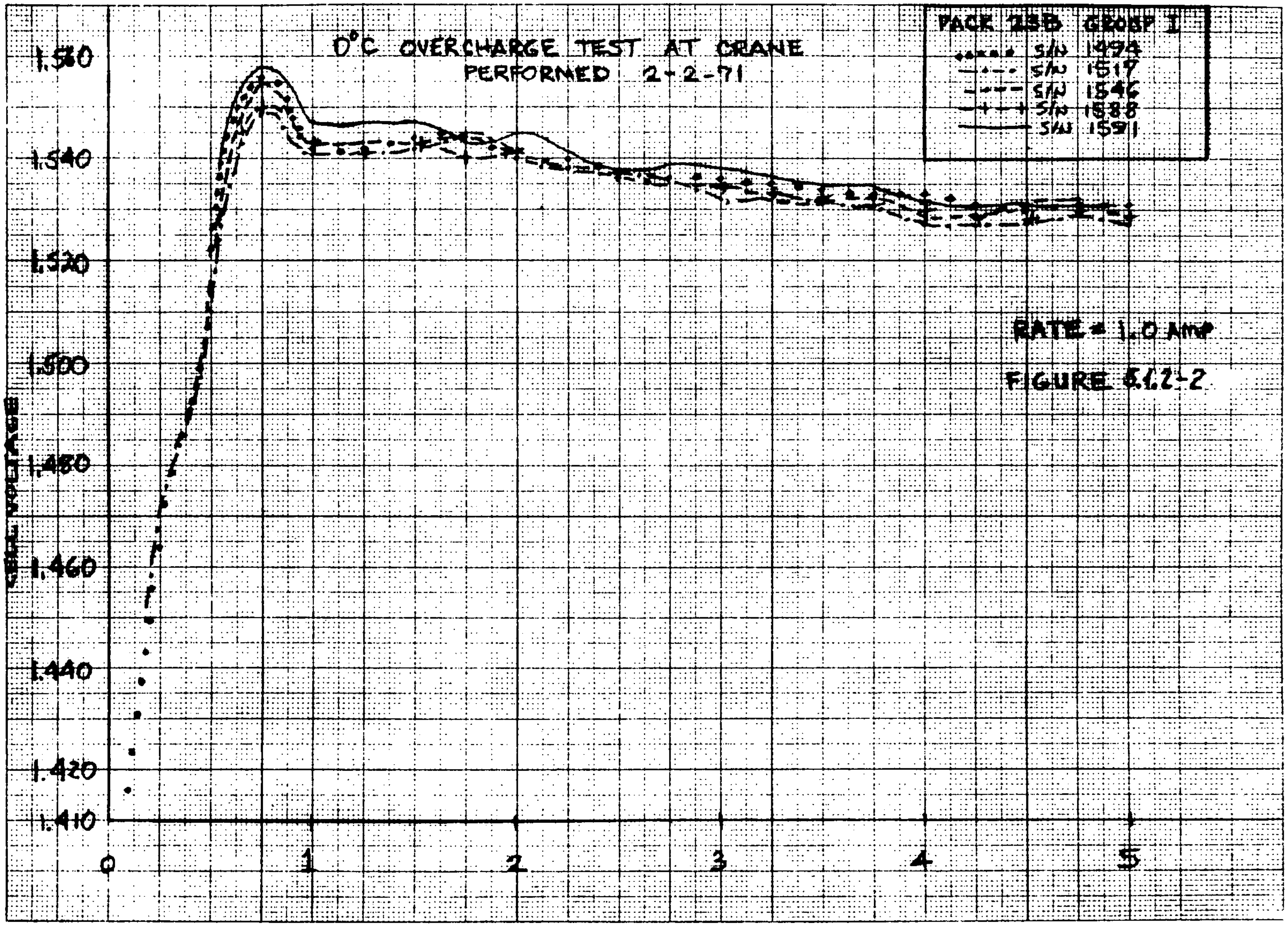
TABLE 5.1.2-2



INITIAL TAPER CHARGE
1-30-71

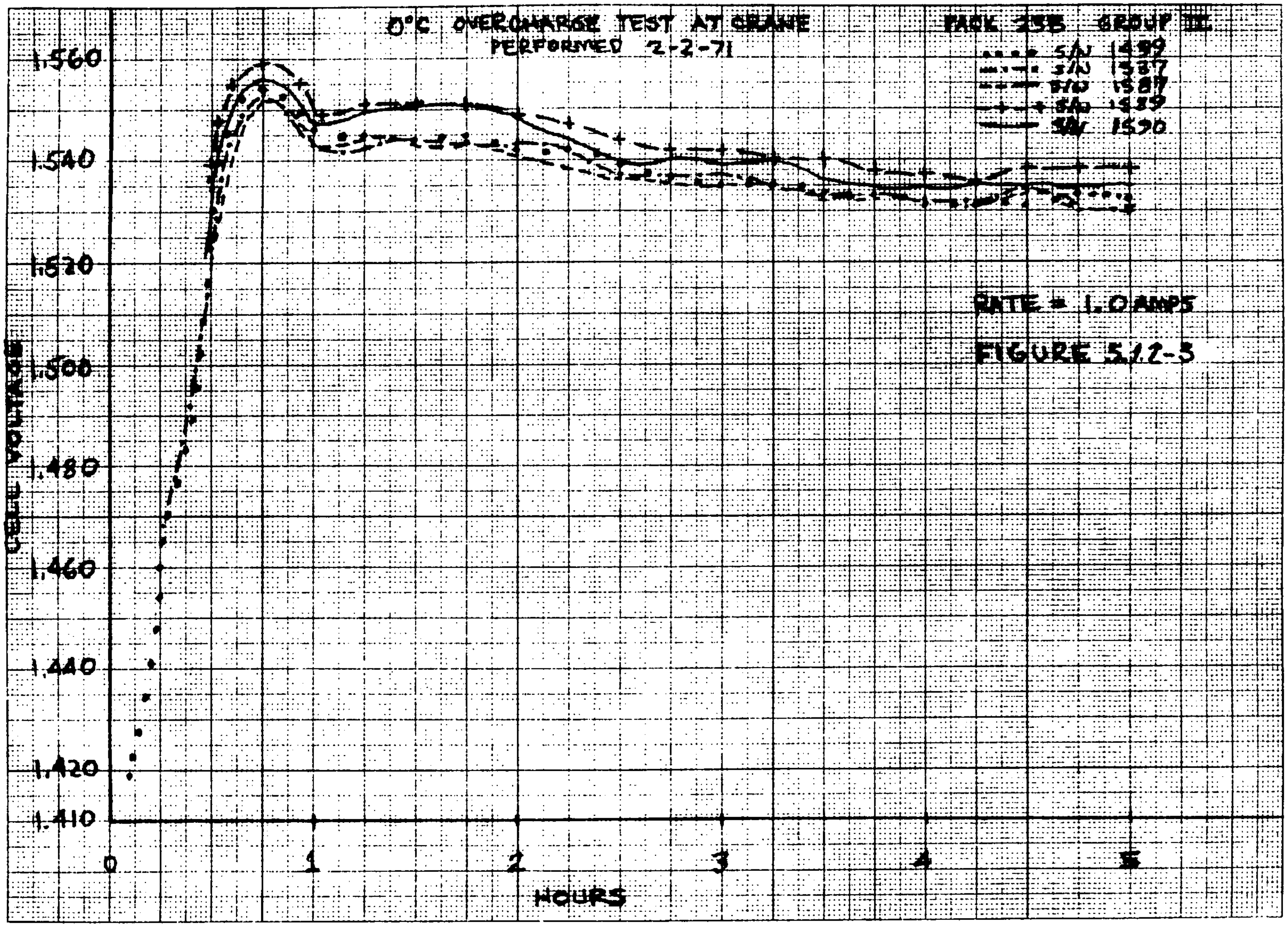
PACK 23B GROUPS I & II

FIGURE 5.1.2-1



0°C OVERCHARGE TEST AT CRANE
PERFORMED 2-2-71

FIGURE 5.1.2-2



0°C OVERCHARGE TEST AT CRANE
PERFORMED 2-2-71

RATE = 1.0 AMPS

FIGURE 5.12-3

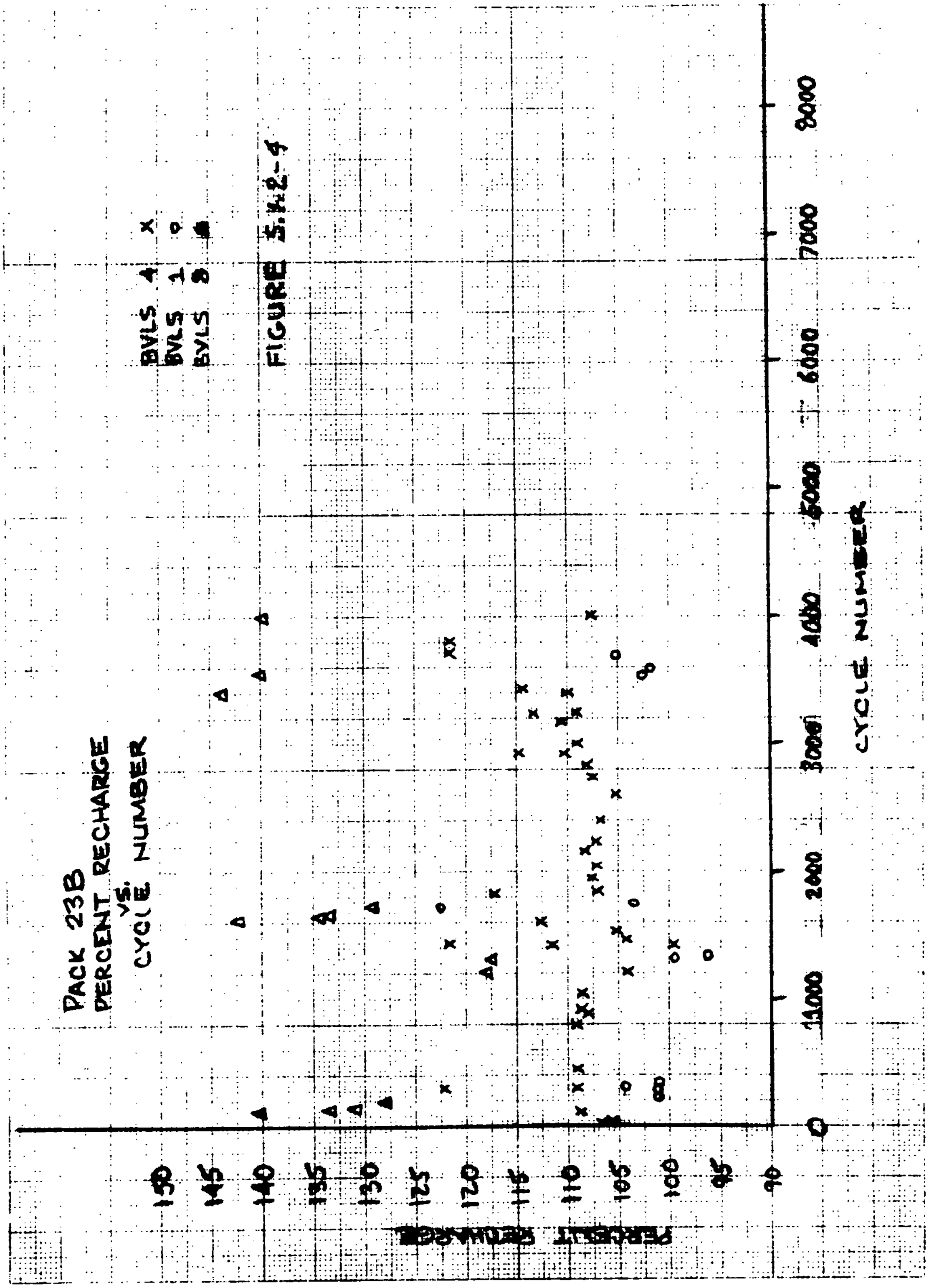
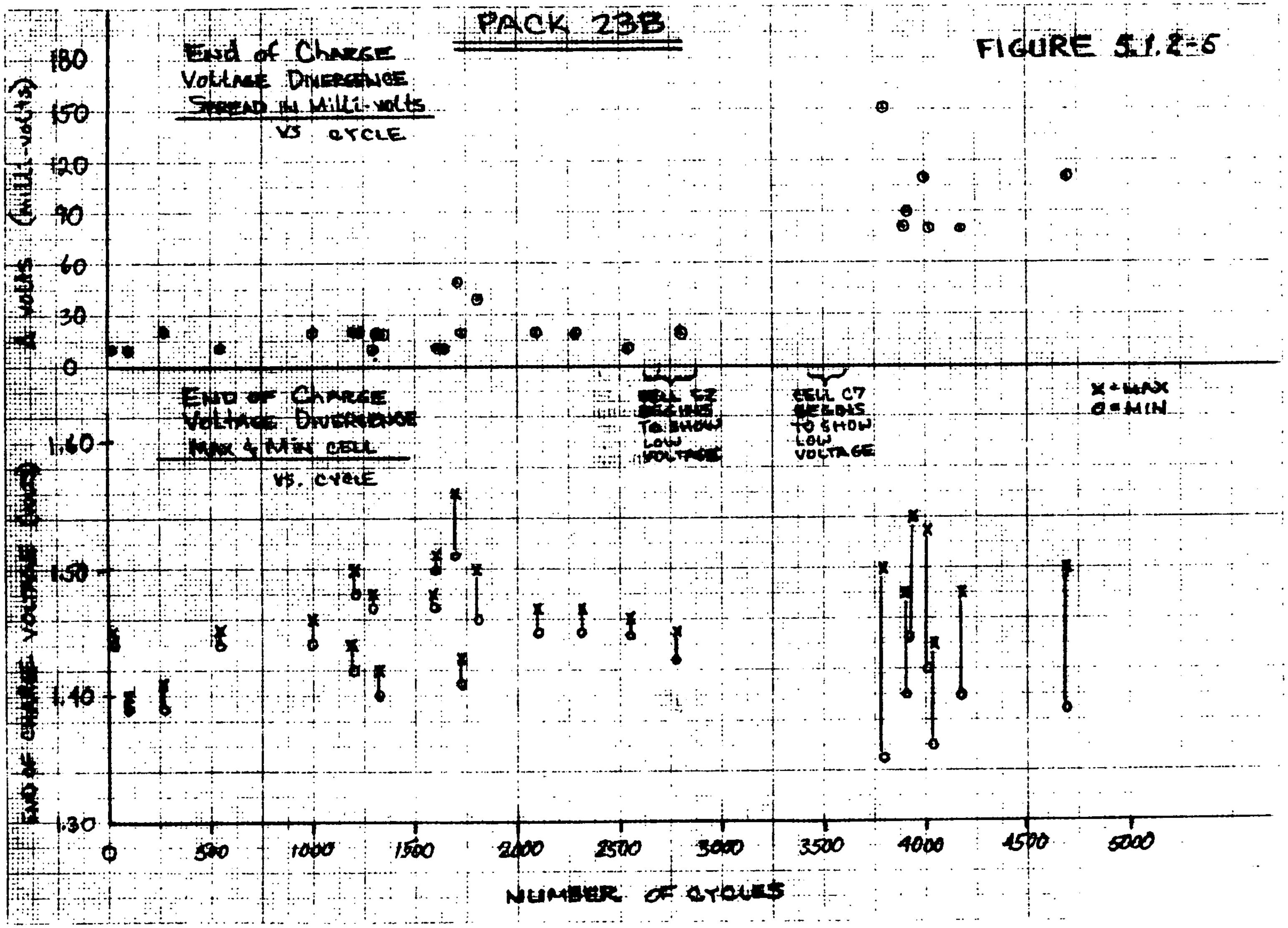
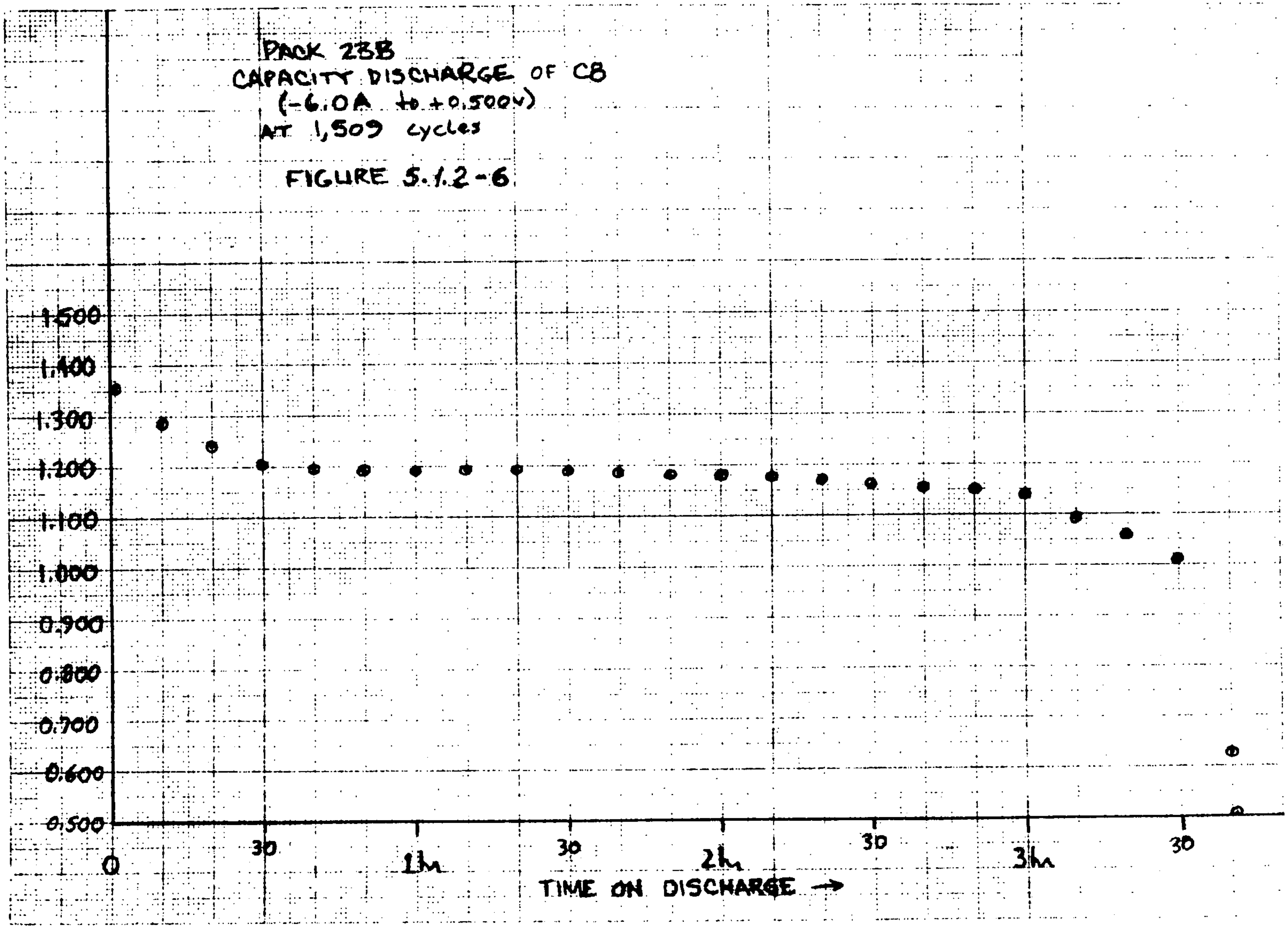

PACK 23B
PERCENT RECHARGE
VS.
CYCLE NUMBER
BVLS 4 x
BVLS 1 o
BVLS 8 ▲
PERCENT RECHARGE
150
145
140
135
130
125
120
115
110
105
100
95
90
0
1000
2000
3000
4000
5000
6000
7000
8000
CYCLE NUMBER

FIGURE 5.1.2-4

PACK 23B
FIGURE 5.1.2-5
End of Charge
Voltage Divergence
Spread in Milli-volts
VS CYCLE
End of Charge
Voltage Divergence
Max & Min Cell
VS. CYCLE
Δ VOLTS (MILLI-VOLTS)
END OF CHARGE VOLTAGE (VOLTS)
180
150
120
90
60
30
0
1.60
1.50
1.40
1.30
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
NUMBER OF CYCLES
CELL C2 BEGINS TO SHOW LOW VOLTAGE
CELL C7 BEGINS TO SHOW LOW VOLTAGE
X = MAX
O = MIN



PACK 23B
CAPACITY DISCHARGE OF C8
(-6.0A to +0.500V)
AT 1,509 cycles

FIGURE 5.1.2-6

TABLE 5.1.2-3

Representative End-Of-Charge Voltages for Cycles 2,289 Through 5,600

Pack 23B BVLS 4 Control

Cycle No.	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
2,289	1.46	1.47	1.46	1.46	1.46	1.45	1.45	1.45	1.45	1.45
2,815	1.45	1.39	1.45	1.45	1.45	1.44	1.45	1.44	1.44	1.43
3,710	1.47	1.40	1.47	1.47	1.46	1.46	1.40	1.46	1.47	1.45
4,171	1.48	1.40	1.48	1.48	1.48	1.47	1.42	1.47	1.48	1.47
4,696	1.49	1.40	1.48	1.49	1.49	1.45	1.39	1.48	1.49	1.48
5,600	1.40	1.41	1.51	1.49	1.51	1.39	1.36	1.50	1.50	1.48

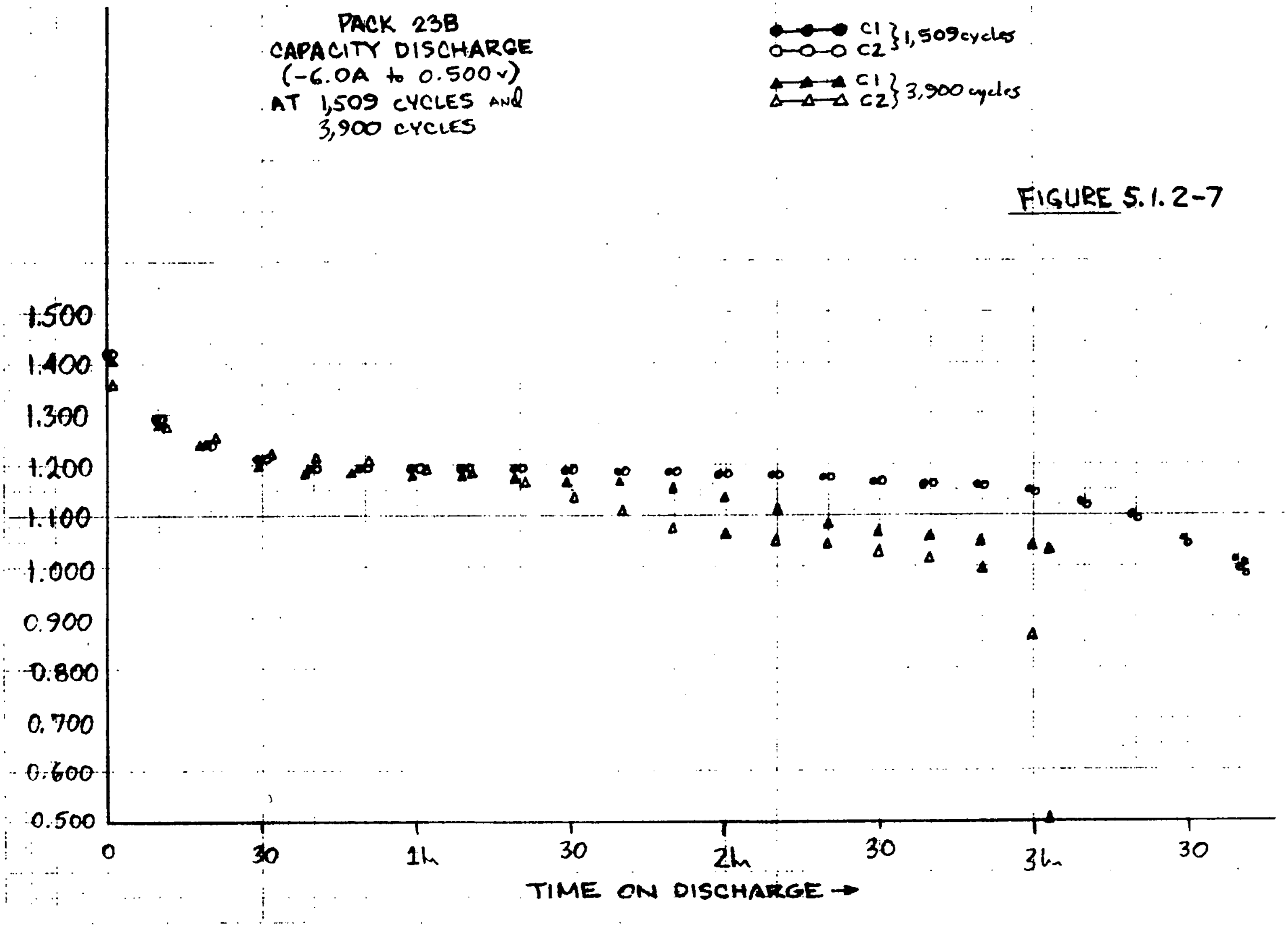

PACK 23B
CAPACITY DISCHARGE
(-6.0A to 0.500v)
AT 1,509 CYCLES AND
3,900 CYCLES
C1 } 1,509 cycles
C2
C1 } 3,900 cycles
C2
1.500
1.400
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0
30
1h
30
2h
30
3h
30
TIME ON DISCHARGE →

FIGURE 5.1.2-7

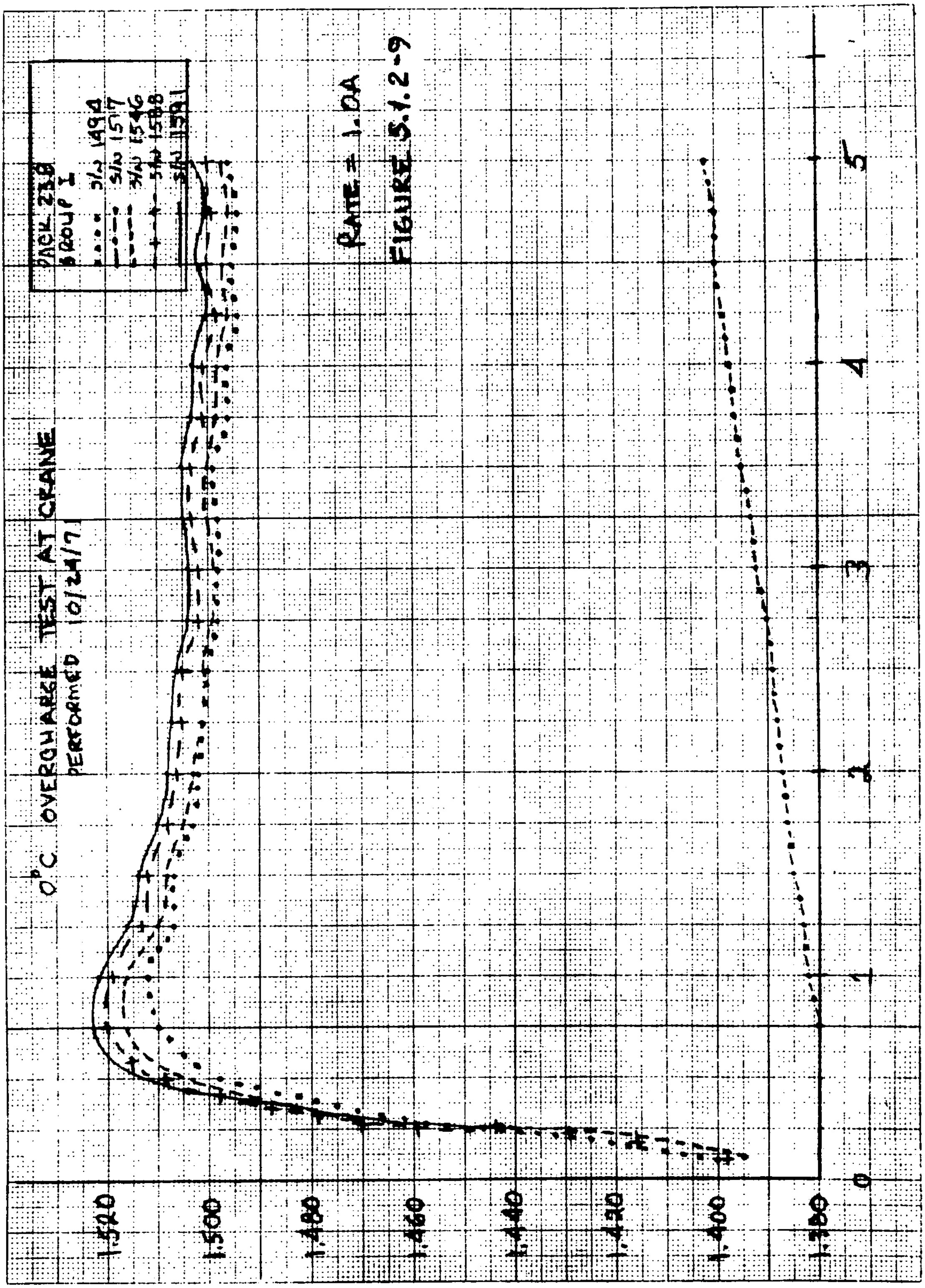
average, about 70 mV lower than the other nine cells in the pack for about 1000 cycles. By cycle 3,710 cell C7 (S/N 1537) had also fallen in end-of-discharge voltage to approximately 60 mV lower than the rest of the pack. Cycling continued and these two cells, C2 and C7, remained consistently lower than the remainder of the pack.

During cycle 3,900 cells C1 and C2 were given a capacity discharge to +0.500 volts while the remainder of the pack continued on cycling. Figure 5.1.2-7 shows the voltage profile of the cells on discharge. Although both C1 and C2 had accumulated an equal number of cycles (3,900) without a low discharge (to +0.500 volts), it is apparent that C2 has a lower second voltage plateau than C1, and it reaches this plateau sooner in the discharge. A comparison of the ampere-hours returned during this discharge with that returned during an earlier cycle (#1,509) is shown in Table 5.1.2-4.

		Ampere-Hour	
Cycle#	Cell No.	Capacity to +1.0 Volts	Capacity to +0.5 Volts
Cycle 1,509	C1	22.1	
	C2	22.0	
Cycle 3,900	C1	19.0	
	C2	16.5	18.3

TABLE 5.1.2-4

It was decided that a low temperature overcharge be given the entire pack to determine how C2 and C7 would behave if they were charged without being tied to a voltage limit. The overcharge was performed on 10/24/71 at approximately cycle #4,000. Figures 5.1.2-9 and 5.1.2-10 show the voltage profile during the test. As can be seen, both C2 and C7 failed to come up in voltage with the other cells in the groups. Likewise their pressures barely increased during the 5-hour overcharge. Cell C2 increased from -6" at start-of-overcharge to -4" upon completion of the five hours, while C7 changed from -5" to -4". The other cells in the pack started into the overcharge with slightly positive pressures (+6 psig to +11 psig) and ended with pressures ranging from +22 psig to +31 psig. The positive electrodes in C2 and C7 were either not gassing or else the negative electrodes were recombining the oxygen as fast as it was evolving. Following the overcharge the pack was again placed on 10°C cycling. Figures 5.1.2-11 and 5.1.2-12 show a typical charge cycle approximately 200 cycles after the overcharge test. The peculiar behavior of C2 and C7 is still


0°C OVERCHARGE TEST AT CRANE
PERFORMED 10/24/71
PACK 238
GROUP I
S/N 1494
S/N 1517
S/N 1546
S/N 1588
S/N 1591
RATE = 1.0A
FIGURE 5.1.2-9
1.520
1.500
1.480
1.460
1.440
1.420
1.400
1.380
0
1
2
3
4
5

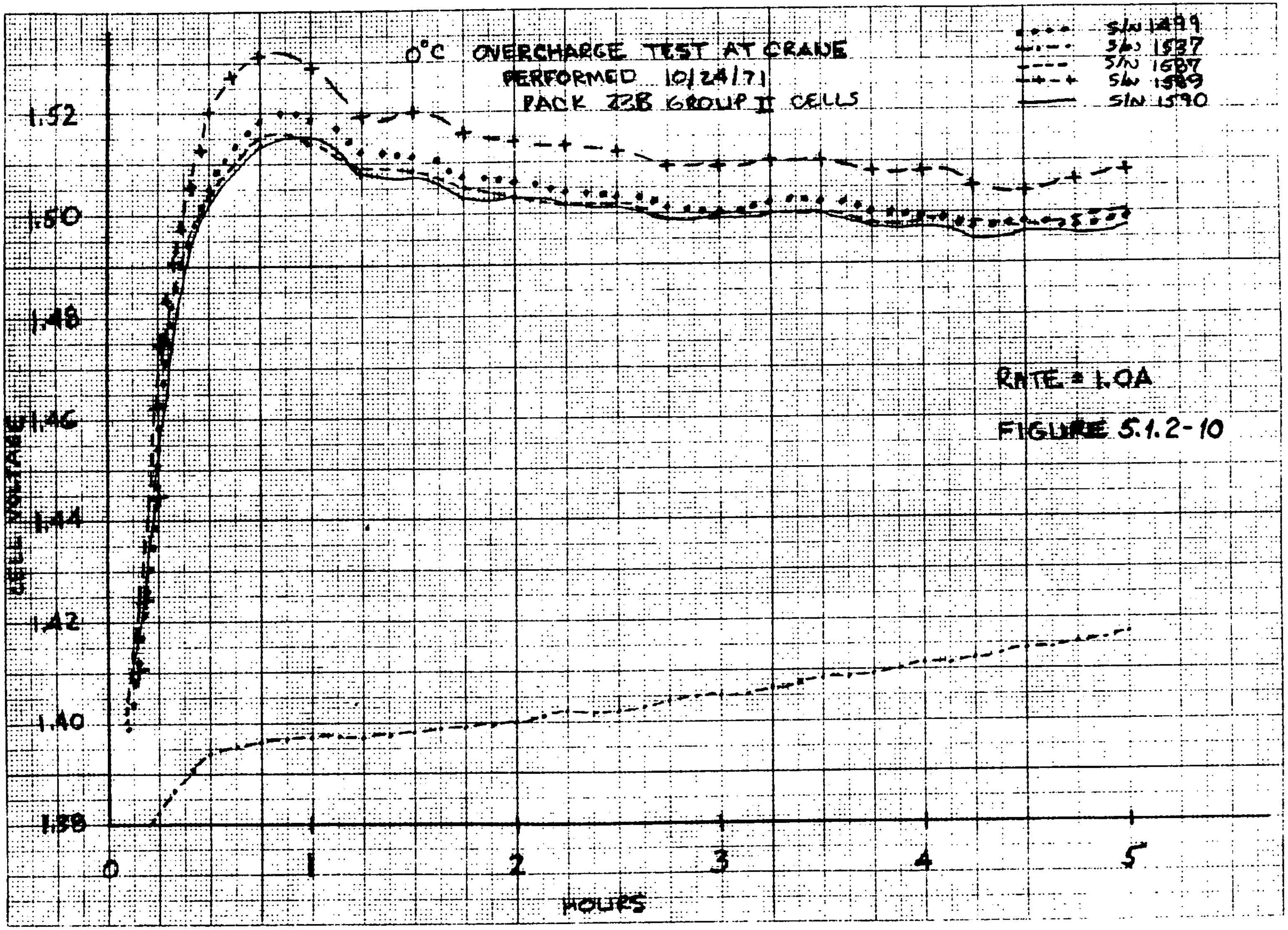
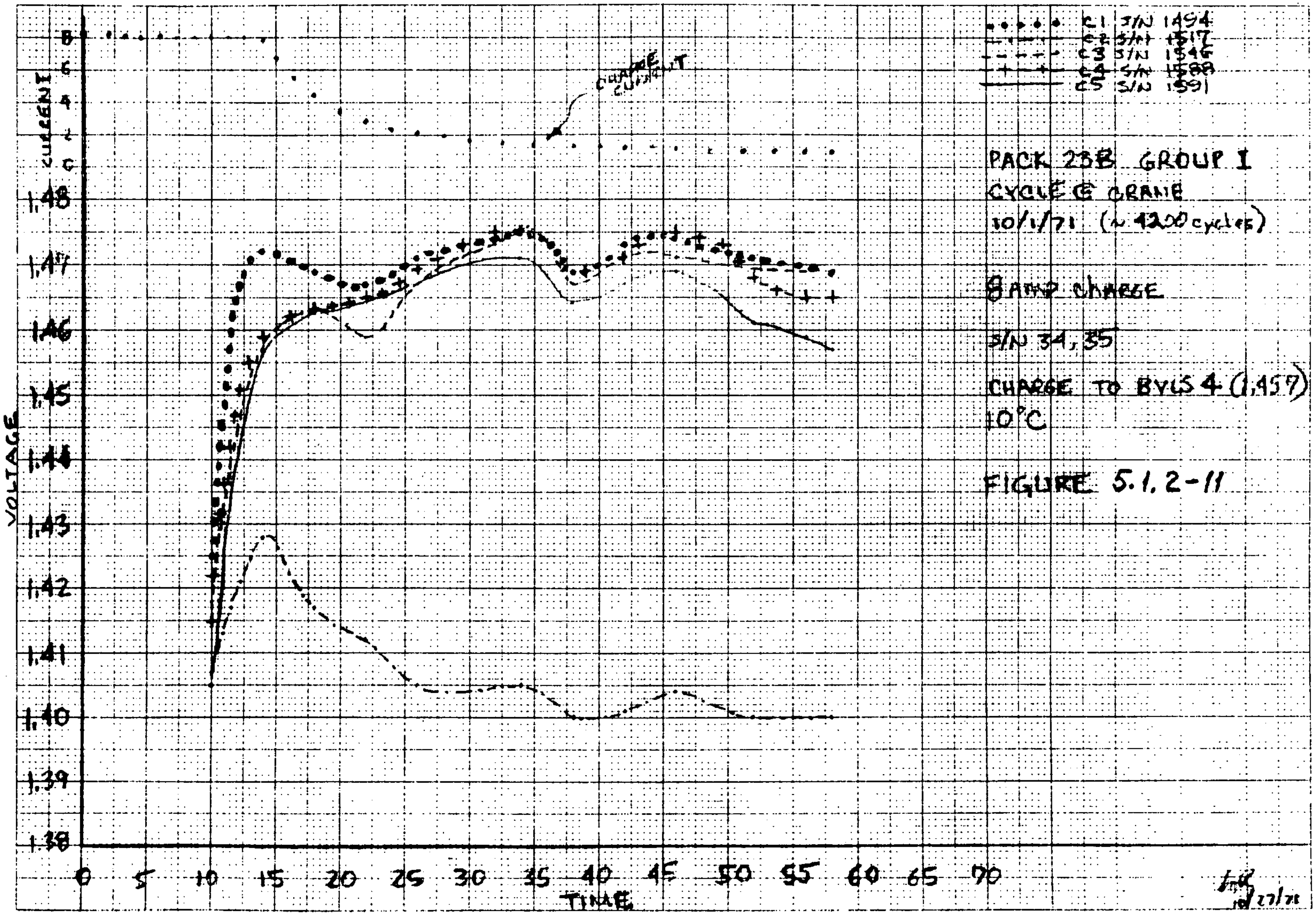


FIGURE 5.1.2-10



PACK 23B GROUP I
CYCLE @ CRANE
10/1/71 (~4200 cycles)

8 AMP CHARGE

S/N 34, 35

CHARGE TO BYLS 4 (1.457)
10°C

FIGURE 5.1.2-11

10/27/71

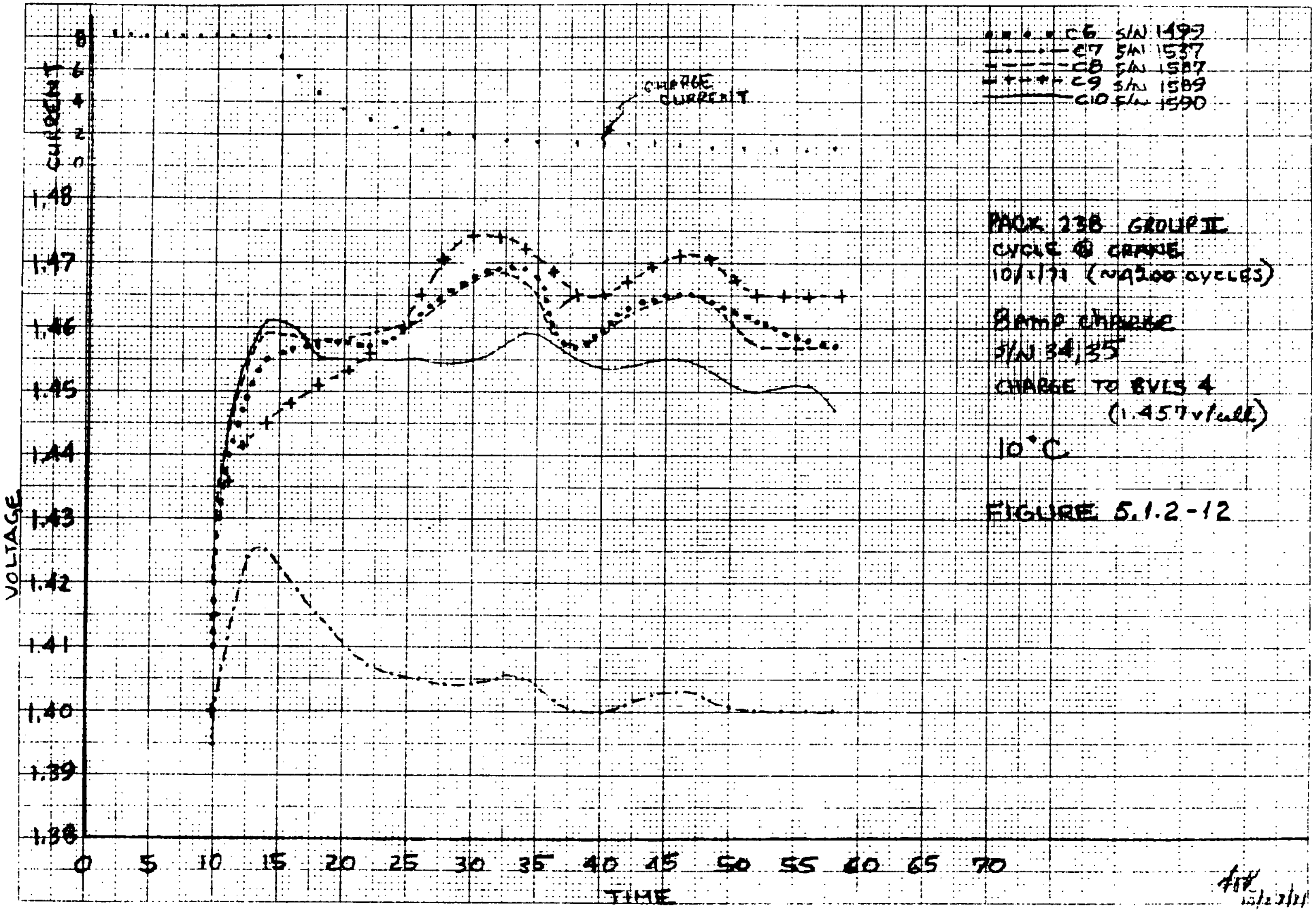


FIGURE 5.1.2-12

apparent.

A special test was performed in February, 1972, on two cells which exhibited a large voltage difference at the end of each charge cycle. Just prior to the test these cells (C7 and C8) had acquired a total of approximately 5600 cycles without a deep discharge and the total pack was receiving a recharge of 135.6%. The voltages at this time were as follows:

. . . .	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
E.O.C.V.	1.400	1.408	1.508	1.488	1.508	1.388	1.362	1.496	1.499	1.476
E.O.D.V.	1.196	1.249	1.200	1.214	1.218	1.200	1.120	1.208	1.212	1.208

Cells C7 (S/N 1537) and C8 (S/N 1587) were selected for the special tests based on their end-of-charge voltage difference (134 mV). The test regime shown in Table 5.1.2-5, was conducted with the intent to perform a chemical/physical analysis afterwards to see if the voltage divergence had any physical manifestations in the cells. It was found, however, that both cells appeared "normal" upon completion of the electrical tests. The chemical/physical analyses, therefore, were not performed on these two cells as had been planned. The initial discharge of C7 and C8 after they had been removed from pack 23B is shown in Figure 5.1.2-13. Both cells to this point had received 5,600 cycles without receiving a deep discharge yet, as in the case of C1 and C2, their voltage profiles are not the same. Cell C8 has two definite plateaus; the higher at around 1.18 volts (the OAO spacecraft URG level) and the lower around 1.05-1.07 volts. Cell C7, on the other hand, shows only a single, lower, plateau and falls below +1.00 volts much sooner than C8. The capacity to +1.00 volts and +0.5 volts shows a marked reduction from the original capacity measured for cell C7 while C8 shows little difference.

		Ampere-Hour	
Cycle #	Cell No.	Capacity to +1.0 Volts	Capacity to +0.5 Volts
Cycle 1,509	C7	22.2	
	C8	21.0	22.1
Cycle 5,600	C7	17.0	17.7
	C8	22.0	23.5

TABLE 5.1.2-6

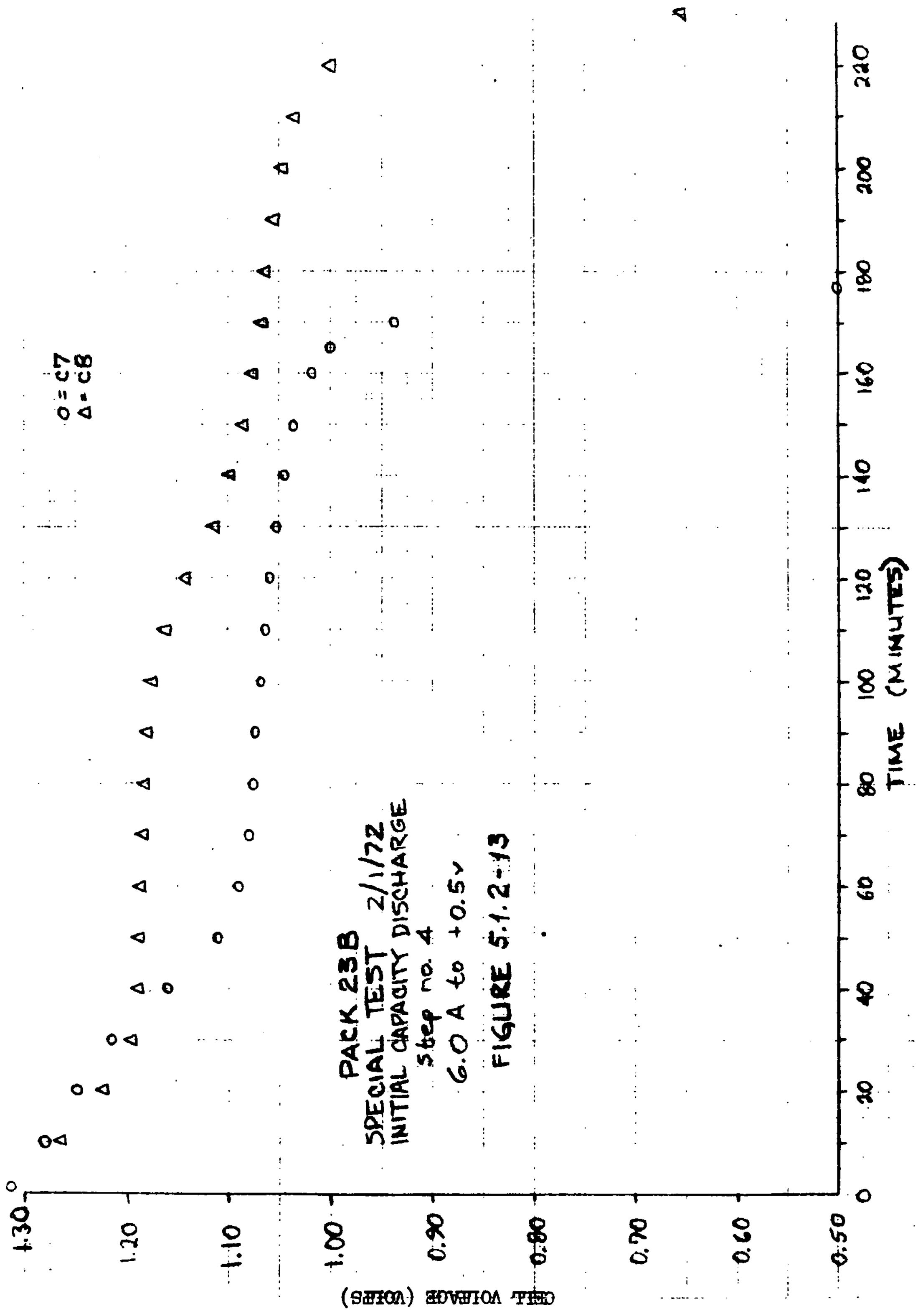
Although, as Table 5.1.2-6 indicates, cell C8 shows an increase of only about one ampere hour of capacity, a comparison of Figures 5.1.2-6 and 5.1.2-13 shows that

TABLE 5.1.2-[illegible]

Special Test on Cells C7 & C8 of
Pack 23B During February 1972

TABLE OF EVENTS

Step Number	Step Description
1.	Run pack 23B on tally prior to removing C7 and C8.
2.	Remove C7 and C8 from pack. Place pack back on life cycling.
3.	Run 10 life-cycles on C7 and C8 as a pack using the OAO test regime with a voltage limit of 1.403 v/c.
4.	Discharge each cell @ 6.0 amps to +0.5 volts.
5.	Taper charge each cell.
6. (a) (b) (c) (d) (e)	Overcharge test @ 0°C followed by leak test and gas sample.
7.	Discharge at C/2 rate to +0.5 volts per cell.
8.	Taper charge each cell.
9.	Run 10 life-cycles.
10.	Discharge @ C/2 rate to +0.5V per cell. Place 1Ω resistors across cells for 16 hours. Remove resistor and read OCV for 24 hours.
11.	Charge each cell for 48 hours @ C/20 rate.
12.	Perform leak test at end of 48 hour charge
13.	Discharge @ C/2 rate to +0.5V each cell.
14.	Taper charge each cell.
15.	Run 10 life cycles.
16.	Discharge @ C/2 rate to +0.5V per cell. Place 1Ω resistors across cell when discharge is complete. End of test.



PACK 23B
SPECIAL TEST 2/1/72
INITIAL CAPACITY DISCHARGE
Step no. 4
6.0 A to +0.5v

FIGURE 5.1.2-13

the discharge profile of C8 has changed significantly. Upon closer inspection we see that the average wattage is lower for cycle 5,600 from about ninety minutes until completion of the cycle. Table 5.1.2-7 shows the watt-minute accumulation to +1.0 volts for C8 at 1,509 cycles and 5,600 cycles.

		Cycle 1,509			Cycle 5,600		
Time Interval	T	Avg. Volt.	Avg. Watt.	Accumulated Watt-Min.	Avg. Volt.	Avg. Watt	Accumulated Watt-Min
0-10 min.	10	1.32	7.92	79.2	1.29	7.74	77.4
10-30 min.	20	1.25	7.50	229.2	1.23	7.38	225.0
30-60 min.	30	1.20	7.20	445.2	1.19	7.14	439.2
60-100 min.	40	1.19	7.14	730.8	1.18	7.08	722.4
100-150 min.	50	1.18	7.08	1084.0	1.13	6.78	1061.4
150-180 min.	30	1.15	6.90	1291.8	1.07	6.42	1254.0
180-200 min.	20	1.10	6.60	1423.8	1.05	6.30	1380.0
200-210 min.	10	1.03	6.18	1485.6	1.04	6.24	1442.4
210-220 min.	10	--	--	--	1.02	6.12	1503.6
	TOTAL WATT-MINUTES TO +1.0 V			1,485.6			1,503.6

TABLE 5.1.2-7

We see from Table 5.1.2-7 that the total watt-minutes delivered from C8 is nearly the same in both cases although the average voltage delivered by C8 is lower during the later cycle.

C8 thus appears to perform in a manner typical of the OAO flight and test cells generally. C7, on the other hand, (and C2 as heretofore noted) seems to have experienced an exceptionally accelerated degradation of some kind. Not only was discharge voltage significantly lower, but ampere-hour capacity was also severely reduced (see Figure 5.1.2-13). At the same time, the prior 0°C overcharge test data showed both a much lower voltage for C7 than the rest of the group, and a rising characteristic rather than a falling one (see Figure 5.1.2-10). These two sets of observations lead to the questions of how well C7 was accepting and storing charge, and what the possible causes may be. Since a few cells in this lot exhibited similar characteristics, answers to these questions are important. Accordingly, investigations are ongoing at this time.

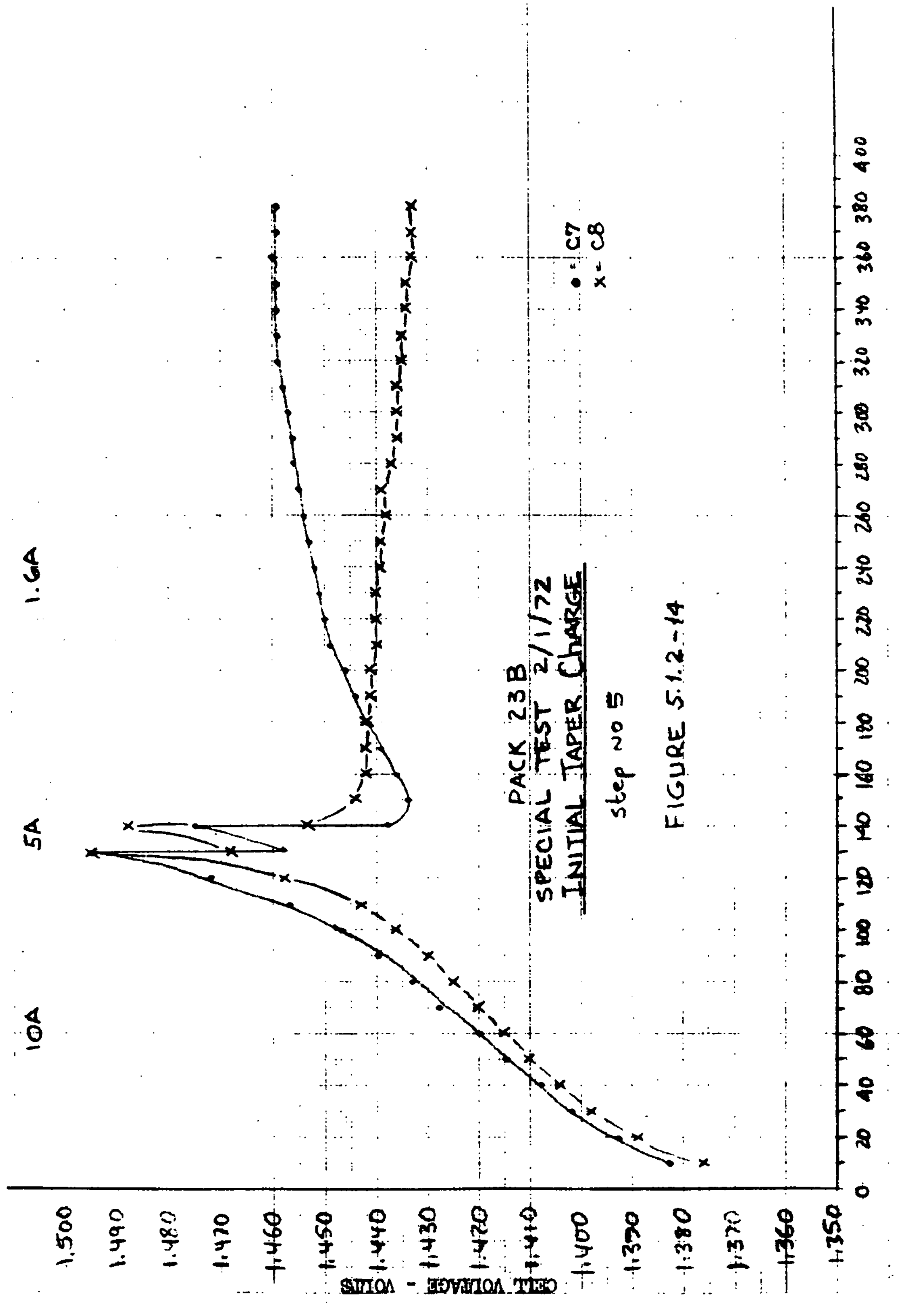
Following the discharge, the two cells were recharged via a taper charge. As Figure 5.1.2-14 shows, both cells reached the limiting voltage (1.496 volts) after approximately 130 minutes on the 10 amp rate. This compares favorably with the taper charge @ 1,509 cycles when C7 and C8 hit the limiting voltage at around 128 minutes on the 10 amp rate. Notice, however, that the end-of-charge voltage of C8 is 27 mV lower than C7. In the overcharge test which followed, cell C7 became the higher voltage cell of the two (see Figure 5.1.2-15). This is contrary to what would be expected since earlier tests had shown that the cells which exhibited low end-of-charge voltages on cycling also showed low voltages during overcharges. When the cells were discharged (Figure 5.1.2-16) the profile does not show a double-plateau as it had earlier. Ampere hour capacity to +1.0 volts on C7 and C8 was 22.8 A-hr. and 21.0 A-hr. respectively, and to +0.5 volts was 23.6 A-hr., and 21.8 A-hr. respectively. All indications were that the low voltage cell had been "conditioned" and no longer displayed the low end-of-charge voltages or lower discharge plateau voltage that it had previously shown. The conditioning was probably due to the low discharge (to +0.5 volts) incurred during step No. 4. The ability of deep discharges to eradicate the double plateau effect has been demonstrated elsewhere (see Appendix E) although it was not previously known if a deep discharge would bring a low voltage cell on charge up to a nominal end-of-charge voltage. Subsequent discharges (Figures 5.1.2-17 through 5.1.2-20) show that the capacity of the two cells remained fairly uniform throughout the remainder of the tests.

On 2/23/72, another 88 day capacity check was performed on two cells from pack 23B. The cells selected for this capacity check were C5 (S/N 1591) and C6 (S/N 1499). Table 5.1.2-8 shows the end-of-charge voltages before and after the capacity check as well as the percent recharge. It is apparent that the capacity discharge improved the voltage of C6 and brought it from 30-40 mV lower than C5 to less than 20 mV lower than C5. Cells C7 and C8 are displaying voltages approximately 30 mV higher than other cells in the pack. Apparently the series of charges and discharges encountered during the special test of February 1972, conditioned these cells so well that they now respond better than the other pack cells. Cells C1 and C2 are lower by 60-70 mV than the pack average. Cell C2 has remained low since approximately cycle 2,400 or so, while C1 has exhibited a divergence only after about 5000 cycles. Figure 5.1.2-21 shows the capacity discharge of C5 and C6 at 6,000 cycles. As Table 5.1.2-9 indicates there is no appreciable capacity change in C5 from 1,509 to 5,600 cycles. However, C5 shows a decrease of 6 A-hr. in the later cycles. This is verified from Figure 5.1.2-21. We can see, furthermore, that although C5 delivered the same capacity to +1.0 volts, it does so at a lower voltage. Therefore, it shows a net decrease in watt-hours returned over the earlier cycles.

	Cycle 1,509		Cycle 6,000	
	Ampere-Hour		Ampere-Hour	
Cell No.	Cap. to +1.0V	Cap. to +0.5V	Cap. to +1.0V	Cap. to +0.5V
C5	22.1	--	20.8	23.3
C6	22.1	--	16.2	18.7

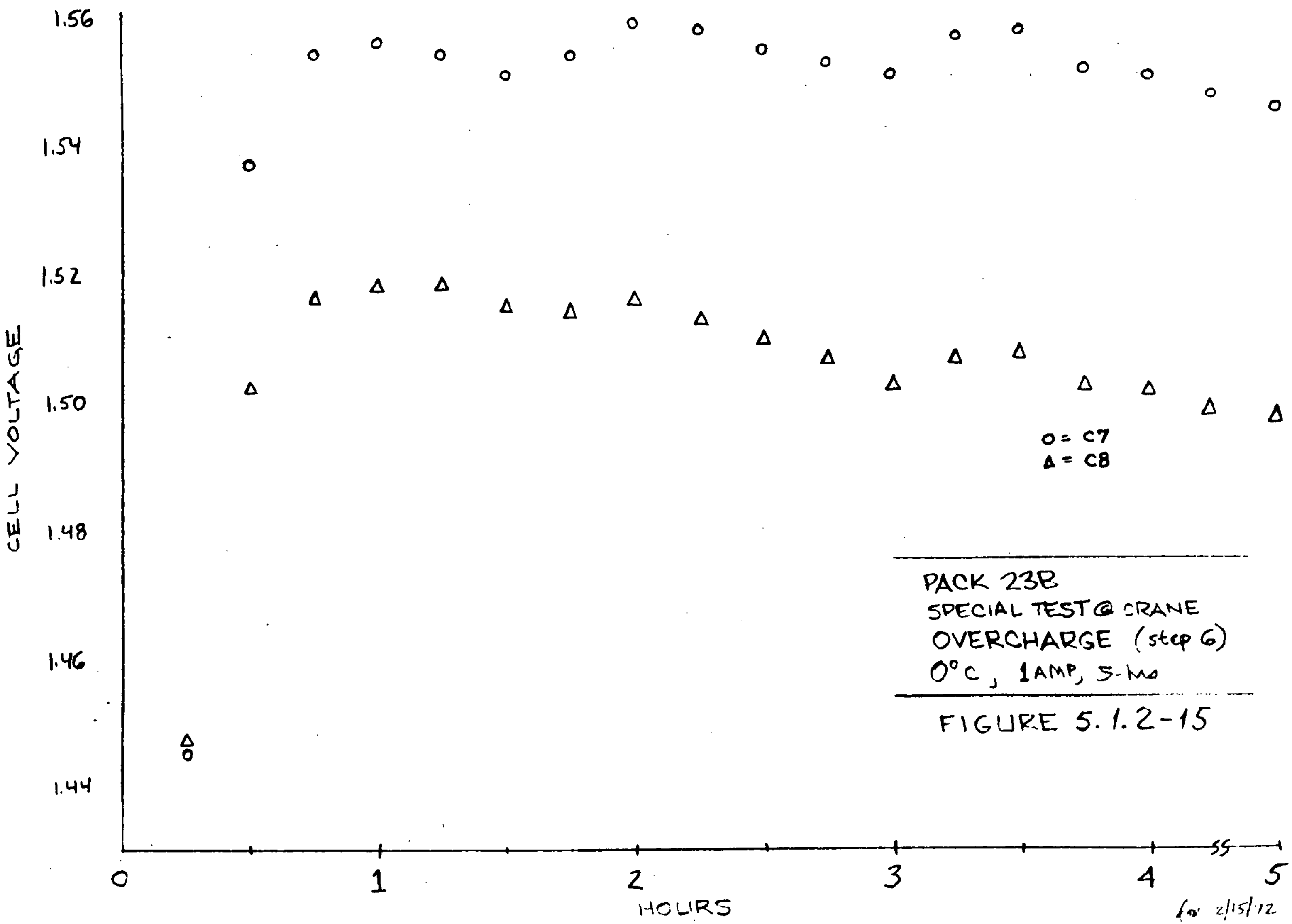
TABLE 5.1.2-9

Following the capacity check of C5 and C6, cells C7 and C8 were reunited into the pack. All four cells received a taper charge first before being placed into the pack. Cycling was continued on BVLS 4 until 3/2/72, when the voltage limit was lowered to BVLS 1.



PACK 23B
SPECIAL TEST 2/1/72
INITIAL TAPER CHARGE
step no 5

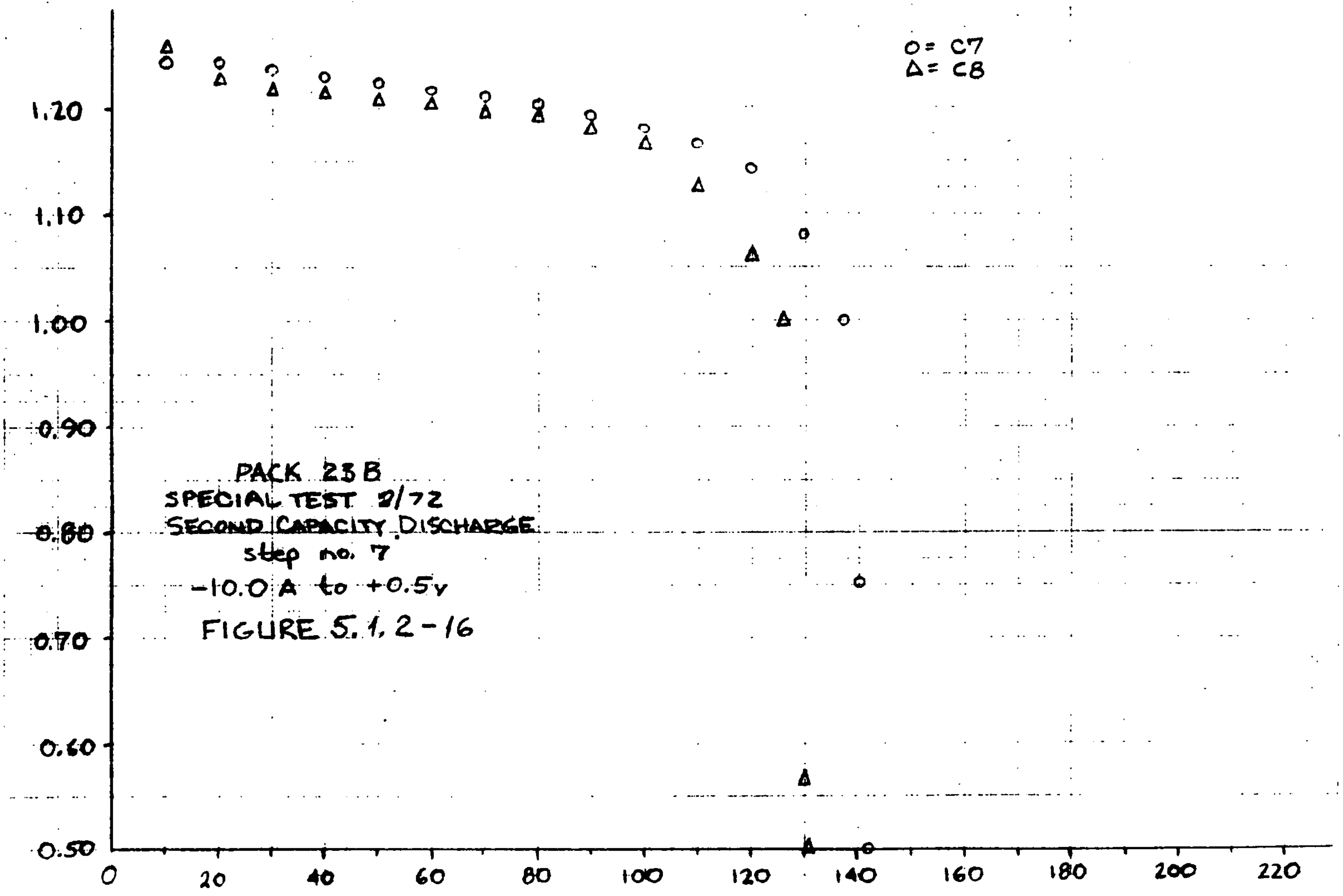
FIGURE 5.1.2-14



PACK 23B
SPECIAL TEST @ CRANE
OVERCHARGE (step 6)
0°C, 1AMP, 5-hrs

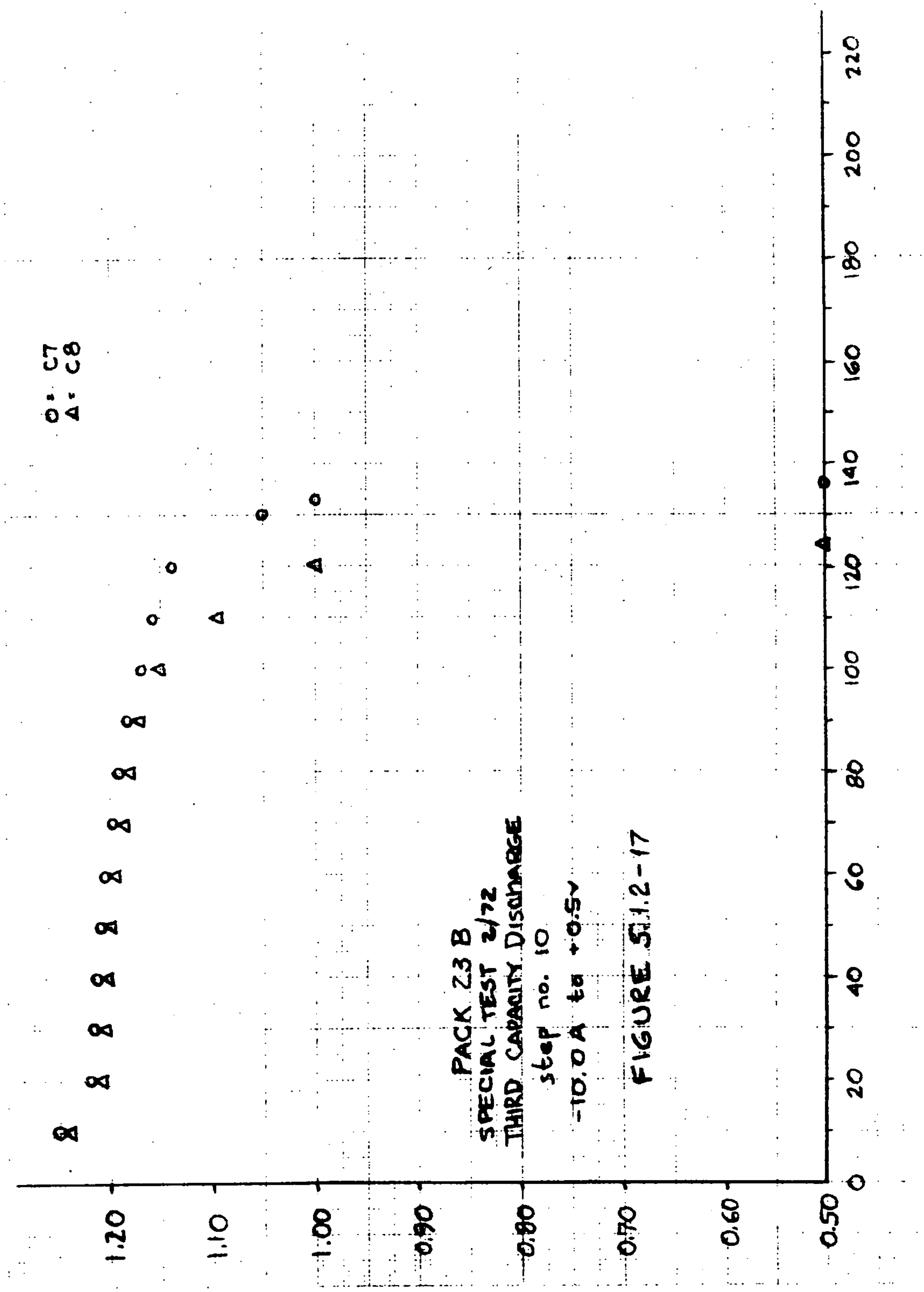
FIGURE 5.1.2-15

fw 2/15/72



PACK 23B
SPECIAL TEST 2/72
SECOND CAPACITY DISCHARGE
step no. 7
-10.0 A to +0.5v

FIGURE 5.1.2-16



PACK 23 B
SPECIAL TEST 2/72
THIRD CAPACITY DISCHARGE
step no. 10
-10.0A to +0.5v

FIGURE 5.1.2-17

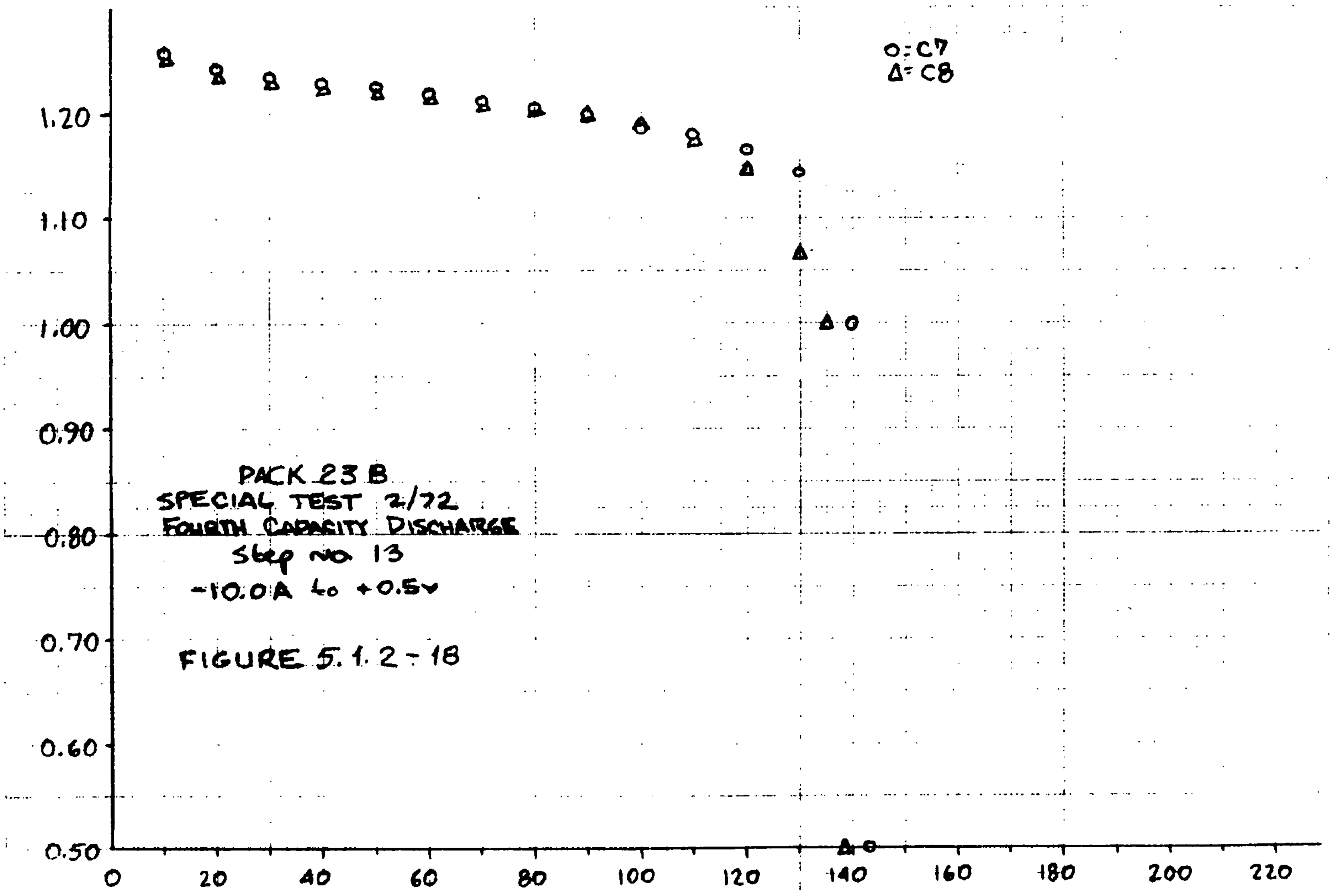


FIGURE 5.1.2-18

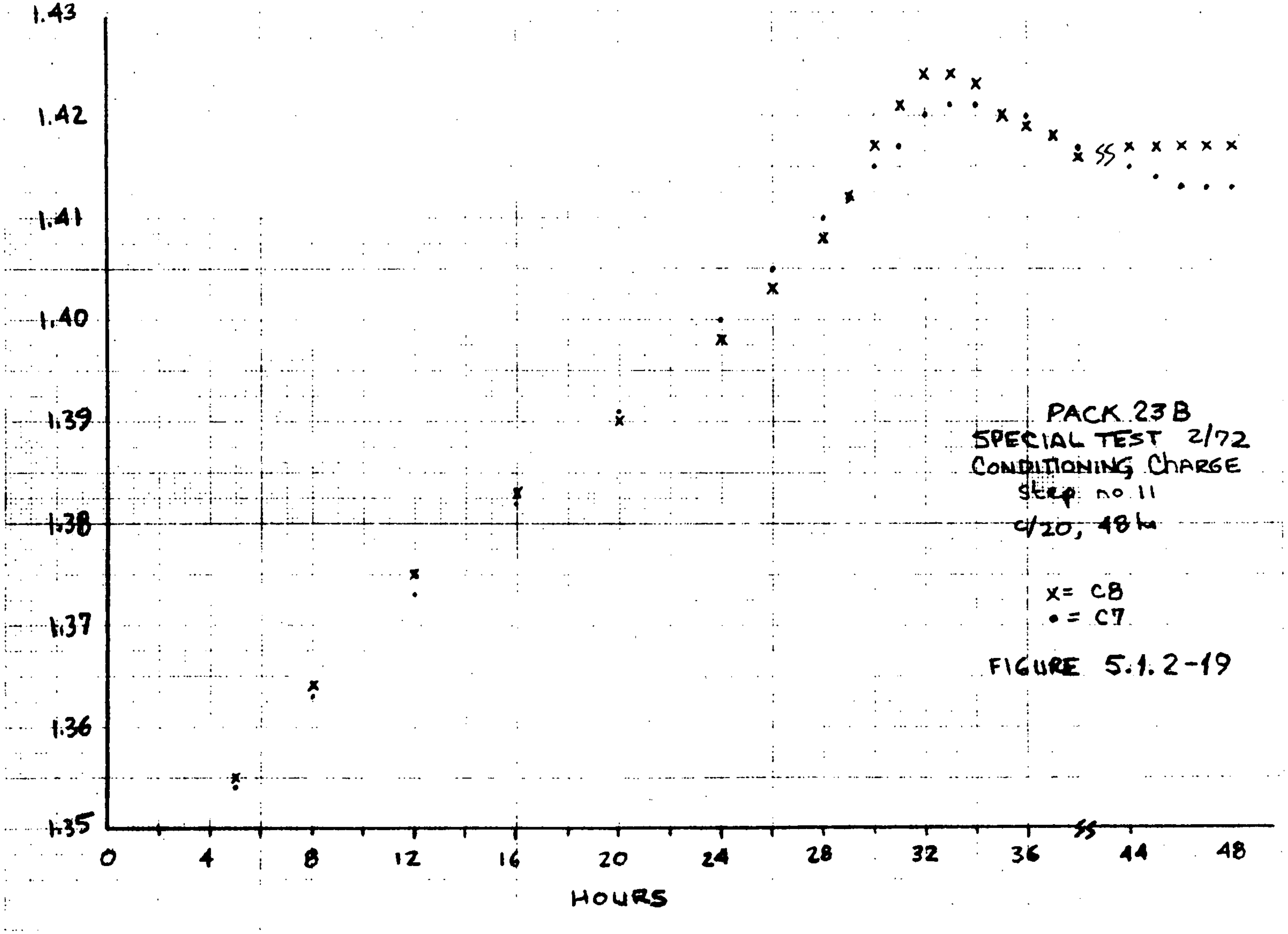
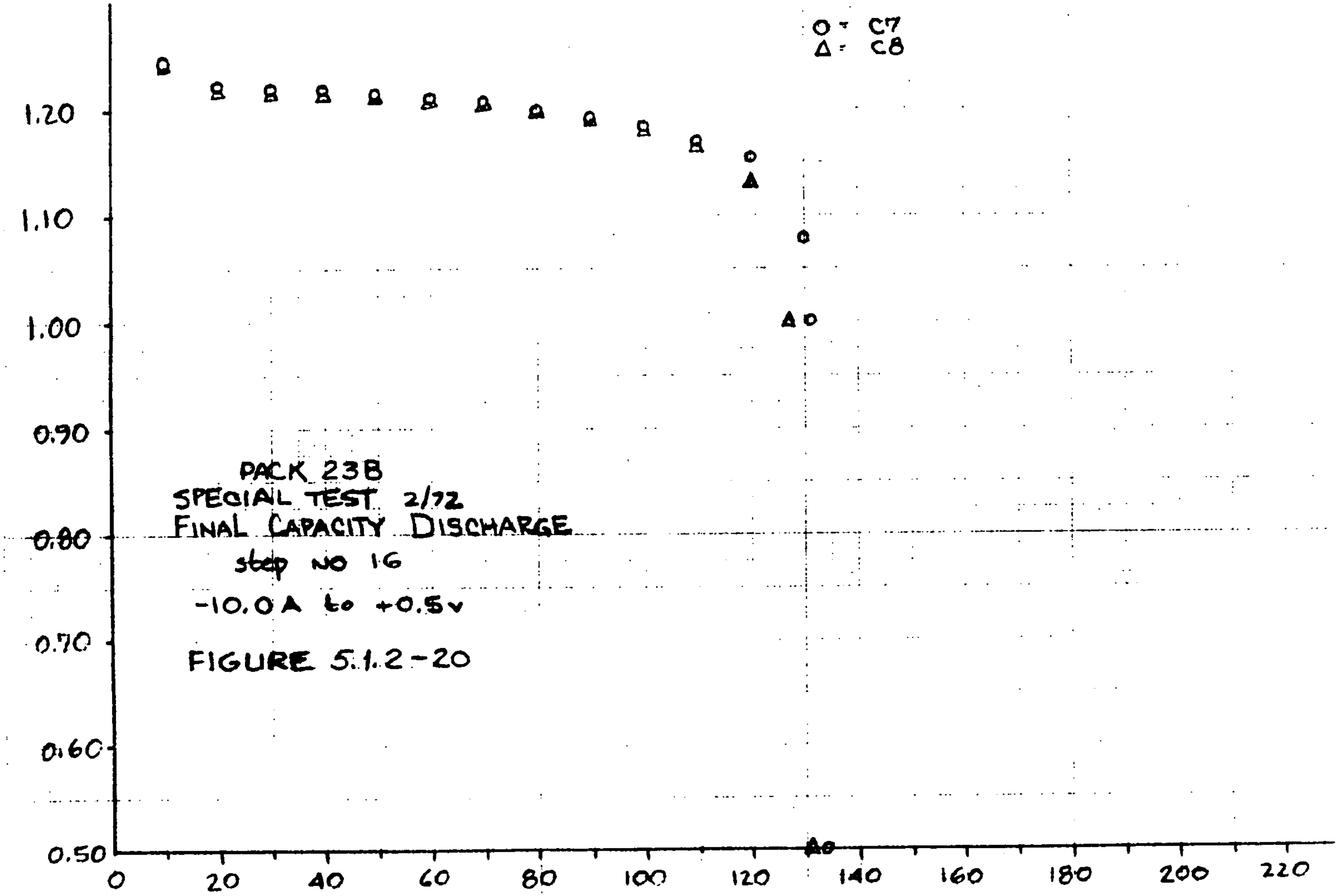


FIGURE 5.1.2-19



PACK 23B
SPECIAL TEST 2/72
FINAL CAPACITY DISCHARGE
step NO 16
-10.0A to +0.5v

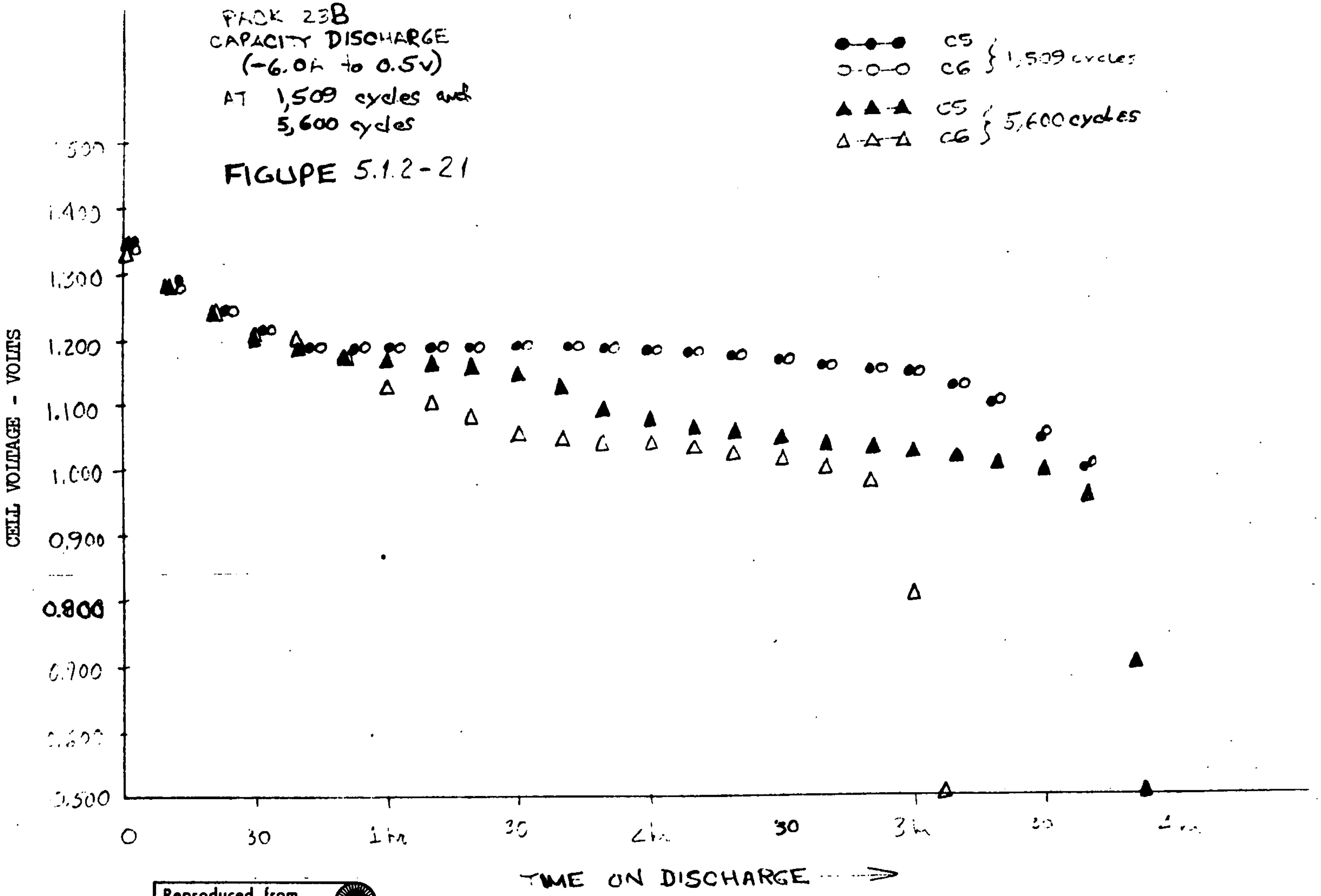
FIGURE 5.1.2-20

Date	Cycle	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	% Recharge
2/21/72	5950	1.424	1.420	1.469	1.469	1.465	1.436	*	*	1.468	1.460	120.7%
2/23/72	6000	1.436	1.404	1.474	1.474	1.474	1.432	*	*	1.474	1.464	119.5%
2/23/72	6000	CAPACITY CHECK ON C5 & C6; C7 & C8 PUT BACK IN PACK AFTER TAPER CHARGE OF C5 THROUGH C8										
2/24/72	6000	1.388	1.376	1.466	1.461	1.478	1.460	1.489	1.484	1.454	1.548	127.5%
2/29/72	6100	1.420	1.388	1.464	1.456	1.466	1.449	1.498	1.484	1.454	1.448	--
3/2/72	6100	1.410	1.396	1.468	1.464	1.468	1.452	1.480	1.480	1.460	1.448	121.0%
3/2/72	6100				PACK LOWERED TO BVLS 1							

End of Charge Voltages for Pack 23B

TABLE 5.1.2-8

* Cells removed for "Special Test"


PACK 23B
CAPACITY DISCHARGE
(-6.0A to 0.5V)
AT 1,509 cycles and
5,600 cycles

FIGUPE 5.1.2-21

5.2 SUMMARY OF TEST REGIME FOR PACK 5

- No. of series connected cells in pack: 5
- Cells from OAO battery S/N 34, 35 spare lot
- Cell serial nos.:

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1514	518A	1526	526A	1531	-	-	-	-	-

- On test at:

  NAD, Crane ○ Goddard Space Flight Center Ⓧ

- Depth of discharge: 15%
- Temperature: 12-13°C
- Cycle Period: 100 min.
- Charge Rate: 8A
- Discharge Rate: 5A
- Date Test Began: 7/71
- Type of Charge Control: BVLS 4

TEST DETAILS -

- This pack underwent approximately 1200 cycles of cell verification testing under BVLS control before beginning these life cycling tests.

PACK 5

5.2.1 Pack Description and Test Results

Pack 5 consists of five, series-connected cells from the spare lot of OAO battery S/N 34, 35. The pack underwent 1200 cycles during cell verification testing before being placed on life cycling at Goddard Space Flight Center in July of 1971. The cycling regime consists of a 6 amp, 15% depth discharge and an 8 amp, charge to BVLS 4, at 13°C.

Table 5.2.1-1 lists the events that the pack has experienced to date. Initial end-of-charge voltage divergence was low, about five millivolts. Percent recharge stabilized to approximately 122% in the first 120 days and remained at that level until day 250. At this time (cycle 1608) an overcharge test at 0°C was performed. Following this overcharge the pack showed a dramatic increease in end-of-charge voltage divergence, paralleled with a rise in end-of-charge pressure and percent recharge (see Figure 5.2.1-1). This rise in voltage divergence is shown in Figure 5.2.1-2. A capacity check performed at cycle 2,408 temporarily reduced this divergence but the end-of-charge voltage spread quickly returned to its pre-discharge conditions.

In an attempt to check the steady rise in voltage divergence, pressure and percent return, it was decided to lower the voltage charge level from BVLS 4 to BVLS 3. This was performed at cycle 2,785 and, after a few hundred cycles, the pack showed favorable performance changes. By cycle 3000 the end-of-charge voltage spread among the cells had decreased from 130 mV at the peak (cycle 2,800) to nearly 65 mV. Percent recharge had dropped from 175% to 162% with an accompanying 10 psia decrease in end-of-charge pressures. At cycle 3000 the voltage charge level was again lowered, this time from BVLS 3 to BVLS 2. Again the cycles immediately following the change showed a rise in divergence followed by another decrease in divergence, recharge and pressure. The charge voltage level was finally reduced to the lowest level, BVLS 1, at cycle 3,158. This had the effect of reducing the voltage divergence to about 35 mV at which value it levelled off and remained. Percent recharge stabilized at 110-115% and cell end-of-charge pressure converged at around 5-15 psia.

By cycle 4000 cell voltage divergence had again appeared and therefore an attempt was made to control the divergence by lowering the input charge rate. On cycle 3,996 the rate was reduced from an 8 amp to a 4 amp charge and 88 cycles later it was reduced further to 3 amps. This had the effect of lowering the percent recharge into the pack while maintaining the cells at a full state-of-charge at each cycle. The voltage divergence, however, did not decrease significantly as seen in Figure 5.2.1-2. A precharge adjustment was made on

TABLE OF EVENTS

PACK 5

Cycle No.	Event
1,606	Performed low temperature ($0^\circ C$) overcharge test
2,408	Capacity discharge to +1.0 V/cell
2,785	From BVLS 4 to BVLS 3
2,918 to 2,973	Temperature rise to $20^\circ C$
2,973	Temperature return to $13^\circ C$
3,015	From BVLS 3 to BVLS 2
3,158	From BVLS 2 to BVLS 1
3,996	Charge rate lowered from 8A to 4A
4,084	Charge rate lowered from 4A to 3A
4,250	Removed 2 A-hr. oxygen gas (precharge adjustment) from cell #5

TABLE 5.2.1-1

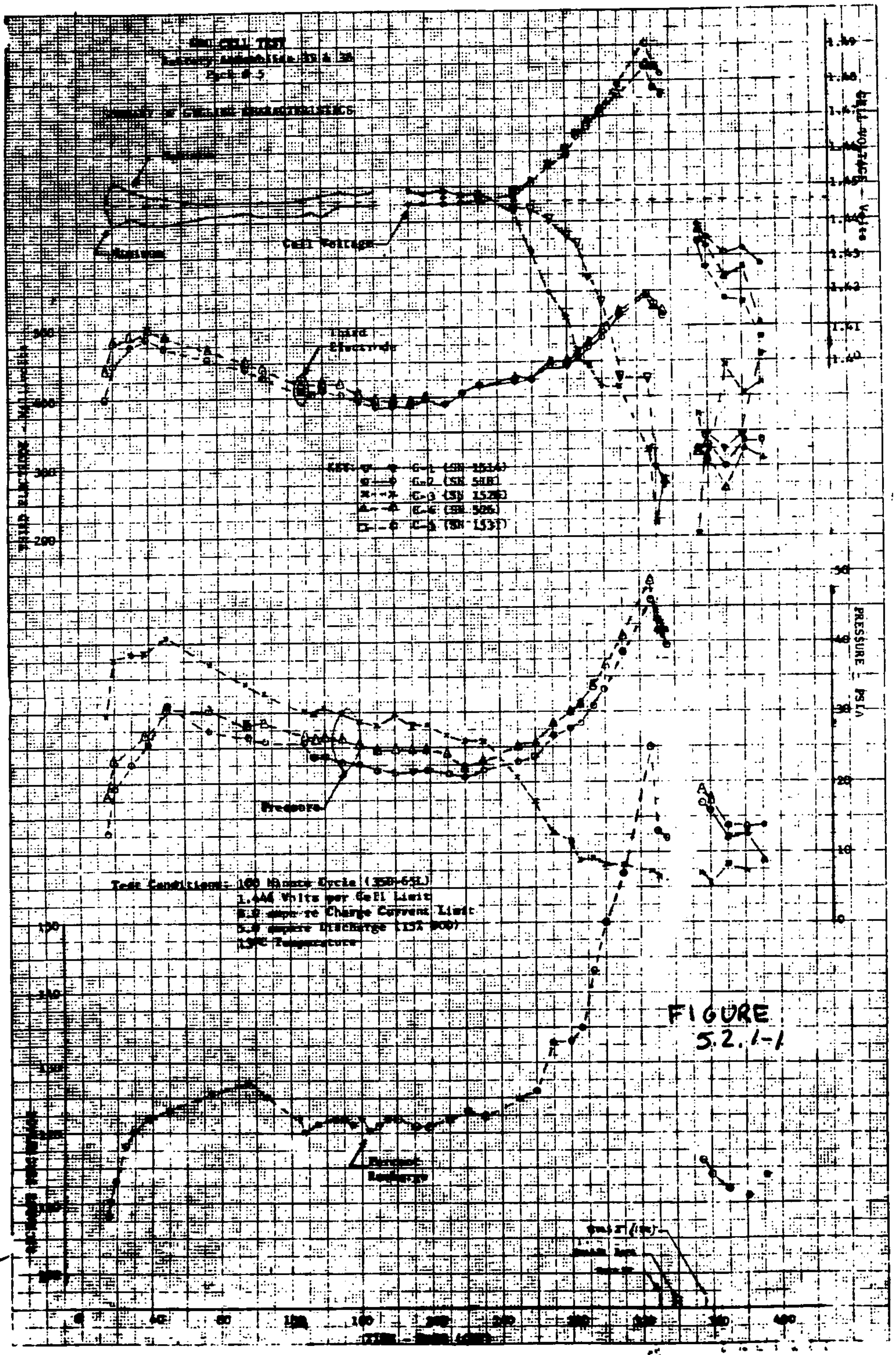
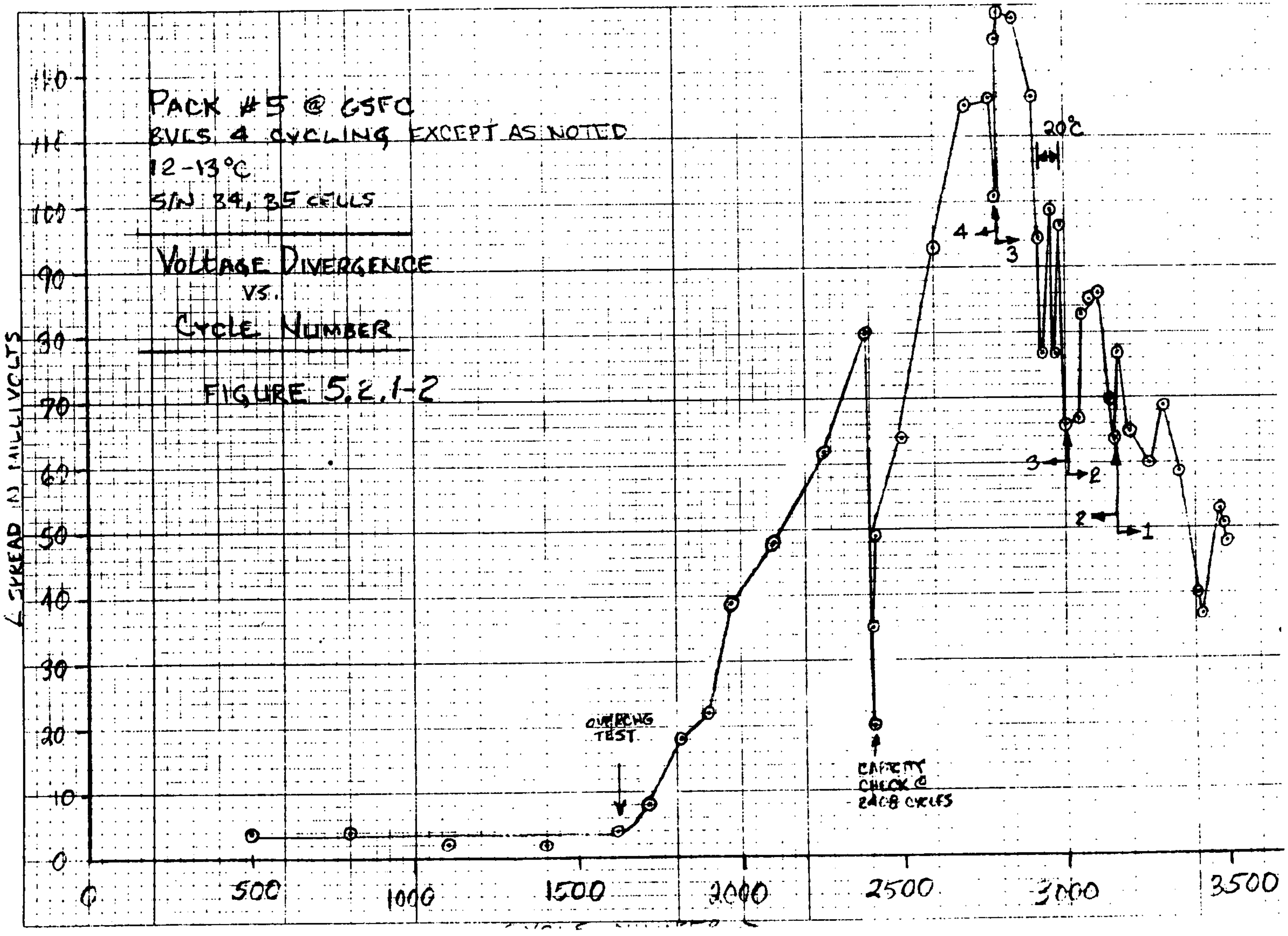

K·E 10 X 10 TO THE CENTIMETER 47 1516
CELL TEST
Cycle # 5
Cell Voltage
Third Electrode
THIRD ELECTRODE
KEY: C-1 (SN 1514)
C-2 (SN 588)
C-3 (SN 1526)
C-4 (SN 506)
C-5 (SN 1531)
Pressure
Test Conditions: 100 Minute Cycle (35D-65L)
1.444 Volts per Cell Limit
ampere Charge Current Limit
ampere Discharge (15% DOD)
Temperature
Percent Recharge
CELL VOLTAGE – Volts
1.49
1.48
1.47
1.46
1.45
1.44
1.43
1.42
1.41
1.40
PRESSURE – PSIA
50
40
30
20
10
0
500
400
300
200
0
40
80
100
200
300
400
TIME

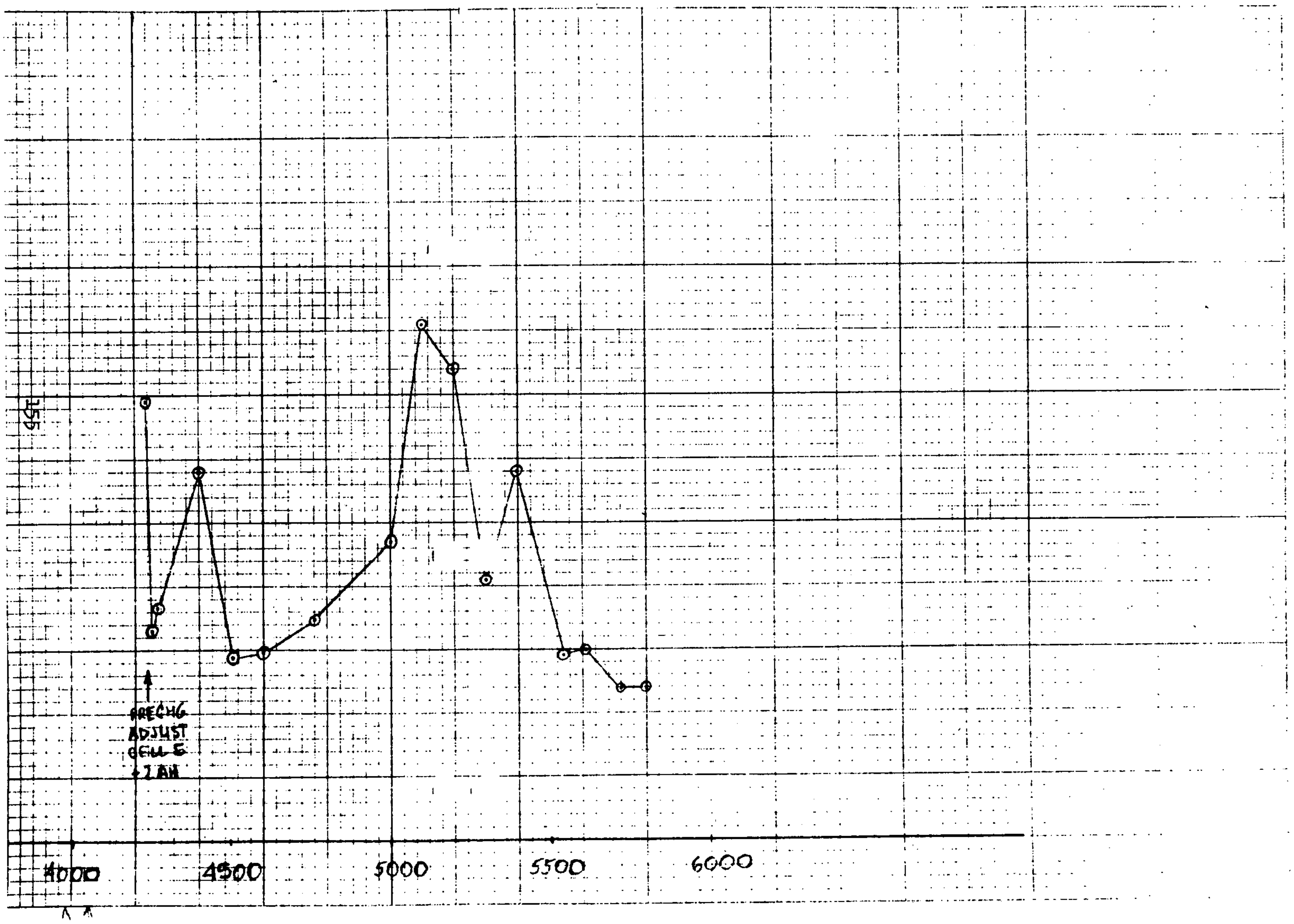
FIGURE 5.2.1-1



PACK #5 @ GSFC
BVLS 4 CYCLING EXCEPT AS NOTED
12-13°C
S/N 34, 35 CELLS

VOLTAGE DIVERGENCE
VS.
CYCLE NUMBER

FIGURE 5.2.1-2


RECHG
ADJUST
CELL 5
+2 AH
4000
4500
5000
5500
6000

one cell in the pack (#5) by charging the pack until a positive pressure existed and then venting it to remove oxygen gas in the equivalent amount of 2 A-hr. This was performed at cycle 4,250. As seen from Figure 5.2.1-2 the adjustment was followed by an immediate rise in voltage divergence followed by a decrease to pre-adjustment levels. Subsequent to cycle 4,500, the end-of-charge voltage spread in the pack again increased and reached a 81 mV peak about a thousand cycles after the adjustment was made. Beyond cycle 5,000, end-of-charge voltages again converged to a minimum of 24 mV by cycle 5,800. This reduction in divergence was paralled by a reduction in percent recharge as shown in Table 5.2.1-2. Although energy balance is shown to be maintained at low recharge levels (less than 110%), the table seems to indicate that the recharge is running down but at a very slow rate. However, end-of-discharge voltages are not showing any consistent degradation, indicating that changes in end-of-charge voltage and recharge do not seem to impair the ability of the cells to function normally.

Cycle No.	Percent Recharge	End-of-Discharge Max. V.	Min. V.	End-of-Charge Max. V.	Min. V.	Max. P.	Min. P.
5,000	108%	1.218(2)	1.157(3)	1.440(2)	1.393(1,3,5)	11.13	5.63
5,101	106%	1.218(2)	1.145(1)	1.469(2)	1.388(5)	8.98	4.82
5,200	106%	1.217(2)	1.166(3)	1.463(2)	1.389(5)	7.46	5.08
5,300	104%	1.225(2)	1.197(1,3)	1.439(2)	1.398(1,3)	7.20	4.67
5,400	106%	1.220(2)	1.167(3)	1.444(2)	1.386(5)	6.68	4.88
5,500	104%	1.209(2)	1.184(1)	1.426(2)	1.397(5)	7.07	4.98
5,605	104%	1.208(2)	1.177(1)	1.426(2)	1.396(5)	7.04	4.98
5,720	102%	1.213(2)	1.182(1)	1.423(2)	1.399(5)	6.91	4.69
5,800	104%	1.222(2)	1.179(1)	1.426(2)	1.402(3,5)	6.78	4.54

End-of-Charge and Discharge Voltages

Pressures and Percent Recharge for Pack # 5

NOTES:

All voltages (V) in volts

All pressures (P) in psia

Cell S/N shown in parenthesis

All cycles to BVLS 1 @ +3 amp charge rate

TABLE 5.2.1-2

5.3 SUMMARY OF TEST REGIME FOR PACK 6

- No. of series connected cells in pack: 5
- Cells from OAO battery S/N 34, 35 spare lot
- Cell serial nos.:

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1542	495A	1554	497A	1575	-	-	-	-	-

- On test at:

  NAD, Crane ○ Goddard Space Flight Center ⊗

- Depth of discharge: 15%
- Temperature: 12-13°C
- Cycle Period: 100 min.
- Charge Rate: 8A
- Discharge Rate: 5A
- Date Test Began: 7/71
- Type of Charge Control: BVLS 4, except between cycles 1501-2360 and 3650-5900 when BVLS 1 was applied.

TEST DETAILS -

- This pack had received approximately 1200 cycles of cell verification testing at BVLS 8 combined with third electrode control before beginning these life cycle tests. Third electrode control involved a bi-level decrease to BVLS 1 when auxiliary signal reached its limit.

PACK 6

5.3.1 Test Description and Results

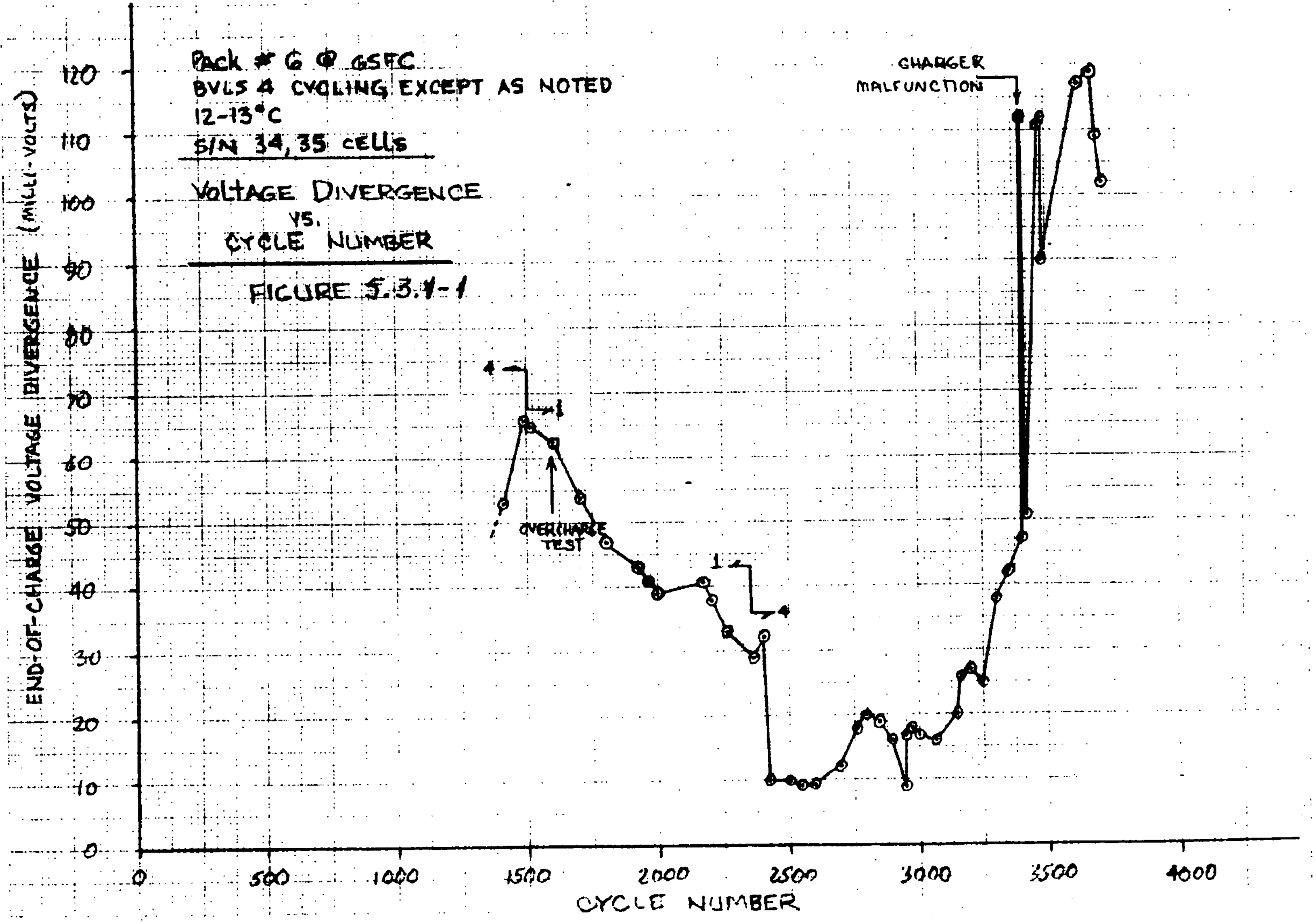
Pack number 6 consists of five (5) series connected cells taken from OAO battery lot S/N 34 and 35. These cells had first received cell verification testing at NASA/GSFC where they were cycled at BVLS 8 in combination with third electrode control.[14]

Following this test, in July 1971, this pack was placed on life test at BVLS 4 at 13°F temperature. Figure 5.3.1-1 shows an end of charge voltage divergence of 65 mV, observed after, 1500 orbital cycles. The limit was reduced to BVLS 1 from cycles 1501 through 2360. This resulted in a smaller divergence -- about 30 mV -- by cycle 2360. The test was then returned to BVLS 4 to determine if a return to the original divergence value would occur. Slowly, an increase was noted, and by cycle 3400 it had reached a value of 47 mV. At cycle 3,413 the charger malfunctioned, exceeding its preset voltage. Cell #5 in the pack reached 1.573 volts, and total divergence was 112 mV. Three cycles later the mishap was corrected. Then, with the voltage controlled at BVLS 4 on all subsequent cycles, another 112 mV divergence occurred at cycle 3,480.

The direct relationship between voltage divergence and BVLS level (as the control of charge regime) has been previously noted. Generally, divergence value seems nearly linear function of BVLS level for any given group of cells.

Prior to cycle 3,400, pressures in the pack were about 10 psia, except cell 3 (closer to 20 psia). During those cycles without current cutback, cell 3 reached 82 psia. Later, pressures returned to normal.

Table 5.3.1-1 shows the charge/discharge parameters found in cycles 5000 through 5900. Voltage divergence was low -- 10 to 30 mV. Despite a falling recharge percentage, these cycles demonstrate that 3 amp charge rate at BVLS 1 is sufficient to maintain energy balance for more than 1000 cycles. This is identical to the findings from pack 5 tests.



Pack # 6 @ GSFC
BVLS 4 CYCLING EXCEPT AS NOTED
12-13°C
S/N 34, 35 CELLS

VOLTAGE DIVERGENCE
VS.
CYCLE NUMBER

FIGURE 5.3.4-1

Cycle No.	Percent Recharge	End-of-Discharge Max. V.	End-of-Discharge Min. V.	End-of-Charge Max. V.	End-of-Charge Min. V.	End-of-Charge Max. P.	End-of-Charge Min. P.
5,000	112%	12.15(2)	1.185(3)	1.418(5)	1.394(1)	6.55	4.72
5,100	107%	1.201(4)	1.163(3)	1.433(4)	1.394(2)	5.99	4.62
5,200	104%	1.212(1)	1.176(3)	1.411(1)	1.402(5)	6.61	4.54
5,300	105%	1.198(1)	1.173(3)	1.411(5)	1.402(2)	7.14	5.01
5,410	102%	1.168(5)	1.146(3)	1.411(3)	1.402(4)	6.75	4.42
5,500	103%	1.176(5)	1.154(3)	1.410(3)	1.404(2)	7.33	4.43
5,615	103%	1.182(5)	1.163(3)	1.389(3)	1.383(2)	7.75	4.59
5,729	99%	1.179(5)	1.166(3)	1.409(3)	1.402(2)	7.78	4.34
5,800	101%	1.165(5)	1.143(2)	1.411(3)	1.403(2)	7.86	4.57
5,900	97%	1.169(5,4)	1.150(2)	1.409(3)	1.401(2)	7.86	4.39

End-of-Charge and Discharge Voltages,

Pressures and Percent Recharge for Pack #6

NOTES:

All voltages (V) in volts

All pressures (P) in psia

Cell S/N shown in parenthesis

All Cycles to BVLS 1 @ +3 amp charge rate

TABLE 5.3.1-1

5.4 SUMMARY OF TEST REGIME FOR PACK 35B

- No. of series connected cells in pack: 5
- Cells from OAO battery S/N 34, 35 spare lot
- Cell serial nos.:

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1573	512A	1578	515A	1492	-	-	-	-	-

- On test at:

  NAD, Crane ⊗ Goddard Space Flight Center ○
- Depth of discharge: 15%
- Temperature: 10°C
- Cycle period: 90 minutes
- Charge rate: 8 amp
- Discharge rate: 6 amp
- Date test began: 1/26/71
- Type of charge control: BVLS 4 cycling

TEST DETAILS -

- This pack is similar to pack 23B except for the following details:
  - Has two third-electrode cells (512A and 515A)
  - Has not received any capacity checks
  - Has not received any overcharges greater than the BVLS 4 cycling.
  - The cells received an unmodified Gulton precharge.

PACK 35B

5.4.1 Pack Description and Test Results

Pack 35B consists of five series-connected cells from the spare lot of OAO battery S/N 34, 35. Unlike pack 23B, these cells received an unmodified Gulton precharge. However, the gas vented from each cell was collected and is given in the precharge section of this report. Following the routine electrical testing at the seller facility, the cells were sent to NAD, Crane for additional testing in January 1971.

Upon arrival at NAD, Crane the cells received a C/20, 48-hour conditioning cycle (see Figure 5.4.1-1). Following the conditioning, the pack was discharged at C/2 rate to +0.5 volts each cell. Capacities were as follows:

C1	C2	C3	C4	C5
24.2 A-hr.	23.7 A-hr.	24.0 A-hr.	23.5 A-hr.	24.2 A-hr.

During two taper charges* which followed, the cells developed high pressures in the 5 amp portion of charge since they did not reach the voltage limit -- 1.496 volts -- resulting in an overcharge. The maximum voltage during the first taper charge was 1.487 V (C5) after twenty minutes. In the second, cell C5 was again just short of the voltage limit 1.491 volts after twenty-five minutes at 5 Amp rate. (A similar occurrence was observed on pack 23B.) During the third taper charge, cell C5 reached 1.496 volts at 5 Amp rate after seventeen minutes and no high pressures occurred.

On 2/1/71 a 0°C overcharge test was performed on 35B. Figure 5.4.1-2 shows the results of this test. Cell voltages remained fairly close throughout the overcharge; divergence at the voltage peak was 15 mV while at the end of the charge it was only 11 mV.

After two more taper charges the pack was placed on automatic cycling at BVLS 4. Initial recharge ranged between 108 and 110 percent as shown in Figure 5.4.1-3. Although this pack never displayed the extent of voltage divergence that pack 23B did, by cycle 2300 cell C4 (S/N 515A) was beginning to show higher voltages than the others. Table 5.4.1-1 shows representative end-of-charge voltages from cycles 2301 through 5600 with the pack at BVLS 4:

* Taper charge is defined as follows: C/2 (10 Amp) until first cell reaches 1.496V; then C/4 (5 Amp) until first cell reaches 1.496V; then 1.6 Amp for 4 hours.

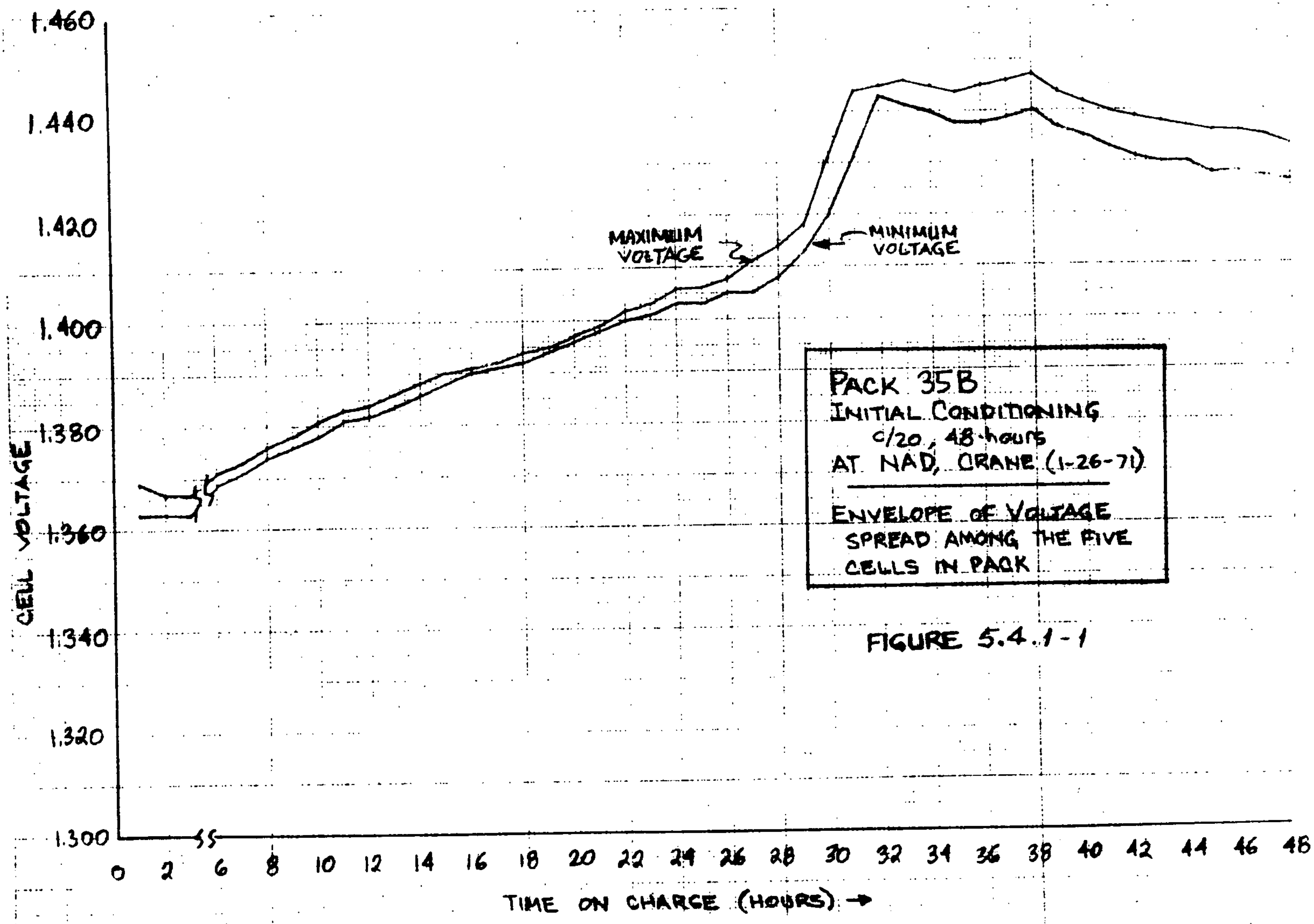
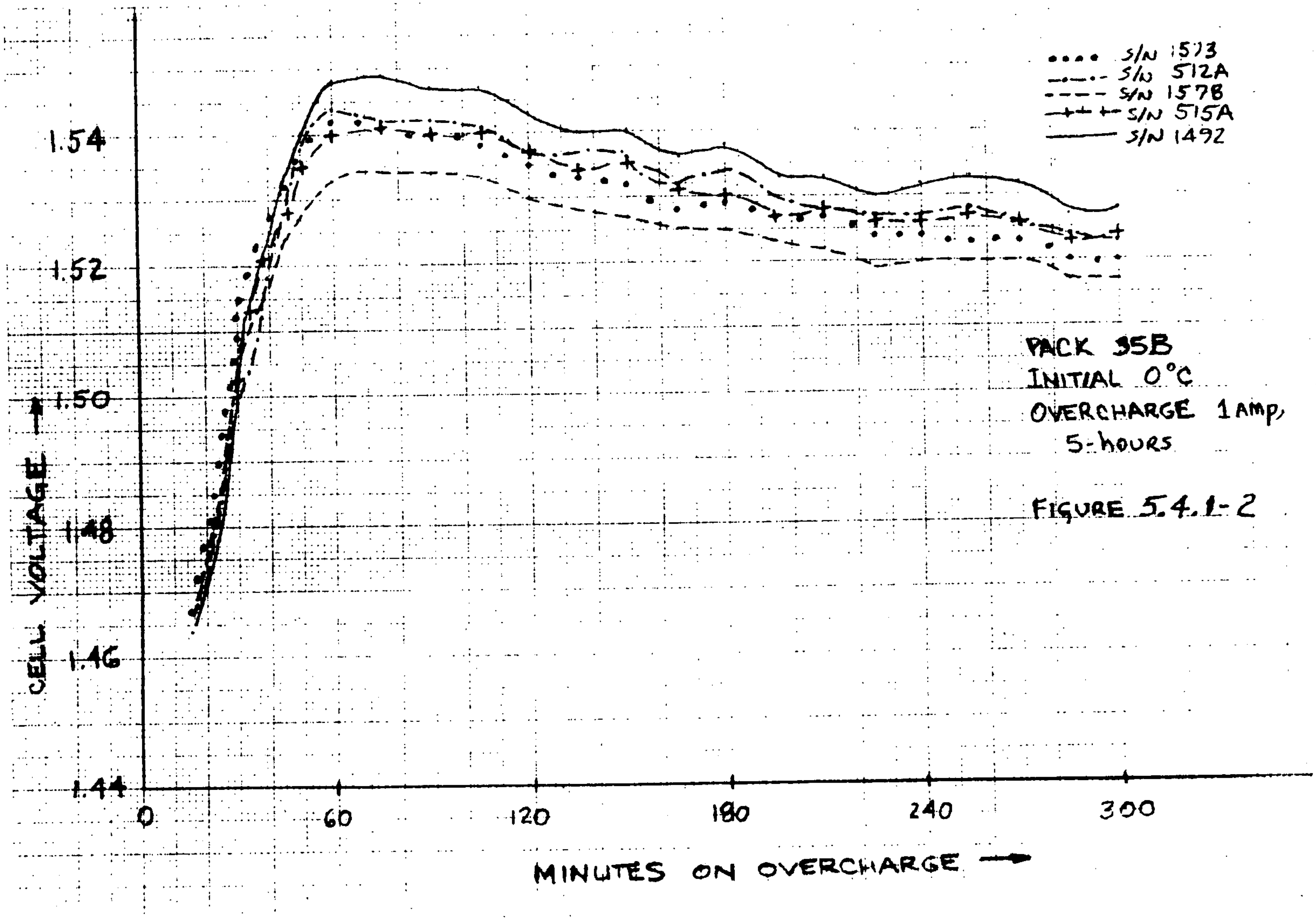

PACK 35B
INITIAL CONDITIONING
c/20, 48 hours
AT NAD, CRANE (1-26-71)
ENVELOPE OF VOLTAGE
SPREAD AMONG THE FIVE
CELLS IN PACK
MAXIMUM VOLTAGE
MINIMUM VOLTAGE
CELL VOLTAGE
1.460
1.440
1.420
1.400
1.380
1.360
1.340
1.320
1.300
0
2
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
TIME ON CHARGE (HOURS) →

FIGURE 5.4.1-1



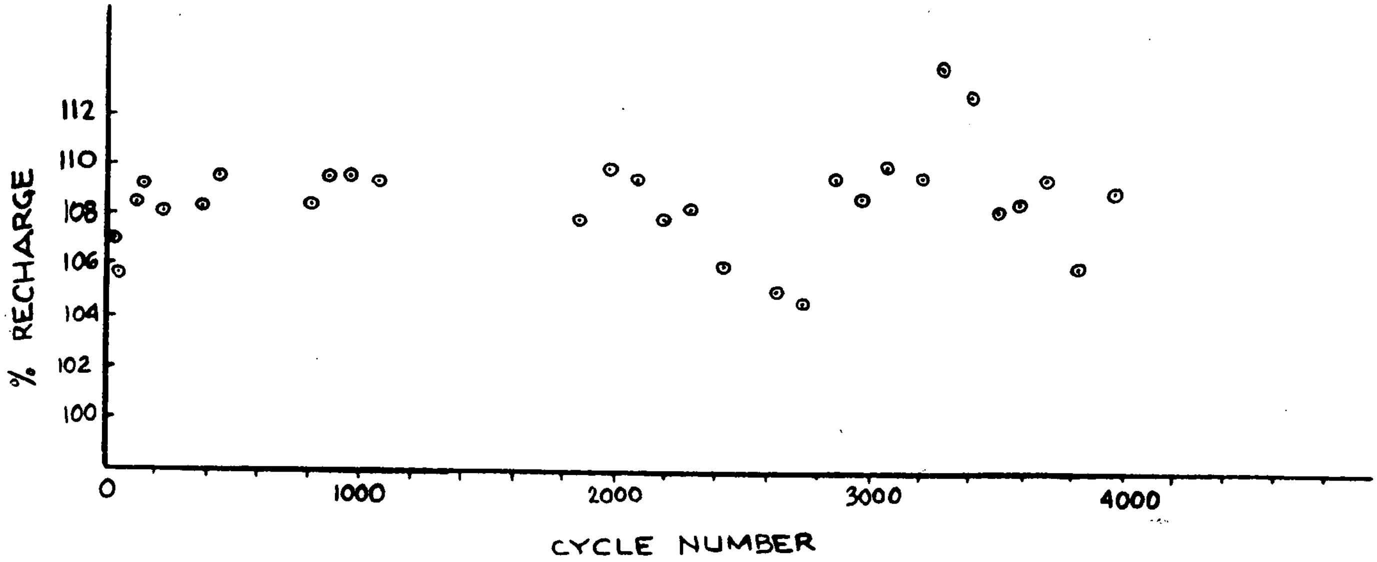
PACK 35B
INITIAL 0°C
OVERCHARGE 1 AMP,
5-hours

FIGURE 5.4.1-2

PACK 35B

CYCLE NUMBER vs. PER-CENT RECHARGE

FIGURE 5.4.1-3



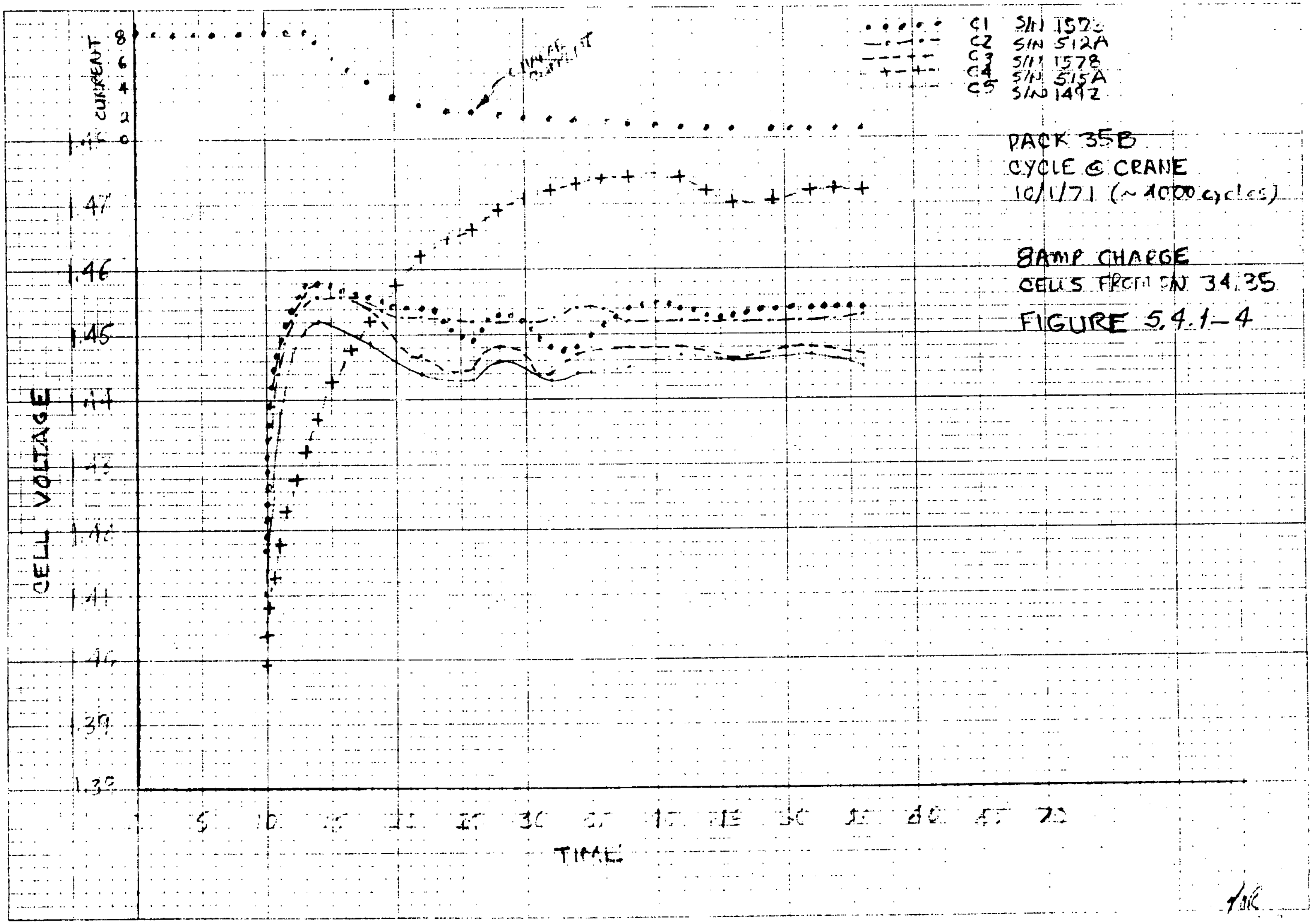
Cycle	C1	C2	C3	C4	C5
2301	1.44	1.43	1.43	1.45	1.42
2477	1.44	1.43	1.43	1.45	1.43
2567	1.44	1.43	1.43	1.45	1.43
2827	1.44	1.45	1.44	1.46	1.45
3336	1.44	1.44	1.43	1.46	1.43
3752	1.44	1.44	1.44	1.46	1.44
4000	1.45	1.45	1.45	1.47	1.45
5600	1.45	1.46	1.45	1.48	1.45

TABLE 5.4.1-1

As can be seen, cell C4 is 20-30 mV higher than the rest by cycle #5600. Pack 23B had a divergence of 150 mV by cycle 5600. A typical charge, around cycle #4000, is shown in Figure 5.4.1-4. The peculiar voltage profile of cell C4, with respect to the rest of the pack, is obvious.

On 10/24/71, at cycle 4200, the pack received a 0°C overcharge to see how cell C4 would behave if not tied to a voltage limit. The results, shown in Figure 5.4.1-5, demonstrate that C4 is truly exhibiting a higher voltage than the rest of the pack for the same charge current.

On 2/23/72, at cycle 5600, the cells exhibited the following end of charge voltages: C1 = 1.450 V, C2 = 1.455 V, C3 = 1.447 V, C4 = 1.475 V, and C5 = 1.451 V. Aside from cell C4, which has a divergence of nearly 30 mV, the rest of the pack shows remarkably close voltages. If we compare this to pack 23B after the same number of cycles, we see that 35B shows much better voltage uniformity. It is not believed the special precharge performed on 23B accounts for its greater voltage divergence since similar divergences have occurred on other cells with the standard precharge adjustment, and from this same battery lot. However, inspection of the cycling regimes of the various packs shows that pack 35B received lower total overcharges in ampere-hours than the other packs. Overcharging seems to cause certain stresses in the cell which may be manifested as voltage divergence. The nature of these stresses are, as yet, unknown, although they have appeared frequently. In an attempt to assess reduction techniques for divergence, the pack was placed on a lower limit (BVLS 1) on 2/24/72 at approximately cycle 5610. This should have the effect of limiting the overcharge each cell would experience since the current is exponentially decreased earlier in the charge period. By 3/17/72 -- approximately three weeks (300 cycles) later -- cell C4 was only 16 mV higher



PACK 35B
CYCLE @ CRANE
10/1/71 (~1000 cycles)

8AMP CHARGE
CELLS FROM S/N 34,35

FIGURE 5.4.1–4

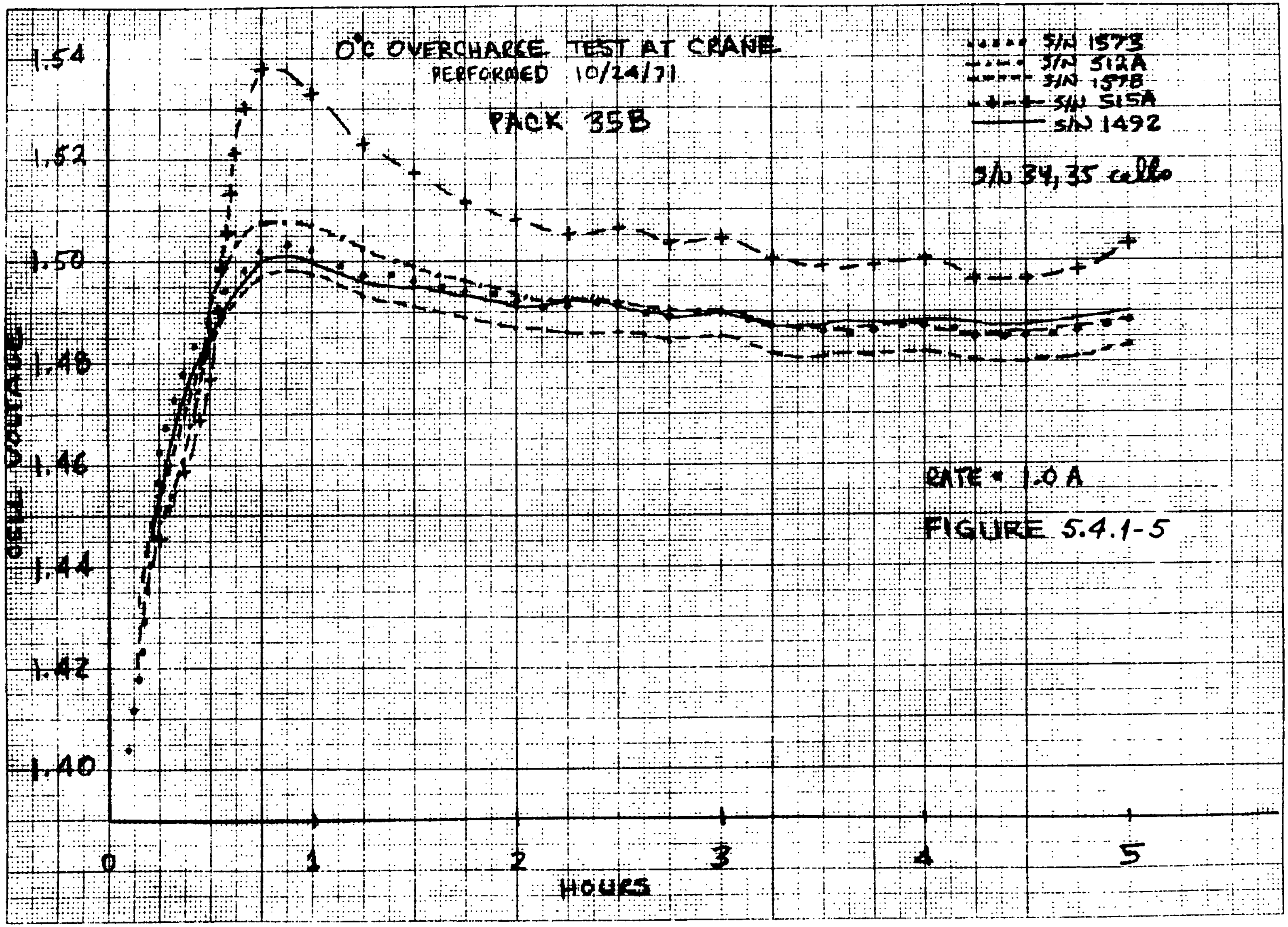

O°C OVERCHARGE TEST AT CRANE
PERFORMED 10/24/71
PACK 35B
S/N 1573
S/N 512A
S/N 1578
S/N 515A
S/N 1492
S/N 34,35 cells
RATE = 1.0 A
CELL VOLTAGE
1.54
1.52
1.50
1.48
1.46
1.44
1.42
1.40
HOURS
0
1
2
3
4
5

FIGURE 5.4.1-5

than the lowest cell in the pack. Voltages at end-of-charge were as follows: C1 - 1.415 V, C2 = 1.423 V, C3 = 1.423 V, C4 = 1.431 V, C5 = 1.419 V. Thus it appears that lowering the degree of overcharge (percent recharge) controls and minimizes voltage divergence. Additional evidence for this is shown for packs 5 and 6 on cycling test at Goddard (see 5.2 and 5.3).

5.5 SUMMARY OF TEST REGIME FOR PACK 12E

- No of series connected cells in pack: 5
- Cells from OAO battery S/N 32, 33 spare lot
- Cell serial nos.:

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
494A	916	954	920	955	-	-	-	-	-

- On test at:

NAD, Crane ⊗ Goddard Space Flight Center ○

- Depth of discharge: 15%
- Temperature: 20°C
- Cycle Period: 90 minutes
- Charge Rate: 8 amp
- Discharge Rate: 6 amp
- Date Test Began: 5/5/70
- Type of Charge Control

TEST DETAILS -

- This pack was on the same regime as pack 35B, except at higher temperature (20°C instead of 10°C)
- This pack was previously tested for 800 cycles at Goddard on various BVLS levels. It was designated Pack #1 at GSFC.

PACK 12E

5.5.1 Pack Description and Test Results

Pack 12E is a five (5)-cell pack on 20°C life cycling at NAD, Crane. The cells, from the spare lot of OAO battery S/N 32, 33 cells were tested for 800 cycles at GSFC on various BVLS levels before being sent to Crane. It began 20°C life cycling in May of 1970.

Upon receipt at NAD, Crane, the pack was given a C/10, 16-hr. conditioning charge after which a C/2 capacity discharge to +0.5 volts was performed. Capacities ranged as follows: C1 = 29.3 A-hr., C2 = 28.0 A-hr., C3 = 28.5 A-hr., C4 = 27.1 A-hr. and C5 = 27.5 A-hr.. The pack was then shorted, and a following open circuit recovery test revealed no shorts. Following a taper charge*, another capacity discharge at C/2 to +0.5 volts gave the following capacities: C1 = 27.3 A-hr., C2 = 27.8 A-hr., C3 = 28.1 A-hr., C4 = 27.8 A-hr., C5 = 27.1 A-hr.. A slight decrease in capacity is seen in a few of the cells. After another taper charge the cells were again discharged, this time at the cycle rate (6 amps) to +0.5 volts. Capacities were lower: C1 = 25.26 A-hr., C2 = 25.38 A-hr., C3 = 25.38 A-hr., C4 = 24.96 A-hr., C5 = 25.56 A-hr.. The pack began active cycling on 5/13/70. Percent recharge for the first thousand cycles remained at 107-108% (Figure 5.5.1-1). The end-of-charge voltages among the cells ranged from 1.42-1.44 volts during this period, a divergence of 15-20 mV. Figure 5.5.1-2 shows the voltage spread between the cells for the first 9000 cycles.

In July of 1970, pack 12E was subjected to its first 0°C overcharge test at approximately cycle 917. During the charge, cell C1 reached a high voltage (over 1.55 volts). The discharge following the overcharge revealed that C1 was the highest capacity cell (C/2 to +1.0 V):

C1 = 29.00 A-hr.
C2 = 27.60 A-hr.
C3 = 26.80 A-hr.
C4 = 25.80 A-hr.
C5 = 27.10 A-hr.

Following the capacity check the pack was taper charged and returned to cycling. On 10/19/70 after 2,477 cycles, the pack was again subjected to 0°C overcharge tests. Cell C1 reached very high voltages during the first overcharge (a maximum of 1.621 volts). The cell was shorted and reversed by 2

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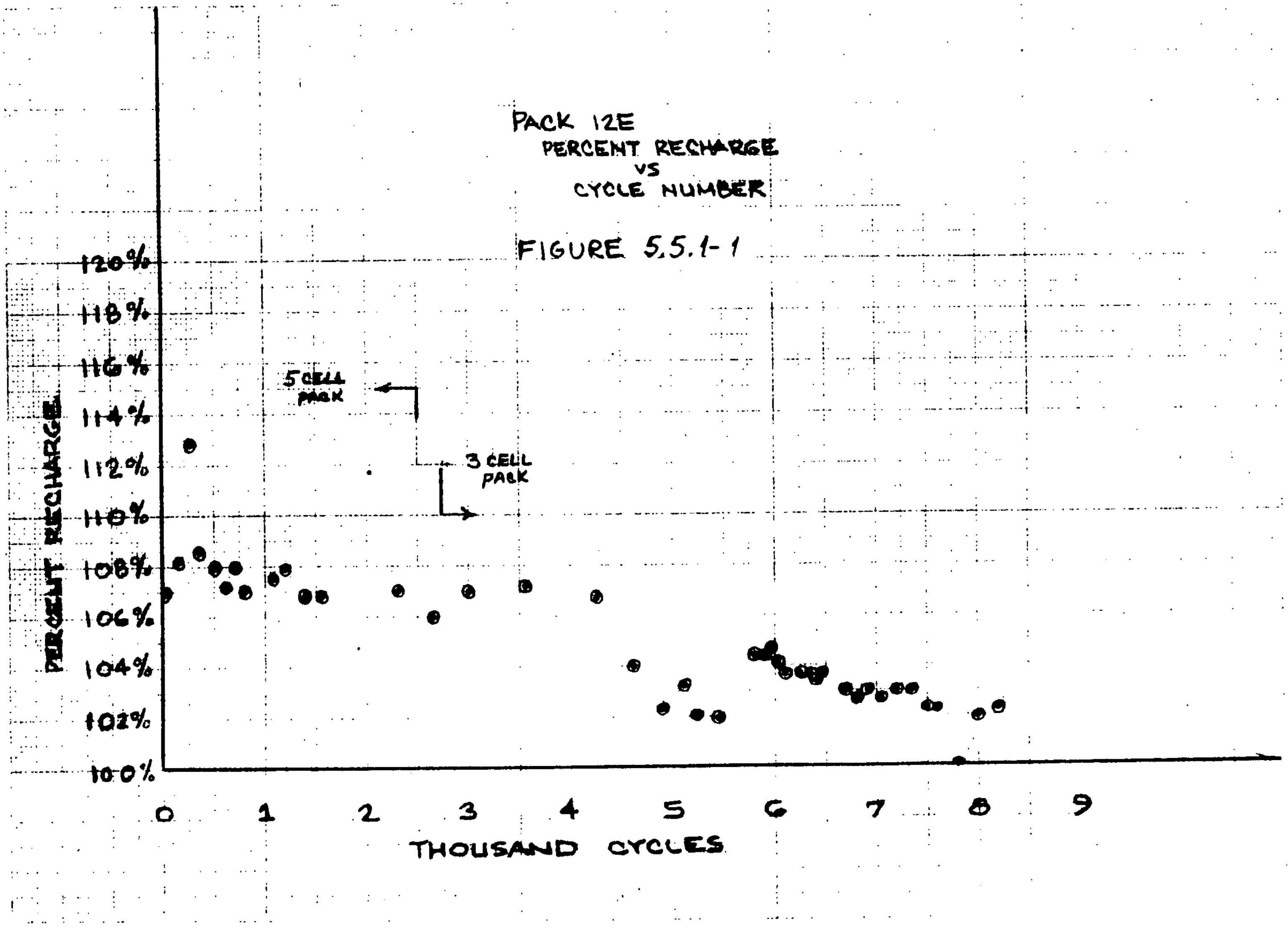
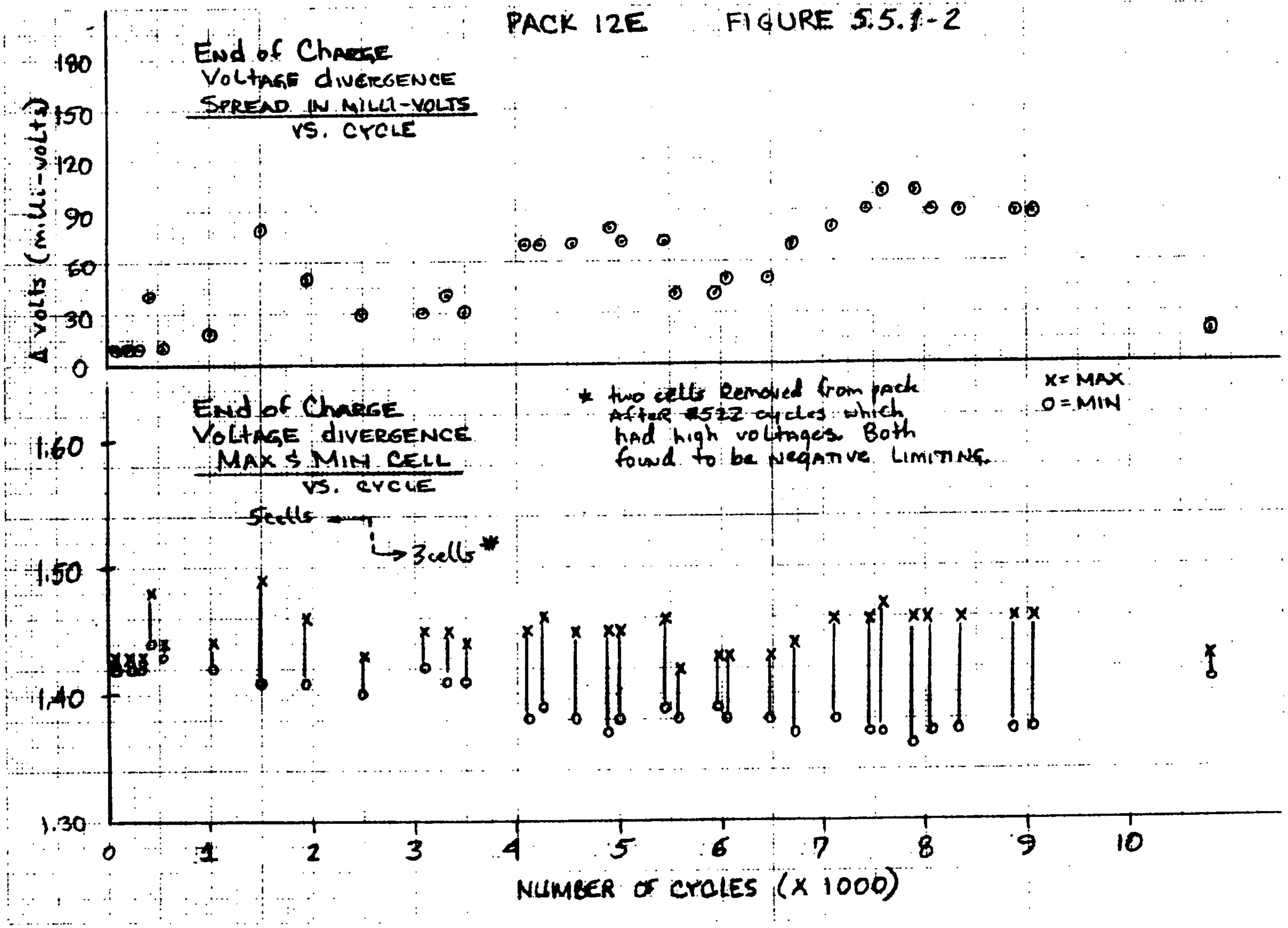
* For this pack taper charges were C/2 to voltage limit then
C/4 to voltage limit then
C/10 for one hour



PACK 12E
PERCENT RECHARGE
VS
CYCLE NUMBER

FIGURE 5.5.1-1

PACK 12E FIGURE 5.5.1-2



A-hr. to discharge the negative electrodes by that amount. The overcharge tests were repeated. Once again cell C1 exhibited high voltage on charge, about 1.612 volts at the peak. At this point it was decided to remove C1 from the pack and perform electrode capacity tests to determine the ratio and distribution of the electrode capacities.

On 10/26/70 this cell (S/N 494) was removed from pack 12E and discharged at 6.0 amps to +0.5 volts. Capacity to +1.0 volt was 28.8 AH and to +0.5 volt was 29.22 A-hr.. A 1 Ω resistor drained the cell for 16 hours prior to performing the electrode capacity ratio tests. The cell was reversed to -1.0 volts to determine the amount of precharged negative capacity. It was then flooded with electrolyte, charged at C/40 for 48 hours, and discharged at a C/2 rate to -1.5 volts. Table 5.5.1-1 shows the results given in ampere-hours:

Precharged Negative Capacity in A-hr.	Capacity to the Following Voltages in A-hr.: +1.0 V	+0.5 V	+0.0 V	-0.5 V	-1.0 V	-1.5 V
7.23	29.50	29.80	30.02	34.90	35.10	35.40

TABLE 5.5.1-1

As indicated, little or no excess negative capacity exists at the charged end; the total excess being in the form of precharged negative. The cell was again charged for 48 hours at C/10 and then discharged at C/2. The results from +1.0 volts to -1.5 volts were: 27.83 A-hr., 28.17 A-hr., 29.00 A-hr., 32.50 A-hr., 32.70 A-hr. and 32.80 A-hr., respectively. Additional tests were performed on individual electrodes removed from the cell case. The nickel and cadmium plates were charged at a 0.222 ampere rate each for 16 to 20 hours. Discharges were performed at a 1.11 amp rate on each plate. The results of tests on two cadmium and two nickel plates from C1 are given in Table 5.5.1-2.

Sample	Type	E.O.C.V.	Capacity (A-hr.)
P1	Cadmium	1.633 V	3.02
P2	Cadmium	1.632 V	3.13
P1	Nickel	--	3.42
P2	Nickel	--	3.25

TABLE 5.5.1-2

We see from Table 5.5.1-2 that the positive capacities exceed the negatives by as much as 12%. Crane reported that the separator "showed excess migration and moderate separator deterioration." It appears that the high voltages experienced during the low temperature overcharges were the result of negative limiting on charge. This should have the effect of establishing high pressures within the cell since the negatives would gas hydrogen with each overcharge. However, no high pressures were indicated.

On 11/10/70 at cycle 2729, cell C4 (S/N 920) was removed from the pack, also due to high voltages. The cell was discharged at C/2 to 0.0 volts and then reversed at C/10 to -1.0 volts to determine the amount of negative precharged capacity. Table 5.5.1-3 gives the results of this precharge measurement as well as a subsequent capacity discharge at C/2 to -1.5 volts.

Precharged Negative	Capacity to the Following Voltages in A-hr.					
Capacity in A-hr.	+1.0 V	+0.5 V	+0.0 V	-0.5 V	-1.0 V	-1.5 V
10.6 A-hr.	24.33	26.83	28.50	--	--	--
	28.00	28.20	29.00	37.70	38.50	38.50

TABLE 5.5.1-3

Table 5.5.1-3 shows essentially the same results as Table 5.5.1-2 showed for cell C1. About 10.6 ampere-hours of precharged negative capacity exists in the cell, representing all of the excess. This cell, like C1, was probably negative limiting on charge, resulting in high voltages and hydrogen gas evolution.

The other three cells in the pack remained on cycling after C1 and C4 were removed. Percent recharge remained about 107% until cycle 4500 after which it dropped to lower than 104%. Divergence in the three-cell pack showed a slight rise after the two cells were removed, but remained less than 100 mV through cycle 9000. End-of-charge voltages at cycle 9042 ranged from 1.403 volts to 1.460 volts. It is likely, in view of the high amount of precharge measured on the two cells removed, that the remaining three cells are also negative limiting on charge. A gas sample taken on 9/1/71, at cycle 7400, revealed 100% H_2 gas in cell 3.

5.6 SPECIAL TESTS ON BATTERY SERIAL NUMBERS 30 AND 31

Nickel-Cadmium Aerospace batteries are rarely used immediately after manufacture. Generally, there are several weeks of pre-flight checkouts, each separated by periods of inactive storage. A prerequisite for maintaining quality battery performance, therefore, is a proper storage mode prior to flight use.

Data on OAO battery S/N 30, 31 indicated that a high voltage divergence among the cells was occurring, and that this was correlatable to the time the battery stood open-circuited. Other data indicated that divergence could be significantly reduced by keeping the batteries short-circuited when not in use.

Figure 5.6-1 shows the overcharge voltage profile of two cells in battery S/N 30, 31 as a function of battery age*. The charge at 15 and 185 days shows no appreciable rise or divergence in voltage. However, after 500 days cell S/N 698 reached the hydrogen evolution voltage limit before three hours into the charge and the current had to be reduced. Even at this reduced rate (0.5 amp) it again reached the hydrogen evolution voltage limit and current had to be further reduced. The trend after 750 days (bottom curve) is similar although the voltage limit was reached even sooner.

Figure 5.6-2 shows the rise in cell voltage with age. As seen, those test cells from the battery S/N 30, 31 which were stored in a shorted condition since they left the seller's facility immediately following their manufacture and test showed neither high overcharge voltage nor a large divergence at over 500 days of age.

Figure 5.6-3 presents the maximum cell voltage spread on low temperature overcharge as a function of the cell's age. Again, the general diverging trend is readily observed.

Voltage rise with age has been attributed to negative electrode capacity loss through a mechanism reducing the amount of active cadmium available for electrochemical reaction. Charging the cell at low temperatures imposes more of a stress on the cadmium electrode than on the nickel electrode. Unless there is a sufficient excess of $Cd(OH)_2$ at the charged end, the cell could become negative limiting, evolving hydrogen. Battery S/N 30, 31 had a low final ratio of negative to positive capacities (1.074-1.279 based on four sample cells from that assembly). Later batteries have been fabricated with higher ratios to ensure sufficient negative excess.

Carbonate in the electrolyte has also been shown to cause an increase in cell voltage, but the amount of carbonate in those cells was not measured and the extent to which carbonate can raise cell voltage is not well known.

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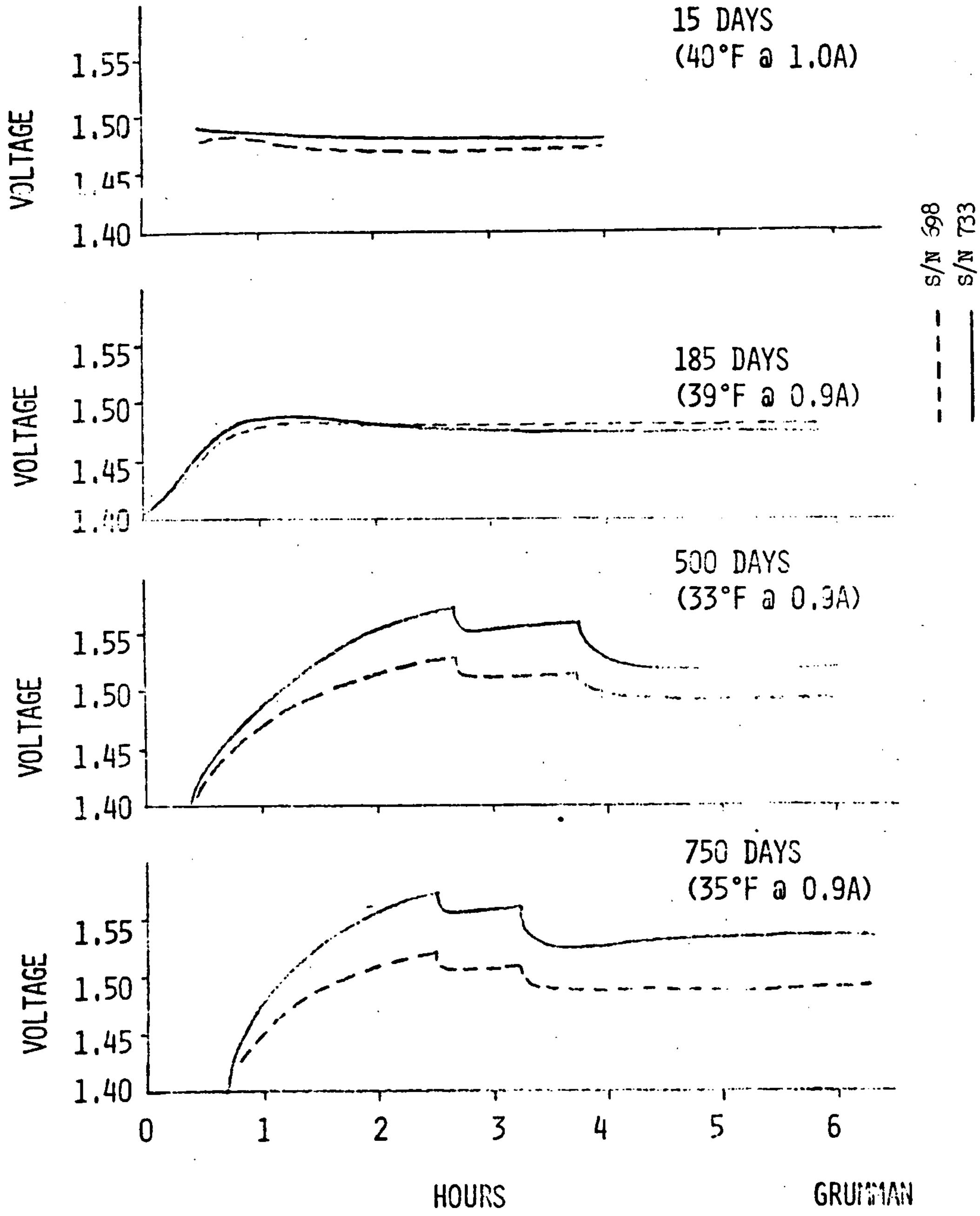
* Age is defined as the time from cell activation to test date.

EFFECTS OF AGE ON LOW TEMPERATURE OVERCHARGE VOLTAGE



GRUMMAN

FIGURE 5.6-2

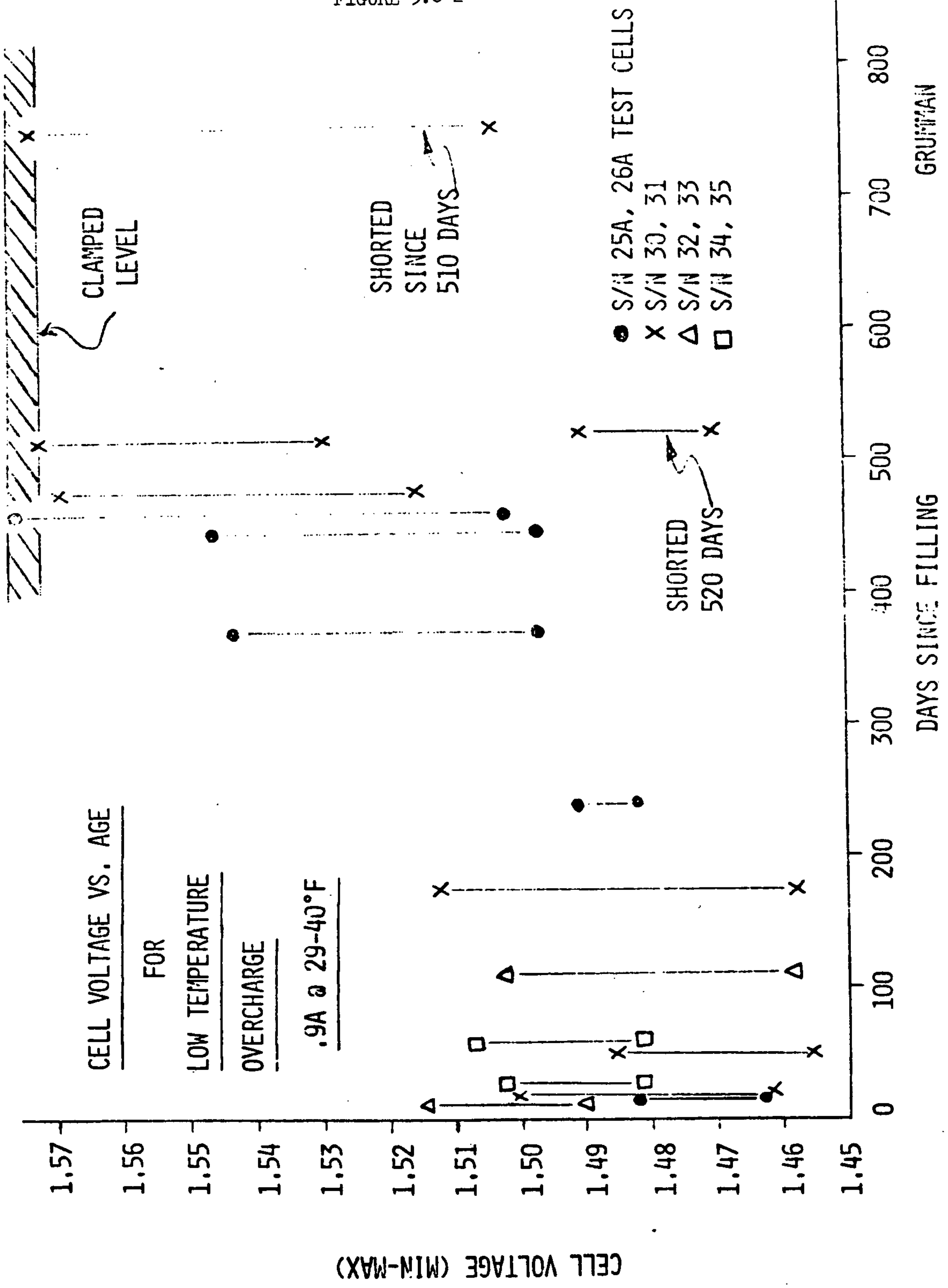
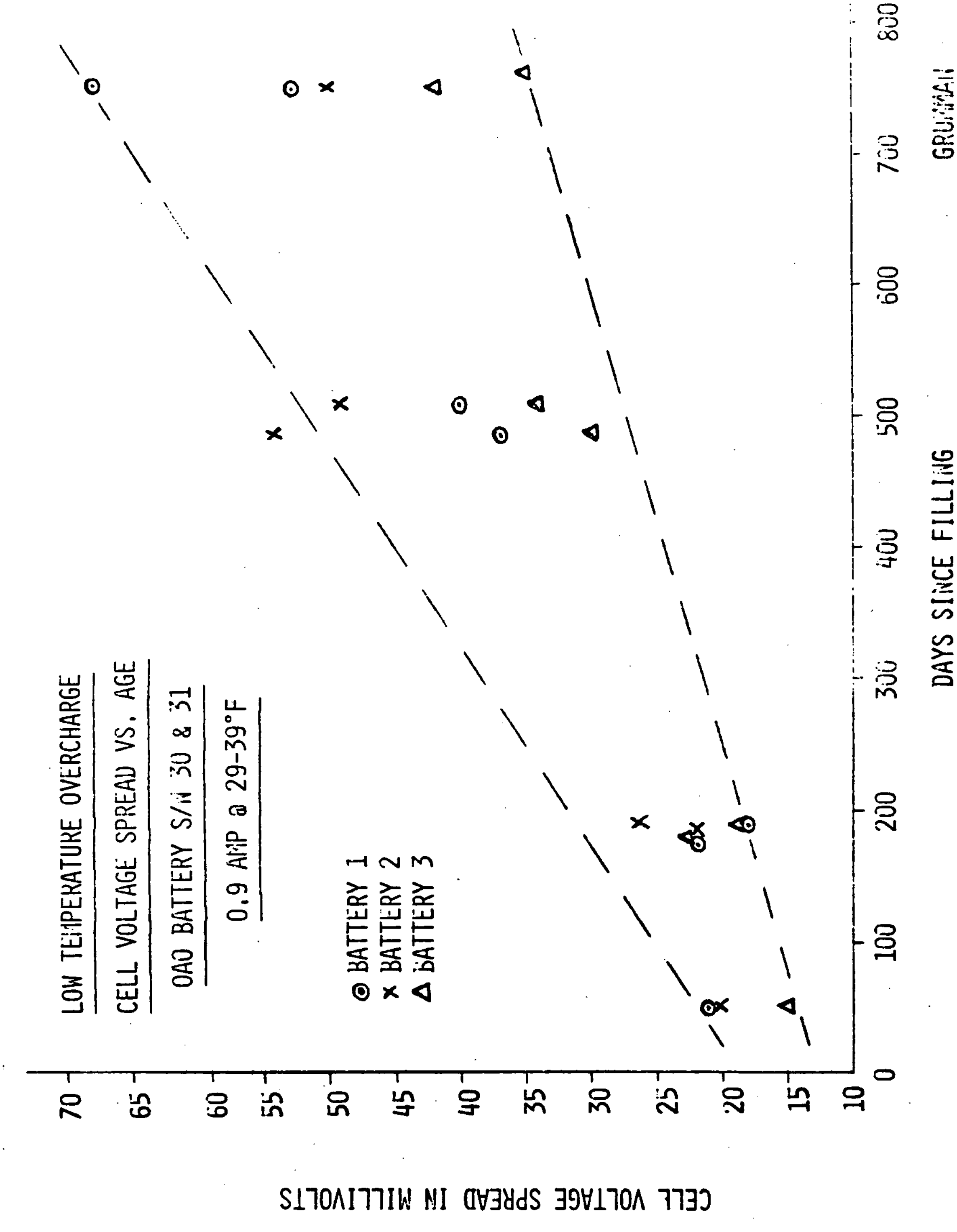

CELL VOLTAGE VS. AGE
FOR
LOW TEMPERATURE
OVERCHARGE
.9A @ 29-40°F
CLAMPED LEVEL
SHORTED SINCE 510 DAYS
SHORTED 520 DAYS
● S/N 25A, 26A TEST CELLS
X S/N 30, 31
Δ S/N 32, 33
□ S/N 34, 35
CELL VOLTAGE (MIN-MAX)
1.57
1.56
1.55
1.54
1.53
1.52
1.51
1.50
1.49
1.48
1.47
1.46
1.45
DAYS SINCE FILLING
0
100
200
300
400
500
600
700
800
GRUMMAN

FIGURE 5.6-3


LOW TEMPERATURE OVERCHARGE
CELL VOLTAGE SPREAD VS. AGE
OAO BATTERY S/N 30 & 31
0.9 AMP @ 29-39°F
⊙ BATTERY 1
× BATTERY 2
Δ BATTERY 3
CELL VOLTAGE SPREAD IN MILLIVOLTS
10
15
20
25
30
35
40
45
50
55
60
65
70
DAYS SINCE FILLING
0
100
200
300
400
500
600
700
800
GRUMMAN

5.7 SUMMARY OF TEST REGIME FOR PACKS 215A, 216A, 217A

- No. of series connected cells in pack: 5 per pack
- Cells from OAO battery S/N 34, 35 spare lot
- Cell serial nos.:

215A	216A	217A
C1 = 508A	C1 = 525A	C1 = 521A
C2 = 1560	C2 = 1555	C2 = 1473
C3 = 1523	C3 = 1478	C3 = 917
C4 = 1509	C4 = 1510	C4 = 1484
C5 = 520A	C5 = 523A	C5 = 522A

- On test at:

  NAD, Crane ☒ Goddard Space Flight Center ○
- Temperature: R.T.
- Date Test Began: 4/14/71
- Depth of Discharge:
- Cycle Period:
- Charge Rate:
- Discharge Rate:
- Type of Charge Control:

TEST DETAILS -

These three packs underwent six-month storage periods in various modes. Pack 215A received a random electrical manipulation to duplicate the conditions which OAO batteries experience during their pre-flight vehicle integration.

Pack 216A was shorted for the full six months while Pack 217A received a continuous trickle-charge for the duration of the storage period. Afterwards, the packs were tested to determine the effects the various storage modes had on their performance. Following these tests all three packs were placed back in their respective storage modes for another six-month period.

5.7.1 Test Results

The packs were stored in various modes for a six month period. Pack 215A underwent a random electrical regime to simulate the type of treatment an OAO battery would receive during the spacecraft integration and checkout period. Pack 216A was kept electrically shorted for the entire six month period, the mode presently used when the OAO batteries are in inactive storage. Pack 217A was on trickle-charge (500 ma) throughout the period. All three packs received electrical characterization cycles upon termination of the storage test period to determine what, if any, changes had occurred in their performance. The results which follow are for the end of the first six month storage. Upon completion of the electrical re-characterization regime the cells were placed back in their respective storage configuration for testing at six month intervals. Tables 5.7.1-1 through 5.7.1-3 list the checkout tests performed on the packs before and after they were stored for the six months.

5.7.2 Analysis of Results

Tables 5.7.2-1, 5.7.2-3 and 5.7.2-5 show the capacity measurements made before and after the storage period. Before the storage period, all packs showed similar capacities; the cells ranging from 23.3 A-hr. to 25.2 A-hr.. Following the storage, pack 215A (Table 5.7.2-1) showed a slight increase in capacity while the other two packs showed slight decreases. It is interesting to notice the large increases in capacity which occurred on packs 215A and 217A on 10/24/71. These two packs received an 11 hour, 1 amp, charge prior to being taper charged. This low rate charge before the taper charge may be responsible for the increased capacity since pack 216A, taper charged without first having the 1 amp charge, did not show any capacity increase. All three packs had been sufficiently overcharged prior to this capacity check and the A-hr. input was similar on all the packs (36.3 AH to 41.6 AH). If the low rate charge is, in fact, responsible for the capacity increase, the mechanism causing the greater return is unknown, although it may "condition" the cell to take the higher rate charge more efficiently. No shorts of any kind seem to have occurred as a result of the storage as evidenced by the open-circuit recovery results shown in Tables 5.7.2-2, 5.7.2-4 and 5.7.2-6.

Of prime interest in these tests was to see how the cells reacted to a low temperature overcharge following storage. Recall that it was the

TABLE 5.7.1-1

CHECKOUT TESTS AT NAD, CRANE (PACK 215A)

DATE	TEST	COMMENTS
4/9/71	C/20 for 48 hours	Initial conditioning charge
4/9/71	Capacity discharge C/2 to 0.5 V each taper charge	Capacity data given in Table 5.7.2-1
4/11/71	Taper charge	See variation of cell voltage on taper charge in Figure 5.7.2-1.
4/12/71	C/2 dischg. until first cell reaches 0.5 V	C5 first to reach 0.5 V after 2 hr. 25 minutes. (24.10 A-hr.)
4/12/71	16 hr., 1Ω -short	
4/12/71	24-hr. open ckt. stand	Open-circuit voltages Table 5.7.2-2
4/13/71	Taper charge	
4/14/71	4-hr. stabilization in 0°C chamber @ 0.5 amp	
4/14/71	Dischg. 6.0 A, 5 minutes	
4/14/71	Overcharge C/20 for 5 hours	See variation of cell voltage in overcharge, Fig. 5.7.2-4
4/14/71	Capacity discharge C/2 to 0.5 V (1st cell)	C5 first to reach 0.5 V after 2 hr. 24 minutes (24.00 A-hr.)
4/14/71	Taper charge	
4/14/71 to 10/19/71	STORAGE TEST	
10/21/71	4-hr. stabilization in 0°C chamber, @ 0.5 amp	
10/21/71	Dischg. 6.0 A, 5 minutes	
10/21/71	Overchg. C/20 for 5 hours	See Figure 5.7.2-4
10/22/71	Capacity discharg. C/2 to 0.5 V ea.	See Table 5.7.2-1
10/22/71	16 hr., 1Ω short	See Table 5.7.2-2
10/23/71	1 amp charge for 10.5 hours	S/B taper (10A) charge instead of (1A) charge rate
10/24/71	Taper charge	
10/24/71	C/2 to 0.5 volt ea.	See Table 5.7.2-1
10/24/71	Taper charge	(NOTE: terminated after 10 minutes on 1.6A due to high cell pressure on cell #508 = +76 psig and cell #520 = +82 psig
10/24/71 to 10/27/71	OPEN CIRCUIT	
10/27/71	4 hr. stabilization in 0°C chamber @ 0.5 amp	
10/27/71	Dischg. 6.0 A, 5 minutes	
10/27/71	Overcharge C/20 for 5 hours	See Figure 5.7.2-4 (NOTE: overcharge terminated after 2 hr.,15 minutes @ 0°C @ 1 amp due to high voltage on cell #508 = 1.553 V).
10/27/71	Capacity dischg. (C/2 to 0.5 volt ea.)	See Table 5.7.2-1 (NOTE: cells discharged past 0.5 V - cell #530 down to 0.171 volts)
10/28/71	Taper charge	See Figure 5.7.2-1 (NOTE: 1.6A rate terminated after 1 hr. 47 min. due to high cell pressure on cell #508 = +64 psig and cell #520 = +75 psig.

TABLE 5.7.1-2

CHECKOUT TESTS AT NAD, CRANE (PACK 21A)

DATE		
4/7/71	C/20 for 48 hrs.	**Initial conditioning cycle**
4/9/71	Capacity dischg. C/2 to 0.5 V ea.	**Capacity data given in Table 5.7.2-3**
4/11/71	Taper charge	**See variation of cell voltage on taper charge, Figure 5.7.2-2**
4/12/71	C/2 dischg. until 1st cell reaches 0.5 V	**C3 first to reach 0.5 V after 2 hr. 27 min. (24.5 A-hr.)**
4/12/71	16 hr. 1Ω short	
4/12/71	24 hr. open-ckt. stand	**open-ckt. voltages Table 5.7.2-4**
4/13/71	Taper charge	
4/14/71	4 hr. stabilization in 0°C chamber @ 0.5 amp	
4/14/71	Dischg. 6.0 A, 5 min.	
4/14/71	Overchg. C/20 for 5 hrs. in 0°C chamber	See variation of cell voltage in overcharge, Figure 5.7.2-5
4/14/71	Capacity dischg. C/2 to 0.5 V (1st cell)	C3 first to reach 0.5 volts after 2 hr. 20 min. (23.33 A-hr.)
4/14/71	Taper charge	
4/15/71	Dischg. C/2 to 0.5 V (1st cell)	C3 first to reach 0.5 volts after 2 hr. 15 min. (22.50 A-hr.)
4/15/71	1Ω short, 16 hrs.	
4/15/71	Dead short each cell	
4/15/71 to 10/20/71	STORAGE TEST	
10/20/71	C/20 for 48 hrs.	Post short conditioning
10/22/71	Temp. stabilization 4 hrs., 0°C @ 0.5 amp	
10/22/71	Dischg. 6.0 A, 5 min.	
10/22/71	Overchg. C/20 for 5 hrs.	See Figure 5.7.2-5
10/22/71	Capacity dischg. to 0.5 V ea.	See Table 5.7.2-3
10/22/71	16 hr. 1Ω short	
10/23/71 to	24 hr. open ckt. stand	See Table 5.7.2-4
10/24/71	24 hr. open ckt. stand	
10/24/71	Taper charge	
10/26/71	Capacity dischg. to 0.5 V ea.	See Table 5.7.2-4
10/27/71	Taper charge	
10/27/71	4 hr. stabilization in 0°C chamber @ 0.5 amp	
10/28/71	Dischg. 6.0 A, 5 min.	
10/28/71	Overchg. C/20 for 5 hrs.	<u>NOTE:</u> Terminated after 45 min. due to high voltages on cells 1.543 V to 1.556 V, all cells).
10/28/71	Capacity dischg. to 0.5 V ea.	See Table 5.7.2-3
10/28/71	Taper charge	See Figure 5.7.2-2
10/28/71	Dischg. C/2 to 0.5 V 1st cell	C2 first to reach 0.5 V after 2 hr. 14 min. (22.33 AH)
10/28/71	Short 1Ω, 16 hrs.	
10/29/71	Dead short each cell	

TABLE 5.7.1-3

CHECKOUT TESTS AT NAD, CRANE (PACK 217A)

DATE		
4/7/71	C/20 for 48 hours	Initial conditioning cycle
4/9/71	Capacity dischg. C/2 to 0.5 V ea.	Capacity data given in Table 5.7.2-5
4/11/71	Taper charge	See variation of cell voltage on taper charge, Figure 5.7.2-3
4/12/71	C/2 dischg. until first cell reaches 0.5 V	C5 first to reach 0.5 volts after 2 hr. 21 min. (23.50 A-hr.)
4/12/71	16 hr., 1Ω short	
4/12/71	24 hr. open-ckt. stand	Open-ckt. voltages, Table 5.7.2-6
4/13/71	Taper charge	
4/14/71	4 hr. stabilization in 0°C chamber @ 0.5 amp	
4/14/71	Dischg. 6.0 A, 5 minutes	
4/14/71	Overchg. C/20 for 5 hrs. in 0°C chamber	See variation of cell voltage in overchg., Figure 5.7.2-6
4/14/71	Capacity dischg. C/2 to 0.5 V (1st cell)	C5 first to reach 0.5 volts after 2 hr. 20 min. (23.30 A-hr.)
4/14/71	Taper charge	
4/15/71	Trickle charge (500 MA)	
4/15/71 to 10/21/71	STORAGE TEST	
10/21/71	Temp. stabilization 4 hr., 0°C @ 0.5 amp	
10/21/71	Dischg. 6.0 amp, 5 min.	
10/21/71	Overchg. C/20 for 5 hours in 0°C chamber	See Figure 5.7.2-6
10/22/71	Capacity dischg. C/2 to 0.5 V ea.	See Table 5.7.2-5
10/22/71	16 hr. 1Ω-short	
10/23/71	24 hr. open ckt. stand	See Table 5.7.2-6
10/23/71	1 amp charge for 11 hrs.	S/B taper (10A)
10/24/71	Capacity dischg. C/2 to 0.5 V ea.	
10/25/71	Taper charge	See Table 5.7.2-5
10/27/71	Temp. stabilization 4 hr., 0°C @ 0.5 amp	
10/27/71	Dischg. 6.0 A, 5 min.	
10/27/71	Overchg. C/20 for 5 hrs. in 0°C chamber	See Figure 5.7.2-6
10/27/71	Capacity dischg. C/2 to lower than 0.5 V	C5 discharged down to 0.195 volt
10/28/71	Taper charge	See Figure 5.7.2-3
10/29/71	Placed back on trickle charge (500 ma).	

TABLE 5.7.2-1

CAPACITY DATA - PACK 215A

(C/2 to + 1.0V)

Date of Test	Temperature	AH$_{in}$ Prior Cycles	Type of Prior Charge	AH$_{out}$ this Cycle
4/9/71	Rm. Ambient	48 AH	C/20 for 48 hours	24.3,24.3,24.7,25.2,24.2
10/22/71	" "	?	C/20 for 5 hrs. @ 0°C	24.5,22.1,23.0,23.8,24.7
10/24/71	" "	37.6 AH	1 amp 10.5 hr. then taper charge	27.5,26.7,26.5,25.7,26.8
10/27/71	" "	33.25 AH	C/20 for 5 hrs. @ 0°C	24.2,23.5,23.7,24.2,23.3

TABLE 5.7.2-2

24-HR. OPEN-CKT. VOLTAGE RECOVERY TEST - PACK 215A

Date of Test	Temperature	Start of 24-Hr. OCV Test (volts)	End of 24-Hr. OCV Test (volts)
4/12/71	Rm. Ambient	0.148,0.249,0.072,0.062,0.173	1.161,1.167,1.179,1.179,1.173
10/22/71	" "	0.035,0.025,0.025,0.024,0.035	1.182,1.175,1.166,1.169,1.188

TABLE 5.7.2-3

CAPACITY DATA - PACK 216A
(C/2 to +1.0V)

Date of Test	Temperature	AH_{in} Prior Cycles	Type of Prior Charge	AH_{out} this Cycle
4/9/71	Rm. Ambient	48 AH	C/20 for 48 hours	24.0,24.3,24.2,24.3,24.5
10/22/71	" "	54.5 AH	C/20 for 5 hr. @ 0°C	23.8,24.5,23.7,24.1,24.1
10/26/71	" "	36.3 AH	Taper Charge	22.7,23.0,22.6,22.8,22.5
10/28/71	" "	34.45 AH	Taper → C/20 0°C for 45 min.	23.2,23.3,23.2,23.2,23.2

TABLE 5.7.2-4

24-HR. OPEN-CKT. VOLTAGE RECOVERY TEST - PACK 216A

Date of Test	Temperature	Start of 24-Hr. OCV Test (volts)	End of 24-Hr. OCV test (volts)
4/12/71	Rm. Ambient	0.391,0.166,0.089,0.093,0.317	1.140,1.158,1.187,1.187,1.136
10/2371	" "	0.591,0.430,0.413,0.390,0.130	1.202,1.202,1.217,1.215,1.204

TABLE 5.7.2-5

CAPACITY DATA - PACK 217A
(C/2 to +1.0V)

Date of Test	Temperature	AH_{in} Prior Cycles	Type of Prior Charge	AH_{out} this Cycle
4/9/71	Rm. Ambient	48 AH	C/20 for 48 hrs.	23.7,23.8,24.7,24.0,23.3
10/22/71	" "	2,268 AH	39.7 (taper) ±2,268 (trickle) +21.5 (overcharge)	24.3,24.3,28.1,24.7,24.8
10/24/71	" "	41.6 AH	11 hr. @ 1 amp then taper	29.7,29.8,30.8,30.0,29.8
10/27/71	" "	46.3 AH	39.8 (taper) 6.5 (overcharge)	24.0,24.8,24.8+,24.3,23.

TABLE 5.7.2-6

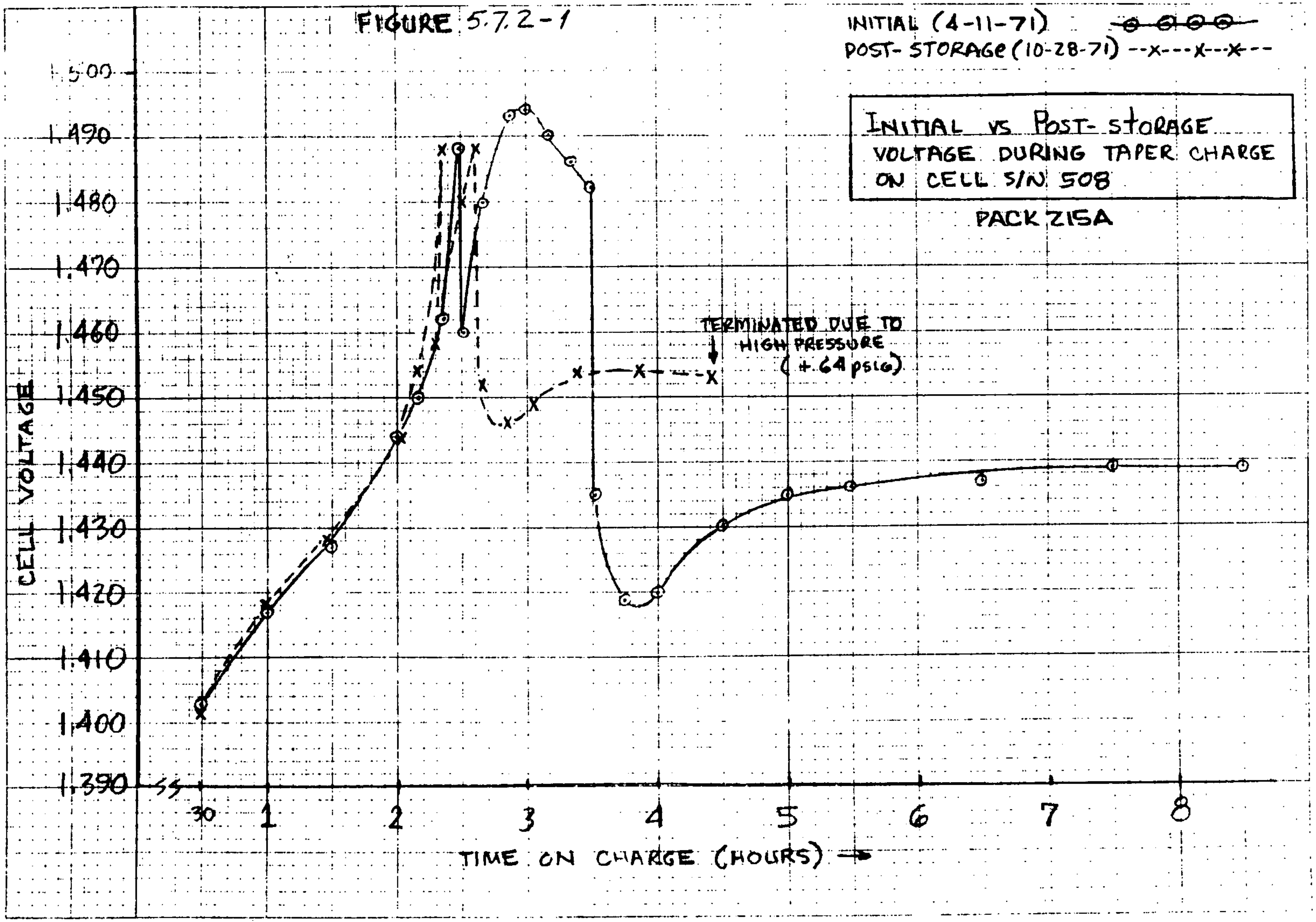
24-HR. OPEN-CKT. VOLTAGE RECOVERY TEST - PACK 217A

Date of Test	Temperature	Start of 24-Hr. OCV Test (volts)	End of 24-Hr. OCV Test (volts)
4/12/71	Rm. Temp.	0.444,0.152,0.063,0.256,0.392	1.152,1.158,1.192,1.143,1.128
10/23/71	" "	0.241,0.149,0.202,0.099,0.292	1.182,1.179,1.174,1.183,1.185

low temperature overcharge tests on OAO battery S/N 30, 31 that revealed a rising end-of-charge voltage trend with age. Low temperature is known to place a stress on the cadmium electrode making it perform poorly on charge. It has been suggested that some undefined mechanism operates to reduce the amount of active cadmium in a cell as a function of age. One such might be growth of the cadmium hydroxide crystal size with age, with the concomitant effect of reducing overall active surface area on the negative electrode. Whatever is occurring, the possibility of negative limiting could be detected in advance by running low temperature overcharge. A cell whose negative-to-positive ratio is approaching unity due to age should become negative limiting under the stresses imposed on the cadmium electrode by the low temperature. On 4/14/71 a 0°C overcharge was performed on the three packs. Before this the cells were charged fully by a taper charge. Figures 5.7.2-1 through 5.7.2-3 show profiles of the three pack voltages during taper charge before and after storage. Before the storage period, all three packs exhibited similar voltages on charge. Each pack reached a maximum of about 1.490 volts while in the 5 amp portion of the charge and did not have to be cut back further in current. In the taper charge following storage, the current for packs 215A and 216A had to be reduced to the lowest rate (1.6A) or some cells would have exceeded the voltage limit in the 5 amp portion. Pack 217A did not exhibit this sharp voltage rise. Pack 215A had to be terminated early into its 1.6 amp charge due to high pressure. A gas sample was not taken.

Figures 5.7.2-4 through 5.7.2-6 show overcharge results for two tests after storage compared to a pre-storage test. Pack 215A again exhibited high pressures as it did during taper charges. On a later overcharge it had to be terminated due to high voltages, another possible indication of a negative-limiting cell. Pack 216A did not appear very different on the first overcharge following the storage period, but had to be prematurely terminated on a later overcharge due to high voltage indications. Pack 217A performed nearly identically both before and after the storage period as can be seen in Figure 5.7.2-6. No evidence is shown that the storage period had any adverse effects on the pack. Although pack 217A did not reach high voltages on overcharge, it exhibited an increase in voltage divergence with storage, as did both the others. Table 5.7.2-7 is a summary of the high and low voltages reached during overcharge tests. The increasing spread in voltage at the

FIGURE 5.7.2-1



INITIAL vs POST-STORAGE VOLTAGE DURING TAPER CHARGE ON CELL S/N 508

PACK 215A

INITIAL (4-11-71)

POST-STORAGE (10-28-71)

TERMINATED DUE TO HIGH PRESSURE (+.64 psig)

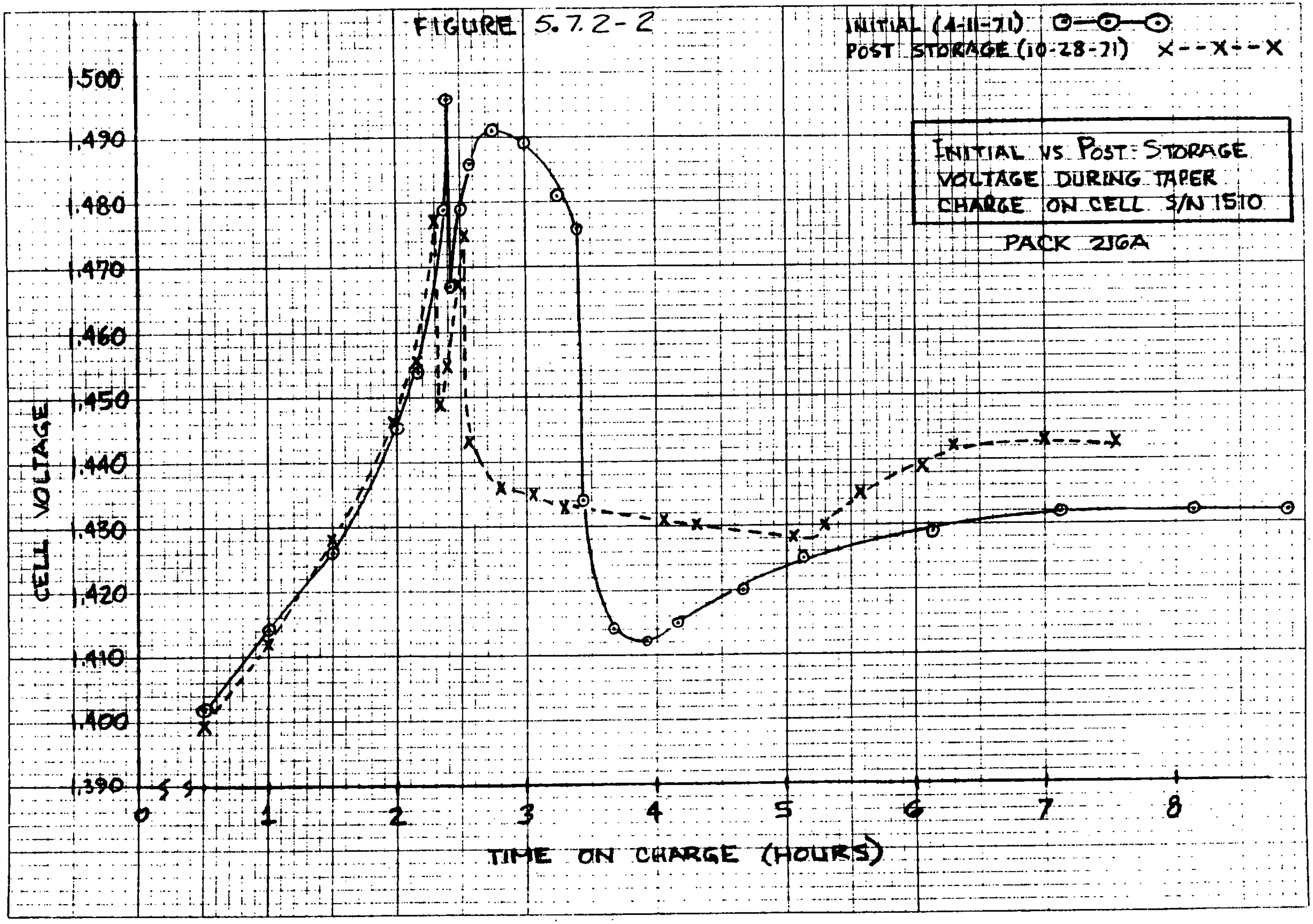


FIGURE 5.7.2-2

INITIAL VS POST-STORAGE VOLTAGE DURING TAPER CHARGE ON CELL S/N 1510

PACK 216A

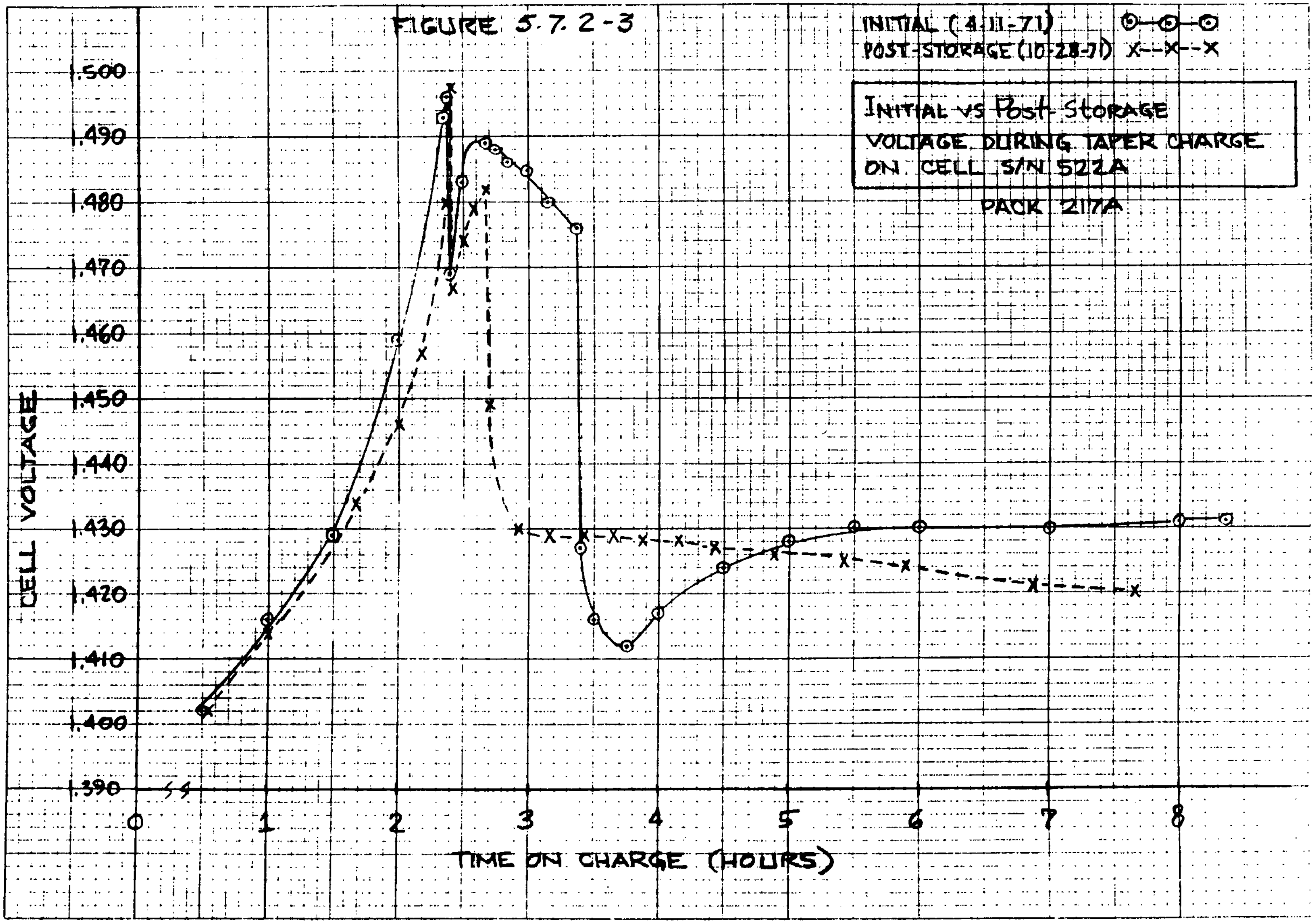


FIGURE 5.7.2-3

INITIAL VS POST STORAGE VOLTAGE DURING TAPER CHARGE ON CELL S/N 522A PACK 217A

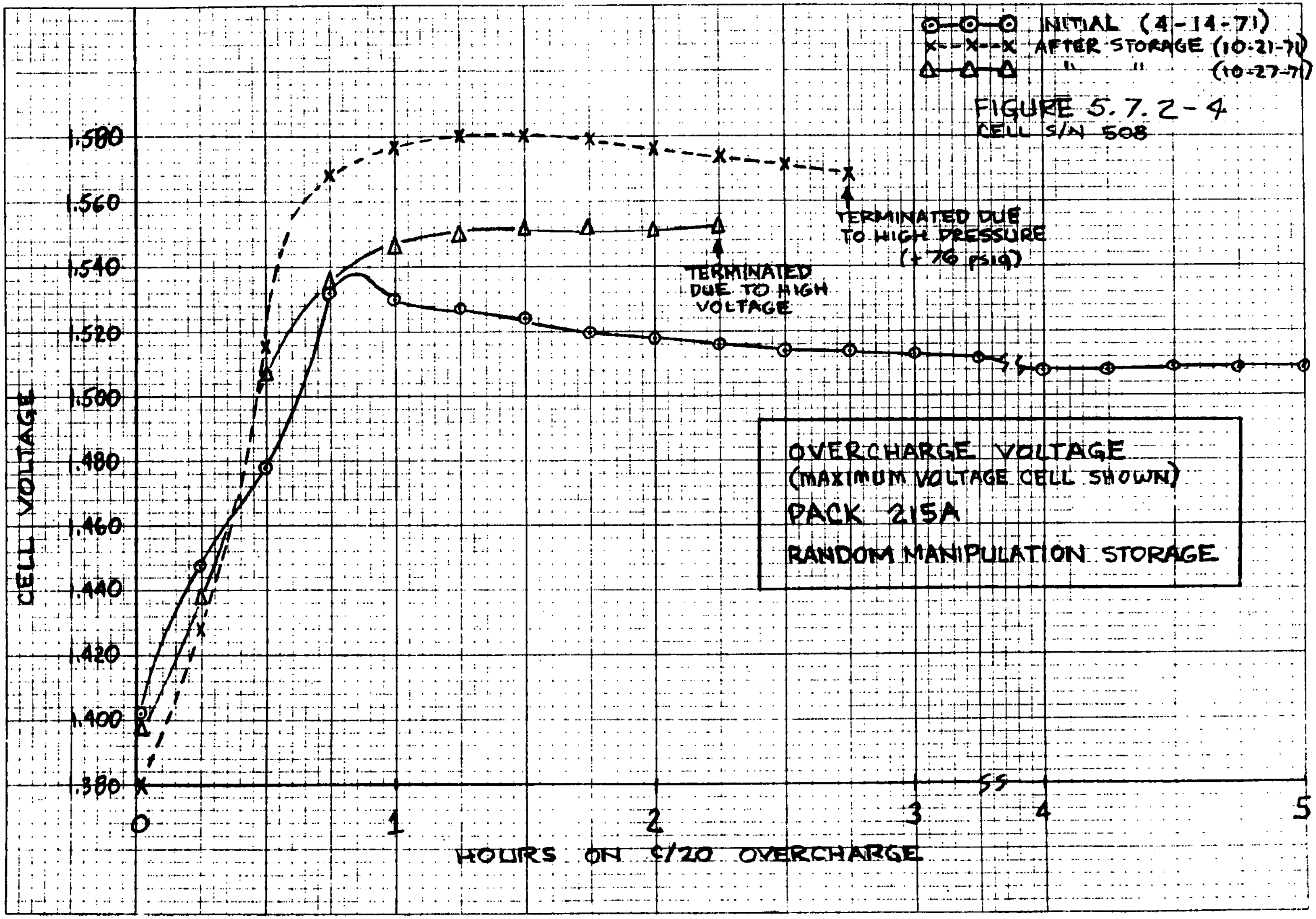


FIGURE 5.7.2-4
CELL S/N 508

NO. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

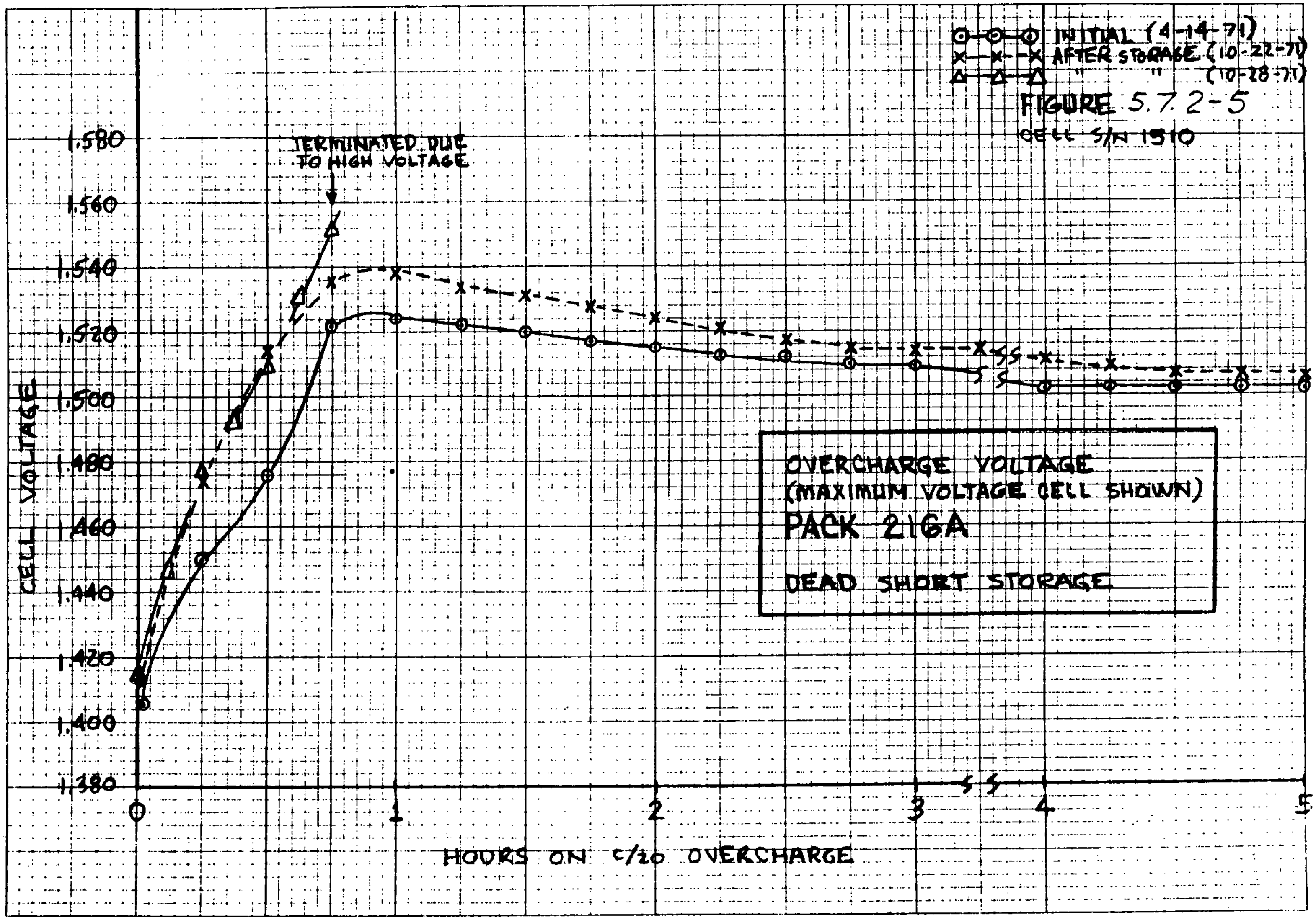


FIGURE 5.7.2-5
CELL S/N 1510

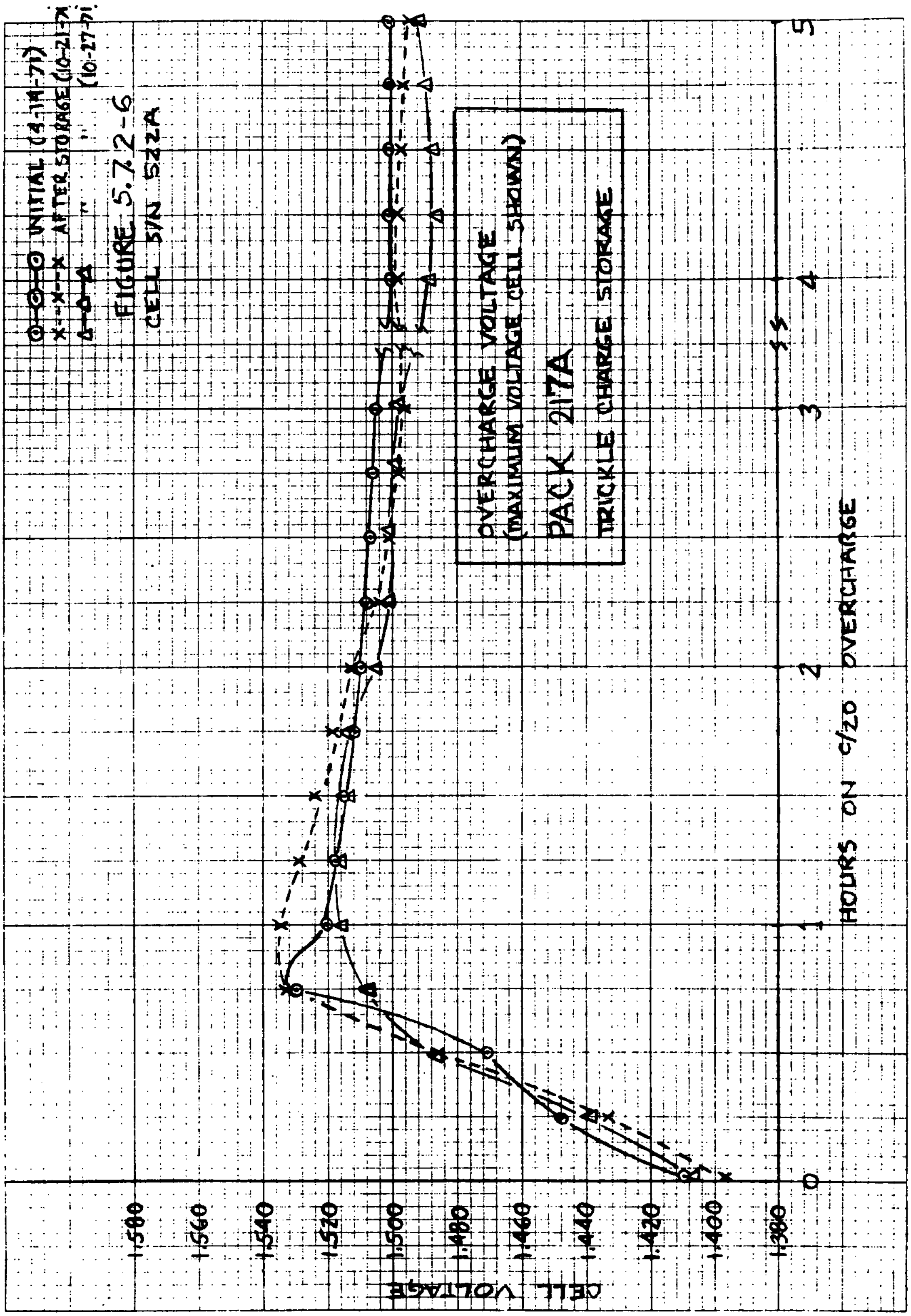


FIGURE 5.7.2-6
CELL S/N 522A

VOLTAGE DIVERGENCE ON LOW TEMPERATURE OVERCHARGE

PACK 215A

Test Date	Max. V	Min. V	Time	Delta (Max.-Min.) (mV)
4/14/71	1.532 V (1)	1.525 V (3)	0+45 min.	7.0
10/21/71	1.580 V (1)	1.541 V (3)	0+90 min.	39.0
10/27/71	1.553 V (1)	1.522 V (3)	0+135 min.*	31.0*

PACK 216A

Test Date	Max. V	Min. V	Time	Delta (Max.-Min.) (mV)
4/14/71	1.528 V (3)	1.522 (1,4,5)	0+45 min.	6.0
10/22/71	1.549 V (5)	1.536 (4)	0+45 min.	13.0
10/28/71	1.556 V (4)	1.543 (1)	0+45 min.*	13.0*

PACK 217A

Test Date	Max. V	Min. V	Time	Delta (Max.-Min.) (mV)
4/14/71	1.530 V (5)	1.523 (1,3)	0+45 min.	7.0
10/21/71	1.541 V (3)	1.522 (2)	0+45 min.	19.0
10/27/71	1.535 V (3)	1.506 (1)	0+45 min.	29.0

* CHARGE TERMINATED, VOLTAGES WERE STILL INCREASING

TABLE 5.7.2-7

PRESSURE CHANGE ON LOW TEMPERATURE OVERCHARGE

PACK 215A - CELL S/N 508

Test Date	Initial Pressure	End-Of-Charge Pressure	Delta Pressure
4/14/71	-08 psig	+07 psig	+15 psig
10/21/71	+22 psig	+76 psig	+54 psig
10/27/71	+15 psig	+44 psig	+29 psig

PACK 216A - CELL S/N 525

Test Date	Initial Pressure	End-Of-Charge Pressure	Delta Pressure
4/14/71	-04 psig	+09 psig	+13 psig
10/22/71	+02 psig	+10 psig	+8 psig
10/28/71	+01 psig	+00 psig	-1 psig*

PACK 217A - CELL S/N 521

Test Date	Initial Pressure	End-Of-Charge Pressure	Delta Pressure
4/14/71	-07 psig	+08 psig	+15 psig
10/21/71	-11 psig	+03 psig	+14 psig
10/27/71	-09 psig	+18 psig	+27 psig

* CHARGE TERMINATED EARLY DUE TO HIGH VOLTAGES

TABLE 5.7.2-8

maximum point during the charge is evident. The voltage values are generally lowest for pack 217A and highest for pack 215A. The pressure data is given in Table 5.7.2-8. Packs 215A and 216A had to be terminated prematurely during the third overcharge and therefore the end-of-charge pressure shown is lower than it might have reached. In general it appears that pack 215A gassed the most during the overcharges with packs 216A and 217A probably gassing similar amounts. Notice, too, that the three packs gassed very similarly during the pre-storage overcharge test (+13 psig to +15 psig).

SECTION 6.0

CONCLUSIONS

This study demonstrates that the OAO design program has indeed improved the quality and lengthened the life of aerospace-grade Ni-Cd cells and batteries. Further, ability to understand and predict performance of these devices under actual operating conditions has been enhanced considerably. It can safely be said that Ni-Cd batteries are now moving from the "art" stage into an engineering phase. Quantitative data to support these statements are contained in this report.

Specific conclusions to be drawn and findings include:

- Improved operating life - shown by $3\frac{1}{2}$ years of successful OAO-2 operation without single cell failure
- Capability to provide flexible full charge control without excessive overcharge - shown by results of using eight (8) BVLS levels and a sensitive third electrode signal
- Necessity to design future spacecraft equipment to accept lower discharge voltages due to "double plateau" effect
- Ability to predict battery performance using a computer model with adequate cell characterization data
  - Improvement of cell characterization techniques
- Cell storage - long term - under about C/40 trickle charge may result in less performance degradation due to apparently negligible parameter changes compared to other techniques (if it can be shown that excessive component degradation will not thereby ensue)
- OAO-2 battery thermal design amply adequate to retain maximum life and performance characteristics - shown by spacecraft data
  - Low temperature spread (cell-to-cell) results in small, negligible characteristic differences
  - Temperature regime safely below nylon separator hydrolysis degradation point
- Cell processing and screening techniques lead to greater uniformity, both initially and after prolonged cycling. Among the items contributing are:
  - Plate weight screening
  - Minimum 24-hour soak after activation
  - Controlled technique for negative precharge adjustment
  - Careful ratio testing as a verification test

- Capacity predictions from sample plate data
- Specification of single lots for a build
  - o Plates
  - o Separators
  - o Electrolyte
- Cell selection testing
  - o Pressure measurement
- Limitation of overcharge in early tests
- Adequate quality assurance provisions
  - o Radiography
  - o Terminal inspection

This study also raised some specific questions, and pointed up areas in which more information is required. These are discussed briefly below.

6.1 CHARGE CONTROL AND THE THIRD ELECTRODE

The multi-level voltage vs. temperature limit (BVLS) charge control is now a proven technique. OAO-2 amply demonstrates its viability. The third electrode experiment also seems to have been successful in that a signal sensitive to state-of-charge was found, and its time of appearance was representative of how much overcharge would occur at any BVLS level. In flight, this fact was used by operations personnel to modify BVLS levels by ground command. What remains, then, are the following questions:

- o How should future spacecraft designers best integrate third electrode with BVLS control?
- o What factors affect third electrode signal performance (e.g.: hydrogen evolution, cell reversal, loading, etc.)?

6.2 OPERATIONAL VOLTAGES AND RECONDITIONING

It has been found that the "double plateau" effect in discharge (i.e.: the tendency for cells and batteries in extended cycling to expend large, increasing portions of their stored energy at low voltage - about 1.05 volts per cell) can be reversed by subjecting the cells to "deep" discharge - to 1.0 volts per cell or less. Ford (Reference 14) and others have determined this "reconditioning" is a temporary effect. Test data taken for this and other recent programs show that recharge rates and/or techniques (up to at least C/2) following deep discharge have no effect on either disappearance of double plateau or the duration of the "reconditioning" effect. These conclusions are borne out by the data presented herein. Several points, however, remain unclear:

- What phenomena are responsible for "double plateau"?
- Why does "reconditioning" work at all, and why is it temporary?
- What is the exact relationship between the lowered discharge voltage of "double plateau" and end-of-charge voltage performance?
- Is there a relationship between "double plateau" and either or both of oxygen and hydrogen evolution?
  - Is there a way to utilize third electrode signal to minimize "double plateau" effects?
  - Is it necessary to have either pressure relief or pressure cut-off for cells and batteries subject to prolonged cycle life?
- Can voltage divergence (cell-to-cell in a battery) be predicted and/or controlled for either charge or discharge?
  - What, if any, are the relationships of divergence to any of the above?
  - Are there maximum divergence limits? Based on what criteria?

Answers to the above and corollary questions would contribute much to understanding the flight performance of batteries, and to the ability to predict and control this performance over long periods of time.

6.3 MULTIPLE REGRESSION ANALYSIS

In the program of which reference 11 is a report, it has been shown that Ni-Cd cell parameters can be related to manufacturing processes and control by means of a mathematical technique called multiple regression analysis. To a limited extent, this program has established the same principle - analysis confirmed observation that a minimum soak time is required after activation to assure stable, predictable precharge adjustment. Other attempts to achieve correlation were less than fruitful. It was concluded that insufficient data were available. This fact, rather than an inherent weakness in the analysis technique, accounts for lack of useful results.

The program reported on by reference 11 relied heavily on electrode processing and construction data - material which was lacking here. Should such information become available, cells be fabricated from the plates reported on, and these cells be subjected to adequate testing, regression analyses would show their usefulness.

SECTION 7.0

RECOMMENDATIONS

7.1 MANUFACTURING AND PROCESS CONTROLS

The material manufacturing and process controls covered herein should be applied to all future builds of aerospace-grade cells and batteries. Plate-processing and manufacturing variables should also be included (Section 7.7). Performance and long-life reliability will thereby be enhanced without any necessity to incur increased cost. Ultimately standardization and lower reject rate, along with reduced screening requirements, will result in cost savings.

7.2 NEGATIVE/POSITIVE RATIO

To insure good performance over long-life, minimum excess negative capacity is required. Actual values may be application oriented. Up to the last battery build, OAO required minimum ratios of 1.30:1.00. For the last build, this was increased to 1.40:1.00. It is recommended that standard minima be established to improve life characteristics, and that adequate sample test requirements be imposed. These should be based on as complete as possible an understanding of negative-limit phenomena for both charge and discharge.

7.3 PRECHARGE

Along with sufficient negative/positive ratio, it is necessary to have proper balance of the excess negative capacity. This can be achieved by a controlled negative precharge adjustment. Wherever possible the gas (oxygen) collection technique should be used since it appears to be the most accurate and reliable method devised to date.

7.4 QUALITY ASSURANCE

To insure cell reliability, battery performance and long life, strictly, but intelligently, enforced quality control should be imposed from the raw material stage through to the finished product. This includes insistence on adequate analysis and lot sample data of all materials and components (e.g. electrodes, separators, electrolyte, etc.), and sufficient in-process inspection and test to assure both good procedures and traceability.

7.5 CELL SELECTION

Adequate criteria should be established for each cell and battery design to assure battery performance in flight systems. Similar requirements to those shown in Appendix B should be used to match cells, with specific items based on known characteristics of the cells.

7.6 CELL CHARACTERIZATION

From each lot of cells built for flight use, a sufficiently large sample should be taken and subjected to prescribed characterization and life tests. These tests would:

- Provide data to verify cell selection
- Update the cell performance prediction model
- Verify spacecraft power system design
- Provide data for analytic process/performance studies

Further suggestions for these efforts include a test facility capable of:

- Automatic cycling simulating predicted orbital, charge and load parameters
- Data format directly compatible with computer programs
- Safe operation against cell or test equipment failure
  - Overpressure
  - Over/under voltage
  - Power faults

Such capability makes this kind of testing economical since it allows for repetitive use of the same equipment and data reduction software, and avoids excessive use of personnel for continuous 24-hour, 7-day testing.

7.7 ANALYTIC STUDIES

It is recommended that the work begun here to relate early test data to actual cell performance and life be extended. An attempt should be made to achieve correlation among early tests, performance and life on one hand, and component characteristics on the other. Such elements as electrode parameters (utilization, strength, active material purity, etc.), separator types and construction, electrolyte concentration and the like should be

7.7 (CONTINUED)

studied from the point of each one's impact on cell results. This effort would require cooperation of the component suppliers, but would eventually lead to greater understanding of nickel-cadmium technology (see ref. 11). Similar work should be undertaken on design and use of oxygen-sensing (adsorbed hydrogen) and fuel-cell electrodes for state-of-charge sensors.

7.8 BATTERY VOLTAGE REGULATION/"DOUBLE PLATEAU" EFFECT

For long-lived systems, especially in low-earth orbit, other on-board equipment should be designed to operate safely, and within normal performance limits, over a voltage range wide enough to include a minimum discharge voltage of 1.05 volts/cell. The "double plateau" effect found in extended cycling does not represent a real capacity loss as previously thought, but is due to the tendency of nickel-cadmium cells to release stored energy at lower voltage spread, requiring using and power conditioning equipment to accept a wider range. Where OAO-2 was specified at 24-35 volts for a 21-cell battery, future designs should reduce the lower figure to approximately 20.75 volts (includes diode drop).

7.9 PRE-FLIGHT TESTS/STORAGE

Batteries designated for flight or flight spares usage should receive a minimum of systems test before launch. At all other times, they should be stored in the recommended manner to avoid excessive component degradation and concomitant shortening of life. Storage techniques should be studied to determine optimum method(s) (e.g. shorted vs. low trickle charge - - see 6.0).

SECTION 8.0

FUTURE EFFORT

8.1 PRESENT PROGRAM EXTENSION

An extension of this program should be made to record, analyze and codify the following material:

- o Cell and battery data for batteries S/N 36 and 37, now being constructed for use as OAO-4 flight spares.
- o Addition of data on extra cells of batteries 34, 35 lot; and batteries 36, 37 lot
    - Characterization tests
    - Life tests
    - Storage tests
- o Review and include OAO-2 flight data past end of this program
- o Include OAO-4 flight data -- launch scheduled for August 1972
- o Include storage test results, second six-month period, packs 215A, 216A, 217A.

8.2 BASIC COMPONENT STUDIES

The following component studies should be undertaken:

- o Effects of adding cobalt to positive electrodes
    - Electrode parameters
    - Initial cell performance
    - Long term cycling performance
    - Life
- o Establishment, with plate manufacturer's cooperation, of manufacturing and process controls.
    - Quality assurance provisions
    - Detailed plate data requirements
        - o Plate chemical analysis

8.3 CELL EFFORTS

The following work should be started to increase knowledge of cell performance and characteristics:

- Investigation to determine capacity retention enhancement by starting charge at low rate
  - Initial (Conditioning) charge only
  - Cyclic charges
- Investigation of storage techniques at less than room temperature (< 20°C)
- Reduction of all cell and component data to computer format
  - Economical bookkeeping, storage
  - Easier to use for analytic purposes
- Continue analytic effort to relate manufacturing, process and early test parameters and data to cell and battery performance
  - Improve controls
  - Improve cell prediction model
  - Optimize early test techniques

SECTION 9.0

REFERENCES

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APPENDIX A

Print-Outs for Regression Analyses
Described in Section

Voltage (Divergence) Regression

Precharge (Gas Evolution) Regression

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VARS( 4, 8)=  0.679556  VARS( 4, 9)= -0.546168  VARS( 4,10)= -0.38 604  VARS( 4,11)= -0.220119
VARS( 4,12)=  0.973323  VARS( 4,13)=  0.664918  VARS( 4,14)=  0.75 750  VARS( 4,15)=  0.806710
VARS( 4,16)=  0.745944  VARS( 4,17)=  0.786043  VARS( 4,18)=  0.76 905  VARS( 4,19)=  0.978129
VARS( 4,20)= -0.197591
VARS( 5, 5)=  1.000001  VARS( 5, 6)=  0.598386  VARS( 5, 7)=  0.53 281  VARS( 5, 8)=  0.106748
VARS( 5, 9)= -0.082710  VARS( 5,10)=  0.108082  VARS( 5,11)=  0.17 901  VARS( 5,12)=  0.201396
VARS( 5,13)=  0.170805  VARS( 5,14)=  0.202777  VARS( 5,15)=  0.22 091  VARS( 5,16)=  0.149143
VARS( 5,17)=  0.209487  VARS( 5,18)=  0.222215  VARS( 5,19)=  0.20 475  VARS( 5,20)=  0.071247
VARS( 6, 6)=  1.000000  VARS( 6, 7)= -0.123802  VARS( 6, 8)=  0.12 717  VARS( 6, 9)=  0.049962
VARS( 6,10)=  0.330748  VARS( 6,11)=  0.345349  VARS( 6,12)=  0.17 877  VARS( 6,13)=  0.210214
VARS( 6,14)=  0.199598  VARS( 6,15)=  0.142551  VARS( 6,16)=  0.18 134  VARS( 6,17)=  0.126897
VARS( 6,18)=  0.247790  VARS( 6,19)=  0.175836  VARS( 6,20)=  0.01 936
VARS( 7, 7)=  1.000000  VARS( 7, 8)= -0.155499  VARS( 7, 9)= -0.08 995  VARS( 7,10)= -0.210713
VARS( 7,11)= -0.151625  VARS( 7,12)=  0.021026  VARS( 7,13)= -0.01 556  VARS( 7,14)=  0.007640
VARS( 7,15)=  0.082901  VARS( 7,16)= -0.027599  VARS( 7,17)=  0.04 636  VARS( 7,18)= -0.058674
VARS( 7,19)=  0.319786  VARS( 7,20)=  0.144675
VARS( 8, 8)=  1.000001  VARS( 8, 9)= -0.373869  VARS( 8,10)= -0.19 422  VARS( 8,11)= -0.152959
VARS( 8,12)=  0.688184  VARS( 8,13)=  0.440119  VARS( 8,14)=  0.45 017  VARS( 8,15)=  0.501095
VARS( 8,16)=  0.516970  VARS( 8,17)=  0.526017  VARS( 8,18)=  0.49 712  VARS( 8,19)=  0.691435
VARS( 8,20)= -0.191744
VARS( 9, 9)=  1.000000  VARS( 9,10)=  0.619118  VARS( 9,11)=  0.33 994  VARS( 9,12)= -0.532333
VARS( 9,13)= -0.298551  VARS( 9,14)= -0.503955  VARS( 9,15)= -0.49 508  VARS( 9,16)= -0.480211
VARS( 9,17)= -0.567894  VARS( 9,18)= -0.471223  VARS( 9,19)= -0.51 346  VARS( 9,20)= -0.420931
VARS(10,10)=  1.000001  VARS(10,11)=  0.687959  VARS(10,12)= -0.34 336  VARS(10,13)= -0.110025
VARS(10,14)= -0.295574  VARS(10,15)= -0.364979  VARS(10,16)= -0.19 481  VARS(10,17)= -0.292920
VARS(10,18)= -0.061220  VARS(10,19)= -0.336110  VARS(10,20)= -0.24 605
VARS(11,11)=  1.000002  VARS(11,12)= -0.227631  VARS(11,13)=  0.02 845  VARS(11,14)= -0.069703
VARS(11,15)= -0.116729  VARS(11,16)= -0.189151  VARS(11,17)= -0.34 400  VARS(11,18)= -0.022117
VARS(11,19)= -0.234602  VARS(11,20)= -0.129373
VARS(12,12)=  1.000002  VARS(12,13)=  0.657181  VARS(12,14)=  0.72 302  VARS(12,15)=  0.775835
VARS(12,16)=  0.795680  VARS(12,17)=  0.815717  VARS(12,18)=  0.82 859  VARS(12,19)=  0.992357
VARS(12,20)= -0.185404
VARS(13,13)=  1.000001  VARS(13,14)=  0.819772  VARS(13,15)=  0.77 691  VARS(13,16)=  0.528521
VARS(13,17)=  0.560052  VARS(13,18)=  0.631257  VARS(13,19)=  0.66 916  VARS(13,20)= -0.190018
VARS(14,14)=  1.000000  VARS(14,15)=  0.883873  VARS(14,16)=  0.54 807  VARS(14,17)=  0.567823
VARS(14,18)=  0.804741  VARS(14,19)=  0.735163  VARS(14,20)= -0.09 667
VARS(15,15)=  1.000002  VARS(15,16)=  0.582835  VARS(15,17)=  0.60 439  VARS(15,18)=  0.594335
VARS(15,19)=  0.787488  VARS(15,20)= -0.121041
VARS(16,16)=  1.000000  VARS(16,17)=  0.901412  VARS(16,18)=  0.84 636  VARS(16,19)=  0.777467
VARS(16,20)= -0.094850
VARS(17,17)=  1.000000  VARS(17,18)=  0.846428  VARS(17,19)=  0.81 460  VARS(17,20)= -0.061948
VARS(18,18)=  1.000001  VARS(18,19)=  0.805991  VARS(18,20)= -0.17 539
VARS(19,19)=  1.000001  VARS(19,20)= -0.204453

         FOR ANOVA, TOTAL SUM OF SQUARES=            4336323.000

STEP NUMBER  1            ENTER VARIABLE  3
STANDARD ERROR OF ESTIMATE=   173.98671
 VAR(  3) SSQ=             1064104.0000, RESIDUAL SSC. BY ADDN OFV R. SSQ=            3271916.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.49539
GOODNESS OF FIT,F(   1, 101)=          32.8474
CONSTANT TERM=    568.256397

VAR        COEFF      STD DEV         T VALUE       BETA COEFF
                       COEFF
  3     265.788296    47.0730     5.7313       0.4954

STEP NUMBER  2            ENTER VARIABLE  9
STANDARD ERROR OF ESTIMATE=   149.56607
 VAR(  9) SSQ=             1034916.0000, RESIDUAL SSC. BY ADDN OFV R. SSQ=            2237000.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.69576
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DEPENDENT VARIABLE
= ml gas evolved on precharge

TRANSFORMATIONS USED:
V4 = V21 = 90°F overchg press
V12 = V20 = 40°F " "
V20 = V28 = ml gas evolved

210

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GOODNESS OF FIT,F(  2, 100)=           46.9158
CONSTANT TERM=    443.081514

VAR        COEFF       STD DEV       T VALUE       BETA COEFF
                        COEFF
  3      304.218024     39.4431      7.7129        0.5586
  9     -160.860626     23.6499     -6.8017       -0.4926

STEP NUMBER   3             ENTER VARIABLE 19
STANDARD ERROR OF ESTIMATE=   139.19380
 VAR( 19) SSQ=                346346.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=          1890654.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.75098
GOODNESS OF FIT,F(  3,  99)=           42.6820
CONSTANT TERM=    392.515846

VAR        COEFF       STD DEV       T VALUE       BETA COEFF
                        COEFF
  3      260.306985     37.8747      6.8728        0.4780
  9     -208.722549     24.5726     -8.4941       -0.6392
 19     -167.035334     39.2231     -4.2586       -0.3330

STEP NUMBER   4             ENTER VARIABLE  1
STANDARD ERROR OF ESTIMATE=   131.95528
 VAR(  1) SSQ=                184260.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=          1706394.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.77876
GOODNESS OF FIT,F(  4,  98)=           37.7555
CONSTANT TERM=    389.844492

VAR        COEFF       STD DEV       T VALUE       BETA COEFF
                        COEFF
  1      149.505352     45.9663      3.2530        0.3056
  3      254.184737     36.2152      7.0191        0.4667
  9     -249.171387     29.0303     -8.5833       -0.8243
 19     -134.495454     38.7658     -3.4693       -0.2681

STEP NUMBER   5             ENTER VARIABLE  4
STANDARD ERROR OF ESTIMATE=   127.85573
 VAR(  4) SSQ=                120628.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=          1585766.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.79442
GOODNESS OF FIT,F(  5,  97)=           33.6461
CONSTANT TERM=    352.572021

VAR        COEFF       STD DEV       T VALUE       BETA COEFF
                        COEFF
  1      188.263229     46.7776      4.0246        0.3845
  3      198.212097     40.6528      4.8710        0.3640
  4     -145.214737     53.4588     -2.7164       -0.3292
  9     -310.786133     32.7591     -9.4755       -0.9518
 19      -33.115943     53.0703     -0.6237       -0.0659

STEP NUMBER   6             ENTER VARIABLE 12
STANDARD ERROR OF ESTIMATE=   126.59531
 VAR( 12) SSQ=                 47235.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=          1538531.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.80323
GOODNESS OF FIT,F(  6,  96)=           29.0925
CONSTANT TERM=    349.341797

VAR        COEFF       STD DEV       T VALUE       BETA COEFF
                        COEFF
  1      189.543751     46.3212      4.0924        0.3872
  3      198.532742     40.2515      4.9324        0.3649
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211

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   4    -344.961670    127.8240   -2.6987    -0.7821
   9    -313.635169     32.5172   -9.6453    -0.9695
  12     246.074934    143.3268    1.7168     0.5406
  14     -93.257309     60.0523   -1.3864    -0.1660

STEP NUMBER   7          ENTER VARIABLE  6
STANDARD ERROR OF ESTIMATE=   124.89816
 VAR(  6) SSQ=                  56574.0000, RESIDUAL SSQ, BY ADDN OFV R. SSQ=           1461957.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.81131
GOODNESS OF FIT,F(   7,  95)=             26.1368
CONSTANT TERM=    312.678711

VAR        COEFF        STD DEV        T VALUE       BETA COEFF
                        COEFF
  1      155.025236     49.1666     3.1531       0.3167
  3      233.058573     39.8161     5.0998       0.3729
  4     -357.194326    125.6451    -2.8992      -0.8325
  6       90.734039     47.1157     1.9044       0.1306
  9     -318.037169     33.2159    -9.5617      -0.9433
 12      281.116860    143.5067     1.9712       0.6176
 14     -124.643583     63.1058    -1.9751      -0.2435

STEP NUMBER   8          ENTER VARIABLE  8
STANDARD ERROR OF ESTIMATE=   123.05864
 VAR(  8) SSQ=                  38475.0000, RESIDUAL SSQ, BY ADDN OFV R. SSQ=           1423482.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.81958
GOODNESS OF FIT,F(   8,  94)=             24.0412
CONSTANT TERM=    310.627686

VAR        COEFF        STD DEV        T VALUE       BETA COEFF
                        COEFF
  1      146.294373     48.6464     3.0071       0.2988
  3      207.472426     39.2540     5.2800       0.3810
  4     -363.048096    124.8015    -2.9090      -0.8231
  6       96.316054     46.5465     2.0693       0.1402
  8      -77.474517     39.4275    -1.9650      -0.1635
  9     -304.426223     31.7651    -9.6140      -0.9353
 12      345.416032    144.3210     2.3967       0.7599
 14     -149.569272     63.4051    -2.3509      -0.2972

STEP NUMBER   9          ENTER VARIABLE 16
STANDARD ERROR OF ESTIMATE=   123.03415
 VAR( 16) SSQ=                  15704.0000, RESIDUAL SSQ, BY ADDN OFV R. SSQ=           1407778.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82178
GOODNESS OF FIT,F(   9,  93)=             21.4939
CONSTANT TERM=    301.542236

VAR        COEFF        STD DEV        T VALUE       BETA COEFF
                        COEFF
  1      152.832909     49.1580     3.1268       0.3143
  3      203.351219     39.4540     5.1489       0.3734
  4     -354.241675    125.0745    -2.8324      -0.8032
  6       93.537700     46.6175     2.0064       0.1361
  8      -77.938753     39.4232    -1.9769      -0.1645
  9     -304.476991     31.7755    -9.6439      -0.9386
 12      315.347434    147.2874     2.1456       0.6942
 16       71.454367     70.1535     1.0186       0.1210
 14     -177.474617     69.4124    -2.5624      -0.3546

STEP NUMBER  10          ENTER VARIABLE 13
STANDARD ERROR OF ESTIMATE=   123.42316
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212

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 VAR( 13) SSQ=                6317.0000, RESIDUAL SSQ. BY ADDN DEV R. SSQ=        1401461.0000000
 MULTIPLE CORRELATION COEFFICIENT =  0.82267
 GOODNESS OF FIT,F( 10,  92)=          19.2641
 CONSTANT TERM=   256.805908

 VAR        COEFF       STD DEV       T VALUE      BETA COEFF
                         COEFF
   1     146.371353     50.6955      2.8873       0.2990
   3     211.050568     41.6391      5.0695       0.3892
   4    -329.553223    131.2059     -2.5117      -0.7472
   6      97.403137     47.1456      2.0658       0.1417
   8     -78.281067     39.5505     -1.9793      -0.1552
   9    -300.607422     33.1580     -9.0659      -0.9206
  12     311.025785    147.9215      2.1027       0.6833
  13     -36.906879     57.3172     -0.6439      -0.0575
  16      64.246414     71.2603      0.9016       0.1098
  18    -169.383423     70.8649     -2.3902      -0.3377

 STEP NUMBER 11             ENTER VARIABLE 15
 STANDARD ERROR OF ESTIMATE=   123.81331
  VAR( 15) SSQ=               6456.0000, RESIDUAL SSQ. BY ADDN DEV R. SSQ=        1395005.0000000
 MULTIPLE CORRELATION COEFFICIENT =  0.82357
 GOODNESS OF FIT,F( 11,  91)=          17.4409
 CONSTANT TERM=     255.618408

 VAR        COEFF       STD DEV       T VALUE      BETA COEFF
                         COEFF
   1     137.595487     52.4704      2.6299       0.2819
   3     223.255109     45.4176      4.9157       0.4100
   4    -340.719482    132.7408     -2.5668      -0.7725
   6     100.396539     47.5231      2.1126       0.1461
   8     -74.898743     40.0164     -1.8717      -0.1591
   9    -291.513770     36.0246     -8.0926      -0.8930
  12     308.107178    148.4573      2.0754       0.6769
  13     -72.357224     79.3100     -0.9123      -0.1128
  15      45.174011     69.6134      0.6489       0.0918
  16      57.175896     72.3102      0.7908       0.0968
  18    -158.874466     72.9101     -2.1790      -0.3167

 STEP NUMBER 12             ENTER VARIABLE  2
 STANDARD ERROR OF ESTIMATE=   124.30864
  VAR(  2) SSQ=               4258.0000, RESIDUAL SSQ. BY ADDN DEV R. SSQ=        1390737.0000000
 MULTIPLE CORRELATION COEFFICIENT =  0.82417
 GOODNESS OF FIT,F( 12,  90)=          15.8834
 CONSTANT TERM=     290.549072

 VAR        COEFF       STD DEV       T VALUE      BETA COEFF
                         COEFF
   1     -13.437192    292.8853     -0.0459      -0.0275
   2     164.210129    312.4307      0.5256       0.3617
   3     222.271393     45.6380      4.8703       0.4081
   4    -339.257324    133.3008     -2.5451      -0.7692
   6     104.418198     48.3228      2.1608       0.1520
   8     -79.456623     41.0554     -1.9331      -0.1677
   9    -313.370117     54.9761     -5.7001      -0.9597
  12     304.747314    149.1883      2.0427       0.6695
  13     -76.207840     79.9636     -0.9530      -0.1199
  15      52.767838     71.3657      0.7394       0.1073
  16      60.513646     72.8793      0.8306       0.1025
  18    -159.476546     73.2108     -2.1783      -0.3179
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213

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STEP NUMBER 13          ENTER VARIABLE 19
STANDARD ERROR OF ESTIMATE=   124.77666
 VAR( 19) SSQ=                  5078.0000, RESIDUAL SSQ, BY ADDN OFV R. SSQ=            1385659.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82488
GOODNESS OF FIT,F(  13,  89)=          14.5769
CONSTANT TERM=     295.013428

VAR        COEFF       STD DEV        T VALUE       BETA COEFF
                        COEFF
  1      -47.457367    299.9648      -0.1582       -0.0959
  2      213.737564    325.3816       0.6569        0.4708
  3      219.003143     46.1660       4.7438        0.4021
  4     -307.446730    144.9262      -2.1213       -0.6970
  6       99.727493     49.1555       2.0272        0.1451
  8      -77.854431     41.3487      -1.8829       -0.1643
  9     -321.021240     56.7667      -5.6531       -0.9831
 12      436.496967    263.5479       1.6369        0.9370
 13      -72.443130     80.5359      -0.8995       -0.1129
 15       56.165269     71.8764       0.7806        0.1140
 16       63.075254     73.2654       0.8607        0.1069
 18     -155.335674     73.8433      -2.1036       -0.3097
 19     -157.646591    276.0516      -0.5710       -0.3546

STEP NUMBER 14          ENTER VARIABLE  7
STANDARD ERROR OF ESTIMATE=   125.34796
 VAR(  7) SSQ=                  2594.0000, RESIDUAL SSQ, BY ADDN OFV R. SSQ=            1382665.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82530
GOODNESS OF FIT,F(  14,  88)=          13.4262
CONSTANT TERM=     288.514648

VAR        COEFF       STD DEV        T VALUE       BETA COEFF
                        COEFF
  1      -66.912430    304.6162      -0.2197       -0.1367
  2      224.975067    327.8835       0.6861        0.4956
  3      221.864975     46.8285       4.7368        0.4074
  4     -304.249117    145.7846      -2.0869       -0.6898
  6      105.032196     50.8530       2.0638        0.1529
  7       16.427277     37.6328       0.4365        0.0298
  8      -73.773727     42.5770      -1.7327       -0.1557
  9     -317.592041     57.5651      -5.5152       -0.9726
 12      410.185697    264.3514       1.5514        0.9012
 13      -76.476166     81.4297      -0.9392       -0.1192
 15       57.182098     72.2476       0.7915        0.1162
 16       61.016663     73.7765       0.8270        0.1033
 18     -153.707932     74.2754      -2.0694       -0.3064
 19     -145.924622    278.6526      -0.5237       -0.3242

STEP NUMBER 15          ENTER VARIABLE 14
STANDARD ERROR OF ESTIMATE=   125.94127
 VAR( 14) SSQ=                  2741.0000, RESIDUAL SSQ, BY ADDN OFV R. SSQ=            1379924.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82568
GOODNESS OF FIT,F(  15,  87)=          12.4249
CONSTANT TERM=     289.935791

VAR        COEFF       STD DEV        T VALUE       BETA COEFF
                        COEFF
  1      -83.055817    308.5112      -0.2692       -0.1697
  2      241.861588    331.9297       0.7287        0.5328
  3      225.165024     47.7249       4.7180        0.4135
  4     -302.327148    146.5472      -2.0630       -0.6854
  6      103.495670     51.2683       2.0186        0.1506
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214

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   7     18.767075    38.2275    0.4909     0.0341
   8    -71.842781    43.0256   -1.6696    -0.1516
   9   -315.471974    58.0820   -5.4315    -0.9661
  12    413.891104   265.7510    1.5572     0.9093
  13    -94.775574    92.9032   -1.0202    -0.1477
  14     34.552002    83.1661    0.4158     0.0659
  15     43.332870    79.8677    0.5426     0.0991
  16     63.695395    74.4037    0.8560     0.1078
  18   -152.720291    74.6647   -2.0454    -0.3045
  19   -153.911096   280.6135   -0.5481    -0.3460

STEP NUMBER 16            ENTER VARIABLE 10
STANDARD ERROR OF ESTIMATE=   126.54884
 VAR( 10) SSQ=                 2668.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=            1377256.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82606
GOODNESS OF FIT,F(  16,  86)=           11.5471
CONSTANT TERM=    292.916748

VAR        COEFF       STD DEV         T VALUE       BETA COEFF
                       COEFF
   1   -100.236217    312.8457    -0.3204      -0.2048
   2    260.256113    336.5669     0.7733       0.5733
   3    227.610474     48.3281     4.7097       0.4179
   4   -305.485746    147.4580    -2.0717      -0.6926
   6    110.974570     54.6838     2.0294       0.1615
   7     18.127365     38.4435     0.4715       0.0329
   8    -68.325468     44.0865    -1.5499      -0.1442
   9   -309.204102     60.3496    -5.1236      -0.9469
  10    -18.695633     45.8156    -0.4081      -0.0433
  12,   394.206387    271.3516     1.4531       0.8663
  13    -98.121994     93.7108    -1.0471      -0.1529
  14     38.118027     83.9633     0.4540       0.0726
  15     43.066520     80.2557     0.5366       0.0875
  16     60.856689     75.0840     0.8105       0.1031
  18   -135.802444     85.7180    -1.5843      -0.2707
  19   -145.176270    282.7603    -0.5134      -0.3265

STEP NUMBER 17            ENTER VARIABLE  5
STANDARD ERROR OF ESTIMATE=   127.24864
 VAR(  5) SSQ=                  918.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=             1376338.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82618
GOODNESS OF FIT,F(  17,  85)=          10.7520
CONSTANT TERM=    288.812988

VAR        COEFF       STD DEV         T VALUE       BETA COEFF
                       COEFF
   1    -98.685867    314.6428    -0.3136      -0.2016
   2    262.170654    339.5222     0.7745       0.5775
   3    226.658386     48.7992     4.6485       0.4162
   4   -302.051514    148.9730    -2.0276      -0.6848
   5    -15.590799     65.3564    -0.2384      -0.0315
   6    123.327789     75.5538     1.6323       0.1795
   7     28.693405     58.8056     0.4879       0.0521
   8    -65.767349     45.6144    -1.4418      -0.1388
   9   -311.086182     61.1546    -5.0836      -0.9527
  10    -18.000137     46.1612    -0.3899      -0.0417
  12    387.267314    274.4495     1.4110       0.8508
  13   -100.171295     94.6204    -1.0587      -0.1561
  14     38.728531     84.4663     0.4585       0.0738
  15     44.761292     81.0120     0.5525       0.0910
  16     59.116074     75.8514     0.7794       0.1001
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215

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  18    -130.010666     85.5502   -1.4518     -0.2592
  19    -145.916016    284.3406   -0.5132     -0.3282

STEP NUMBER 18            ENTER VARIABLE 11
STANDARD ERROR OF ESTIMATE=   127.96060
 VAR( 11) SSQ=                   630.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=            1375408.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82631
GOODNESS OF FIT.F(  18.  84)=          10.0451
CONSTANT TERM=    288.256143

VAR      COEFF       STD DEV        T VALUE       BETA COEFF
                      COEFF
   1    -94.955274    316.7503    -0.2998      -0.1940
   2    259.498779    340.6013     0.7619       0.5716
   3    226.966339     49.0491     4.6273       0.4168
   4   -308.726543    152.4088    -2.0256      -0.6999
   5    -16.767822     65.9479    -0.2543      -0.0339
   6    122.423560     76.0714     1.6093       0.1782
   7     29.675474     59.2835     0.5006       0.0539
   8    -64.041000     46.4294    -1.3790      -0.1352
   9   -310.235258     61.6257    -5.0331      -0.9501
  10    -26.227371     57.8745    -0.4532      -0.0607
  11     10.667910     44.8180     0.2380       0.0236
  12    374.154785    281.4128     1.3296       0.8220
  13   -100.265089     95.1506    -1.0538      -0.1563
  14     38.964630     84.9447     0.4587       0.0743
  15     41.303556     82.7473     0.4992       0.0940
  16     62.590032     77.6517     0.8059       0.1060
  18   -129.911409     90.0923    -1.4426      -0.2590
  19   -126.615615    297.1104    -0.4264      -0.2850

STEP NUMBER 19            ENTER VARIABLE 17
STANDARD ERROR OF ESTIMATE=   129.65182
 VAR( 17) SSQ=                  1652.0000, RESIDUAL SSQ. BY ADDN OFV R. SSQ=            1373756.0000000
MULTIPLE CORRELATION COEFFICIENT =  0.82654
GOODNESS OF FIT.F(  19.  83)=          9.4197
CONSTANT TERM=    291.250771

VAR      COEFF       STD DEV        T VALUE       BETA COEFF
                      COEFF
   1    -95.822662    318.8733    -0.3130      -0.2039
   2    264.834914    342.8579     0.7724       0.5834
   3    226.226280     49.3556     4.5846       0.4155
   4   -312.885160    153.7573    -2.0344      -0.7094
   5    -19.291534     66.7836    -0.2889      -0.0390
   6    124.912680     76.6475     1.6180       0.1995
   7     30.451050     59.6538     0.5105       0.0553
   8    -63.045194     46.7557    -1.3473      -0.1331
   9   -308.192871     62.3102    -4.9461      -0.9438
  10    -29.166140     58.8561    -0.4942      -0.0674
  11     18.148148     50.9011     0.3565       0.0401
  12    396.597402    289.6560     1.3533       0.8433
  13   -102.949951     96.0402    -1.0719      -0.1604
  14     43.857697     86.7563     0.5053       0.0936
  15     39.304138     83.4356     0.4711       0.0739
  16     59.906430     78.5652     0.7612       0.1013
  17     26.994467     85.4659     0.3160       0.0522
  18   -144.354059    101.4276    -1.4233      -0.2878
  19   -139.923539    301.6233    -0.4639      -0.3147

STEP NUMBER 20            ENTER VARIABLE 17
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Volt drive
rep

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     MEASURED GAS AS DEPENDENT VARIABLE  DATA S/N 34.35

   CONTROL CARD USED FOR THIS REGRESSION
 2917   014 1 0.0   0.0   1 0 21110 00 0 0010 00    0

   TRANSFORMATIONS SPECIFIED FOR THIS REGRESSION
  9 4 4 1 91212 1 91313 1 91414 1 91515 1 9 3 3 1 1 421 0 11220 0 11319 0
  11418 0 11517 0 1 316 0 11628 0 11729 0

   CONSTANT CARDS USED IN THIS REGRESSION
    0.0

          RAW DATA LISTING

 CELL NO  VARIABLES IN NUMERICAL ORDER


               791.600   879.900    10.000    74.000   540.600   258.100   278.500     1.492     6.000    24.170
      0         23.850    46.000    54.000    30.000     9.000   771.000     5.000
               806.500   898.300     3.000    21.000   542.200   260.700   277.600     1.479    72.000    24.670
      1         23.660    11.000    12.000    18.000    16.000   190.000     7.000
               787.800   875.400    14.000   100.000   537.100   259.500   273.600     1.492     6.000    23.000
      2         23.510    62.000    69.000    38.000    24.000   223.000     3.000
               797.200   889.600     4.000    23.000   537.700   258.600   275.200     1.476    72.000    24.600
      3         23.680    12.000    15.000    20.000    17.000   105.000     7.000
               794.000   881.400    -8.000    68.000   540.200   257.300   278.900     1.489     6.000    23.170
      4         23.510    40.000    46.000    26.000    26.000   277.000     7.000
               788.900   876.700    10.000    46.000   539.200   259.200   276.000     1.481     6.000    23.500
      5         23.500    26.000    30.000    36.000    30.000   494.000     5.000
               804.700   890.100     0.001    13.000   540.800   268.600   274.200     1.483    48.000    24.670
      6         23.600     5.000    16.000    11.000     8.000   565.000     2.000
               785.300   873.400    16.000    75.000   537.700   255.500   278.200     1.488     6.000    23.170
      7         23.000    48.000    64.000    60.000    46.000   360.000     6.000
               795.400   887.700     2.000    14.000   536.100   257.400   274.400     1.481    48.000    24.500
      8         23.680     6.000     9.000    12.000    10.000   323.000     1.000
               792.100   879.800     8.000    31.000   538.000   257.700   276.800     1.486     6.000    23.670
      9         23.170    22.000    22.000    31.000    33.000  1050.000     5.000
               784.600   872.400    10.000    64.000   537.500   256.400   277.100     1.494     0.001     0.001
     10         23.170    40.000    48.000    38.000    29.000   815.000     4.000
               786.900   874.700     8.000    55.000   539.200   259.500   275.800     1.490     0.001     0.001
     11         23.510    36.000    41.000    32.000    24.000   811.000     1.000
               784.000   871.700     5.000    58.000   537.800   267.600   276.200     1.491     0.001     0.001
     12         23.510    36.000    40.000    28.000    21.000   790.000     5.000
               789.100   877.000     5.000    62.000   537.700   258.300   275.400     1.491     0.001     0.001
     13         23.510    37.000    43.000    28.000    21.000   796.000     6.000
               792.400   880.500     2.000    31.000   538.200   256.300   277.000     1.487     0.001     0.001
     14         23.340    18.000    20.000    17.000    12.000   784.000     5.000
               781.300   869.100     6.000    60.000   536.000   257.200   277.000     1.490     0.001     0.001
     15         23.340    20.000    36.000    28.000    22.000   828.000     5.000
               784.300   872.600     6.000    64.000   539.400   259.400   276.500     1.490     0.001     0.001
     16         23.600    39.000    46.000    35.000    26.000   794.000     1.000
               786.900   875.300    10.000    68.000   540.700   257.400   278.900     1.488     0.001     0.001
     17         23.170    44.000    52.000    38.000    31.000   820.000     5.000
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          786.200   874.600     6.000    52.000   538.100   258.900   275.300     1.493     0.001     0.001
   18      23.510    43.000    39.000    26.000    21.000   810.000     7.000
          791.400   879.500     6.000    46.000   536.900   250.200   277.000     1.490     0.001     0.001
   19      23.340    30.000    34.000    26.000    19.000   824.000     5.000
          789.800   878.100     9.000    29.000   539.500   258.900   276.000     1.484     6.000    24.170
   20      24.000    21.000    22.000    30.000    23.000  1022.000     5.000
          799.200   891.900     6.000    26.000   538.500   256.400   278.100     1.477    72.000    24.000
   21      23.510    14.000    17.000    14.000    21.000   555.000     5.000
          789.600   877.700    11.000    40.000   538.100   257.100   277.000     1.487     6.000    23.500
   22      23.830    24.000    26.000    32.000    28.000   786.000     5.000
          795.900   888.100    -1.000    13.000   536.800   250.400   276.400     1.476    72.000    24.000
   23      23.170     7.000     6.000    17.000    13.000   550.000     8.000
          787.600   875.700    28.000    62.000   542.100   259.300   278.800     1.488     6.000    24.000
   24      23.500    42.000    46.000    70.000    46.000   464.000     4.000

 CODING MAX.. VARIABLES IN NUMERICAL ORDER


    806.500   898.300    28.000   100.000   542.200   260.700   278.900     1.494    72.000    24.670
     24.000    62.000    69.000    70.000    46.000  1050.000

 CODING MIN.. VARIABLES IN NUMERICAL ORDER
    781.300   869.100    -8.000    13.000   536.100   255.500   273.600     1.476    -0.001     0.001
     23.000     6.000    -8.000    11.000     8.000   105.000

 CODED DATA LISTING

 CELL NO  VARIABLES IN NUMERICAL ORDER
           -0.183    -0.260     0.0       0.402     0.475    -0.000     0.849     0.778    -0.833     0.959     0.700
    0       0.439     0.506    -0.356    -0.947     0.410     5.000
            1.000     1.000    -0.389    -0.816     1.000     1.000     0.509    -0.667     1.000     1.000     0.360
    1      -0.789    -0.869    -0.763    -0.579    -0.820     7.000
           -0.484    -0.560     0.222     1.000    -0.672     0.538    -1.000     0.778    -0.833     0.865     0.020
    2       1.000     1.000    -0.085    -0.158    -0.750     3.000
            0.262     0.404    -0.333    -0.770    -0.475     0.192    -0.396    -1.000     1.000     0.986     0.360
    3      -0.754    -0.770    -0.695    -0.526    -1.000     7.000
            0.008    -0.150    -1.000     0.264     0.344    -0.308     1.000     0.444    -0.833     0.878     0.020
    4       0.228     0.246    -0.492    -0.053    -0.036     7.000
           -0.397    -0.479     0.0      -0.241     0.016     0.423    -0.094    -0.444    -0.833     0.905     0.0
    5      -0.263    -0.279    -0.153     0.158    -0.177     5.000
            0.857     0.849    -0.555    -1.000     0.541     0.192     0.736    -0.222     0.333     1.000     0.360
    6      -1.000    -0.738    -1.000    -1.000    -0.026     2.000
           -0.683    -0.705     0.333     0.425    -0.475    -1.000     0.736     0.333    -0.833     0.878    -1.000
    7       0.509     0.506     0.525     1.000    -0.443     5.000
            0.119     0.274    -0.444    -0.977    -1.000    -0.269     0.698     0.444     0.333     0.986     0.360
    8      -0.965    -0.967    -0.466    -0.695    -0.539     1.000
           -0.143    -0.267    -0.111    -0.506    -0.377    -0.154     0.208     0.0      -0.833     0.919    -0.660
    9      -0.404    -0.541    -0.322     0.316     1.000     6.000
           -0.738    -0.774     0.0       0.172    -0.541    -0.654     0.321     1.000    -1.000    -1.000    -0.660
   10       0.228     0.311    -0.085     0.105     0.503     4.000
           -0.656    -0.616    -0.111    -0.034     0.016     0.538     0.170     0.556     1.000     1.000     0.020
   11       0.088     0.082    -0.288    -0.158     0.494     1.000
           -0.786    -0.822    -0.278     0.034    -0.443    -0.192    -0.019     0.667    -1.000    -1.000     0.020
   12       0.008     0.049    -0.424    -0.316     0.450     6.000
           -0.381    -0.416    -0.278     0.126    -0.475     0.077    -0.321     0.667    -1.000    -1.000     0.020
   13       0.123     0.146    -0.424    -0.316     0.460     5.000
           -0.119    -0.219    -0.444    -0.566    -0.311    -0.692     0.283     0.222     1.000     1.000     0.320
   14      -0.544    -0.607    -0.797    -0.789     0.437     5.000
           -1.000    -1.000    -0.222    -0.149    -0.377    -0.346     0.283     0.556    -1.000    -1.000    -0.320
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      15       -0.474   -0.082   -0.424   -0.263    0.530    5.000
               -0.762   -0.700   -0.111    0.172    0.082    0.600    0.094   -0.556   -1.000   -1.000    0.0
      16        0.193    0.246   -0.186   -0.105    0.458    1.000
               -0.556   -0.575    0.0      0.264    0.508   -0.269    1.000    0.333   -1.000   -1.000   -0.660
      17        0.368    0.443   -0.085    0.211    0.513    5.000
               -0.611   -0.623   -0.222   -0.103   -0.344    0.308   -0.359    0.889   -1.000   -1.000    0.020
      18        0.333    0.016   -0.424   -0.316    0.492    7.000
               -0.198   -0.286   -0.222   -0.241   -0.082    0.038    0.283    0.556   -1.000   -1.000   -0.320
      19       -0.123   -0.148   -0.492   -0.421    0.522    5.000
               -0.325   -0.384   -0.056   -0.632    0.115    0.308   -0.094   -0.111   -0.833    0.959    1.000
      20       -0.439   -0.541   -0.085   -0.211    0.941    5.000
                0.421    0.562   -0.222   -0.701   -0.213   -0.654    0.698   -0.889    1.000    0.946    0.020
      21       -0.684   -0.705   -0.898   -0.316   -0.048    5.000
               -0.341   -0.411    0.056   -0.379   -0.344   -0.386    0.283    0.222   -0.833    0.906    0.660
      22       -0.333   -0.410   -0.288    0.053    0.446    5.000
                0.159    0.301   -0.611   -1.000   -0.115    0.115    0.057   -1.000    1.000    0.946   -0.660
      23       -0.930   -1.000   -0.797   -0.737   -0.058    6.000
               -0.500   -0.548    1.000    0.126    0.967    0.461    0.962    0.333   -0.833    0.946    0.0
      24        0.298    0.246    1.000    1.000   -0.240    4.000
   -0.18254  -0.26027   0.0       0.40230   0.47539  -0.00005   0.84911
    0.77779  -0.83336   0.95946   0.69998   0.43860   0.50820  -0.35593
   -0.94737   0.40952   5.00000
    1.00000   1.00000  -0.30889  -0.81609   1.00000   1.00000   0.50943
   -0.66673   1.00000   1.00000   0.35999  -0.78947  -0.86885  -0.76271
   -0.57895  -0.82011   7.00000
   -0.48413  -0.56850   0.22222   1.00000  -0.67213   0.53848  -1.00000
    0.77779  -0.83336   0.06461   0.01999   1.00000   1.00000  -0.08475
   -0.15789  -0.75026   3.00000
    0.26190   0.40411  -0.33333  -0.77011  -0.47689   0.19226  -0.39619
   -1.00000   1.00000   0.96622   0.35999  -0.75439  -0.77049  -0.69491
   -0.52632  -1.00000   7.00000
    0.00795  -0.15763  -1.00000  -0.26437   0.34427  -0.30775   1.00000
    0.44441  -0.83336   0.87039   0.01999   0.22807   0.24590  -0.49153
   -0.05263  -0.63598   7.00000
   -0.39682  -0.47945   0.0      -0.24138   0.01640   0.42308  -0.09428
   -0.44443  -0.83336   0.90515   0.0      -0.26316  -0.27869  -0.15254
    0.15790  -0.17672   5.00000
    0.85715   0.84932  -0.55550  -1.00000   0.64094   0.19226  -0.73587
   -0.22221   0.33332   1.00000   0.35999  -1.00000  -0.73770  -1.00000
   -1.00000  -0.02645   2.00000
   -0.60254  -0.70547   0.33333   0.42529  -0.47539  -1.00000   0.73587
    0.33336  -0.83336   0.87039  -1.00000   0.50877   0.50820   0.52542
    1.00000  -0.44339   5.00000
    0.11905   0.27399  -0.44444  -0.97701  -1.00000  -0.26926  -0.69809
   -0.44443   0.33332   0.96622   0.35999  -0.96491  -0.96721  -0.96610
   -0.89474  -0.53862   1.00000
   -0.14285  -0.26712  -0.11111  -0.58621  -0.37701  -0.15385   0.20752
    0.0      -0.83336   0.91693  -0.66000  -0.40351  -0.54098  -0.32203
    0.31579   1.00000   5.00000
   -0.73610  -0.77397   0.0       0.17241  -0.64094  -0.65387   0.32076
    1.00000  -1.00000  -1.00000  -0.66000   0.22807   0.31147  -0.08475
    0.10526   0.50265   4.00000
   -0.55554  -0.61644  -0.11111  -0.03448   0.01640   0.53848  -0.16983
    0.55557  -1.00000  -1.00000   0.01999   0.08772   0.08197  -0.28814
   -0.15769   0.49418   1.00000
   -0.78571  -0.82191  -0.27778  -0.03448  -0.44264  -0.19236  -0.01883
    0.66663  -1.00000  -1.00000   0.01999   0.08772   0.04918  -0.42373
   -0.31579   0.44974   5.00000
   -0.38095  -0.41762  -0.27778   0.12644  -0.47539   0.07686  -0.32074
    0.66663  -1.00000  -1.00000   0.01999   0.12281   0.14754  -0.42373
   -0.31579   0.46032   5.00000
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 -0.11905  -0.21916  -0.44444  -0.58621  -0.31146  -0.67238   0.28307
  0.22221  -1.00000  -1.00000  -0.32001  -0.54386  -0.60656  -0.79661
 -0.78947   0.43704   5.00000
 -1.00000  -1.00000  -0.22222  -0.14943  -0.37701  -0.34616   0.28307
  0.55557  -1.00000  -1.00000  -0.32001  -0.47368  -0.08197  -0.42373
 -0.26316   0.53016   5.00000
 -0.76190  -0.76027  -0.11111   0.17241   0.08197   0.49998   0.09439
  0.55557  -1.00000  -1.00000   0.0       0.19298   0.24590  -0.18644
 -0.10526   0.45820   1.00000
 -0.55554  -0.57535   0.0       0.26437   0.50821  -0.26920   1.00000
  0.33336  -1.00000  -1.00000  -0.66000   0.36842   0.44262  -0.08475
  0.21053   0.51323   5.00000
 -0.61110  -0.62329  -0.22222  -0.10345  -0.34427   0.30768  -0.35851
  0.88884  -1.00000  -1.00000   0.01999   0.33333   0.01639  -0.42373
 -0.31579   0.49206   7.00000
 -0.19841  -0.28766  -0.22222  -0.24138  -0.08197   0.03845   0.28307
  0.55557  -1.00000  -1.00000  -0.32001  -0.12281  -0.14754  -0.49153
 -0.42105   0.52169   5.00000
 -0.32539  -0.38356  -0.05556  -0.63218   0.11478   0.30768  -0.09428
 -0.11116  -0.83336   0.95946   1.00000  -0.43860  -0.54098  -0.06475
 -0.21053   0.94074   5.00000
  0.42064   0.56165  -0.22222  -0.70115  -0.21307  -0.65387   0.69810
 -0.88895   1.00000   0.94568   0.01999  -0.68421  -0.70492  -0.89830
 -0.31579  -0.04762   5.00000
 -0.34126  -0.41095   0.05556  -0.37931  -0.34427  -0.38466   0.28307
  0.22221  -0.83336   0.90516   0.65997  -0.33333  -0.40984  -0.28814
  0.05263   0.44550   5.00000
  0.15874   0.30138  -0.61111  -1.00000  -0.11479   0.11536   0.05663
 -1.00000   1.00000   0.94568  -0.66000  -0.92982  -1.00000  -0.79661
 -0.73684  -0.05820   8.00000
 -0.50000  -0.54794   1.00000   0.12644   0.96718   0.46149   0.96223
  0.33336  -0.83336   0.94568   0.0       0.29825   0.24590   1.00000
  1.00000  -0.24021   4.00000

AVERAGES
VAR( 1)=     -0.2375  VAR( 2)=     -0.2594  VAR( 3)=     -0.1600  VAR( 4)=     -0.2092
VAR( 5)=     -0.0872  VAR( 6)=     -0.0093  VAR( 7)=      0.2061  VAR( 8)=      0.1644
VAR( 9)=     -0.5133  VAR(10)=      0.1632  VAR(11)=     -0.0264  VAR(12)=     -0.1523
VAR(13)=     -0.1541  VAR(14)=     -0.3600  VAR(15)=     -0.2105  VAR(16)=      0.1167
VAR(17)=      4.6800

STANDARD DEVIATIONS
VAR( 1)=      0.4969  VAR( 2)=      0.6312  VAR( 3)=      0.3683  VAR( 4)=      0.5231
VAR( 5)=      0.4965  VAR( 6)=      0.4746  VAR( 7)=      0.5329  VAR( 8)=      0.6044
VAR( 9)=      0.7606  VAR(10)=      0.9699  VAR(11)=      0.4778  VAR(12)=      0.5364
VAR(13)=      0.5393  VAR(14)=      0.4470  VAR(15)=      0.6125  VAR(16)=      0.5591
VAR(17)=      1.8868

SIMPLE CORRELATION COEFFICIENTS
VARS( 1, 1)=  1.000000  VARS( 1, 2)=  0.980610  VARS( 1, 3)= -0.466343  VARS( 1, 4)= -0.675209
VARS( 1, 5)=  0.339694  VARS( 1, 6)=  0.221237  VARS( 1, 7)=  0.155457  VARS( 1, 8)= -0.717139
VARS( 1, 9)=  0.811991  VARS( 1,10)=  0.577950  VARS( 1,11)=  0.328227  VARS( 1,12)= -0.666562
VARS( 1,13)= -0.677771  VARS( 1,14)= -0.619332  VARS( 1,15)= -0.522795  VARS( 1,16)= -0.468636
VARS( 1,17)=  0.192104
VARS( 2, 2)=  1.000000  VARS( 2, 3)= -0.461844  VARS( 2, 4)= -0.716948  VARS( 2, 5)=  0.279018
VARS( 2, 6)=  0.201299  VARS( 2, 7)=  0.106574  VARS( 2, 8)= -0.773287  VARS( 2, 9)=  0.882656
VARS( 2,10)=  0.570298  VARS( 2,11)=  0.312649  VARS( 2,12)= -0.709854  VARS( 2,13)= -0.717840
VARS( 2,14)= -0.643144  VARS( 2,15)= -0.641847  VARS( 2,16)= -0.494576  VARS( 2,17)=  0.182801
VARS( 3, 3)=  1.000000  VARS( 3, 4)=  0.456245  VARS( 3, 5)=  0.130441  VARS( 3, 6)=  0.084938
VARS( 3, 7)=  0.081498  VARS( 3, 8)=  0.287209  VARS( 3, 9)= -0.360525  VARS( 3,10)=  0.057055
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220

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VARS( 3,11)= -0.083933  VARS( 3,12)=  0.501308  VARS( 3,13)=  0.476338  VARS( 3,14)=  0.853456
VARS( 3,15)=  0.693207  VARS( 3,16)=  0.094285  VARS( 3,17)= -0.246660
VARS( 4, 4)=  1.000000  VARS( 4, 5)= -0.020278  VARS( 4, 6)= -0.044593  VARS( 4, 7)=  0.048196
VARS( 4, 8)=  0.783310  VARS( 4, 9)= -0.691388  VARS( 4,10)= -0.302272  VARS( 4,11)= -0.227387
VARS( 4,12)=  0.971969  VARS( 4,13)=  0.990124  VARS( 4,14)= -0.639919  VARS( 4,15)= -0.488674
VARS( 4,16)=  0.037027  VARS( 4,17)= -0.146342
VARS( 5, 5)=  1.000000  VARS( 5, 6)=  0.462608  VARS( 5, 7)=  0.675402  VARS( 5, 8)= -0.096267
VARS( 5, 9)=  0.093484  VARS( 5,10)=  0.193054  VARS( 5,11)=  0.213225  VARS( 5,12)= -0.002266
VARS( 5,13)=  0.021029  VARS( 5,14)=  0.205886  VARS( 5,15)=  0.002474  VARS( 5,16)= -0.066896
VARS( 5,17)=  0.128874
VARS( 6, 6)=  1.000000  VARS( 6, 7)= -0.317104  VARS( 6, 8)= -0.113042  VARS( 6, 9)= -0.149836
VARS( 6,10)=  0.115736  VARS( 6,11)=  0.442812  VARS( 6,12)=  0.000885  VARS( 6,13)= -0.043959
VARS( 6,14)=  0.024154  VARS( 6,15)= -0.160174  VARS( 6,16)= -0.179733  VARS( 6,17)= -0.087558
VARS( 7, 7)=  1.000000  VARS( 7, 8)=  0.017073  VARS( 7, 9)= -0.025272  VARS( 7,10)=  0.104695
VARS( 7,11)= -0.193040  VARS( 7,12)=  0.029160  VARS( 7,13)=  0.092505  VARS( 7,14)=  0.219017
VARS( 7,15)=  0.270526  VARS( 7,16)=  0.081959  VARS( 7,17)=  0.204339
VARS( 8, 8)=  1.000001  VARS( 8, 9)= -0.871135  VARS( 8,10)= -0.615566  VARS( 8,11)= -0.154281
VARS( 8,12)=  0.792631  VARS( 8,13)=  0.812254  VARS( 8,14)=  0.445230  VARS( 8,15)=  0.260350
VARS( 8,16)=  0.448587  VARS( 8,17)= -0.264533
VARS( 9, 9)=  1.000001  VARS( 9,10)=  0.552793  VARS( 9,11)=  0.179372  VARS( 9,12)= -0.706714
VARS( 9,13)= -0.707351  VARS( 9,14)= -0.562429  VARS( 9,15)= -0.436908  VARS( 9,16)= -0.581329
VARS( 9,17)=  0.243093
VARS(10,10)=  1.000001  VARS(10,11)=  0.351641  VARS(10,12)= -0.303346  VARS(10,13)= -0.330967
VARS(10,14)= -0.011075  VARS(10,15)=  0.021994  VARS(10,16)= -0.550533  VARS(10,17)=  0.165109
VARS(11,11)=  1.000000  VARS(11,12)= -0.219349  VARS(11,13)= -0.237037  VARS(11,14)= -0.230675
VARS(11,15)= -0.433774  VARS(11,16)= -0.089844  VARS(11,17)= -0.122637
VARS(12,12)=  1.000000  VARS(12,13)=  0.971221  VARS(12,14)=  0.679725  VARS(12,15)=  0.522238
VARS(12,16)=  0.095934  VARS(12,17)= -0.113710
VARS(13,13)=  1.000000  VARS(13,14)=  0.654678  VARS(13,15)= -0.486626  VARS(13,16)= -0.089660
VARS(13,17)= -0.195468
VARS(14,14)=  1.000000  VARS(14,15)=  0.875488  VARS(14,16)=  0.087277  VARS(14,17)= -0.098742
VARS(15,15)=  1.000000  VARS(15,16)=  0.038236  VARS(15,17)=  0.000002
VARS(16,16)=  1.000000  VARS(16,17)= -0.136492

            FOR ANOVA, TOTAL SUM OF SQUARES=                86.4402

STEP NUMBER  1              ENTER VARIABLE  8
STANDARD ERROR OF ESTIMATE=     1.85872
 VAR(  8) SSQ=                          5.9789, RESIDUAL SSQ, BY ANOV OFVAR. SSQ=               79.4611359
MULTIPLE CORRELATION COEFFICIENT =  0.26453
GOODNESS OF FIT,F(    1,  23)=             1.7306
CONSTANT TERM=        4.615784

VAR         COEFF        STD DEV      T VALUE       BETA COEFF
                          COEFF
  8        -0.825749      0.6277    -1.3155      -0.2645

STEP NUMBER  2              ENTER VARIABLE  7
STANDARD ERROR OF ESTIMATE=     1.85538
 VAR(  7) SSQ=                          3.7280, RESIDUAL SSQ, BY ANOV OFVAR. SSQ=               76.7331696
MULTIPLE CORRELATION COEFFICIENT =  0.33706
GOODNESS OF FIT,F(    2,  22)=             1.4099
CONSTANT TERM=        4.665206

VAR         COEFF        STD DEV      T VALUE       BETA COEFF
                          COEFF
  7         0.739643      0.7107     1.0407       0.2089
  8        -0.836883      0.6267    -1.3355      -0.2681

STEP NUMBER  3              ENTER VARIABLE  3
STANDARD ERROR OF ESTIMATE=     1.85763
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221

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 VAR(  3) SSQ=                    3.2663, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=                72.4669189
MULTIPLE CORRELATION COEFFICIENT =  0.38967
GOODNESS OF FIT,F(   3,  21)=            1.2532
CONSTANT TERM=        4.455845

VAR          COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   3        -1.049158       1.0784     -0.9729        -0.2048
   7         0.795190       0.7139      1.1139         0.2246
   8        -0.654127       0.6549     -0.9980        -0.2096

STEP NUMBER  4            ENTER VARIABLE 12
STANDARD ERROR OF ESTIMATE=      1.61616
 VAR( 12) SSQ=                    6.4979, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=                65.9690247
MULTIPLE CORRELATION COEFFICIENT =  0.47738
GOODNESS OF FIT,F(   4,  20)=            1.4758
CONSTANT TERM=        4.787731

VAR          COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   3        -1.833494       1.1932     -1.5366        -0.3579
   7         0.808375       0.6980      1.1581         0.2283
   8        -1.784087       1.0287     -1.7344        -0.5715
  12         1.801196       1.2833      1.4036         0.5121

STEP NUMBER  5            ENTER VARIABLE 13
STANDARD ERROR OF ESTIMATE=      1.69699
 VAR( 13) SSQ=                   11.2531, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=                54.7159576
MULTIPLE CORRELATION COEFFICIENT =  0.69967
GOODNESS OF FIT,F(   5,  19)=            2.1338
CONSTANT TERM=        4.494587

VAR          COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   3        -1.860619       1.1160     -1.6687        -0.3632
   7         1.191741       0.6604      1.7514         0.3366
   8        -1.191186       1.0069     -1.1831        -0.3816
  12         6.948456       2.8667      2.4238         1.9766
  13        -5.815373       2.9419     -1.9768        -1.6623

STEP NUMBER  6            ENTER VARIABLE  4
STANDARD ERROR OF ESTIMATE=      1.66662
 VAR(  4) SSQ=                    4.7190, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=                49.9969177
MULTIPLE CORRELATION COEFFICIENT =  0.64407
GOODNESS OF FIT,F(   6,  18)=            2.1267
CONSTANT TERM=        4.761749

VAR          COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   3        -1.481709       1.1330     -1.3078        -0.2892
   4         7.160782       5.4937      1.3035         1.9854
   7         1.448152       0.6966      2.0788         0.4090
   8        -0.691981       1.0604     -0.6526        -0.2217
  12         5.733154       2.9658      1.9331         1.6299
  13       -12.119619       5.6338     -2.1512        -3.4643

STEP NUMBER  7            ENTER VARIABLE  1
STANDARD ERROR OF ESTIMATE=      1.60366
 VAR(  1) SSQ=                    1.6059, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=                48.1909790
MULTIPLE CORRELATION COEFFICIENT =  0.66028
GOODNESS OF FIT,F(   7,  17)=            1.8772
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CONSTANT TERM=        4.465587

 VAR         COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   1       -0.929821      1.1649      -0.7982         -0.2449
   3       -1.879785      1.2485      -1.5056         -0.3069
   4        6.310068      5.6514       1.1166          1.7495
   7        1.607057      0.7314       2.1973          0.4639
   8       -1.162799      1.2229      -0.9508         -0.3725
  12        6.149091      3.0411       2.0220          1.7482
  13      -11.741479      5.7112      -2.0559         -3.3662

STEP NUMBER  8             ENTER VARIABLE  9
STANDARD ERROR OF ESTIMATE=     1.68880
 VAR(  9) SSQ=                       2.5583, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=              45.6327057
MULTIPLE CORRELATION COEFFICIENT =  0.68258
GOODNESS OF FIT,F(   8,  16)=          1.7447
CONSTANT TERM=        4.660356

 VAR         COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   1       -1.670356      1.4060      -1.1880         -0.4399
   3       -1.812019      1.2544      -1.4446         -0.3537
   4        6.914739      5.7044       1.2122          1.9171
   7        1.811132      0.7646       2.3688          0.5116
   8       -0.165316      1.6168      -0.1022         -0.0530
   9        1.116593      1.1790       0.9471          0.4501
  12        6.574475      3.0833       2.1323          1.8691
  13      -13.030397      5.8880      -2.2130         -3.7246

STEP NUMBER  9             ENTER VARIABLE  2
STANDARD ERROR OF ESTIMATE=     1.61567
 VAR(  2) SSQ=                       6.4767, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=              39.1559753
MULTIPLE CORRELATION COEFFICIENT =  0.73601
GOODNESS OF FIT,F(   9,  15)=          1.9701
CONSTANT TERM=        4.862652

 VAR         COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   1       14.901560     10.6064       1.4050          3.9244
   2      -19.597778     12.4417      -1.5752         -6.5172
   3       -1.842795      1.2002      -1.5354         -0.3597
   4        2.602895      6.1054       0.4263          0.7217
   7        1.501850      0.7574       1.9830          0.4242
   8        0.240255      1.5661       0.1532          0.0770
   9        4.437709      2.3912       1.8559          1.7889
  12        6.460135      2.9506       2.1894          1.8366
  13       -9.303879      6.1097      -1.5228         -2.6594

STEP NUMBER 10             ENTER VARIABLE 15
STANDARD ERROR OF ESTIMATE=     1.64360
 VAR( 15) SSQ=                       1.3362, RESIDUAL SSQ, BY ADDN OFVAR, SSQ=              37.8197632
MULTIPLE CORRELATION COEFFICIENT =  0.74666
GOODNESS OF FIT,F(  10,  14)=          1.7628
CONSTANT TERM=        4.678252

 VAR         COEFF        STD DEV          T VALUE       BETA COEFF
                           COEFF
   1       17.002899     11.1958       1.5187          4.4776
   2      -22.534714     13.3279      -1.6908         -6.3440
   3       -1.361850      1.3994      -0.9731         -0.2658
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     4       2.272463     6.2267    0.3648      0.6301
     7       1.758426     0.8525    2.0628      0.4967
     8      -0.233414     1.7315   -0.1348     -0.0748
     9       4.741658     2.4706    1.9193      1.9115
    12       7.169570     3.1666    2.2641      2.0383
    13      -9.452861     6.2189   -1.5200     -2.7020
    15      -0.928375     1.3200   -0.7033     -0.2522

 STEP NUMBER 11            ENTER VARIABLE 14
 STANDARD ERROR OF ESTIMATE=      1.69169
  VAR( 14) SSQ=                   0.6161, RESIDUAL SSQ, BY ADDN OFVAR. SSQ=                 37.2036743
 MULTIPLE CORRELATION COEFFICIENT =  0.75137
 GOODNESS OF FIT.F(  11,  13)=           1.5323
 CONSTANT TERM=        5.013990

 VAR        COEFF       STD DEV        T VALUE       BETA COEFF
                         COEFF
     1      15.608483    11.9008    1.3107      4.1106
     2     -20.779709    14.2298   -1.4603     -5.8499
     3      -2.069436     2.1293   -0.9613     -0.4078
     4       3.033292     6.6174    0.4584      0.6410
     7       1.693990     0.8883    1.9069      0.4785
     8      -0.088960     1.8092   -0.0492     -0.0285
     9       4.576906     2.5677    1.7825      1.8450
    12       6.875870     3.3202    2.0709      1.9548
    13     -10.147925     6.5738   -1.5437     -2.9007
    14       1.405810     3.0300    0.4640      0.3330
    15      -1.357466     1.6435   -0.8259     -0.3687

 STEP NUMBER 12            ENTER VARIABLE  6
 STANDARD ERROR OF ESTIMATE=      1.73985
  VAR(  6) SSQ=                   0.8789, RESIDUAL SSQ, BY ADDN OFVAR. SSQ=                 36.3240130
 MULTIPLE CORRELATION COEFFICIENT =  0.75819
 GOODNESS OF FIT.F(  12,  12)=           1.3521
 CONSTANT TERM=        6.280496

 VAR        COEFF       STD DEV        T VALUE       BETA COEFF
                         COEFF
     1      18.165970    13.1332    1.3830      4.7641
     2     -23.377563    15.4065   -1.5172     -6.5613
     3      -2.156919     2.1935   -0.9833     -0.4210
     4       2.113567     7.0165    0.3012      0.5860
     6      -0.571670     1.0609   -0.5389     -0.1438
     7       1.411484     1.0534    1.3400      0.3987
     8      -0.168659     1.8665   -0.0904     -0.0540
     9       4.926009     2.7200    1.8110      1.9366
    12       7.023371     3.4256    2.0502      1.9968
    13      -9.363029     6.9161   -1.3538     -2.6763
    14       2.042043     3.3324    0.6128      0.4837
    15      -1.748374     1.8394   -0.9506     -0.4749

 STEP NUMBER 13            ENTER VARIABLE 10
 STANDARD ERROR OF ESTIMATE=      1.77992
  VAR( 10) SSQ=                   1.4755, RESIDUAL SSQ, BY ADDN OFVAR. SSQ=                 34.8493195
 MULTIPLE CORRELATION COEFFICIENT =  0.76949
 GOODNESS OF FIT.F(  13,  11)=           1.2284
 CONSTANT TERM=        6.125571

 VAR        COEFF       STD DEV        T VALUE       BETA COEFF
                         COEFF
     1      22.306870    14.7442    1.5129      5.8746
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   2      -27.096450     16.6797   -1.6246     -7.6208
   3       -2.199236      2.2448   -0.9797     -0.4293
   4        2.158669      7.1784    0.3007      0.5985
   6       -0.955599      1.2225   -0.7817     -0.2404
   7        1.106900      1.1664    0.9490      0.3127
   8       -0.701548      2.0630   -0.3401     -0.2247
   9        5.391535      2.8643    1.8823      2.1734
  10       -0.510017      0.7473   -0.6824     -0.2622
  12        6.873244      3.5110    1.9591      1.9555
  13       -9.078595      7.0876   -1.2809     -2.5950
  14        3.240359      3.8348    0.8450      0.7676
  15       -2.207290      1.9983   -1.1046     -0.5996

 STEP NUMBER 14          ENTER VARIABLE 16
 STANDARD ERROR OF ESTIMATE=      1.86518
  VAR( 16) SSQ=                   0.0604. RESIDUAL SSQ. BY ADDN OFVAR. SSQ=          34.7888794
 MULTIPLE CORRELATION COEFFICIENT =  0.76996
 GOODNESS OF FIT.F( 14. 10)=            1.0400
 CONSTANT TERM=       6.327283

 VAR      COEFF        STD DEV       T VALUE      BETA COEFF
                        COEFF
   1       21.970271     16.6603    1.4043      6.7881
   2      -26.515442     18.0296   -1.4707     -7.4647
   3       -2.362166      2.6574   -0.8889     -0.4611
   4        2.772054      8.8477    0.3134      0.7687
   6       -0.975835      1.2902   -0.7564     -0.2455
   7        1.028611      1.3589    0.7569      0.2905
   8       -0.667194      2.1046   -0.3170     -0.2201
   9        5.414508      3.0066    1.8009      2.1827
  10       -0.510962      0.7832   -0.6524     -0.2627
  12        6.654308      4.0524    1.6420      1.8918
  13       -9.346673      7.7006   -1.2138     -2.6717
  14        3.512352      4.5173    0.7775      0.8321
  15       -2.198746      2.0951   -1.0495     -0.6973
  16        0.203355      1.5428    0.1318      0.0603

 STEP NUMBER 15          ENTER VARIABLE  5
 STANDARD ERROR OF ESTIMATE=      1.96529
  VAR(  5) SSQ=                   0.0276. RESIDUAL SSQ. BY ADDN OFVAR. SSQ=          34.7613068
 MULTIPLE CORRELATION COEFFICIENT =  0.77016
 GOODNESS OF FIT.F( 15.  9)=            0.8747
 CONSTANT TERM=       6.236260

 VAR      COEFF        STD DEV       T VALUE      BETA COEFF
                        COEFF
   1       22.065969     16.5159    1.3354      6.8066
   2      -26.493561     18.9991   -1.3945     -7.4585
   3       -2.385931      2.8141   -0.8479     -0.4657
   4        2.755275      9.3248    0.2955      0.7639
   5       -0.560121      6.6302   -0.0845     -0.1480
   6       -0.590472      4.7598   -0.1241     -0.1485
   7        1.490183      5.6482    0.2638      0.4209
   8       -0.805773      2.6781   -0.3009     -0.2581
   9        5.326155      3.3361    1.5965      2.1471
  10       -0.541988      0.9032   -0.6000     -0.2786
  12        6.730164      4.3633    1.5424      1.9134
  13       -9.390454      8.1304   -1.1550     -2.6842
  14        3.737252      5.4537    0.6853      0.8853
  15       -2.363822      2.9481   -0.8018     -0.6421
  16        0.182308      1.6445    0.1109      0.0540
```

```
STEP NUMBER 16          ENTER VARIABLE 11
STANDARD ERROR OF ESTIMATE=     2.06443
 VAR( 11) SSQ=                      0.0026, RESIDUAL SSQ, BY ADDN OFVAR. SSQ=                  34.7587433
MULTIPLE CORRELATION COEFFICIENT =  0.77018
GOODNESS OF FIT.F(  16,   8)=            0.7290
CONSTANT TERM=       6.244474

VAR          COEFF       STD DEV       T VALUE       BETA COEFF
                          COEFF
  1        22.250015     19.2591      1.1553        5.8596
  2       -26.695465     21.8038     -1.2243       -7.5153
  3        -2.395309      3.0096     -0.7959       -0.4675
  4         2.678067     10.3902      0.2577        0.7425
  5        -0.625601      7.5329     -0.0830       -0.1653
  6        -0.566601      5.1429     -0.1102       -0.1425
  7         1.535947      6.2809      0.2445        0.4338
  8        -0.835613      3.0989     -0.2697       -0.2678
  9         5.352530      3.7018      1.4459        2.1577
 10        -0.560625      1.2283     -0.4564       -0.2882
 11         0.038734      1.5977      0.0242        0.0098
 12         6.745022      4.6683      1.4449        1.9176
 13        -9.315187      9.1651     -1.0164       -2.6627
 14         3.767046      5.9134      0.6370        0.6924
 15        -2.366163      3.1283     -0.7564       -0.6420
 16         0.176406      1.7517      0.1019        0.0529

 S/N        ACTUAL        ESTIMATE      RESIDUAL   NORMAL DEVIATE       SSQ RESIDUALS
  0        5.00000       4.79195       0.20805      0.09981                 0.0433
  1        7.00000       6.61717       0.38283      0.18366                 0.1898
  2        3.00000       3.12974      -0.12974     -0.06224                 0.2067
  3        7.00000       5.78721       1.21279      0.58184                 1.6775
  4        7.00000       7.30852      -0.30852     -0.14801                 1.7727
  5        5.00000       4.41770       0.58230      0.27936                 2.1118
  6        2.00000       2.12265      -0.12265     -0.05884                 2.1269
  7        5.00000       5.18713      -0.18713     -0.08978                 2.1619
  8        1.00000       2.23284      -1.23284     -0.59145                 3.6818
  9        5.00000       5.06938      -0.06938     -0.03329                 3.6866
 10        4.00000       4.65164      -0.65164     -0.31262                 4.1112
 11        1.00000       3.88633      -2.88633     -1.38471                12.4421
 12        5.00000       5.83511      -0.83511     -0.40064                13.1395
 13        5.00000       3.02607       1.97393      0.94699                17.0359
 14        5.00000       5.89987      -0.89987     -0.43171                17.8457
 15        5.00000       3.10977       1.89023      0.90683                21.4187
 16        1.00000       3.50941      -2.50941     -1.20389                27.7158
 17        5.00000       3.86140       1.13860      0.54624                29.0122
 18        7.00000       4.83256       2.16744      1.03983                33.7100
 19        6.00000       4.37429       0.62571      0.30018                34.1015
 20        5.00000       4.85376       0.14624      0.07016                34.1229
 21        5.00000       5.71327      -0.71327     -0.34219                34.6316
 22        5.00000       4.65180       0.34820      0.16706                34.7529
 23        8.00000       8.01849      -0.01849     -0.00887                34.7532
 24        4.00000       4.11143      -0.11143     -0.05346                34.7656

STEP NUMBER 17          ENTER VARIABLE 11
STANDARD ERROR OF ESTIMATE=     2.22843
 VAR( 11) SSQ=                     -0.0026, RESIDUAL SSQ, BY ADDN OFVAR. SSQ=                  34.7614220
MULTIPLE CORRELATION COEFFICIENT =  0.77016
GOODNESS OF FIT.F(  17,   7)=            0.6003
CONSTANT TERM=      -6.236269

VAR          COEFF       STD DEV       T VALUE       BETA COEFF
```

APPENDIX B

OAO Cell SPECIFICATION

AV 252CS-25G

GRUMMAN AEROSPACE CORPORATION
Bethpage, L. I., N. Y.
Code Ident. No. 26512

Page 1 of 86
Specification No. AV-252CS-25G

SPECIFICATION

Release Date 4-25-72
Superseding AV-252CS-25F
dated 6-11-71 with
Amendment 1 dated 7-4-71
and Amendment 2 dated
11-10-71.

NICKEL-CADMIUM STORAGE CELLS
POWER SUPPLY SUBSYSTEM
ORBITING ASTRONOMICAL OBSERVATORY
SPECIFICATION FOR

C. Monaco C Monaco
Specifications Engr

F. Burgess
Approved ~~by Gr. Ldr.~~ Engineering

L. Needle
Approved by Vehicle Design Proj. Engr

A. Gartenberg
Approved by Subsystem Project Engr

T.J. Heuermann
Approved by OAO Engineering Manager

Contract No.

228

Eng 200.1 7-66

List No. __

REVISION DESCRIPTION

Spec No. AV-252CS-25G

Rev.	Date	Description
D	6-20-68	Revised per latest requirements of S/C 3 and subsequent. Bars to the right of paragraphs indicate revisions subsequent to AV-252CS-25C.
E		Revised per latest requirement of S/C 3 and subsequent.
F		Revised to incorporate the requirements of Amendments 1 thru 5 of AV-252CS-25E, to incorporate the requirements for the Auxiliary Electrode Cells, previously covered by AV-252CS-89A with Amendment 1 thru 5, to incorporate changes associated with State-Of-Charge adjustments and to incorporate changes agreed with or requested by the GSFC. Bars to the right of paragraphs indicate revisions subsequent to Amendment 5 to AV-252CS-25E.
G	4-21-72	Incorporated Amendments 1 and 2 and revised per latest requirements. Bars to the right of paragraphs indicate revisions subsequent to Amendment 2 to AV-252CS-25F.

GRUMMAN AEROSPACE CORPORATION

Bethpage, L. I., N. Y.
Code Ident. No. 26512

SPECIFICATION

No. AV-252CS-25G

NICKEL-CADMIUM STORAGE CELLS

POWER SUPPLY SUBSYSTEM

ORBITING ASTRONOMICAL OBSERVATORY

SPECIFICATION FOR

1 SCOPE

1.1 General. - This specification establishes the requirements for a hermetically sealed, Nickel-Cadmium Storage Cell (Cell) which is to be used in the fabrication of the Storage Battery for the Orbiting Astronomical Observatory (OAO). This specification also includes the requirements for the Auxiliary (Signal) electrode. The Signal electrode shall be included in the cell if specified by part number in the Purchase Order.

2 APPLICABLE DOCUMENTS

2.1 General. - The following specifications, standards, drawings and publications, of current issue, form a part of this specification to the extent specified herein:

Grumman

RC-252CS-14C	Subcontractor Reliability Control - OAO Specification for
AV-252CS-26D	Nickel-Cadmium Storage Battery Assembly, Power Supply Subsystem - OAO - Specification for
SP-252CS-38C	Material Selection and Processes - OAO General Specification for
ET-252CS-39C	Vendor's Environmental Testing - OAO General Specification for
AV-252-I-88	Rework Procedure Battery Terminal Solder Termination

230

2.1 (Continued)

LSP-14-14201D	Dielectric Sealing (Potting) of Electrical Connectors and Components for High Temperature
GSS 7011	Safety Solvents - Cleaning
<u>Federal</u>	
QQS-766	Steel, Plate and Strip, Corrosion Resisting
<u>Military</u>	
MIL-B-7883-1	Brazing of Steels, Copper, Copper Alloys and Nickel Alloys
MIL-W-8611A	Welding, Metal Arc and Gas, Steels, and Corrosion and Heat Resistant Alloys, Process for
MIL-F-14072	Finishes for Ground Signal Equipment
STANDARDS	
<u>Military</u>	
MIL-STD-202C	Military Standard, Test Methods for Electronic and Electrical Component Parts
DRAWINGS	
<u>Grumman</u>	
252SCAV110	Nickel-Cadmium Storage Cell - Avionics Power Supply Subsystem
252SCAV113	Nickel-Cadmium Auxiliary Storage Cell-Avionics Power Supply Subsystem.
HANDBOOKS	
<u>Aero Propulsion Lab, Wright Patterson AFB, Ohio</u>	
Screening Method, Edited by: J.E. Cooper and A. Fleischer	Characteristics of Separators for Alkeline Silver Oxide-Zinc Secondark Batteries

2.2 Precedence. - When the requirements of the purchase order, this specification or subsidiary specifications are in conflict, the following precedence shall apply:

(a) Purchase Order - The Purchase Order shall have precedence over any specification.

(b) This Specification - This specification shall have precedence over all referenced subsidiary specifications.

2.3 Availability of Documents. - Copies of this specification and other specifications and documents referenced herein may be obtained, upon request from Grumman Aircraft Engineering Corporation, Bethpage, Long Island, New York, 11714; Attention: OAO Specifications Group. Requests for Military Documents listed herein should be addressed to the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

3 REQUIREMENTS

3.1 Qualification. - The cells furnished under this specification shall be products which have been tested and have passed the Qualification Tests listed in Section 4.

3.2 Reliability and Operating Life. -

3.2.1 Reliability. - Each storage cell shall be designed and constructed so that a 99.8 percent probability of successful operation during the launch and orbital lifetime (See Note) is achieved. The achievement of the specified reliability shall be assured by the implementation of a comprehensive subcontractor reliability program in accordance with Specification RC-252CS-14C.

NOTE: Orbital Lifetime = Minimum of 5200 orbital cyclings during a minimum operating period of one (1) year.

3.2.2 Operating Life. - All components and component parts shall have a minimum operating life of 26,250 (See Note) hours as well as a charge-discharge capability of 10,000 cycles during this period. The operating life shall be defined as wearout or deterioration to an extent which causes the equipment to deviate from the performance limits specified herein. Environmental test conditions representative of ground operations, launch and orbit shall be as specified in ET-252CS-39C, except as otherwise specified herein.

NOTE: 17,500 hours to be electrically active and balance in electrically drained and shorted (inactive) condition.

232

3.3 Materials. - Materials used in the manufacture of storage cells shall of high quality, suitable for the purpose intended, and shall be selected in accordance with the requirements of SP-252-38C. Plates, separator and electrolyte are the only items to be installed in a cell. All materials must be approved by Grumman prior to their being used. A list of materials shall be supplied by seller.

3.4 Design and Construction. - Individual cells shall be hermetically sealed to permit operation within the environmental requirements of this specification. Cells shall contain the necessary plates and terminal posts and shall be secured so that no motion of the plates, relative to the container or hold-down arrangement, can occur. The detailed mechanical and electrical design of the nickel-cadmium storage cells shall be accomplished by the Seller subject to the requirements of this specification.

3.4.1 Interchangeability. - All cells of a given Seller's part number shall be dimensionally and functionally interchangeable with each other. The Seller's part number shall be identical with the Seller's drawing number for the same cells.

3.4.2 Cell Lot. - Cells purchased under one lot shall use components from one specific batch only and shall be assembled as one batch under identical production techniques. This requirement shall be further defined as follow:

> Components from one batch are mandatory for all active components such as; separator material, electrolyte, plates (one batch = one melange or 2 randomized melanges*). For all other cell components, one batch is desirable. This requirement must be strictly adhered to. Complete records must be kept of each component batch and be made available to Grumman upon request. Each cell shall be serialized with a non-recurring number.

* A melange shall be used to fabricate the cell order. In the event one melange is not adequate to manufacture the cell order, two or more melanges may be used if mixed and randomized prior to cell production.

3.4.3 Separators. - Separators shall be of a Grumman approved type, free from flaws, cracks, contamination and/or other imperfections likely to permit short circuits and/or other failure mechanisms. They shall be fabricated from materials which are physically and chemically stable in the presence of potassium hydroxide. (Materials shall be selected in accordance with SP-252CS-38C). They shall have a low electrical resistance and shall be capable of absorbing and retaining large quantities of potassium hydroxide electrolyte when subjected to the environmental conditions given in Tables I and II of Specifications ET-252CS-39C. Separators shall also be capable of withstanding without damage the thermal tests (See paragraphs 4.5.11, 4.5.12, and 4.5.13) which are representative of environmental conditions anticipated during the two years of minimum battery life.

3.4.3.1 Separator Quality Assurance Provisions. - The following tests shall be conducted on the separator and is to be used for cells purchased under this specification. Sample Data Sheets as shown in the attached (Appendix 1 and Appendix 3) shall be prepared by the seller. Two copies of each Data Sheet and a separator sample of 100 sq. in. minimum size shall be furnished to Grumman for approval prior to start of further processing. Material traceability shall be required.

3.4.3.1.1 Separator Manufacturer's Information. - Record all information requested under 1.0 on sample Data Sheets of Appendix 1.

3.4.3.1.2 Electrolyte Absorption, Dimensional Change, Electrolyte Retention and Porosity. - Six samples of each material shall be cut (in the machine direction) to 6.50 cm. by 2.50 cm. and individually measured using a standard die. The thickness of each sample shall be measured using an Ames gauge Model 262 platform dial micrometer with a 0.5 in. diameter stainless steel anvil. The dial shall be graduated in 0.001 mm. An equivalent thickness measurement system is acceptable. Each sample shall be weighed to the nearest one milligram on an analytical balance and then immersed in approximately 100 cc of aqueous potassium hydroxide (KOH) solution in non-corrosive containers with air tight covers. The concentration of the KOH solution shall be the same percent as used in the cell filling and shall be of the same

3.4.3.1.2 (Continued)

quality. Dimensional changes shall be measured after three hours of equilibration. The samples shall be returned to their individual containers for an additional hour. At the end of one hour, the equilibrated samples shall be wiped across a clean lucite plate until no droplets are left on the plate. Then re-weigh the sample.

(a) Electrolyte Absorption - Electrolyte absorption is the difference between the wet equilibrated samples and the dry sample weights. Record data on dimensions, dimensional changes and absorption in a manner similar to that delineated under 2.1 on the Sample Data Sheets of Appendix 1.

(b) Electrolyte Retention - Electrolyte retention shall be measured on the same samples after draining for 15 ± 5 minutes on a clean lucite plate positioned at a 45 ± 2 degree angle. The samples shall be re-weighted. During draining, the samples shall be enclosed in an inert atmosphere. Record data on electrolyte retention in a manner similar to that delineated under 2.2 on Sample Data Sheets of Appendix 1.

(c) Porosity - Porosity shall be calculated in a manner similar to that delineated under 2.3 on the Sample Data Sheets of Appendix 1.

3.4.3.1.3 Separator Resistance - DC Method. - The resistance of three samples of separator material shall be measured. Each sample shall be cut from a different roll. This method is essentially that described by Lander in Chapter 6a of the Cooper-Fleischer Handbook.

The cell used is a modification of that used in the AC method. The platinized platinum current electrodes are replaced by disc cadmium electrodes (capacity 0.7 A-hr) which are maintained in a partially discharged state. The voltage drop across the membrane is measured using two Hg/HgO reference electrodes which fit into ports in either cell half. The bottom of each port is connected by a diagonally drilled capillary to the membrane surface.

235

3.4.3.1.3 (Continued)

Equilibration technique and sample size are the same as in the AC method. The sample is introduced between the cell halves and the cell promptly filled with electrolyte and the reference electrodes placed. Current is passed by means of a constant current source to give 50 ma/cm^2. The voltage drop is measured between the two reference electrodes using either an electrometer or a potentiometer. A blank determination is made and subtracted from the cell resistance with the membrane in the path.

(a) Calculations -

(1) Separator Resistance

$$R'' = \frac{E_r - E_b}{I} A$$

R" = Separator resistance ohm-cm^2

E_r = Voltage drop between Hg/HgO electrodes with separator in path - volts

E_b = Voltage drop between Hg/HgO electrodes with separator out of path - volts

I = Current - amperes

A = Separator area exposed cm^2

(b) Separator Specific Resistivity -

$$P'' = \frac{R''}{t_w}$$

P" = Separator specific resistivity ohm-cm

R" = Separator resistance ohm-cm^2

t_w = Equilibrated separator thickness cm

Perform calculations above and record data in a manner similar to that delineated under 3.1 on the Sample Data Sheets of Appendix 1.

3.4.3.1.4 Separator Wettability. - Separator wettability of three samples of separator material shall be measured. Each sample shall be cut from a different roll. Separator wettability shall be measured by placing the dry separator sample in the resistivity cell, filling the cell with electrolyte, and recording the time required to attain a stable resistance. Measurements shall be made at five second intervals. Plot the data of the three determinations on one graph, 10 x 10 to the inch.

3.4.3.1.5 Tensile Strength at Break. - Tensile strength at break shall be measured on at least six samples, each two samples cut from a different roll. Separator tensile strength measurements shall be made on die cut specimens 12.7 cm by 2.5 cm, cut in the roll direction, each of which must be carefully examined for flaws. Samples containing cracks, nicks or inclusions must be discarded. At least five samples of each material shall be run and the mean value reported. The tensile strength at break shall be measured on samples which are conditioned both at 75 ± 5°F, TBD ± 5% relative humidity for 24 hours, and after 24 hour immersion in 34% KOH. A cross head speed of 2 inches per minute shall be used and the specimens positioned in rubber faced jaws so that the grip separation is 3 in. Elongation measurements can be obtained by measuring the grip separation as the test progresses using the value at break to calculate % elongation. For the tensile measurement, the load in pounds shall be measured at the breaking point. Samples breaking outside the area between the jaws are not included.

Temperature and humidity at test site shall be recorded on data sheet. Perform calculations as follows:

Calculations -

$$\text{Tensile Strength at Break} = \frac{\text{Breaking Load lbs.}}{\text{C.S.A.}}$$

C.S.A = sample cross sectional area

$$\% \text{ Elongation} = \frac{L - L_o \times 100}{L_o}$$

L = Sample length at break

L_o = Original length

231

3.4.3.1.5 (Continued)

Record data in a manner similar to that delineated under 5.1 on the Sample Data Sheets of Appendix 1. Also record the appearance of break, (i.e., clean or fuzzy). Repeat the test on six samples that have been stored for 24 hours at 70°C in cell electrolyte CO_2 free atmosphere. Record data in a manner similar to that delineated under 5.2 on the Sample Data Sheets of Appendix 1. The seller may suggest alternate methods to Grumman for approval.

3.4.3.1.6 Extractable Organic Content. - At least three samples, each from a different roll shall be analyzed for soluble organic material. The sample size shall be a 10 cm. square. The following method of extraction of organics is recommended. If a different method is used, it shall be submitted to Grumman for approval.

(a) Weigh the separator sample on an analytical balance.

(b) Determine volume of separator sample.

(c) Put the sample in a weighed container with methanol, reagent grade. Use a volume ratio of 20 solvent to one of separator, cover container.

(d) Stir with a magnetic stirrer for a minimum of 16 and a maximum of 24 hours.

(e) Remove separator sample and weigh after drying.

(f) Evaporate solvent.

(g) Determine weight of residue and weight loss of separator.

(h) Perform IR analysis of residue. Submit copy of IR trace to Grumman and indicate major organic constituents. (If a larger residue sample is required to perform this task, a proportionally larger sample is permissible).

(i) Record data in a manner similar to that delineated on the Sample Data Sheets of Appendix 1.

NOTE: Target Specification - Less than 2.0% by weight of total organics.

3.4.3.1.7 Inorganic Content. - At least three samples, each from a different roll, shall be analyzed for inorganic materials. The sample size from which inorganics are to be extracted shall be a 10 cm. square. Quantitative analysis of the following will be determined: Carbonate, silica, zinc, chloride, nitrate and nickel titanium. Submit a description to Grumman of the method used. Record data in a manner similar to that delineated under 7.1 on the Sample Data Sheets of Appendix 1.

NOTE: Target Specification - Less than 1.0% by weight of total inorganics as determined by ignition residue.

3.4.3.1.8 Discoloration of Samples in Electrolyte. - During testing of samples requiring equilibration in electrolyte, report any discoloration of the sample in a manner similar to that delineated under 8.1 on the Sample Data Sheets of Appendix 1.

3.4.3.1.9 Thickness Variation. - The separator thickness shall be measured at minimum intervals of one measurement for each 20 cells constructed. Each measurement shall be made on samples of two feet in length, taking 10 thickness readings at approximately two inch intervals. The gauge described in 3.4.3.1.2 shall be used. Record data in a manner similar to that delineated under 9.1 on Sample Data Sheets of Appendix 1.

3.4.3.1.10 Materials Used In Cell Formation. - Apply the sampling criteria and test procedures specified in 3.4.3.1.6 and 3.4.3.1.7 for the separator used in cell formation. Record data in a manner similar to that delineated under 6.0 and 7.1 on the Sample Data Sheets of Appendix 1. Where applicable, furnish information in a manner similar to that delineated on Sample Data Sheet 1 of Appendix 1.

3.4.4 Cell Container. -

3.4.4.1 Cell Case. - The cell case shall be Type 304L stainless steel, condition A per Specification QQS-766. Material thickness shall be 0.030 inch stock. Electric are welding using inert gas shielding per Specification MIL-W-8611 shall be used. All welded areas shall be passivated in accordance with Specification MIL-F-14072, Finish E-300.

3.4.4.2 Cover. - The cell cover shall be made from class 304L stainless steel, condition A, in accordance with Specification QQS-766.

3.4.4.3 Metal Container Quality Assurance Provision. - The seller must supply with every order, the supplier, name, alloy designation, batch number and chemical composition of raw material with certified analysis. Two copies of this information shall be furnished to Grumman prior to further processing. The tolerances on the cell case wall thickness shall be within ± 1.5 mil. The completed cell must conform to Grumman Drawing 252SCAV110. Each can shall be visually examined for blemishes, pits, cuts, cracks, burrs, file marks, weak points, incomplete weld penetration and/or any other defects. Metal containers not meeting these requirements shall be rejected.

3.4.5 **Electrodes and Electrode Assemblies**. -

3.4.5.1 General. - The electrode materials shall be identical to those used in cells for the cell Qualification Program as stated herein. No changes in material quality, contents and manufacturing technique shall be made without prior written approval by Grumman.

3.4.5.2 Electrode Quality Assurance Provisions. - Two copies of either the electrode purchasing specifications and/or the manufacturing process specifications delineating the process from raw materials through impregnation and storage for use on cells as specified herein shall be furnished to Grumman prior to start of further processing. Two copies of the electrode suppliers certification for both positive and negative electrodes used herein shall be furnished to Grumman prior to start of further processing. This certification shall contain the following minimum information:

(a) Assigned plate batch number (melange)

(b) Spiral number

(c) Dates of impregnation

(d) Percent porosity

3.4.5.2 (Continued)

(e) Weight of active material per plate.

(f) Positive capacity obtained.

(g) Negative capacity obtained.

(h) Plate thickness.

(i) Maximum Plate Compression

(j) Hydrate totals (gm/dm^2)

  (1) Average

  (2) Range

NOTE: Sample results based on a reasonable sample from each positive and negative spiral are acceptable for items (d) through (j) above. Tolerances are to be supplied by seller.

3.4.5.3 Electrode Assembly Quality Assurance Provisions. - Manufacturing and inspection operations on completed positive and negative plates shall be controlled as follows prior to their formation:

(a) Inspection of cutting, coining and other operations affecting the integrity of the sinter and grid.

(b) Edges shall be coined to prevent flaking of sinter material.

(c) Visual inspection of plates. (100 percent inspection on positive and negative plates prior to assembly into formation pack).

NOTE: Inspection criteria will be established by the seller reflecting items listed in paragraph (d) (1) through (9) and (e). Sample plates showing each type defect shall be posted at inspection station.

241

3.4.5.3 (Continued)

(d) Plates shall be rejected if defects as listed below are found:

(1) Crack detected in sinter exceeds 0.50 inch in length, 0.005 inch in depth, or 0.001 inch in width.

(2) Rough edges, burrs and snags exceeding 0.0005 inch. (Inspection will be made with nylon gloves to feel for pulls on fibers of glove. Inspection will include the entire electrode surface).

(3) Pimples, blisters, and peeling of sinter material. Pimples and blisters in excess of 0.002 inch above electrode surfaces or evidence of sinter material breaking away from grid.

(4) Electrodes shall be of uniform thickness over entire surface area (± 0.001 inch). A 10% random sample shall be selected for thickness determination. If all samples can meet this thickness requirement then all plates are acceptable. If one or more plates from this sample cannot meet this thickness requirement, then a 100% sample is required in order to eliminate all electrodes which cannot meet this thickness. Rejection is final.

(5) Tab shall be free of sinter material.

(6) Coining of edges shall be uniform, (i.e., within ± 0.015 inch, visual verification only).

(7) Grid support for sinter material shall be free of any breaks or cracks.

(8) Cut edges of plates shall be coated with polystyrene to prevent flaking of sinter material.

(9) Dimensional checks shall show that plates are in accordance with applicable drawings.

NOTE: The seller may submit an alternate procedure subject to Grumman approval. Two copies of the specifications and documentation for use shall be furnished to Grumman prior to application.

3.4.5.3 (Continued)

(e) Plate Weight Screening - Establish the average weight of the positive electrode and negative electrode by a screening method. Then each plate shall be screened by a GO-NO-GO technique. Each plate weight shall be within 3.5% of the average established plate weight (i.e., ± 3.5%). The seller shall establish detail procedures and submit to Grumman for approval prior to start of task. Weigh and record each auxiliary electrode strip. The Seller shall establish an acceptance procedure and furnish information to Grumman.

(f) Plate Samples - The seller shall supply Grumman with 10 unformed acceptable positive electrodes and 10 unformed acceptable negative electrodes and 5 auxiliary electrode strips from each plate lot (melange) used in the production of this cell lot. Each electrode type shall be placed in a polyethylene bag, heat sealed, and permanently marked with the plate lot (melange) number.

3.4.5.3.1 Auxiliary Electrode Construction. - The auxiliary electrode shall be made of sintered nickel plaque which contains a pure nickel grid or substrate. The electrode shall be free of noble metals such as gold, platinum, etc. The auxiliary electrode tab shall be pure nickel and an integral part of the substrate. Location of the auxiliary electrode within a cell shall be such as to minimize the possibility of shorting to the cell plates, with specific emphasis on preventing shorting to the positive plates. Details of location and procedure are subject to Grumman approval. The completed cell must conform to Grumman Drawing 252SCAV113.

3.4.5.3.2 Auxiliary Electrode Signal Requirements. - The auxiliary electrode signal voltage shall start to increase when the cell is at approximately 80% state-of-charge. The signal voltage shall reach its end-of-charge value when the cell is fully charged (100% state-of-charge). The signal voltage shall decrease to 70% of its end-of-charge value within the first ten (10) minutes of discharge and continue to decrease for the remainder of the discharge.

(a) The end-of-charge value shall be 200 millivolts minimum when the auxiliary electrode is externally loaded by a forty seven (47) ohm resistor.

(b) The end-of-charge value shall remain constant within ± 10% over the operational life of the battery 10,000 cycles.

3.4.5.3.3 Auxiliary Electrode Characteristics. - The auxiliary electrode signal characteristics shall be established for each cell. It shall be shown that each auxiliary electrode signal is continuous. Auxiliary electrode signal characteristics as a function of pressure shall be established when cell is charged at the c/2 (10 ampere) rate and a 47 ohm resistor is connected between the negative terminal and the auxiliary electrode terminal. For continuous overcharge currents up to the limits shown in Figure 4, the auxiliary electrode signal, (when discharged through a 47 ohm resistor), shall not exceed those values shown in Figure 7.

3.4.5.4 Quality Assurance Provisions for Production Processing of Electrode Assemblies. - Production processing and test operations on cell electrode assemblies consisting of initial inspection of plates, through formation, addition of KOH and sealing of cell with gauge assembly shall be controlled as follows.

3.4.5.4.1 General. -

3.4.5.4.1.1 Atmospheric Environment. - The environment of the formation facility shall be monitored with respect to humidity and temperature.

3.4.5.4.1.2 Handling of Materials. - All plates, separators and materials shall be handled with gloves and shall be sealed in clean room grade plastic bags when not being processed.

3.4.5.4.2 Operational Conditions. - The following conditions shall be observed during operations associated with 3.4.5.4:

(a) KOH level in formation container shall be maintained above top of plate stack.

(b) Charge and discharge times shall be maintained as specified by seller within ± 4% of designated time periods.

NOTE: (1) Exact time of each charge and each discharge shall be recorded to nearest minute. Deviation from periods specified shall be subject to immediate Grumman notification and joint material review board action.

244

3.4.5.4.2 (Continued)

NOTE: (Continued)

(2) In case of power failure, a notation shall be made and shall be clearly visible in a manner similar to that delineated on the Sample Data Sheets.

(c) Where constant currents for charge or discharge are specified, and/or current measurements are used for calculations of ampere hour capacity, currents shall be regulated within ± 2.0 percent of specified value.

(d) Positive and negative current leads of each formation series circuit shall have an ammeter inserted in series with each lead. One ammeter shall be marked "control"; the second ammeter marked "monitor". Readings of two meters shall always be within ± 2.0%.

(e) Voltage of each formation cell, and current of series formation circuit measurements shall be made not more than five minutes prior to end of all charge or end of all discharge periods.

3.4.5.4.3 Electrode Formation. -

3.4.5.4.3.1 Formation Pack Identification. - Sufficient numbers of previously inspected positive and negative electrodes constituting a cell pack shall have a formation pack identification number assigned. Formation pack identification numbers shall be referred to for all data recording during formation. Numbers shall be visible on each formation pack.

3.4.5.4.3.2 Separator Material (or Materials). - Separator material or materials used to wrap plate groups for formation shall be inserted such that the outside surface of the two outer electrodes is covered with separator material.

3.4.5.4.3.3 Formation Cell Fabrication. - All formation packs shall be fabricated from alkali resistant materials such as nylon, plexiglass, etc. The adhesive or epoxy used to assemble the containers shall also be alkali resistant.

3.4.5.4.3.4 Electrical Clips and Leads. - Electrical clips and leads must be stainless steel, nickel or nickel plated steel. Means for attaching leads to clips must be alkali resistant.

3.4.5.4.3.5 Formation Pack Connectors. - The connectors holding the plates together in the formation packs shall be constructed of 316 or 304 stainless alloy, and shall be washed and rinsed in deionized water prior to installation.

3.4.5.4.3.6 Addition of Electrolyte and Water to Formation Packs. - Electrolyte bubbling out of the pack during formation shall be avoided. At the end of the first formation cycle, electrolyte shall be added to a preset mark. Use 34% KOH to maintain preset mark.

3.4.5.4.3.7 Assembled Formation Packs. - Assembled formation packs shall be soaked in KOH 36 ± 0.5°Be, for a minimum of 16 hours and a maximum of 24 hours prior to the first electrical operation of formation.

3.4.5.4.3.8 Pack Formation. - Formation shall be performed in accordance with sellers schedule. Exceptions to certain operations are listed below and apply to all cells manufactured herein. The following steps shall be adhered to during the final capacity determination of positive and negative electrodes. The cell pack shall consist of 10 negative and 9 positive electrodes:

(a) Last formation discharge to determine capacity of positive electrodes shall be made at the C/2 constant current rate (10.0 Amps) to a cell voltage of 0.70 ± 0.1 volt. The time for each pack to reach 0.70 ± 0.1 volt shall be recorded.

(b) Voltage of each pack and discharge current shall be recorded at 15 minute intervals during capacity discharge. More frequent voltage monitoring is required to obtain a discharge time to an accuracy of one minute.

(c) Each pack shall be removed from the discharge circuit at the specified voltage and individually placed under a 0.1 ohm ± 10% resistive load such that the voltage decreases to 0.1 ± 0.1 volt. The resistor may be removed from the pack as soon as it reaches its specified voltage range.

3.4.5.4.3.8 (Continued)

(d) Ampere hour capacity of positive electrodes as determined in paragraph (a) shall be a minimum of 24.0 ampere hours to a maximum of 30.0 ampere hours. Any pack exhibiting capacities outside this range shall be permanently rejected.

(e) Formation discharge shall be continued at 2.0 ampere rate when all pack voltages in a series formation circuit are less than +0.1 ± 0.1 volt. Each pack voltage shall be recorded before starting the 2 ampere discharge.

(f) Positive electrodes shall be verified as limiting electrodes by sampling one pack from each series formation circuit. Series formation circuit consists of up to 26 packs.

(g) Discharge time at the 2 amp rate shall be such that the negative plate capacity of packs in the series formation circuit are discharge by a minimum of 1.3 times the average of the positive plate capacity of the packs in the series formation circuit as determined in paragraph (a), and each pack shall be discharged to -0.20 $^{+.00}_{-.02}$ volt. Any pack to be acceptable must show a minimum capacity ratio of 1.3:1.00. This capacity ratio is defined as the ratio of the negative ampere hour capacity obtained, divided by the positive ampere hour capacity obtained for each respective pack.

(h) Pack voltage and series string current shall be recorded at least every 15 minutes during the 2 ampere discharge. More frequent voltage monitoring is required to obtain a discharge time to accuracy of one minute. Total time that each pack is on 2 ampere discharge shall be recorded.

3.4.5.4.4 <u>Wash, Rinse and Drying of Plates</u>. -

3.4.5.4.4.1 <u>Plate Stacks</u>. - Plate stacks shall be removed from formation packs and immediately submerged in deionized water having the initial required resistivity measurement per 3.4.6.3.1. Plates from a series

3.4.5.4.4.1 (Continued)

formation circuit shall not be mixed with plates from other circuits. Wash and rinse shall be completed when a Ph reading of 8.0 or less is demonstrated from the last dripping taken from plate samples pulled from wash container. Ph reading shall be recorded.

3.4.5.4.4.2 Drying. - Drying of plates shall be accomplished in air at 50 ± 5°C. Drying time shall be a minimum of 16 hours and a maximum of 24 hours. Oven temperature not exceeding the maximum limit specified during drying operation shall be demonstrated. "Time-in" and "time out" of oven on each group of plates shall be recorded.

NOTE: All internal cell components shall be handled with lint-free cotton gloves in an area designated for aerospace cells. Good housekeeping procedures are required.

3.4.5.4.4.3 Carbonate and Nitrate Tests. - The carbonate and nitrate content of the negative and positive electrodes respectively shall be measured by the Seller. The nitrate content of the positive (Ni) electrode shall not exceed 330 micrograms per gram of the active material, sinter and substrate. The carbonate content of the negative (Cd) electrode shall not exceed 10 milligrams per gram of the active material, sinter and substrate. Design goal carbonate content is less than 5 milligrams per gram of electrode. The test procedure for determining these contaminant contents shall be submitted for Grumman approval.

3.4.5.4.5 Assembly of Cells. -

3.4.5.4.5.1 Inspection and Weighing of Electrode Assemblies. - Inspection on each electrode shall be performed in accordance with 3.4.5.3. Particular attention shall be given to bent corners on grid and blisters on sintered material. Positive, negative and auxiliary electrodes for each cell shall be grouped and their weight per cell shall be recorded to the nearest 0.1 gram.

3.4.5.4.5.2 Weld Plates to Combs. - Plates shall be stacked and welded. Welds shall be in accordance with Specification MIL-W-8611 as applicable and shall be reasonably free of oxidation upon visual inspection. Welds shall be inspected for burn through of plate grid or comb and inspected for loose materials. Plate edge alignment shall be maintained

3.4.5.4.5.2 (Continued)

during welding by use of an alignment fixture. The seller shall supply weld procedures used and rejection criterial to Grumman for approval prior to start of task.

3.4.5.4.5.3 Plate Stack Wrap (Separator Material). - Separator material shall be tested in accordance with 3.4.3.1. Lot number and type of separator material shall be recorded on cell data sheets. Alignment of plate edges utilizing an alignment gage shall be performed.

3.4.5.4.5.4 Resistance Test of Plate Stack Assembly. - Electrode assemblies shall be compressed to the minimum equivalent final stack thickness of 0.724 ± 0.005 inches.

NOTE: Controlled periodic calibration required if conducted on a test jig.

While under compression, minimum resistance, (at 50 VDC) shall be tested. Cells with less than 100 megohms shall be identified. One rework cycle is allowed for cells not meeting the 100 megohms minimum requirement during the first test. Subsequent failures are cause for rejections.

3.4.5.4.5.5 Radiographic Examination. - Radiographs shall be taken of each unit for inspection of workmanship, foreign metallic particles and drawing compliance. Three radiographic views shall be provided for each cell. Prior to welding the cover to case, one edge view along the Zc axis (as defined in Figure 6) and one flat view along the Xc axis (as defined in Figure 6) shall be provided. After welding of cover to case and pinch-off, one flat view along the Xc axis shall be provided. No more than three cells shall be included in each radiograph taken of the flat view and no more than four cells shall be included in each radiograph taken of the edge view. As a minimum, each radiograph shall contain, cell serial number, positive or negative terminal location, view number, suitable control number, date radiograph was taken and an image quality indicator. All radiographs shall have good clarity. Prior to the performance of this task, the seller shall submit to Grumman for review and approval a Radiographic Examination Procedure. Radiographs of all cells purchased herein shall be submitted to Grumman prior to shipment of the cells.

3.4.5.4.5.5.1 Rejection Criteria. - Cells shall be rejected if the following is observed:

(a) Foreign particles greater than 0.010 inch in any direction (*).

(b) Tab bends greater than 90 degrees.

(c) Poor Workmanship and non-conformance to drawings.

* The exception shall be those cells which have completed one rework cycle and still show foreign particles greater than 0.010 inch in any direction. These cells are permissible for use as test cells, provided that they can successfully pass all electrical and mechanical requirements specified herein. These cells shall be tagged and prior to shipment they shall be marked FOR TEST USE ONLY.

3.4.5.4.5.5.2 Rework. - One rework cycle on defects detected prior to welding of cover to case is permissible. Additional rework requirements are:

(a) Workmanship - Each cell stack shall be closely re-examined, prior and during re-insertion in the container, for quality workmanship standards. Any degradation in workmanship standards, after or during rework, from those existing at the time of original manufacture shall be cause for rejection.

(b) Complete replacement of the stack wrapper is required if the stack was completely removed from its container during the rework.

(c) Each cell, if the stack was completely removed from its container during the rework, shall be subjected to the resistance test requirements of para. 3.4.5.4.5.4 and shall meet the requirements specified therein.

(d) A complete rework log shall be maintained and submitted to Grumman.

(e) A complete radiographic re-examination shall be conducted on the reworked unit.

(f) No rework shall be permitted on units where defects are detected after cover weld and/or pinch-off is completed.

250

3.4.5.4.6 Activation of Cells. -

3.4.5.4.6.1 KOH Fill. - KOH shall be prepared and tested in accordance with 3.4.6.3.3. Data from batch card on cell data sheet shall be recorded. Each cell with dust cap shall be weighed to the nearest 0.1 gram before KOH is added. Contamination of KOH shall be prevented by utilizing burets while filling and by minimizing KOH exposure to atmospheric conditions. The amount of KOH shall be specified by the seller subject to Grumman approval.

3.4.5.4.6.1.1 Wet Stand Time. - Subsequent to KOH filling each cell is required to meet a Wet Stand Time of 24 hours minimum before any electrical operations are performed on the cell.

3.4.5.4.6.2 Cell Weight. - Each cell shall be weighed immediately after fill and the dust cap installed to fill tube. Cell weight with dust cap shall be recorded to the nearest 0.1 gram. Weight gain must be within +3% of nominal value specified by seller. Pre-tested gage assemblies shall be installed within 10 minutes of filling operation. Cells left unsealed longer than 10 minutes shall be rejected. Immediately after installation of gage assembly, cells shall be evacuated to 25 inches minimum gage vacuum. All fittings, gages and associated components of the gage assembly shall be of non-corrosive material in a KOH environment. Jacket must be put on cells to assure surface of plates are parallel then torqued to a specified value.

3.4.5.4.6.3 Leak Test of Cell and Gage Assembly. - If a cell reaches 20 inches minimum gage vacuum prior to the Veeco leak test from the original 25 inches minimum gage vacuum, it shall be permanently rejected. The leak rate of the completed assembly shall be established prior to further processing. The cell shall be backfilled with helium at 0.0 ± 2.0 psig and placed in a Veeco to measure its leak rate. The leak rate shall be recorded and shall not exceed 10^{-5} cc/sec. If minimum rate cannot be established, a repeat of test with another gage assembly is permitted provided care is exercised in refitting gage assembly. The cell shall be evacuated to a 25 inch vacuum or greater and the valve closed as soon as vacuum is obtained.

3.4.5.4.6.3 (Continued)

The integrity of this seal condition is to be maintained through all tests prior to pinch of the fill tube. Any intentional or accidental opening of the valve assembly without Grumman approval is reason for rejection of the cell. During the State of Charge Adjustment, as specified in para. 3.4.5.4.7 the gage valve may be opened.

3.4.5.4.7 State of Charge Adjustment. - The Seller shall provide a procedure to adjust the charge on the negative electrodes of each cell. The procedure used shall include sufficient quantitative measurement of each cell parameter such that calculations can be made to determine exact charge adjustment on negative electrodes. The procedure shall be as noted in para. 3.4.5.4.7.1 and shall be submitted for Grumman approval.

The State-of-Charge adjustment shall yield a precharged excess negative capacity (I_o (TN1) of 1.0 to 3.15 ampere-hours. TN-1 shall be verified on a sampling basis in accordance with para. 3.4.5.4.8.

3.4.5.4.7.1 State-of-Charge (SOC) Adjustment. - The SOC of the negative electrode shall be adjusted in accordance with the following:

(a) Connect cells in series.

(b) Charge each cell at 3.1 amp until it reaches the equivalent of 4.6 ± .1 Amphours precharge.

(c) Open vents when each cell pressure reaches 2-5 psi.

(d) Measure and record the gas evolved from each cell. (Note: total gas is ≈1050 cc.)

(e) Record end of charge voltage.

(f) Close cell vent at charge completion.

(g) Remove cell from charge circuit.

(h) Allow cell to remain open circuit for two hours minimum.

(i) Evacuate to 25" HG.

3.4.5.4.7.1 (Continued)

(j) Discharge at 10 amp. to 1.0 volt per cell.

(k) Record time and capacity.

(l) Short with one ohm resistor for 4 hours minimum and until each cell is cool.

(m) All test data shall be recorded on data sheets.

3.4.5.4.8 Quality Assurance Provisions for Electrode Capacity Test (Ratio Test). - The Electrode Capacity, or Ratio Test, shall measure the individual discharge capacities of the positive and negative electrodes. The test shall be conducted on a sampling basis as specified by para. 3.4.5.4.8.2. The sample cells represent specific production lots which are constrained by successful completion of the Ratio tests. The Ratio test shall determine the excess negative capacity beyond complete discharge of the positive (or excess positive beyond the negative if the cell is negative limited on discharge) in addition to determining total electrode capacities. Failure of the Ratio tests shall be cause for rejection of the cell lot represented by the samples. The data shall be used to determine the following:

(a) Range and distribution of positive capacities. (I_o (TP_3)

(b) Range and distribution of negative capacities. (I_o (TN_3)

(c) Difference between and/or ratio of total negative and positive capacities.

(d) Excess negative (or positive) on discharge. (I_o (TN_1)

3.4.5.4.8.1 Ratio Test Requirements. - The average of the Ratio Test cells from each lot shall successfully meet the following criteria:

(a) Post-Formation Samples.

1. Negative to Positive Ratio - 1.30:1.00
2. TN1 - (Information Only)

253

3.4.5.4.8.1 (Continued)

(b) Post Rinse and Dry Sample

(1) Negative to Positive Ratio - 1.35:1.00 (design goal); 1.30:1.00 minimum

(2) TN1 - (Information Only)

(c) Finished Cell

(1) Negative to Positive Ratio - 1.40:1.00

(2) TN_1 - 1.0 to 3.1 A-H (design goal, only)

3.4.5.4.8.2 Ratio Test Sampling Rate. -

(a) Two cells from each formation group of 52 cells (or less) shall be randomly selected at the conclusion of the electrical formation cycles. The test cell(s) shall be selected prior to further processing. Electrolyte level shall be adjusted to a minimum of 1/4 inch above the separator. Tests shall start as soon as possible but bot to exceed 2 days.

(b) A minimum of one cell from each formation group of 52 cells (or less) shall be randomly selected at the conclusion of the plate neutralization and drying operation. The test cell shall be fabricated with formation hardware to a standard cell core configuration (i.e., 9 positive and 10 negative electrodes). The cell shall be flooded with 34% KOH solution to a level 1/4 inch minimum above the separator. Tests shall be performed as soon as possible but prior to activation of cells of this particular formation lot.

(c) Two cells from each formation group of 52 cells (or less) shall be randomly selected at the completion of the standard capacity test. (Discharge capacity immediately prior to pinch tube closure). Following the standard one-ohm short period, the test sample(s) shall be opened by removal of the gage assembly and flooded with 34% KOH.

3.4.5.4.8.2 (Continued)

NOTE: Cells rejected for cosmetic or radiographic reasons only may be used for this test; provided each cell meets insulation resistance and electrical test requirements.

3.4.5.4.8.3 Ratio Test Applicable Conditions. - The following conditions are applicable:

(a) Cell temperature shall be between 75 ± 5°F.

(b) Cell terminal voltage shall be recorded.

(c) Voltage from both positive and negative terminals to the reference electrode shall be recorded continuously or at intervals not to exceed 15 minutes.

NOTE: Since the cell is in a stainless steel container, and both electrode terminals are insulated from the container, the container itself may be used as a rough substitute for a reference electrode. Even though the container potential is a function of the pressure O_2 or H_2 in the cell, the changes in electrode voltage at end of capacity are relatively large and usually can be clearly identified using the container as a reference.

3.4.5.4.8.4 Ratio Test Procedures. -

3.4.5.4.8.4.1 Residual Negative Electrode Capacity. I_o (TN_1) - A one ohm resistor shall be placed across the cell terminals for 16 hours. Then discharge at 10.0 amperes until terminal voltage indicates -1.0 volt. Terminal (cell voltage and voltage from both positive and negative terminals to reference electrode shall be recorded.

3.4.5.4.8.4.2 Filling. - Cells shall be filled until flooded with 34% KOH solution. KOH quantity required and additional electrolyte added during entire test shall be recorded.

3.4.5.4.8.4.3 Charge. - Cells shall be charged at 2.0 amperes for a minimum period of 40 hours. The charge is completed when a minimum cell voltage of 1.51 or a 64 hour charge period is obtained. Cell and reference cell voltages shall be recorded continuously or at intervals not to exceed 1 hour.

3.4.5.4.8.4.4 Discharge. - Cells shall be discharged at 10.0 amperes until terminal voltage indicates -1.0 volt. Positive and negative terminal to reference voltages shall be time recorded when the cells' terminals reach:

(a) +1.0 volt

(b) +0.5 volt (TP_3)

(c) 0.0 volt

(d) -0.5 volt

(e) -1.0 volt (TN_3)

NOTE: The cells shall be protected from further contact with the atmosphere in the event further testing is required.

3.4.5.4.8.5 Ratio Test Calculations. -

Let

(TN_1) = time to -1.0 v (as delineated in 3.4.5.4.8.4.1)

= time to discharge precharged negative

(TP_3) = time from start of discharge (full charge) to +0.5 v (as delineated in 3.4.5.4.8.4.4(b))

= time to discharge positive electrode

(TN_3) = time to -1.0 v as delineated in 3.4.5.4.8.4.4(e))

= time to discharge total negative electrode

I_0 = discharge current = 10.0 amps.

3.4.5.4.8.5 (Continued)

Then

I_0 $(TN_3) - (TP_3)$ = excess capacity of total negative over positive

I_0 (TN_1) = precharged negative capacity

I_0 $(TN_3)-(TP_3)-(TN_1)$ =Excess (discharged) negative capacity at charged end.

$\frac{(TN_3)}{(TP_3)}$ = Negative to positive ratio

3.4.5.4.8.6 Submittal of Data. - Two copies of all information obtained shall be submitted to Grumman prior to further processing.

3.4.6 Terminals. - Terminals provided for positive and negative electrodes shall be rated at not less than 35 amperes continuous duty. The terminals shall be made from 304 stainless steel, condition A, complying with Specification QQS-776. Both terminals shall be insulated from the cell cover by means of a ceramic insulator having an alumina content of not less than 99.4 percent. The insulator-to-cover junction shall employ a stress-relief configuration such that relative motion between the terminal assembly and the cover applies minimum stress to the insulator and to the metal-to-insulator bonds. The collar-to-insulator and insulator-to-terminal bonds shall be made using a metal-to-ceramic bonding process subject to approval by Grumman. Any silver containing braze materials used for metal-to-ceramic bonding or elsewhere in the cell shall be nickel plated to a minimum thickness of 0.00015 inches. A dull-matte nickel plating process shall be used and the process specification shall be subject to approval by Grumman. The cell terminals shall be constructed as shown in Figure 5.

3.4.6.1 Control and Testing of Feedthrough Terminals and Seals. - Materials, manufacturing and test operations on the cell feedthrough terminals, seals and related hardware shall be controlled by the following criteria. Two copies of all data obtained herein shall be furnished to Grumman prior to further processing.

3.4.6.1.1 Ceramic Material. - The ceramic material shall be alumina of 99.4 percent purity minimum.

3.4.6.1.2 Mechanical Inspection. -

(a) Dimensions - sampling 2.5 A.Q.L.

(b) Chips, cracks, grain structure (uniform density), voids - 100% inspection

3.4.6.1.3 Cleaning. - Components shall be cleaned by ultrasonic bath using freon.

3.4.6.1.4 Lot Tensile Test. - Each new lot of active metal and each new lot of ceramic shall be subjected to an ASTM tensile specimen test. A minimum of three sets shall be treated identical to standard production processes, then vacuum brazed using an iron-nickel alloy 42 washer. Sample tensile strength must exceed 6000 psi. The seller may propose an alternate test, subject to approval by Grumman.

3.4.6.1.5 Braze Alloy. - An alloy with a minimum of carbon contents shall be used. Each new lot of active metal shall be subjected to a semi-quantitative spectographic analysis. In addition to the expected elements, the carbon content shall be measured. Allowable impurity limits shall be established by the cell seller and made available to Grumman. A braze flag test shall be run on each lot to determine solidus and liquidus points, or supplier's certification on each lot used herein shall be furnished to Grumman. Immediately after completion, a 2% sample of brazed headers shall be supplied to Grumman for metallurgical studies.

3.4.6.1.6 **Cover Assembly.** -

3.4.6.1.6.1 **Metal Parts.** - Metal parts shall be inspected for conformance to drawings, physical dimensions, surface defects, and burrs that may interfere with intended function.

3.4.6.1.6.2 **Cleaning.** - Chemical cleaning shall be utilized on all parts and a combination of chemical cleaning and furnace firing shall be utilized on cup and collar to prepare them for vacuum brazing.

3.4.6.1.6.3 **Welding of Pinch Tube to Cover.** - Welding of pinch tube to cover shall be controlled by a process specification to insure adequate weld strength and seal integrity. The weld shall also be tested as an integral part of the cover.

3.4.6.1.7 **Inspection.** - Cracks, porosity, excessive burning, oxidation and foreign inclusions shall be inspected 100%. 100% inspection shall be performed on all pinch tube cover welds and they shall be capable of passing a helium leak test (leak rate 1 x 10^{-8} std cc/sec). Samples shall be tested periodically for weld quality by metallurgical sectioning.

3.4.6.1.7.1 **Assembly Fixturing.** - Mechanical fixturing shall be adequate to insure maintainance of part positions during brazing operation. Self-jigging features shall be included where possible. Particular attention shall be paid to alignment of terminal post and ceramic to maintain concentricity. Provision for periodic cleaning of fixture shall be made.

3.4.6.1.8 **Vacuum Braze Operations.** - Processes shall be established which ensure clean handling of parts and fixtures. A brazing inspection plan shall be submitted by seller subject to mutual approval.

3.4.6.1.9 **Visual Inspection.** - All units shall receive inspection of terminal location, seal junction continuity, braze joint quality, pinholes, and flowout shall be visually inspected using magnification aids where required.

3.4.6.1.10 **Insulator Resistance.** - All units shall receive an insulation resistance check. Each unit must exhibit resistance above 100 megohms at 50 VDC.

3.4.6.1.11 Leak Check. - The complete cover assembly shall pass a 100% sample leak check of 1 x 10^{-8} cc/sec of helium.

3.4.6.1.12 Nickel Plating. -

3.4.6.1.12.1 Fixture. - The cover assembly shall be mounted in a fixture designated to prevent access of plating solutions to ceramic-metal terminal well.

3.4.6.1.12.2 Cover Assembly Preparation. - Cover assembly preparation shall consist of hydrohone and wash in water.

3.4.6.1.12.3 Inspection Criteria. -

(a) Plating Thickness - Plating thickness shall be checked by 2.5 AQL sampling. Thickness shall be measured with magnagage or equivalent. Any part outside of limits shall be rejected.

(b) Plating Quality - Blisters shall be checked by 100% sampling. Adhesion shall be checked by 2.5 AQL sampling using test tape.

(c) Corrosion - Corrosion shall be checked by 100% sampling. All cover assemblies shall be checked for evidence of plating solution leakage following removal of the fixture. Any stains or evidence of wetness on the cover surface in the vicinity of the ceramic-terminal post seal shall be cause for rejection. A 5% sample of finished assemblies shall be subjected to a halide test. Any evidence of halide shall cause 100% of the lot to be subjected to the test. All samples showing positive halide shall be rejected.

(d) Insulator Resistance - Insulator resistance shall be tested by by 100% sampling. The resistance across each insulator shall exceed 100 megohms when 50 VDC is applied. After completion of cell assembly the resistance shall be measured, using a megohmeter applying 50 VDC as follows:

(1) (+) terminal to (-) terminal, resistance shall be 100 megohms or greater.

(2) (+) terminal to case
(3) (-) terminal to case } Resistance shall be 5 megohms or greater.

3.4.6.2 Tinning of Terminals. - The negative and positive terminals shall be cleaned, tinned and inspected to the following requirements.

3.4.6.2.1 Pre-Tin Cleaning. - The terminals shall be cleaned prior to tinning in accordance with the requirements of Grumman procedure AV-252-I-88.

260

3.4.6.2.2 Tinning of Terminals. - Both positive and negative terminals shall be tinned after cell container closure. Prevention of flux from entering the terminal pockets shall be accomplished by applying EC1663(*) between post and ceramic. Terminal pockets area shall be inspected to assure complete coverage with EC1663 material prior to flux application. During the dip in flux (Type LA-CO-N12A), the cell container shall be inverted (terminals facing down).

(*)Components as specified in Grumman Specification LSP-14-14201D, (EC1663A, EC1663B and Nuocure 28 in ratios of 2.5g; 25g and 4 drops respectively).

3.4.6.2.3 Cleaning of Terminals After Tinning. -

(a) After pre-tinning, posts shall be washed with running hot water (110°F) and scrubbed thoroughly during this wash for a minimum of 30 seconds using a nylon tooth brush or test tube brush.

(b) Terminal area shall be dipped in a solution of 5% Ammonium Hydroxide and posts immersed for a minimum of 10 seconds.

(c) Rinse terminal area with water.

(d) Rinse terminal area in acetone.

(e) Place cell under a minimum vacuum of 25" Hg.

3.4.6.2.4 Analytical Check For Flux Traces. - A standard fluoride-chloride test (silver nitrate) shall be conducted as follows:

(a) Pour 40 cc of boiling distilled water over the terminal areas and collect water in a beaker.

(b) Conduct a standard fluoride-chloride test on this collected water.

(c) If the analytical check is negative (showing absence of fluoride-chloride traces), the EC1663 potting can be removed and the cell can go to the next production step.

(d) If the analytical check is positive (showing presence of fluoride-chloride traces), repeat steps (a) through (e) of 3.4.6.2.1.

3.4.6.3 Control and Testing of Water and Electrolyte. - The electrolyte solutions and wash water used for cells specified herein shall be of high purity. Two copies of all data obtained herein shall be submitted to Grumman prior to further processing.

361

3.4.6.3.1 Deionized Water. - Deionized water used in all wash water, dilutant, or additive shall have a resistivity of greater than 1.0 megohm-cm. In the event the resistivity drops below 1.0 megohm-cm the process shall be stopped until the resistivity is restored to the specified limits. The resistivity is to be determined prior to each operation in which the water is used. A suitable conductivity cell calibrated less than two weeks prior to start of water requirement tests used on cells constructed under this specification shall be used. Criteria for calibration shall be as follows:

(a) The conductivity cell shall be re-calibrated at two week intervals (maximum) until completion of the water requirement tasks.

(b) The calibration shall be conducted in a 0.1% potassium chloride solution and shall record a conductivity of 1410 ± 20 micromhos at 25°C (a temperature correction as per the handbook of Chemistry and Physics may be used). If conductivity is not within these tolerances, the conductivity cell must be replaced or replatinized.

(c) The silica content in the water shall not exceed 1 ppm.

(d) The solids content of the water must be determined by the seller. The maximum solids content shall not exceed 50 PPM.

3.4.3.6.2 Distilled Water. - Distilled water used either as wash water, dilutant or additive shall be tested and shall meet the requirements of 3.4.6.3.1(c) and (d) above.

3.4.6.3.3 Electrolyte. - The supplier, batch number, grade, analysis, date of purchase and date container is opened must be recorded. The potassium hydroxide "mercury cell" grade electrolyte concentrate as defined by Allied Chemical Company or equivalent, shall be mixed with the distilled water to make-up a solution with a tolerance of ± 0.5 Baume. Each batch of electrolyte shall be analyzed for carbonate content and hydroxyl ion concentration using the double titration method of phenolphthalein end point followed by methyl purple or orange end point. Carbonate concentration must be less than 0.01 gm/liter. The hydroxyl ion concentration shall be determined by analytical methods. The concentration tolerance of KOH shall be ±20 mg/cc. The electrolyte shall be analyzed for nitrate content. The tolerable level is 1 mg/liter nitrate or less, using a colorimetric analysis technique. The Seller shall prepare procedure details and submit them to Grumman for approval. The shelf life of the standard acid used in the titration shall not have been exceeded.

3.4.6.3.3.1 Sample. - The seller shall supply Grumman with an electrolyte sample of each electrolyte batch (after dilution to the proper concentration) used in the cell construction. The quantity of electrolyte sample shall be approximately 1 oz. It shall be supplied in capped polyethylene bottle(s) permanently marked to identify the cell serial numbers this electrolyte batch was used for.

3.4.6.3.4 Spectrochemical Analysis. - A spectrochemical analysis shall be performed on the electrolyte from each batch used for cells. The content of the following impurities shall be determined and reported:

(a) Silver

(b) Cobalt

(c) Copper

(d) Iron

(e) Sulfur

(f) Zinc

Any other impurity found to be present in concentrations greater than 100 ppm shall also be reported.

3.4.7 Cover-to-Case Junction. - The cover shall be electric-arc welded to the container using inert gas shielding. No welds beyond dimensional limits shall be permitted. Weld joints shall not be ground or polished. Weld beads shall be smooth and free of folds. Porosity, cracks, and excessive oxidation are not acceptable. Prior to case to cover weld and prior to complete insertion of the cell stack, the exterior of the cell container shall be permanently serialized. Any technique other than electro-etch requires prior Grumman approval.

3.4.8 Electrolyte Leakage. - The cell shall show no evidence of electrolyte leakage whenever subjected to the test of 4.5.15 after a two (2) year period.

3.4.9 Size and Weight. - The size and weight of the storage cell shall not exceed the limitations specified in Specifications Control Drawing 252SCAV110. The Seller shall establish such weight control procedures as are necessary to insure meeting this guarantee.

3.4.10 Operating Position. - The cell shall operate normally in any position and under any gravity conditions from zero "g" to 11.3 "g". (See paragraphs 4.5.7 and 4.5.9).

3.4.11 Operating Temperature. - The cell shall be capable of functioning normally, shall have dimensional stability, and shall deliver at least 80 percent of the respective rated capacities within the specified voltages, when operating at temperature extremes of 30°F and 110°F.

3.4.12 Thermal Vacuum. - The cell shall be capable of operating in a pressure of 10^{-6} mm Hg without evidence of mechanical or electrical failure or electrolyte leakage.

3.4.13 Vibration. - The cell shall be capable of operating under vibration as specified in paragraph 4.5.8 without internal cell mechanical failure or leakage.

3.4.14 Mechanical Shock. - The cell shall be capable of operating under shock as specified in paragraph 4.5.10 without showing evidence of mechanical or electrical failure.

3.4.15 Gas Tightness of Cells. - The cell shall be hermetically sealed and shall be capable of withstanding an internal gas pressure of at least 225 psia at 145°F without leakage for 30 minutes at any ambient pressure from one atmosphere down to a vacuum of 9×10^{-6} Torr mercury or better. In order to permit satisfactory leak detection procedures to be used on sealed equipment, all such items shall contain between 2 percent and 5 percent of helium gas by volume. The design objective for each item shall be zero leakage at the expected pressure differential. The maximum allowable leak-rate of the sealed cell shall be 10^{-6} atmosphere cc of helium per second per atmosphere of helium in the cell.

3.4.16 Acceleration. - The cell shall be capable of withstanding accelerations as specified in paragraph 4.5.9 without mechanical or electrical failure.

3.4.17 Container Finish. - The cell container shall be made of an alkaline resistant material or thoroughly covered with an alkaline resistant material. It shall be capable of withstanding 1.33 specific gravity potassium hydroxide (KOH) for at least 168 hours at any temperature from -37°F to +182°F without penetration of electrolyte, whitening, checking, blistering, or showing any trace of corrosion or appreciable change in hardness. This finish shall also withstand a test for flexibility after heat treatment of 200°F. The interior of the cell container shall be constructed and the applicable parts lined with an alkaline resistant material so that it will be capable of withstanding 1.33 specific gravity KOH for a period of 150 hours at 200°F without physical change in the lining material such as blistering, sagging, checking, or breakdown in dielectric strength.

3.4.18 Identification of Product. - The manfacturer shall identify each cell by branding or stamping a serial number plus date of activation on an accessible area. In addition, cells that are delivered to Grumman shall be stamped or tagged as follows:

Weight ______________ A.H. at 1-hour Rate ______________

Date of Activation __________ Type ______________

Manufacturer Model No. ______________

Manufacturer Serial No. ______________

GAEC Specification Control Drawing No and Dash No.______________

3.4.19 Polarity Markings..- The polarity of the positive terminal shall be plainly indicated on the container by electrol-etch.

265

3.4.20 Manufacturing Data. - The manufacturer shall maintain a log on the history of each cell by recording the following data:

(1) Serial number of cell

(2) Date of manufacture (date of pinch-off)

(3) Date of activation (addition of electrolyte)

(4) Type and duration of electrical tests performed on cells

(5) Charge and discharge method and rate used in electrical tests

(6) End of charge and discharge voltages

(7) Test conditions

(8) Test results including failures

(9) Material traceability (consisting of complete records of cell components including batch numbers and components).

This log shall be maintained on all cells manufactured for the OAO program and shall be available to Grumman on request.

3.4.21 Workmanship. - The cells, including all parts and accessories, shall be manufactured in a thorough workmanlike manner. Particular attention shall be paid to neatness and cleanliness.

3.4.21.1 Neatness. - To include thoroughness of soldering, wiring, impregnation of coils, potting, conformal coating, marking of parts, and assemblies, plating, painting, riveting, machine screw assemblage, welding, brazing and freedom of parts from burrs and sharp edges.

3.4.21.2 Cleanliness. - Each part, component of the equipment shall be free from residual contaminants such as corrosion inhibiting oils, cutting oils, forming oil lubricants, greases, dyes, wire clippings, solder balls, non-metallic shim stock, extraneous debris and dirt.

3.4.21.2 (Continued)

Precautions shall be taken to prevent contamination of the equipment during manufacturing, handling, and shipping. The seller shall maintain adequate controls to assure consistency in maintaining acceptable workmanship and cleanliness levels. Quality workmanship and cleanliness standards, including any required visual aids, shall be established and submitted to Grumman for approval.

3.5 Performance. -

3.5.1 Capacity. - The cell shall meet the following capacity tests:

Condition	Temp. (°F)	Discharge Current (amps.)	Discharge Time	Min. Cut-off V.	Min. Req'd. % Rated cap. (100% = 20 A.H.)
1	75 ± 3	10	2 hrs.	1.00	> 100%
2	75 ± 3	20	1 hr.	1.00	100%
3	75 ± 3	60	5 min.	1.00	--
4	75 ± 3	70	3 min.	1.00	--

3.5.2 Life. - The cell shall be capable of withstanding a 10,000 cycle charge-discharge test as specified in paragraph 4.5.3.

3.5.3 Retention of Capacity. - The cell shall be designed to meet the retention of capacity after tests specified in 4.5.4.

3.5.4 **Storage.** -

3.5.4.1 In Dry (Unfilled) Condition. - The fully assembled, dry (unfilled) cell, when stored for periods up to three (3) years, shall show no detrimental performance effects. After activation, the cell shall be capable of meeting all performance requirements stated herein and shall show no performance deviations.

3.5.4.2 In Filled (Sealed) Condition. - The cell in filled (sealed) condition shall be designed to meet the storage test of paragraph 4.5.5.

3.5.5 Thermal Requirements. - The thermal requirements for the nickel-cadmium cells are based on a semi-active temperature control system which is dependent on the battery container thermal design. (See Grumman Specification AV-252CS-26D.) Specific operating temperatures will vary depending on an observatory orientation in a circular orbit of 500 Statute miles with the observatory in the sun from 65 percent to 83 percent of the orbital time. Since the cell operating temperatures are dependent on battery container design, the maximum and minimum cell temperatures to be used for cell qualification tests are as specified by the battery case thermal design. Specific thermal design criteria for the nickel-cadmium cells are as follows:

(a) The semi-active cooling system depends on radiating the heat generated in the battery container to the skin of the observatory. The thermal design of the cells shall be such that satisfactory operation of the cells is assured under all operating conditions (including overcharge) when the battery container heat sink surface temperature is 35°F to 110°F. The Seller's thermal design shall include provision for conducting or radiating the heat generated in the cells to the battery container heat sink surface, and radiating that heat to the observatory skin.

3.5.5 (Continued)

(b) The observatory will have an outer skin absorptivity to solar radiation of 0.18 and an emissivity of 0.70. Grumman approval of the packaging and thermal analysis of the equipment is required to insure adequacy of the Seller thermal design as well as compatibility with the overall observatory thermal design.

(c) The Seller shall make provision in the thermal design for maintaining the cell container in good thermal contact with the battery container.

(d) The temperature range specified in 3.5.6(a) is the anticipated operational temperature range that the heat sink surface of the battery will be expected to experience in orbit. All equipment operation, performance and reliability requirements must be met within these extremes. The qualification temperature extremes of 16 to 129°F provide for satisfactory operation outside the anticipated orbital extremes.

3.5.5.1 In view of the stringent requirements placed on the thermal design by the semi-active cooling arrangement, the thermal analysis and the design of the cell must be submitted to Grumman for review to insure its compatibility with the overall thermal design of the OAO. Grumman will work in close cooperation with the Seller to determine surface properties and materials that will be suitable for application to the surface of the Seller's equipment.

3.5.6 <u>Charging</u>. - All cells shall be capable of being charged at a maximum charge rate of 30 amperes. Charging shall be accomplished within the maximum limiting voltage constraint specified in Figure 1. Each cell shall be capable of being fully charged from 65 percent to 100 percent state of charge in a maximum of 65 minutes without exceeding the limiting voltage value specified in Figure 1. (This charge shall include the overcharge necessary to account for the ampere-hour efficiency value of the cell at a particular temperature.) (See Figure 2.)

3.5.6 (Continued)

All cells shall be capable of accepting continuous overcharge currents up to the maximum values shown in Figure 4 without exceeding 75 psig internal cell gas pressures and the limiting voltage value specified on the lowest curve in Figure 1.

3.5.7 Retention of Charge. - Each cell shall be free of short circuiting paths between negative and positive terminals and shall maintain an open circuit voltage of no less than 1.15 volts when tested in accordance with the provisions of 4.5.16.

3.5.8 Internal Impedance. - Each cell shall have an internal impedance not greater than 0.010 ohm when measured in accordance with the specified test of 4.5.1.3.

4 QUALITY ASSURANCE PROVISIONS

4.1 Classification of Tests. - The inspection and testing of the Nickel-Cadmium Storage Cells and component parts shall be classified as follows:

(a) Development Tests

(b) Qualification Tests

(c) Quality Assurance Tests

4.2 Development Tests. - Development Tests are those tests conducted at the discretion of the Seller for the purpose of providing data to be used in the design of the Nickel-Cadmium Storage Cells.

4.3 Qualification Tests. - Qualification Tests are those tests conducted on prototype units of the Nickel-Cadmium Storage Cells. The units are "prototype" only in the sense that they are intended for evaluation and test purposes; they are to be identical in manufacture to production units. Qualification tests shall consist of two (2) parts:

(a) Performance Tests

(b) Environmental Tests

270

4.3.1 <u>Performance Tests</u>. - Performance Tests shall be conducted under laboratory conditions for the purpose of demonstrating that the electrical performance and container characteristics of the Nickel-Cadmium Storage Cells meet the requirements of this specification. Performance tests shall include but not necessarily be limited to the following:

		<u>Spec. Paragraph</u>
(a)	Examination of product	4.5.1
(b)	Capacity	4.5.2
(c)	Life-cycling	4.5.3
(d)	Retention of Capacity	4.5.4
(e)	Storage	4.5.5
(f)	Modified constant potential	4.5.6
(g)	Operating position	4.5.7
(h)	Electrolytic leakage test	4.5.15
(i)	Retention of charge	4.5.16

4.3.2 <u>Environmental Tests</u>. - Environmental Tests shall be conducted in accordance with the requirements of Specification ET-252CS-39C, except as noted herein, for the purpose of demonstrating that the Nickel-Cadmium Storage Cells can withstand the environmental requirements specified for the OAO. Since the Nickel-Cadmium Storage Cells are required to operate during launch, they shall be operated during all Environmental Tests as indicated herein. Environmental Tests shall include but not necessarily be limited to the following:

4.3.2 (Continued)

		Spec. Paragraph
(a)	Sinusoidal and random vibration	4.5.8
(b)	Acceleration	4.5.9
(c)	Shock	4.5.10
(d)	High temperature	4.5.11
(e)	Low temperature	4.5.12
(f)	Thermal vacuum	4.5.13
(g)	Leak detection	4.5.14

4.3.3 Qualification Test Plans. - Qualification tests are those tests conducted on the test samples specified in 4.3.3.1, for the purpose of demonstrating that the cells meet all the requirements of this specification. The Seller shall propose complete qualification testing of the cells and provide the necessary facilities for accomplishing this task. Available facilities for environmental testing shall be described. Testing procedure and equipments shall be subject to Grumman approval. Qualification tests shall be proposed to Grumman in the form of test plans submitted 45 days prior to the start of the tests. These plans shall contain details as to the scope and purpose of the tests, the determination of the test conditions, a description of the test setup and procedures, and other pertinent data. Upon approval of the test plan by Grumman, the tests shall be conducted in accordance with the approved test procedure. Grumman shall be advised when tests are to be conducted so that a representative may be designated to witness the tests when so desired. Photographs shall be obtained wherever practicable and test logs shall be maintained to record all significant observations and events during the test. Qualification test plans shall be in accordance with the requirements of Specifications ET-252CS-39C and RC-252CS-14C.

4.3.3.1 **Sampling Instructions**. - Qualification test samples shall consist of a specified number of cells identical in manufacture to production units. Samples shall be identified as such and they shall be used as follows:

(a) A specified number of cells shall be subjected to Capacity and Life tests.

(b) A specified number of cells shall be subjected to all the Qualification cell tests of this specification except Life tests.

NOTE: The purchase order will specify the number of test samples to be used for each test.

4.4 Quality Assurance Tests. - The Seller shall conduct a performance test on each production unit of the Nickel-Cadmium Storage Cell to demonstrate the continuance of quality of each unit intended for orbit.

4.4.1 Performance Tests. - Performance tests shall be conducted under laboratory conditions for the purpose of demonstrating that the electrical performance of the Nickel-Cadmium Storage Cells meets the requirements of this specification. Performance tests shall include but not necessarily be limited to the following:

		Spec. Paragraph
(a)	Examination of product	4.5.1
(b)	Leak Detection	4.5.14
(c)	Electrolyte leakage test	4.5.15
(d)	Retention of charge	4.5.16
(e)	Cell electrical operations requirements	6.0

273

4.4.2 Data Approval. - Two copies of all data obtained on the tests described in 4.4.1 shall be furnished to GAEC for approval prior to further processing.

4.5 Test Methods. -

4.5.1 Examination of Product. - Each complete cell, submitted for qualification and acceptance under contract, shall be inspected as Grumman may deem necessary to determine compliance with this specification and the applicable drawing with respect to workmanship, construction, interchangeability, sealing, cell container, weight, dimensions, identification marking, packaging and packing, and terminals.

4.5.1.1 Inspection of Cell Assembly. - The final cell assembly shall be witnessed by a Grumman quality assurance representative to verify the integrity of internal and external component parts.

4.5.1.2 Hermetic Seal. - The cell shall be tested for seal leakage (Helium) in accordance with Standard MIL-STD-202C, Method 112, Test Condition C, Procedure IV, at a chamber pressure no greater than 10^{-5} millimeters of mercury maintained until the leak rate stabilizes. The hermetic seal shall meet the requirements of 3.4.15.

4.5.1.3 Internal Impedance. - The cell impedance shall be measured between the positive and negative terminals at 60 cycles/sec. The impedance shall be measured by passing a known AC current through the cell and measuring the AC voltage developed. The circuit shown in Figure 3, or its equivalent, shall be used. The impedance shall be measured when the cell is charged to a minimum of 10 percent of full charge.

4.5.2 Capacity. - Unless otherwise specified, capacity tests shall be run at 75 ± 3°F ambient temperature. Ampere hour capacities shall be measured to the cutoff voltages given for the rates specified and shall not be less than the capabilities specified in 3.5.1. Capacity measurements shall be made by sequentially charging and discharging the cell a total of six cycles, a cycle being defined as one charge-discharge routine.

Two cycles are allowed for capacity development at the cells maximum charge rate. A "tapered charge" (see note 2) may be utilized. The maximum capacity returned to the Cell for cycles 1, 2 and 3 shall be 33 AH. On the third discharge, the Cell shall develop more than 20 AH at the 2-hour discharge rate (10 amps). The Cells shall then be charged, thereafter, and discharged at the 1-hour rate (20 amps) and shall deliver a minimum of 20 AH (cycle 4). The Cells shall then be recharged and deliver a minimum of 60 amperes for 5 minutes, and 70 amperes for 3 minutes, in cycles 5 and 6 respectively. At no time shall the voltage at charge exceed the specified maximum Cell voltage shown in Figure 1, and at no time shall the discharge voltage fall below 1.00 volts (or 1.00 volts for 60 to 70 amps).

NOTES: (1) The voltage at charge shall never exceed the specified maximum cell voltage shown in Figure 1.

(2) A tapered charge is defined as follows:

10.0 amperes to voltage in Figure 1, 5.0 amperes to voltage in Figure 1, 2.0 ampere for either 1.0 hour or maximum cell voltage in Figure 4 whatever occurs first.

(3) Each cell voltage, cell pressure and external cell case temperature (a minimum of two temperature sensors for a group of 26 cells is permissible) shall be recorded as follows:

(a) Immediately prior and after start of each charge or discharge step

(b) At one hour maximum intervals during all charges

(c) At 15 minute maximum intervals during all discharges.

4.5.3 Life. - All cells shall have a minimum operational life of 10,000 cycles of charge and discharge. The life tests shall be at temperatures and charge rates specified by Grumman. All cells shall be discharged at 5.0 ± 1 amperes for 36 minutes. The cutoff voltage shall not be less than 1.10 volts. At all temperature, the cells shall be exposed to ambient air on all four sides and top.

4.5.3.1 Cycling. - The 101-minute orbit time of the OAO shall be simulated in cycling tests. Each cycle shall consist of 65 minutes of charge, followed by 36 minutes of discharge. Cycling shall be continuous for 10,000 cycles, all of which shall be counted as life cycles.

4.5.4 Retention of Capacity. - The test cells shall be fully charged during each cycle of the life test. After every 100th charge cycle, one cell at the low temperature and one cell at the high temperature specified in 4.5.3 shall be disconnected from the charge/discharge circuitry and immediately discharged at the 2-hour rate to end voltage of 1.0 volts. Both cells shall deliver a minimum of 80 percent of their 1-hour rated capacity. The same cells selected from each respective temperature value shall always be used during this test. Thereafter, the cells shall be recharged and placed back in the life test.

4.5.5 Storage Tests. - Two cells shall be stored in a discharged and shorted condition for at least 12 months but not more than 24 months from the date of manufacture at a temperature of 60 to 80°F. At the end of this time, each cell shall be charged at the 2-hour rate (*) to a voltage not to exceed that specified in Figure 1, and shall be capable of deliverying 100 percent of its rated capacity at its 1-hour rate. Three charge-discharge cycles shall be allowed for capacity build-up.

4.5.6 Modified Constant Potential Charge. - A cell which is in a discharged condition shall be charged at its highest charging rate per 3.5.6 for 1-hour to a voltage not to exceed that specified in Figure 1. (Three cycles of charge and discharge are allowed for capacity buildup.) The cell shall then deliver not less than 85 percent of the 2-hour rated capacity if discharged immediately.

(*) After reconditioning

276

4.5.7 Operating Position. - A normal discharge shall be made on the fully charged cell at the highest continuous test rate at 73 ± 3°F and to the corresponding cutoff voltage specified in Specification Control Drawing 252SCAV110. After 1.2 minutes of discharge the cell shall be inverted without interrupting the discharge, and after 1.2 additional minutes, the cell shall be returned to the normal operating position. The voltage records shall include readings, taken 5 seconds before and 5 seconds after each change in the position to the cell. The cell shall deliver full rated capacity in this discharge, and the voltage change as a result of the inversion shall not exceed 0.025 volt. There shall be no leakage of electrolyte when the cell is in any position.

4.5.8 Vibration. - Qualification Test cells shall be subjected to the sinusoidal and random vibration requirements specified in Tables I and II. During these vibration tests, test cells shall be discharged at frequent intervals at the one-hour rate for periods of 30 seconds. The current and voltage values observed during these discharges shall show no fluctations, and visual inspection of the cells, upon completion of the test, shall show no mechanical failure. This cell shall be under a "clamp up" load of 2500 pounds applied through a stiff metal plate.

4.5.9 Acceleration, Centrifugal. - Qualification Test cells shall be mounted on the test apparatus (centrifuge) in the applicable positions defined in Table I of ET-252CS-39C to produce the required acceleration in the direction specified. The centrifuge shall be brought up to the rotational speed required to produce the radial acceleration specified. Longitudinal and lateral accelerations shall be combined to occur simultaneously for the durations indicated. This may be accomplished by four orthogonal tests for each basis longitudinal direction, or by rotating the test unit 360° about x-x axis during a period of nine minutes. During the above test, for each direction indicated, the test cells shall be discharged at frequent intervals at the 1-hour rate for periods of 30 seconds. The acceleration gradient across the cell shall not exceed 15%. The current and voltage values observed during these discharges shall show no fluctuations, and visual inspection of the cells upon completion of the test shall show no mechanical failure.

4.5.10 Shock. - Qualification Test cells shall be subjected to the Shock Test indicated in Table I of Specification ET-252CS-39C. The cell shall be discharged at the 1-hour rate and the discharge voltage shall be recorded by a recording voltmeter, such as a Memo-scope. During the period of each Shock Test, any discontinuity in the voltage resulting from a shock in any direction shall be cause for rejection.

4.5.11 High Temperature Operation. - A fully charged cell shall be discharged at the 1-hour rate at 73 ± 3°F, recharged and then placed in an oven at a high temperature of 110 + 5°F. This temperature shall be maintained for 24.5 hours. The cell shall then be discharged at this temperature at the 2-hour rate and its capacity measured to 1.0 volts. The cell shall then be returned to room temperature and charged at the 2-hour rate. Following this charge, the cells shall again be discharged at the 2-hour rate. The capacity of this second discharge shall be 100 percent of the capacity specified in Drawing 252SCAV110.

4.5.12 Low Temperature Operation. - A fully charged cell shall be discharged at the 1-hour rate at 73° ± 3°F, recharged and then placed in a chamber at a low temperature of 30 ± 5°F. This temperature shall be maintained for 24.5 hours. The cell shall be discharged at this temperature at the 2-hour rate and its capacity measured to 1.0 volts. The cell shall then be returned to room temperature and then charged at the 2-hour rate. Following this charge, the cells shall again be discharged at the 2-hour rate. The capacity of this second discharge shall be 100 percent of the capacity specified in Drawing 252SCAV110.

4.5.13 Thermal Vacuum. - Two fully charged cells shall be discharged at the 1-hour rate at 75° ± 3°F, recharged and then placed in a vacuum chamber. One surface of each cell shall be adjusted to a high temperature of 110 ± 2°F and the chamber shall be exhausted to 9×10^{-6} Torr. This conditions shall be maintain for a period of 24.5 hours. During this period each cell shall be cycled sequentially for a minimum of one cycle of charge and discharge as specified in 4.5.3. The above procedure shall be repeated except that one cell surface shall be maintained at a low temperature of 30 + 5°F. The above procedure shall be repeated a a third time at 75 ± 5°F except that the test time shall be for four hours. The cells shall show no evidence of failure following these tests.

4.5.14 Leak Detection. - To permit satisfactory leakage detection, all cells shall be sealed with 5 percent of helium gas by volume. A fully charged cell shall be allowed to cool to 73 ± 3°F, at which time a leakage test shall be made. Cells shall have a leakage rate of less than the limits specified in Specification ET-252CS-39C.

4.5.15 Electrolyte Leakage. - This test shall occur immediately after completion of charge, during which cell must have received some overcharge to assure a positive cell pressure with respect to atmospheric pressure. The cell shall be thoroughly cleaned with distilled water and alcohol prior to start of charge. All mechanically sealed areas on the cell cover shall be swabbed with phenolphthalein solution.* A red indication on the swab is evidence of electrolyte leakage. In the event of a positive indication, the cell shall be again cleaned and the test repeated. If a positive indication of leakage is present during the second test, the cell shall be rejected.

4.5.16 Retention of Charge. - This test shall occur if the cell was discharged to 1.00 volt. Drain cell for 16 ± 1 hours at 73 ± 3°F ambient temperature using a one (1) ohm resistor. Let cell stand at open circuit for 24 ± 0.5 hours at 73 ± 3°F ambient temperature. The cell voltage at the end of this open-circuit stand shall be 1.15 volts or higher.

4.6 Rejection and Retest. - When any test sample fails to meet the requirements outlined herein, the product shall be rejected. If for any reason the cells of the lot represented have already left the contractor's plant, they shall be subject to return to correct the defects and resubmitted for all the specified tests. Before resubmitting, full particulars concerning previous rejection and the action taken to correct the original defects shall be furnished to Grumman. Units rejected after retest shall not be resubmitted without the specific approval of Grumman. This retest, however, is only permissible if doubt exists with respect to the test equipment employed, test procedure applied or incomplete cell conditioning is suspected.

4.6.1 Failure Reporting and Analysis. - When failures occur during test operations, the procedures of paragraph 3.9 of Grumman Specification RC-252CS-14C shall apply.

(*): 0.5% phenolphthalein in 50% alcohol and 50% distilled water solution. All areas where phenolphthalein was applied shall be subsequently rinsed with distilled water; then all areas shall be rinsed with acetone and cell shall be placed in a vacuum chamber for one hour at a pressure of 1 mm Hg or less.

4.6.1 (Continued)

Permanent rejection is applicable if the following has occurred:

(a) Unit was exposed to temperatures outside the 0 to +120°F range* regardless of time duration of overtemperature exposure.

(b) Unit had received currents in excess of 10% over the maximum currents (33 amperes for charge and 77 amperes for discharge for maximum time of 3.3 minutes.)

(c) Unit had exhibited voltages 0.12V above the uppermost curve in Figure 1.

(d) Unit was over discharged below 0.0 volts after sealing.

(e) Unit was physically damaged in any manner.

4.7 Equipment Changes. - After successful completion of the qualification test, no changes shall be incorporated in the cell design or manufacturing techniques unless approved in writing by Grumman.

5 PREPARATION FOR DELIVERY

5.1 Application. - The requirements of Section 5 apply to direct purchases by or direct shipments to Grumman.

5.2 Preservation, Packaging and Packing. - After completion of tests each unit shall be preserved within one week by performing the following:

(a) Each unit shall be discharged below 0.1 volt by clipping a one ohm resistor across the cell terminals.

(b) Remove the one ohm resistor and short the cell terminals by wrapping a copper wire around cell terminals.

(*) Except for Qual. Units where the temperature extremes specified herein shall be considered the permissible temperature range.

280

5.2 (Continued)

(c) Each unit shall be placed in a polyethlene bag and an inert drying agent shall be added to exclude moisture. Bag shall be heat sealed.

NOTE: Cell serial number shall be clearly visible from the outside of the bag.

(d) Each unit shall be packaged in a manner to avoid damage during shipment.

5.3 Marking of Shipments. - Interior packages and exterior shipping containers shall be marked in accordance with Grumman instructions.

6 NOTES

6.1 Intended Use. - The cells covered by this specification are intended for continuous duty in electrical systems of satellites. They will be used in combination with a solar cell array to provide energy storage and furnish peak power demands. (See Specification AV-252CS-26C for storage battery design.)

6.2 Storage Conditions for Cells. - All cells which are kept on long term storage (periods in excess of one week) shall be stored as follows:

(a) Same as 5.2(a)

(b) Same as 5.2(b)

(c) Same as 5.2(c)

(d) Same as 5.2(d)

(e) Each unit shall be stored in a clean dry area at a temperature between 59 to 85°F.

241

6.3 **Definitions.** -

6.3.1 **Cell Capactiy.** - Cell capacity is the discharge measured quantitatievly in ampere hours at the specified discharge rate to the specified cutoff voltage.

6.3.2 **Cutoff Voltage.** - The cutoff voltage of a cell is defined as that discharge voltage which represents the complete discharge condition of the cell for a particular rate. Discharge beyond this voltage would yield an insignificant amount of useful energy.

6.3.3 **Constant Current Discharge.** - The discharge made at the rate specified until the final voltage reaches the specified cutoff value.

6.4 **Charging Instructions.** - The Seller shall furnish, with cells, one reproducible printed copy of charging instructions.

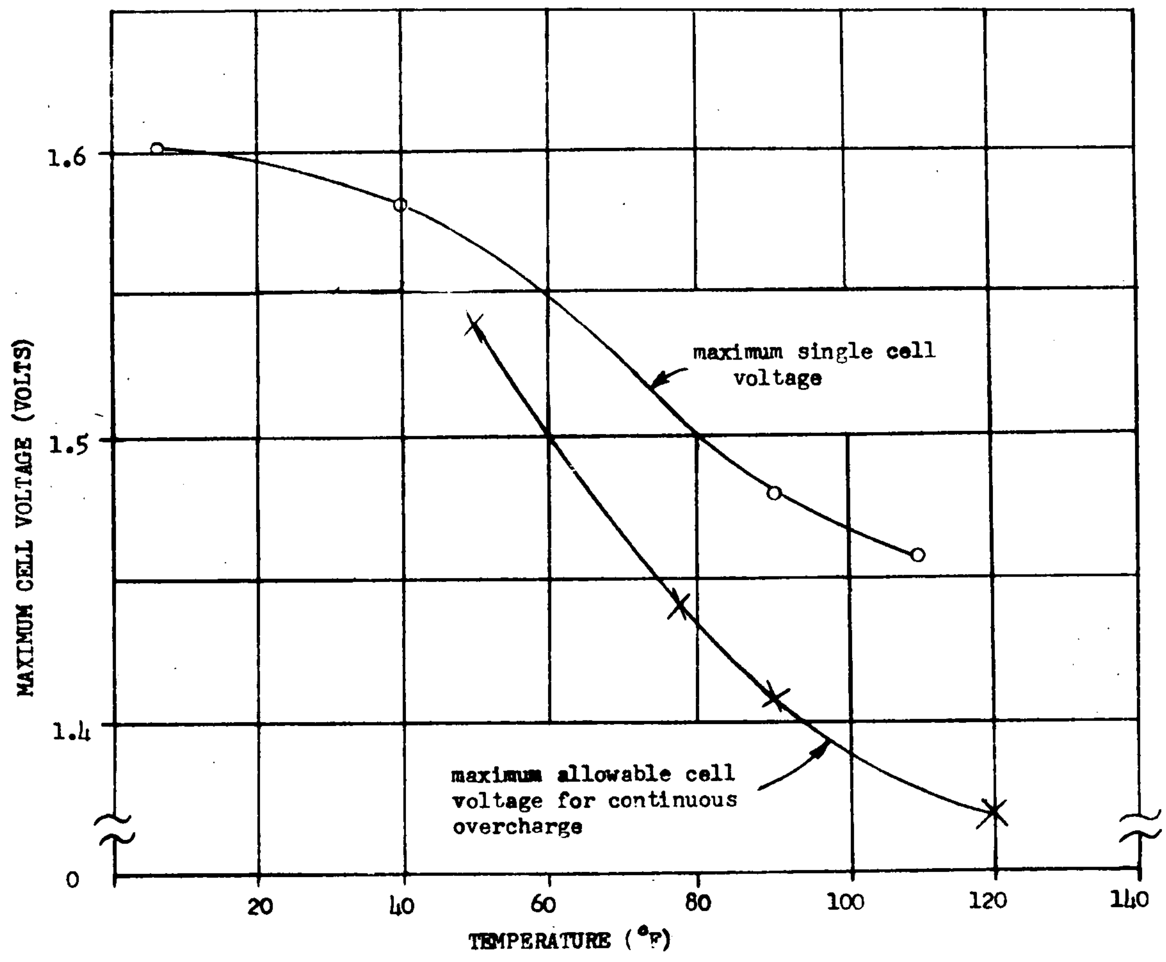
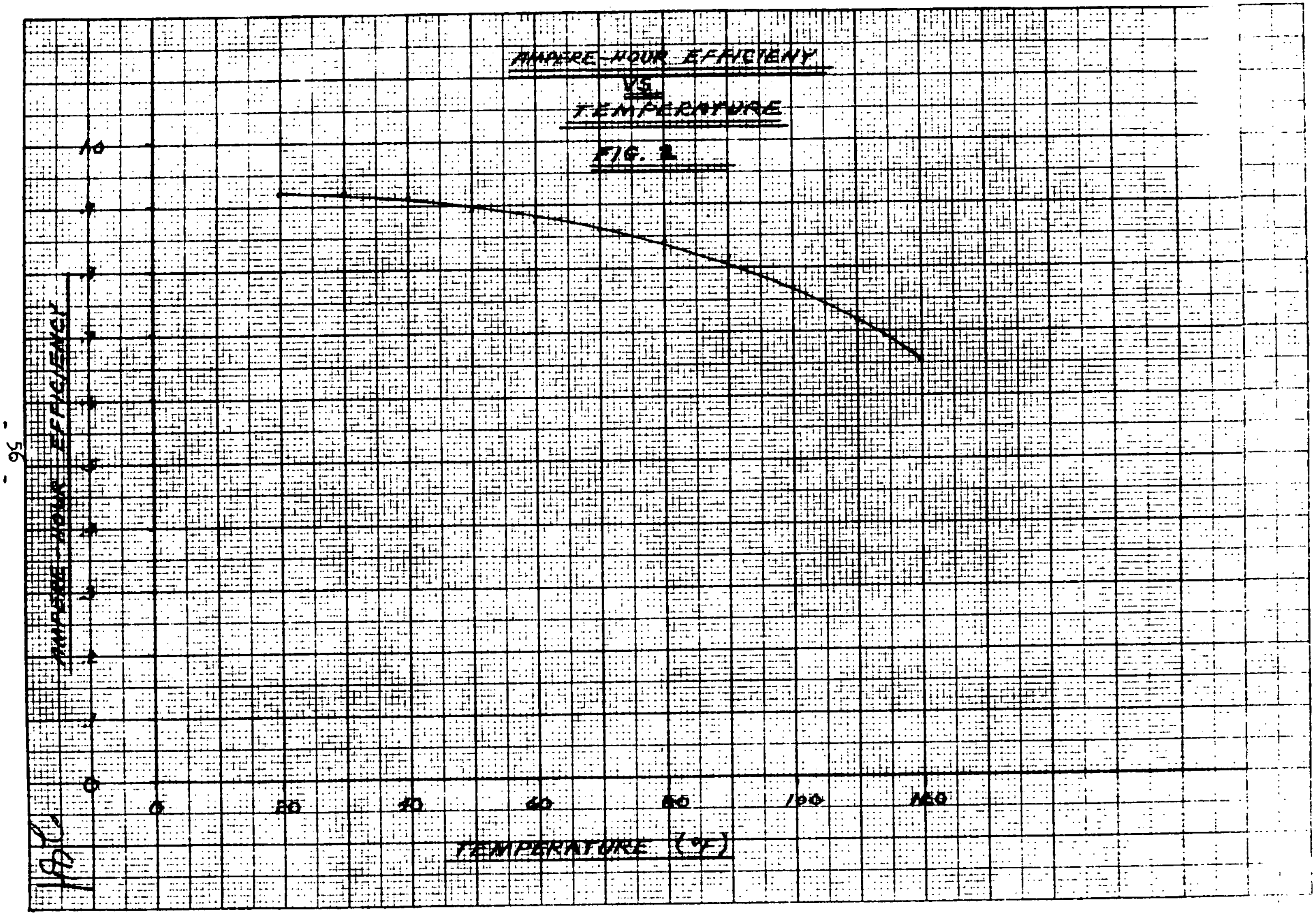
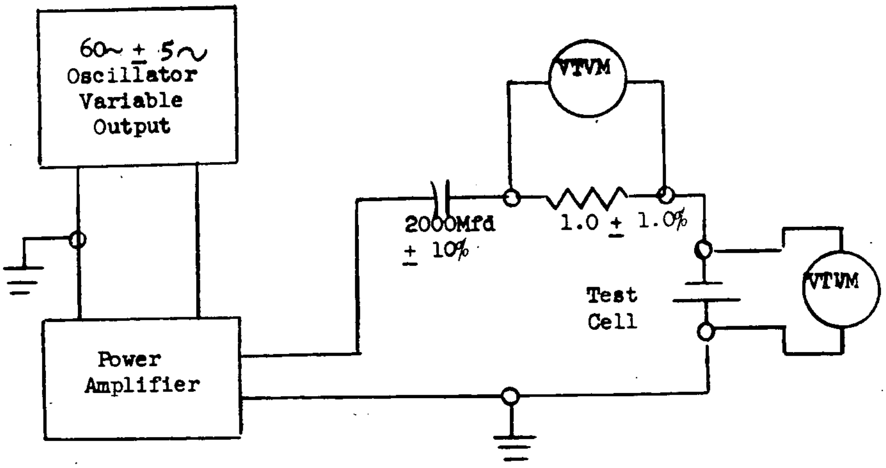


FIGURE 1. MAXIMUM LIMITING VOLTAGE FOR CHARGE CONTROL OF HERMETICALLY SEALED NICKEL-CADMIUM CELLS



AMPERE HOUR EFFICIENY
VS.
TEMPERATURE

FIG. 2



INTERNAL IMPEDANCE CIRCUIT

FIGURE 3

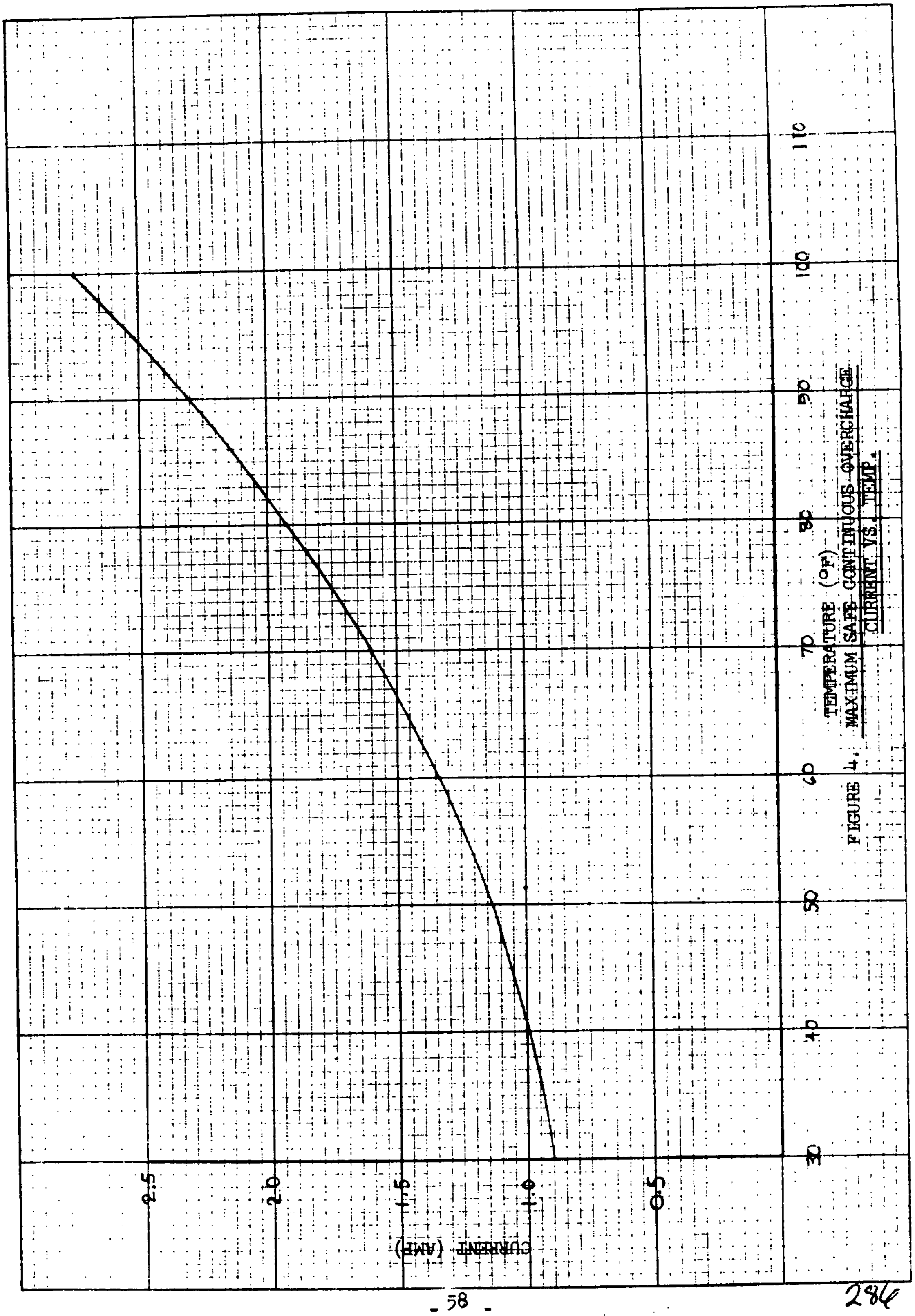
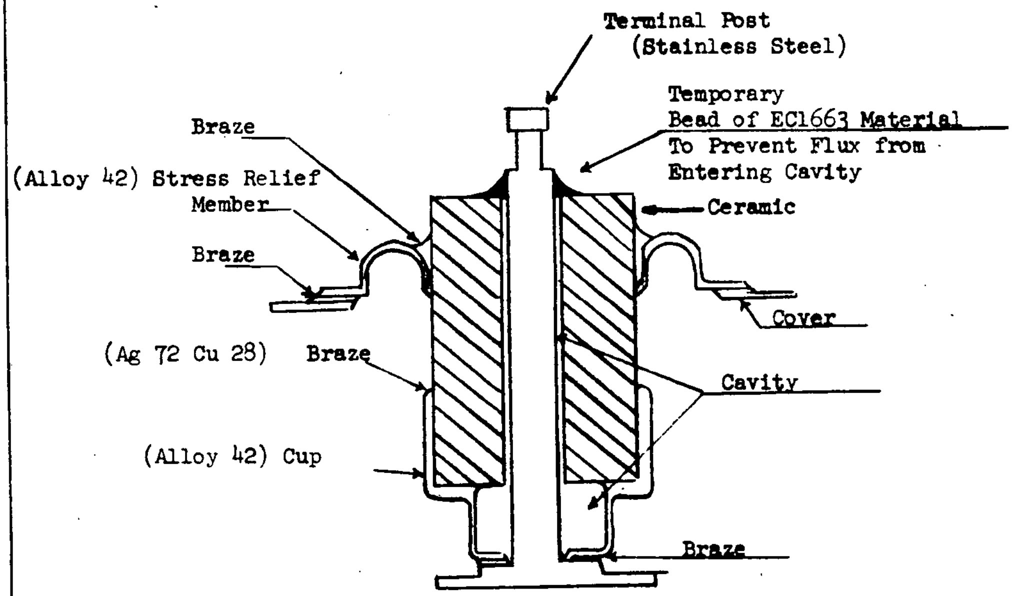


FIGURE 4. MAXIMUM SAFE CONTINUOUS OVERCHARGE CURRENT VS. TEMP.



Ceramic-To-Metal Seal Terminal

Cross Sectional View

Figure 5

287

AXES FOR VIBRATION – STORAGE CELLS

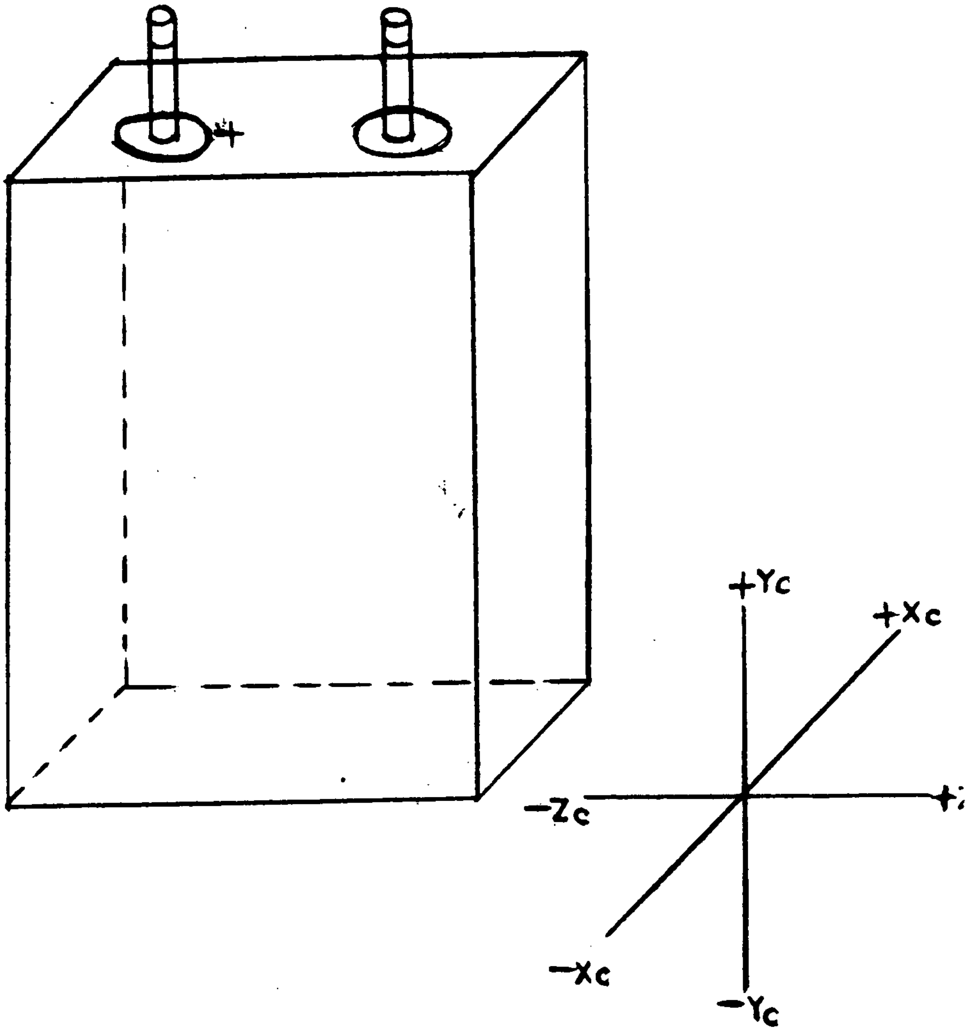


FIGURE 6

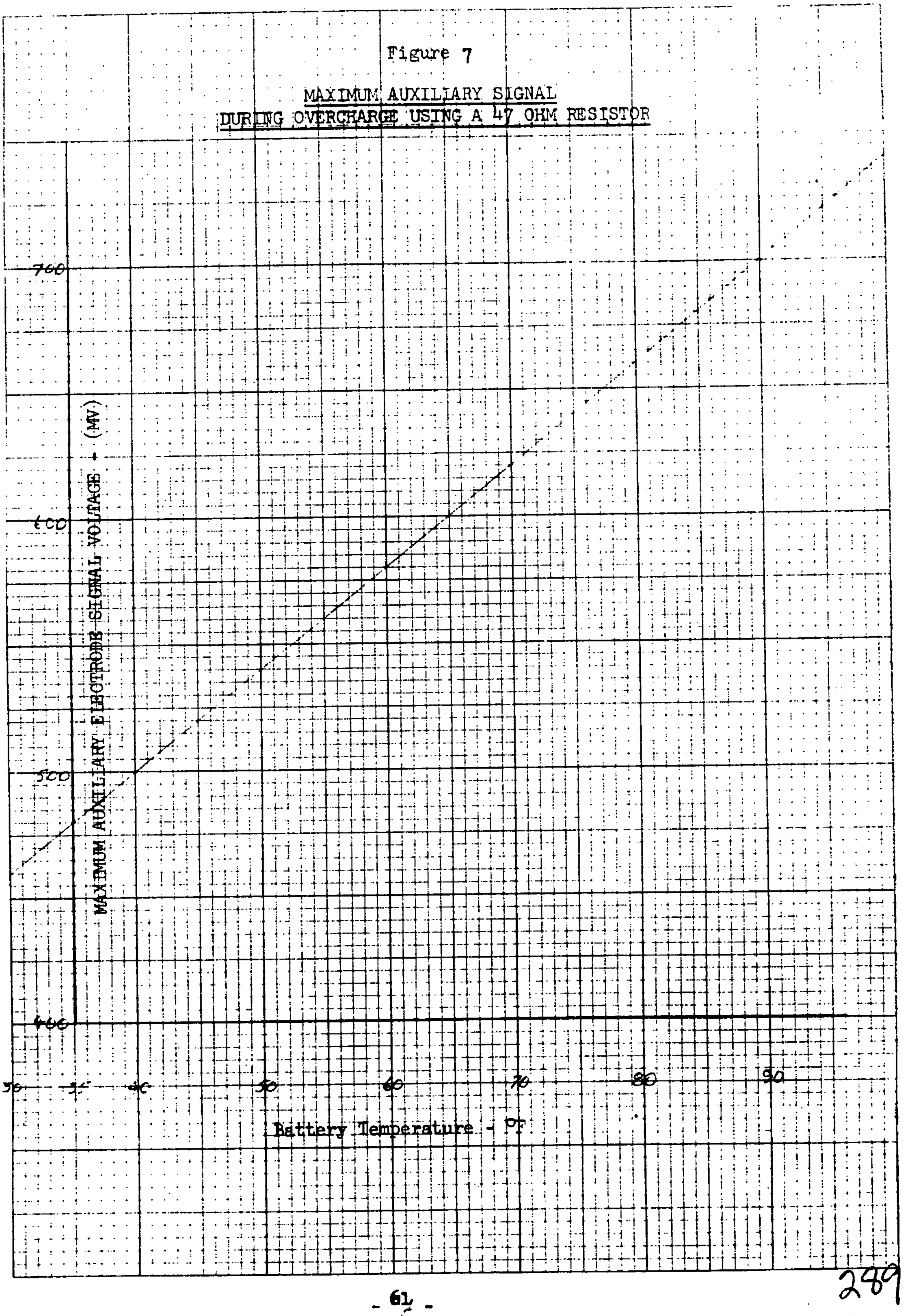


Figure 7

MAXIMUM AUXILIARY SIGNAL
DURING OVERCHARGE USING A 47 OHM RESISTOR

TABLE I

QUALIFICATION VIBRATION TEST REQUIREMENTS FOR

NICKEL-CADMIUM STORAGE CELLS

SINUSOIDAL VIBRATION SWEEP AT 2 OCTAVES PER MINUTE		RANDOM VIBRATION RUN FOR 4 MINUTES PER AXIS	
x_c, y_c and z_c axes		x_c, y_c and z_c axes	
Freq.	Level	Freq.	Level
5-35HZ	$\frac{1}{2}$" DA	15HZ	$.023g^2/Hz$
35-350	30g	15-30	15 db/oct incr
350-2000	60g	30-1200 Hz	$0.7g^2/Hz$
		1200-1400 Hz	21 db/oct incr
		1400-1700 Hz	$2.0g^2/Hz$
		1700-2000 Hz	24 db/oct decr to $0.5g^2/Hz$

NOTE: Sine levels to be applied using tracking filter control

TABLE II

QUALIFICATION VIBRATION REQUIREMENTS

Sinusoidal Vibration. - The control signal shall be filtered for sinusoidal testing, if harmonic distortions is evident this can be determined by viewing the control signal on an oscilloscope during the fixture survey.

MAXIMUM TOLERANCES

Sinusoidal Vibration Amplitude:	± 10%
Sinusoidal Vibration Frequency:	± 2%
Random Vibration:	± 3 db (The overall rms-g applied shall be maintained within a tolerance of $^{+15\%}_{-\ 5\%}$

Sinusoidal Vibration. - The vibration input levels shall be measured at or near the test unit mounting location. Whenever more than four mounting locations exist, only four points need be monitored. Any accelerometer fastened at any one of the mounting locations can be used as the servo control input provided that:

(a) The control input maintains levels at the test frequency within ± 1 db of the requirements.

TABLE II (Continued)

(b) The level at any input location is within ± 4 db of the requirements at the test frequency.

(c) The average of all inputs at the test frequency is within ± 2 db of the requirements.

Exceeding the lower limits of the above tolerances shall be cause for rejection of the delinquent portion of the test and shall necessitate rerunning only that portion of the vibration test. Selection of the control point shall be subject to Grumman approval.

Random Vibration. - The vibration input for this test shall be controlled from the same accelerometer as used to control the sinusoidal vibration test.

Vibration Fixtures. - The fixture, and its connection to the shaker head, shall be capable of transmitting the vibrations specified herein. It shall be a design objective that the fixture be free of resonances within the test frequencies. In any event, the fundamental resonance of the fixture compensated for test unit mass shall be above 750 Hz. The transverse motion (crosstalk) in any direction produced by these fixtures shall not exceed the vibration levels in the transverse direction specified herein. The requirements outlined above shall be verified by a sinusoidal vibration sweep at test frequencies using a mass simulated dummy test item. The vibration input for this sweep shall be monitored with tri-axial accelerometers.

X-Y Plots. - X-Y plots of vibration test control accelerometers shall be made and included in the test report. For sinusoidal vibration tests, the following ground rules shall be used:

a. The control signal shall be filtered if harmonic distortion is evident. This can be determined by viewing the control signal on an oscilloscope during the fixture survey.

TABLE II (Continued)

b. If a filtered control signal is used, then the X-Y plots shall be filtered.

X-Y plots for sinusoidal tests shall show peak "g" vs Hz. For random tests, the plots shall show the Spectral Density (PSD) analysis in g^2/Hz vs Hz. Parallel filter or tracking filter analysis can be used. Both sinusoidal and random X-Y plots should be made using on-line or taped signals from the control accelerometer and reduced using automatic X-Y plotters. Plotting of meter readings by hand is not acceptable.

NOTE: If track filter PSD analysis is used, the analyzing filter bandwidths should not exceed 20 Hz for frequencies below 200 Hz and should not exceed 50 Hz for frequencies between 200 and 2000 Hz. Analyzing constants such as averaging time, sweep rate and tape loop length should be consistent with good analysis practice. It is recommended that the statistical quality of the analysis be equivalent to 60 degrees of freedom minimum.

A copy of the X-Y vibration test plots shall be submitted to Grumman within 5 days of the completion of the vibration portion of the environmental test.

293

SPECIFICATION

No. AV-252CS-25G

Appendix I

SAMPLE DATA SHEET I

APPENDIX I

SEPARATOR TEST PROCEDURE

NOTE: The following information is to be supplied on each cell lot production.

Separator Material Supplier:

Base Material:

Fiber Manufacturer:

Part No.
Lot No.
Dat of Mfg.(mo/yr)

Separator Suppliers Style No.

Lot No.
Date of Mfg.

Material Slitted By:

(Do Not Use Anti-Static Agent)

Finishes or Wetting Agents Added By Separator Supplier

Yes ________
No ________

Finishes or Wetting Agents Added By Cell Manufacturer

Yes ________
No ________

State type of wash and number of times separator washed

Applicable Grumman P.O. # ____________________

Prepared by ________________ date ___________

SPECIFICATION

No. AV-252CS-25G

Appendix I (Continued)

Sample Data Sheet 2

Nominal Thickness

Maximum Thickness

Minimum Thickness

1.0 **WEIGHT (gm/m^2)**

Sample 1 ________ **Sample 2** ________ **Sample 3** ________

2.0 **DIMENSIONS AND DIMENSIONAL CHANGES**

	Length(cm)		**Width**		**Thickness**	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
Sample 1						
2						
3						
4						
5						
6						

Applicable Grumman P.O. # ________________

Above tests conducted by ________________ **date** ____________

Prepared by ____________________________ **date** ____________

SPECIFICATION

No. AV-252CS-25G

Appendix I (Continued)

Sample Data Sheet 3

2.0 (Continued)

	% Change In Thickness	Wet Volume (V_w)
Sample 1		
2		
3		
4		
5		
6		

2.1 Electrolyte Absorption

	Dry Weight (gm) W_D	Wet Weight (gm) W_W	Grams of Electrolyte Absorbed ($W_W - W_D$) W_A
Sample 1			
2			
3			
4			
5			
6			

Applicable Grumman P.O. # ____________________

Above tests conducted by ____________________ date ____________

Prepared by ______________________________ date ____________

Sample Data Sheet 4

2.2 **Electrolyte Retained.** -

	Dry Weight (gm) W_D	Wet Weight (gm) W_r	Grams of Electrolyte Retained (W_r-W_D) W_R
Sample 1			
2			
3			
4			
5			
6			

Calculate percent electrolyte retained from the following:

$$\frac{W_R}{W_A} \times 100 = \text{Percent Electrolyte Retained}$$

W_R = Grams of Electrolyte Retained
W_A = Grams of Electrolyte Absorbed

Percent Electrolye Retained

Sample 1
2
3
4
5
6

Applicable Grumman P.O. # ____________________

Above tests conducted by ____________________ date ____________

Prepared by ______________________________ date ____________

SPECIFICATION

No. AV-252CS-25G
Appendix I (Continued)

Sample Data Sheet 5

2.3 **Porosity**. - Porosity or internal void volume is calculated by the following:

$$\frac{W_W - W_D}{V_W \times p} = \text{Percent Porosity}$$

Where

W_W = Wet weight of separator (gm)

W_D = Dry weight of separator (gm)

V_W = Wet volume of separator (cc)

p = Density of absorbed electrolyte. The density of the absorbed elecyrolye is taken to be the same as the density of the equilibrating electrolyte.

Percent Porosity

Sample 1
2
3
4
5
6

3.1 **Separator Resistance**. -

Applicable Grumman P.O. # ______________________

Above tests conducted by ______________________ date __________

Prepared by ______________________ date __________

298

SPECIFICATION

No. AV-252CS-25G
Appendix I (Continued)

Sample Data Sheet 6

3.1 (Continued)

	Separator Resistance ohm-cm^2	Separator Specific Resistivity ohm - cm
Sample 1		
2		
3		

5.1 Tensile Strength at Break, Temperature °F, Humidity %. -

	Tensile Strength At Break Lbs/cm^2	Percent Elongation	Appearance Of Break
Sample 1			
2			
3			
4			
5			
6			

5.2

	Tensile Strength At Break Lbs/cm^2	Percent Elongation	Appearance Of Break
Sample 1			
2			
3			
4			
5			
6			

Record Temperature ______________ °F Record Humidity ______________ %

Applicable Grumman P.O. # ______________________

Above tests conduced by ______________________ date ____________

Prepared by ______________________________ date ____________

Sample Data Sheet 7

6.0 DETERMINATION OF ORGANICS	Sample 1	Sample 2	Sample 3
Weight of separator before extraction (gm)			
Weight of separator after extraction (gm)			
Weight loss (gm)			
Weight of container plus residue (gm)			
Weight of container (gm)			
Weight of residue (gm)			
Percent organics (Weight of residue divided by weight of separator after extraction) X100			

7.1 Determination of inorganics. -

	Inorganic	Percent
Sample 1		
2		
3		

8.1 Discoloration of Samples in Electrolyte. - Describe color change and in which test discoloration occurred.

9.1 Thickness Variation. -

Reading	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1					
2					
3					

Applicable Grumman P.O. # ____________________

Above tests conducted by ____________________ date ____________

Prepared by ______________________________ date ____________

SPECIFICATION

No. AV-252CS-25G
Appendix I (Continued)

Sample Data Sheet 8

9.1 (Continued)

Reading	Sample				
	1	2	3	4	5
4					
5					
6					
7					
8					
9					
10					

Average
Circle maximum and minimum value for each sample.

Reading	6	7	8	9	10
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Applicable Grumman P.O. # ____________

Above tests conducted by ____________ date ____________

Prepared by ____________ date ____________

Appendix I (Continued)

Sample Data Sheet 9

10.1 Dimensions and Dimensional Changes. -

	Length (cm)		Width		Thickness	
	Dry	Wet	Dry	Wet	Dry	Wet
Sample 1						
2						
3						
4						
5						
6						

	% Change In Thickness	Wet Volume (V_W)
Sample 1		
2		
3		
4		
5		
6		

Electrolyte Absorption

	Dry Weight(gm) W_D	Wet Weight(gm) W_W	Grams of Electrolyte Absorbed (W_W- W_D) W_A
Sample 1			
2			

Applicable Grumman P.). # ____________________

Above tests conducted by ____________________ date ______________

Prepared by ______________________________ date ______________

Sample Data Sheet 10

10.1 (Continued)

Sample 3

4

5

6

10.2 Electrolyte Retained. -

	Dry Weight (gm) W_D	Wet Weight (gm) W_r	Grams of Electrolyte Retained $(W_r - W_D)$ W_R
Sample 1			
2			
3			
4			
5			
6			

Calculate percent electrolyte retained from the following:

$$\frac{W_R}{W_A} \text{ X } 100 = \text{Percent Electrolyte Retained}$$

W_D = Grams of Electrolyte Retained

W_A = Grams of Electrolyte Absorbed

Applicable Grumman P.O. # ____________

Above tests conducted by ____________ date ________

Prepared by ____________ date ________

SPECIFICATION

No. AV-252CS-25G

Appendix I (Continued)

Sample Data Sheet 11

10.2 (Continued)

Percent Electrolye Retained

Sample 1

2

3

4

5

6

10.3 Porosity. - Porosity or internal void volume is calculated by the following:

$$\frac{W_W - W_D}{V_W \times p} = \text{Percent Porosity}$$

where

W_W = Wet weight of separator (gm)

W_D = Dry weight of separator (gm)

V_W = Wet volume of separator (cc)

p = Density of absorbed electrolyte. The density of the absorbed electrolye is taken to be the same as the equilibrating electrolyte.

10.4 Plot data of the three determinations on one graph, 10 x 10 to the inch.

10.5 Tensile Strength at Break. -

Applicable Grumman P.O. # ____________________

Above tests conducted by ________________ date ________________

Prepared by ________________________ date ________________________

304

SPECIFICATION

No. AV-252CS-25G

Appendix I (Continued)

Sample Data Sheet 12

10.5 (Continued)

	Tensile Strength At Break Lbs/cm^2	Percent Elongation	Appearance Of Break
Sample 1			
2			
3			
4			
5			
6			

Pore Volume 0.38 cc/GM

Aminco-Winslow Mercury Intrusion Porosity Meter

Applicable Grumman P.O. # ______________

Above tests conducted by ______________ date ____________

Prepared by ______________________ date ____________

305

APPENDIX II

NOTE: This appendix establishes the requirements for the electrical operations of Nickel-Cadmium Storage Cells for OAO applications.

1.0 General. - All cells shall come from one cell lot, constructed at the same time using identical assembly techniques and using components from one single batch.

2.0 Temperature Requirements. - During the cell electrical operation process, the average cell temperature shall be between 70 and 80°F. Once the average cell temperature has been initially determined, it shall not vary more than ±3°F during the entire electrical operation except during overcharge. The maximum temperature gradient across the cell groups shall be less than 6°F. Thermocouples shall be used as necessary to monitor temperature and temperature gradients every hour during the selection procedure. Thermocouple installation shall be subject to Grumman approval. If necessary, the cells charge voltage may be adjusted to maintain the cells temperature within specified limits, but under no circumstances shall the requirements exceed those specified on Figure 1 of Specification AV-252CS-25.

3.0 Technical Data. - Technical data shall be recorded as specified in the text of this appendix. The recorded data shall be submitted to Grumman.

4.0 Grumman Representatives. - Grumman shall be advised when the electrical operation procedures are to be conducted so that OAO Engineering and Quality Assurance representatives may be designated to witness the electrical operation procedures.

5.0 Test Equipment. - Test equipment and automatic recording equipment, of sufficient response to obtain continuous records, shall be used to obtain continuous current readings in each circuit.

6.0 Cell Electrical Operation Requirements. - All cells shall be electrically operated in accordance with the following procedures. Any retest or deviation from this procedure shall be subject to immediate Grumman notification. Information shall be recorded as shown on attached Sample Data Sheets (Appendix 3).

(a) Charge each cell at 2.0 amps for 24 hours minimum. At the end of the charge, record the voltage, the pressure and the results of an Alkali Leak Detection, hereafter referred to as Phenolphthalein or phenol check which shall show no red indication.

  (1) Maximum voltage shall be 1.50 V

  (2) Maximum pressure shall be 50 psi

(b) Connect the cells to automatic cycle. Discharge at 10 amps for 30 minutes and charge at 4 amps for 90 minutes. Perform 10 cycles minimum starting with the discharge. Record low pressure during last cycle.

(c) Remove from automatic cycle and place on overcharge at 2.0 amps. Keep on overcharge for 24 hours. At the end of overcharge, record the voltage, the pressure and result of phenol check:

  (1) Maximum Voltage shall be 1.50 V

  (2) Maximum Pressure shall be 50 psi

(d) Discharge at 10.0 amps to 1.0 volt per cell. Record time, pressure and capacity:

  (1) Minimum capacity shall be 20.0 ampere hours.

  (2) Pressure shall be equal to or less than 0 psi.

(e) Short each cell with one (1) ohm resistor for 16 hours minimum.

(f) Dead short for one (1) hour minimum.

307

6.0 (Continued)

(g) Place on charge at 2.0 amps for 24 hours. At the end of overcharge, record the voltage, the pressure and result of phenol check:

(1) Maximum cell voltage shall be 1.50 V.

(2) Maximum cell pressure shall be 50 psi.

(h) Discharge at 10.0 amps to 1.0 volt per cell. Record time, pressure and capacity:

(1) Minimum capacity shall be 20 ampere hours.

(2) Pressure shall be equal to or less than 0 psi.

(i) Charge at 2.0 amps for 2 hours. Record cell voltage and pressure just prior to charge termination.

(j) Measure internal cell impedance per 4.5.1.3.

(k) Short each cell with one (1) ohm resistor for 20 hours minimum.

(l) Dead short for one (1) hour minimum.

(m) Review all recorded data.

6.1 Auxiliary Cell Electrical Operation Requirements. - All cells shall be electrically operated in accordance with the following procedures. Any retest or deviation from this procedure shall be subject to immediate Grumman notification. Information shall be recorded as shown on attached Sample Data Sheets (Appendix 3).

(a) Charge each cell at 2.0 amps for 24 hours minimum. At the end of the charge, record the voltage, the pressure and the results of an Alkali Leak Detection, hereafter referred to as Phenolphthalein or phenol check which shall show red indication.

6.1 (Continued)

(a) (Continued)

  (1) Maximum voltage shall be 1.50 V

  (2) Maximum pressure shall be 50 psi

(b) Connect the cells to automatic cycle. Discharge at 10 amps for 30 minutes and charge at 4 amps for 90 minutes. Perform 10 cycles minimum starting with the discharge. Record low pressure during last cycle.

(c) Remove from atuomatic cycle and place on overcharge at 2.0 amps. Keep on overcharge for 24 hours. At the end of overcharge, record the voltage, the pressure and result of phenol check:

  (1) Maximum Voltage shall be 1.50 V

  (2) Maximum Pressure shall be 50 psi

(d) Discharge at 10.0 amps to 1.0 volt per cell. Record time, pressure and capacity:

  (1) Minimum capacity shall be 20.0 ampere hours.

  (2) Pressure shall be equal to or less than 0 psi.

(e) Short each cell with one (1) ohm resistor for 16 hours minimum.

(f) Dead short for one (1) hour minimum.

(g) Place on charge at 2.0 amps for 24 hours. At the end of overcharge, record the voltage, the pressure and result of phenol check:

  (1) Maximum cell voltage shall be 1.50 V.

  (2) Maximum cell pressure shall be 50 psi.

6.1 (Continued)

(h) Discharge at 10.0 amps to 1.0 volt per cell. Record time, pressure and capacity:

  (1) Minimum capacity shall be 20 ampere hours

  (2) Pressure shall be equal to or less than 0 psi.

(i) Short each cell with one (1) ohm resistor for 16 hours minimum.

(j) Dead short for one (1) hour minimum.

(k) Charge at the 10.0 Amps to 0 psig. Record cell voltage, auxiliary electrode voltage current, and pressure every 15 minutes. Record the time for the pressure to reach 0 psig to an accuracy of one minute.

  (1) All auxiliary electrode signals will be within ± 50 mv of the average auxiliary electrode signal at 0 psig.

(l) Continue charge to 20 psig. Record cell voltage, auxiliary electrode voltage, and cell pressure every 15 minutes. Record the time, to an accuracy of one minute, for the pressure to reach 20 psig.

  (1) All auxiliary electrode signals will be within ± 50 mv of the average auxiliary electrode signal at 20 psig.

(m) Discharge each cell at the 10.0 Amps to 1.0 volts. Record cell voltage, auxiliary electrode voltage current, and cell pressure every 15 minutes.

(n) Short each cell with a one (1) ohm resistor for 16 hours minimum.

(o) Remove the one (1) ohm resistor and charge at the 10.0 Amps to 20 psig. Record auxiliary electrode voltage, current, cell voltage, and pressure on either continuous recorders or at 5 minute intervals. Record the time to the nearest minute for cells to reach 0, 10, and 20 psig.

  (1) All auxiliary electrode signals shall be within ± 50 mv of the average auxiliary electrode signal at 0, 10, and 20 psig.

6.1 (Continued)

(p) Place each cell on open circuit for a minimum of one hour. Within 5 minutes after the beginning of the open circuit stand and after one hour ± 5 minutes record pressure, auxiliary electrode voltage, current, and cell voltage.

(q) Discharge each cell at the 10.0 Amps to 1.0 volts. Record cell voltage, auxiliary electrode voltage, current, and pressure every 15 minutes.

  (1) Short each cell with (1) ohm resistor for 16 hours minimum.

    a. Maximum pressure at end of 16 hours shall not exceed 20 inches of Hg."

(r) Dead short for one (1) hour minimum.

(s) Review all recorded data.

NOTE: Auxiliary Electrode Resistor and Measurements. -

All third electrode cells shall have 47 ohm resistors connected to the auxiliary electrode and negative terminals for all tests. The third electrode voltages shall be recorded at the same intervals required for cell voltage and pressure data unless otherwise specified.

7.0 Cell Selection Requirements. - All cells purchased herein are subject to cell selection criteria as specified in Appendix A of Specification AV-252CS-26. Whenever cells are purchased as single units in contrast to complete batteries, the applicable capacity selection criteria are hereby modified as follows:

(a) The total number of cells purchased shall be considered as one battery assembly (± 1.0 ampere hour) for capacity matching criteria.

(b) Approximately 1/3 of the total number of cells purchased must meet the capacity matching criteria for each battery (± 0.5 ampere hour).

No. AV-252CS-25G

APPENDIX III

ELECTRICAL OPERATIONS-FLOW CHART

CUSTOMER __________

FACTORY ORDER NO. __________

DELIVERY SCHEDULE __________

	1	2			3		4	5	6		
	On charge at 2.00 amperes for 24 hours minimum	At end of charge, take voltage, pressure and pheno check. Maximum voltage = 1.50 V	Maximum pressure = 50 psi		Hook up to automatic cycle. Discharge current 10.0 AMPS for 30 minutes. Charge current 4.00 AMPS for 90 minutes. Cycle 10 cycles min. Start on discharge cycle.		Record low pressure during last cycle. (Approximately 2/3 through final charge cycle).	Remove from automatic cycle and place on overcharge at 2.00 AMPS. Remain on overcharge for 24 hours minimum.	End of overcharge, record voltage, pressure, and phenol check.	Maximum Volt = 1.50 V	Maximum Pressure = 50 psi
Call #		VOLT	PRESS	PHENO			PRESS		VOLT	PRESS	PHENC
Date											
Time											
Insp. By											

312

Sample Data Sheet 2

APPENDIX III (Continued)

CUSTOMER ____________

FACTORY ORDER NO. ____________

DELIVERY SCHEDULE ____________

	7			8	9	10	11			12		
	Hook up and discharge at 10.0 Amps. to 1.0 Volts per cell. Record time, pressure and capacity. Minimum 20.0 Amp hours capacity. Pressure equal to or less than 0.			Short with one ohm resistor for 16 hours minimum.	Dead short for one hour minimum.	Place on charge at 2.0 Amps for 24 hours minimum.	At end of overcharge, record voltage, pressure, and phenol check. Maximum Volt. = 1.50 V. Maximum Pressure = 50 psi.			Hook up and discharge at 10.0 amps. to 1.0 volts per cell. Record time, pressure and capacity. Minimum 20.0 Ampere Hour cap		Pressure equal to or less than 0.
Cell #	Time	Press	Cap.				Volt	Press	Pheno	Time	Press	Cap.
Insp. By												

Sample Data Sheet 3

APPENDIX III (Continued)

CUSTOMER ____________
FACTORY ORDER NO. ____
DELIVERY SCHEDULE ____

	13	14		15	16	17	18
	On charge at 2.0 amps for 2 hours	Just prior to charge termination, record cell voltage and pressure.		Internal cell impedance per 4.5.1.3.	Short with one ohm resistor for 20 hours minimum.	Dead short for one hour minimum.	Technical review of data.
Cell # Date Time		Volt	Press				
Insp. By							

APPENDIX C

Histograms of Cell Variables

HISTOGRAMS OF CELL VARIABLES

In this section are computer-drawn, histogram plots of the intrinsic cell variables for the subject batteries. Presented with the plots are the various statistical parameters associated with the distributions. These include the mean, standard deviation (sigma), the range, the maximum (VMAX) and minimum (VMIN) values of the data points in the distribution, as well as the total number of data points (NV). The variable number corresponds to the parameters listed in Table XX. A summary of the averages and standard deviations is presented in Table XXI.

STATISTICAL SUMMATION OF CELL VARIABLES

VAR. NO.	DESCRIPTION (BATTERY S/N)	S/N 25A, 26A				S/N 30, 31				S/N 32, 33				S/N 34, 35			
		MEAN		σ		MEAN		σ		MEAN		σ		MEAN		σ	
1	Dry Cell Weight	769.43	--	9.81	--	779.89	800.62	4.96	3.04	794.15	805.44	4.25	5.18	787.85	799.18	4.61	4.83
2	Wet Cell Weight	856.89	--	10.10	--	869.80	893.79	6.80	4.34	881.77	896.65	4.66	5.47	875.92	891.13	5.12	5.26
3	End of Precharge Voltage	1.443	1.456	0.007	0.005	--	--	--	--	1.448	1.457	0.008	0.009	1.436	1.448	0.027	0.007
4	Third Electrode Plate Weight	--	--	--	--	--	--	--	--	--	--	--	--	--	8.76	--	0.093
5	Cell Pack Weight	525.86	--	4.09	--	528.84	528.55	4.45	2.67	--	--	--	--	538.82	538.86	2.90	2.37
6	Positive Plate Group Weight	--	--	--	--	--	--	--	--	257.55	257.54	1.66	2.26	257.74	257.99	1.56	1.30
7	Negative Plate Group Weight	--	--	--	--	--	--	--	--	274.61	274.13	1.94	2.09	276.88	276.34	1.71	1.70
8	Voltage at End of 40°F Overcharge	1.473	1.476	0.010	0.006	1.479	1.482	0.010	0.007	1.489	1.488	0.007	0.006	1.484	1.470	0.008	0.005
9	Time-Filling to Start of Precharge	--	--	--	--	--	--	--	--	17.51	18.20	14.12	11.50	8.52	49.77	6.34	23.87
10	Capacity - 3rd Cycle Elec. Op.	--	--	--	--	--	--	--	--	26.56	27.27	0.51	0.76	23.58	24.23	0.38	0.25
11	Capacity - 3rd Cycle Cell Selection	25.47	25.71	0.625	0.625	25.64	25.58	0.69	0.54	26.18	26.58	0.47	0.65	23.27	23.47	0.33	0.25
12																	
13	Cycle 1 } Pressures at End	4.88	5.90	2.05	1.70	--	--	--	--	13.53	9.27	5.76	4.16	16.12	11.48	5.60	3.81
14	Cycle 2 } of Each Cycle of	4.13	4.50	1.98	1.36	--	--	--	--	14.66	9.15	5.16	3.42	24.04	13.73	6.91	3.40
15	Cycle 3 } Electrical Operations	4.21	3.33	2.41	2.29	--	--	--	--	19.67	14.12	6.49	5.21	31.58	18.78	9.73	5.43
16	Cycle 1 } Pressures at End of	--	--	--	--	--	--	--	--	-0.33	1.68	5.02	5.79	8.87	0.89	5.79	3.40
17	Cycle 2 } Cell Selection	--	--	--	--	--	--	--	--	13.37	12.88	6.19	5.54	28.09	12.00	10.67	3.74
18	Cycle 3 }	--	--	--	--	--	--	--	--	14.54	13.64	5.95	5.43	34.30	14.55	13.69	3.80
19	Room Temperature } Pressures at End of	--	--	--	--	--	--	--	--	11.34	8.15	6.52	5.54	31.47	9.91	15.37	3.58
20	40°F } Each Overcharge Cycle	--	--	--	--	5.28	4.50	3.58	4.15	12.43	6.00	5.24	2.80	28.11	7.68	13.25	3.15
21	90°F } During Cell Selection	8.79	--	2.57	--	8.64	11.83	5.61	6.67	28.70	17.69	--	4.60	44.84	16.14	18.37	4.86
22	TN_1 - In Minutes } Ratio Data	--	--	--	--	--	--	--	--	--	4.94	--	6.34	8.08	12.85	12.08	5.34
23	TN_3 - In Minutes } Ratio Data	--	--	--	--	--	--	--	--	--	177.36	--	2.96	164.57	157.17	2,92	2.34
24	TN_4 - In Minutes } Ratio Data	--	--	--	--	--	--	--	--	--	240.00	--	3.71	2.43.43	240.00	4.81	3.74
25	Time - Formation to End of Drying (Days)	--	--	--	--	--	--	--	--	3.87	3.65	0.81	0.48	--		--	
26	Time - Drying to Cell Sealing (Days)	--	--	--	--	--	--	--	--	47.67	78.64	19.86	13.44	--		--	
27	Time - Cell Sealing to Filling (Days)	--	--	--	--	--	--	--	--	10.33	13.00	8.60	4.60	--		--	
28	Gas Evolved During Precharge - ml	--	--	--	--	--	--	--	--	--	--	--	--	619.83	577.41	206.38	379.09

* ALL WEIGHTS GIVEN IN GRAMS

** ALL PRESSURES GIVEN IN PSIG

*** ALL VOLTAGES ARE IN VOLTS

2

KEY

STD.	AUX.

317

```
H I S T O G R A M
-----------------
                                                        VARIABLE V( 3)

MEAN=  1.45555     SIGMA=      0.00507     RANGE=  0.01000     VMIN=     1.45000     VMAX=     1.46000     NV=     9

------------------------------------------------------------------------------------------------------------------------
           RANGE           FREQ.1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95..100
------------------------------------------------------------------------------------------------------------------------
  1     1.4500      1.4510    4 ****
  2     1.4510      1.4520    0
  3     1.4520      1.4530    0
  4     1.4530      1.4540    0
  5     1.4540      1.4550    0
  6     1.4550      1.4560    0
  7     1.4560      1.4570    0
  8     1.4570      1.4580    0
  9     1.4580      1.4590    0
 10     1.4590      1.4600    5 *****
------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V( 9)

MEAN=  1.47555     SIGMA=      0.00552     RANGE=  0.01900     VMIN=     1.46700     VMAX=     1.48600     NV=     9

------------------------------------------------------------------------------------------------------------------------
           RANGE           FREQ.1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95..100
------------------------------------------------------------------------------------------------------------------------
  1     1.4670      1.4689    1 *
  2     1.4689      1.4708    0
  3     1.4708      1.4727    3 ***
  4     1.4727      1.4746    0
  5     1.4746      1.4765    1 *
  6     1.4765      1.4784    1 *
  7     1.4784      1.4803    2 **
  8     1.4803      1.4822    0
  9     1.4822      1.4841    0
 10     1.4841      1.4860    1 *
------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V(11)

MEAN= 25.71109     SIGMA=      0.62539     RANGE=  2.15001     VMIN=    24.84999     VMAX=    27.00000     NV=     9

------------------------------------------------------------------------------------------------------------------------
           RANGE           FREQ.1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95..100
------------------------------------------------------------------------------------------------------------------------
  1    24.8500     25.0650    2 **
  2    25.0650     25.2800    1 *
  3    25.2800     25.4950    0
  4    25.4950     25.7100    2 **
  5    25.7100     25.9250    1 *
  6    25.9250     26.1400    1 *
  7    26.1400     26.3550    1 *
  8    26.3550     26.5700    0
  9    26.5700     26.7850    0
```

```
HISTOGRAM
                                               VARIABLE V(13)

MEAN=  5.90000     SIGMA=      1.70000     RANGE=  6.00000     VMIN=     3.00000     VMAX=      9.00000      NV=    10
-----------------------------------------------------------------------------------------------------------------------
           RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1      3.0000      3.6000     1 *
  2      3.6000      4.2000     2 **
  3      4.2000      4.8000     0
  4      4.8000      5.4000     0
  5      5.4000      6.0000     0
  6      6.0000      6.6000     3 ***
  7      6.6000      7.2000     3 ***
  8      7.2000      7.8000     0
  9      7.8000      8.4000     0
 10      8.4000      9.0000     1 *
-----------------------------------------------------------------------------------------------------------------------

HISTOGRAM
                                               VARIABLE V(14)

MEAN=  4.50000     SIGMA=      1.36016     RANGE=  4.00000     VMIN=     2.00000     VMAX=      6.00000      NV=    10
-----------------------------------------------------------------------------------------------------------------------
           RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1      2.0000      2.4000     1 *
  2      2.4000      2.8000     0
  3      2.8000      3.2000     2 **
  4      3.2000      3.6000     0
  5      3.6000      4.0000     0
  6      4.0000      4.4000     1 *
  7      4.4000      4.8000     0
  8      4.8000      5.2000     3 ***
  9      5.2000      5.6000     0
 10      5.6000      6.0000     3 ***
-----------------------------------------------------------------------------------------------------------------------

HISTOGRAM
                                               VARIABLE V(15)

MEAN=  3.33333     SIGMA=      2.28522     RANGE=  7.00000     VMIN=     1.00000     VMAX=      8.00000      NV=    6
-----------------------------------------------------------------------------------------------------------------------
           RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1      1.0000      1.7000     1 *
  2      1.7000      2.4000     2 **
  3      2.4000      3.1000     1 *
  4      3.1000      3.8000     0
  5      3.8000      4.5000     1 *
  6      4.5000      5.2000     0
  7      5.2000      5.9000     0
  8      5.9000      6.6000     0
  9      6.6000      7.3000     0
```

```
H I S T O G R A M
-----------------
                                                VARIABLE V( 1)

MEAN=769.42700     SIGMA=      9.80752     RANGE= 33.50000     VMIN=   751.69995     VMAX=   785.19995     NV=   39

---------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1    751.7000    755.0498     2 **
  2    755.0498    758.3997     2 **
  3    758.3997    761.7495     7 *******
  4    761.7495    765.0994     7 *******
  5    765.0994    768.4492     2 **
  6    768.4492    771.7991     1 *
  7    771.7991    775.1489     3 ***
  8    775.1489    778.4988     6 ******
  9    778.4988    781.8486     5 *****
 10    781.8486    785.2000     4 ****
---------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                VARIABLE V( 2)

MEAN=856.89404     SIGMA=     10.09951     RANGE= 35.60010     VMIN=   839.59985     VMAX=   875.19995     NV=   39

---------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1    839.5999    843.1597     2 **
  2    843.1597    846.7195     5 *****
  3    846.7195    850.2793     5 *****
  4    850.2793    853.8391     7 *******
  5    853.8391    857.3989     2 **
  6    857.3989    860.9587     3 ***
  7    860.9587    864.5186     2 **
  8    864.5186    868.0784     8 ********
  9    868.0784    871.6382     3 ***
 10    871.6382    875.2000     2 **
---------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                VARIABLE V( 3)

MEAN=  1.44332     SIGMA=      0.00655     RANGE=  0.02000     VMIN=     1.44000     VMAX=     1.46000     NV=   87

---------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1      1.4400      1.4420    59 ***********************************************************
  2      1.4420      1.4440     0
  3      1.4440      1.4460     C
  4      1.4460      1.4480     0
  5      1.4480      1.4500     0
  6      1.4500      1.4520    27 ***************************
  7      1.4520      1.4540     0
  8      1.4540      1.4560     0
  9      1.4560      1.4580     0
```

```
H I S T O G R A M
-----------------
                                                        VARIABLE V( 5)

MEAN=525.86279     SIGMA=      4.08503     RANGE= 15.20020     VMIN=    518.29980     VMAX=    533.50000     NV=    38

------------------------------------------------------------------------------------------------------------------------
           RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
  1    518.2998    519.8158    3 ***
  2    519.8198    521.3358    3 ***
  3    521.3399    522.8559    3 ***
  4    522.8599    524.3799    4 ****
  5    524.3799    525.8999    5 *****
  6    525.8999    527.4199    4 ****
  7    527.4199    528.9359    8 ********
  8    528.9399    530.4600    5 *****
  9    530.4600    531.9800    2 **
 10    531.9800    533.5000    1 *
------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V( 8)

MEAN=  1.47391     SIGMA=      0.01029     RANGE=  0.05500     VMIN=     1.45800     VMAX=      1.51300     NV=    66

------------------------------------------------------------------------------------------------------------------------
           RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
  1      1.4580      1.4635    9 *********
  2      1.4635      1.4650   11 ***********
  3      1.4690      1.4745   17 *****************
  4      1.4745      1.4800   13 *************
  5      1.4800      1.4855    8 ********
  6      1.4855      1.4910    7 *******
  7      1.4910      1.4965    0
  8      1.4965      1.5020    0
  9      1.5020      1.5075    0
 10      1.5075      1.5130    1 *
------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V(11)

MEAN= 25.46693     SIGMA=      0.62010     RANGE=  2.83000     VMIN=     24.34000     VMAX=     27.17000     NV=    87

------------------------------------------------------------------------------------------------------------------------
           RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
  1     24.3400     24.6230    8 ********
  2     24.6230     24.9060    6 ******
  3     24.9060     25.1890   21 *********************
  4     25.1890     25.4720   11 ***********
  5     25.4720     25.7549   14 **************
  6     25.7549     26.0379   14 **************
  7     26.0379     26.3209    4 ****
  8     26.3209     26.6039    4 ****
  9     26.6039     26.8869    4 ****
```

321

```
H I S T O G R A M
-----------------
                                                   VARIABLE V(13)

MEAN=  4.88369     SIGMA=     2.05406     RANGE=  9.00000     VMIN=      2.00000     VMAX=     11.00000     NV=    85
------------------------------------------------------------------------------------------------------------------------
            RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
   1      2.0000      2.9000     6 ******
   2      2.9000      3.8000    21 *********************
   3      3.8000      4.7000    15 ***************
   4      4.7000      5.6000    17 *****************
   5      5.6000      6.5000    10 **********
   6      6.5000      7.4000     6 ******
   7      7.4000      8.3000     4 ****
   8      8.3000      9.2000     5 *****
   9      9.2000     10.1000     1 *
  10     10.1000     11.0000     1 *
------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(14)

MEAN=  4.12938     SIGMA=     1.90228     RANGE= 11.00000     VMIN=      1.00000     VMAX=     12.00000     NV=    85
------------------------------------------------------------------------------------------------------------------------
            RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
   1      1.0000      2.1000    10 **********
   2      2.1000      3.2000    38 **************************************
   3      3.2000      4.3000     3 ***
   4      4.3000      5.4000    12 ************
   5      5.4000      6.5000    13 *************
   6      6.5000      7.6000     7 *******
   7      7.6000      8.7000     0
   8      8.7000      9.8000     1 *
   9      9.8000     10.9000     0
  10     10.9000     12.0000     1 *
------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(15)

MEAN=  4.21247     SIGMA=     2.41191     RANGE= 11.00000     VMIN=      1.00000     VMAX=     12.00000     NV=    80
------------------------------------------------------------------------------------------------------------------------
            RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
   1      1.0000      2.1000    19 *******************
   2      2.1000      3.2000    20 ********************
   3      3.2000      4.3000    10 **********
   4      4.3000      5.4000    14 **************
   5      5.4000      6.5000     4 ****
   6      6.5000      7.6000     5 *****
   7      7.6000      8.7000     1 *
   8      8.7000      9.8000     3 ***
   9      9.8000     10.9000     3 ***
  10     10.9000     12.0000     1 *
```

322

```
H I S T O G R A M
-----------------
                                                    VARIABLE V(21)

MEAN=  8.78946     SIGMA=     2.56657     RANGE=  9.00000       VMIN=       5.50000      VMAX=     14.00000       NV=     19

-------------------------------------------------------------------------------------------------------------------------
             RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-------------------------------------------------------------------------------------------------------------------------
  1      5.0000       5.9000    3 ***
  2      5.9000       6.8000    1 *
  3      6.8000       7.7000    1 *
  4      7.7000       8.6000    5 *****
  5      8.6000       9.5000    2 **
  6      9.5000      10.4000    2 **
  7     10.4000      11.3000    2 **
  8     11.3000      12.2000    1 *
  9     12.2000      13.1000    1 *
 10     13.1000      14.0000    1 *
-------------------------------------------------------------------------------------------------------------------------
     SCALING FACTOR = 1
-------------------------------------------------------------------------------------------------------------------------
```

323

```
H I S T O G R A M
-----------------
                                                        VARIABLE V( 1)

MEAN=800.62207      SIGMA=      3.04138     RANGE= 12.69995      VMIN=    792.59990      VMAX=    805.59985      NV=     17
-------------------------------------------------------------------------------------------------------------------------------
             RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-------------------------------------------------------------------------------------------------------------------------------
  1    792.5999    794.1697    1 *
  2    794.1697    795.4395    0
  3    795.4395    796.7092    0
  4    796.7092    797.9790    1 *
  5    797.9790    799.2488    2 **
  6    799.2488    800.5186    3 ***
  7    800.5186    801.7883    3 ***
  8    801.7883    803.0581    5 *****
  9    803.0581    804.3279    0
 10    804.3279    805.5999    2 **
-------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V( 2)

MEAN=893.77856      SIGMA=      4.33734     RANGE= 15.50000      VMIN=    886.29980      VMAX=    901.79980      NV=     15
-------------------------------------------------------------------------------------------------------------------------------
             RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-------------------------------------------------------------------------------------------------------------------------------
  1    886.2998    887.8496    1 *
  2    887.8496    889.3994    1 *
  3    889.3994    890.9492    2 **
  4    890.9492    892.4990    2 **
  5    892.4990    894.0488    1 *
  6    894.0488    895.5986    5 *****
  7    895.5986    897.1484    1 *
  8    897.1484    898.6982    0
  9    898.6982    900.2480    0
 10    900.2480    901.7998    2 **
-------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V( 5)

MEAN=528.54590      SIGMA=      2.66927     RANGE=  9.00000      VMIN=    522.59985      VMAX=    531.59985      NV=     17
-------------------------------------------------------------------------------------------------------------------------------
             RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-------------------------------------------------------------------------------------------------------------------------------
  1    522.5999    523.4998    1 *
  2    523.4998    524.3997    1 *
  3    524.3997    525.2996    0
  4    525.2996    526.1995    0
  5    526.1995    527.0994    2 **
  6    527.0994    527.9993    3 ***
  7    527.9993    528.8992    1 *
  8    528.8992    529.7991    2 **
  9    529.7991    530.6990    3 ***
```

```
H I S T O G R A M
                                                VARIABLE V( 8)

MEAN=  1.48178      SIGMA=      0.00662      RANGE=  0.02200      VMIN=      1.47200      VMAX=      1.49400      NV=    14

-----------------------------------------------------------------------------------------------------------------------------
            RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1      1.4720      1.4742      3 ***
  2      1.4742      1.4764      1 *
  3      1.4764      1.4786      0
  4      1.4786      1.4808      1 *
  5      1.4808      1.4830      2 **
  6      1.4830      1.4852      3 ***
  7      1.4852      1.4874      2 **
  8      1.4874      1.4896      1 *
  9      1.4896      1.4918      0
 10      1.4918      1.4940      1 *
-----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
                                                VARIABLE V(11)

MEAN= 25.58380      SIGMA=      0.53968      RANGE=  1.83000      VMIN=     24.84999      VMAX=     26.67999      NV=    13

-----------------------------------------------------------------------------------------------------------------------------
            RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1     24.8500     25.0330      4 ****
  2     25.0330     25.2160      0
  3     25.2160     25.3990      1 *
  4     25.3990     25.5820      2 **
  5     25.5820     25.7650      2 **
  6     25.7650     25.9480      0
  7     25.9480     26.1310      2 **
  8     26.1310     26.3140      0
  9     26.3140     26.4970      1 *
 10     26.4970     26.6800      1 *
-----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
                                                VARIABLE V(20)

MEAN=  4.50000      SIGMA=      4.15331      RANGE= 14.00000      VMIN=     -3.00000      VMAX=     11.00000      NV=     6

-----------------------------------------------------------------------------------------------------------------------------
            RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1     -3.0000     -1.6000      1 *
  2     -1.6000     -0.2000      0
  3     -0.2000      1.2000      0
  4      1.2000      2.6000      0
  5      2.6000      4.0000      1 *
  6      4.0000      5.4000      2 **
  7      5.4000      6.8000      1 *
  8      6.8000      8.2000      0
  9      8.2000      9.6000      0
```

```
H I S T O G R A M
-----------------
                                                  VARIABLE V(21)
--------------------------------------------------------------------------------------------------------------------
MEAN= 11.83333      SIGMA=      6.66875      RANGE= 20.00000      VMIN=      6.30300      VMAX=      26.00000      NV=      6

----------------------------------------------------------------------------------------------------------------------------
           RANGE               FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1      6.0000      8.0000     2 **
  2      8.0000     10.0000     2 **
  3     10.0000     12.0000     0
  4     12.0000     14.0000     1 *
  5     14.0000     16.0000     0
  6     16.0000     18.0000     0
  7     18.0000     20.0000     0
  8     20.0000     22.0000     0
  9     22.0000     24.0000     0
 10     24.0000     26.0000     1 *
----------------------------------------------------------------------------------------------------------------------------
      SCALING FACTOR = 1
----------------------------------------------------------------------------------------------------------------------------
```

```
HISTOGRAM
----------------
                                                         VARIABLE V( 1)

MEAN=779.89453      SIGMA=       4.95606      RANGE= 18.09985      VMIN=   770.69995      VMAX=   788.79980      NV=   119

-----------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1    770.7000    772.5098    3 ***
  2    772.5098    774.3196    4 ****
  3    774.3196    776.1294   10 **********
  4    776.1294    777.9392   17 *****************
  5    777.9392    779.7490   22 **********************
  6    779.7490    781.5588   27 ***************************
  7    781.5588    783.3687   15 ***************
  8    783.3687    785.1785   11 ***********
  9    785.1785    786.9883    6 ******
 10    786.9883    788.7998    2 **
-----------------------------------------------------------------------------------------------------------------------------

HISTOGRAM
----------------
                                                         VARIABLE V( 2)

MEAN=869.79541      SIGMA=       6.80074      RANGE= 47.00000      VMIN=   860.00000      VMAX=   907.00000      NV=   114

-----------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1    860.0000    864.7000   15 ***************
  2    864.7000    869.3999   40 ****************************************
  3    869.3999    874.0999   46 **********************************************
  4    874.0999    878.7998   10 **********
  5    878.7998    883.4998    0
  6    883.4998    888.1997    1 *
  7    888.1997    892.8997    1 *
  8    892.8997    897.5996    0
  9    897.5996    902.2996    0
 10    902.2996    907.0000    1 *
-----------------------------------------------------------------------------------------------------------------------------

HISTOGRAM
----------------
                                                         VARIABLE V( 5)

MEAN=528.83911      SIGMA=       4.45112      RANGE= 18.59985      VMIN=   519.50000      VMAX=   538.09998      NV=   120

-----------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1    519.5000    521.3599    2 **
  2    521.3599    523.2197    6 ******
  3    523.2197    525.0796   12 ************
  4    525.0796    526.9395   16 ****************
  5    526.9395    528.7993   19 *******************
  6    528.7993    530.6592   28 ****************************
  7    530.6592    532.5190   21 *********************
  8    532.5190    534.3789    9 *********
  9    534.3789    536.2388    5 *****
 10    536.2388    538.0999    2 **
```

328

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```
H I S T O G R A M
-----------------
                                                            VARIABLE V( 8)

MEAN= 1.47866      SIGMA=      0.00981      RANGE=  0.07600      VMIN=      1.42100      VMAX=      1.49700      NV=   117

-----------------------------------------------------------------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------
  1      1.4210      1.4286      1 *
  2      1.4286      1.4362      0
  3      1.4362      1.4438      1 *
  4      1.4438      1.4514      0
  5      1.4514      1.4590      0
  6      1.4590      1.4666      1 *
  7      1.4666      1.4742     27 ***************************
  8      1.4742      1.4818     41 *****************************************
  9      1.4818      1.4894     39 ***************************************
 10      1.4894      1.4970      7 *******
-----------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                            VARIABLE V(11)

MEAN= 25.63626     SIGMA=      0.68608      RANGE=  3.66000      VMIN=     24.34000      VMAX=     28.00000      NV=   116

-----------------------------------------------------------------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------
  1     24.3400     24.7060      9 *********
  2     24.7060     25.0720     21 *********************
  3     25.0720     25.4380     18 ******************
  4     25.4380     25.8040     18 ******************
  5     25.8040     26.1700     25 *************************
  6     26.1700     26.5360     11 ***********
  7     26.5360     26.9020     11 ***********
  8     26.9020     27.2680      0
  9     27.2680     27.6340      2 **
 10     27.6340     28.0000      1 *
-----------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                            VARIABLE V(20)

MEAN=  5.28125     SIGMA=      3.50209      RANGE= 21.00000      VMIN=     -1.00000      VMAX=     20.00000      NV=    32

-----------------------------------------------------------------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------
  1     -1.0000      1.1000      2 **
  2      1.1000      3.2000      6 ******
  3      3.2000      5.3000      9 *********
  4      5.3000      7.4000     11 ***********
  5      7.4000      9.5000      1 *
  6      9.5000     11.6000      2 **
  7     11.6000     13.7000      0
  8     13.7000     15.8000      0
  9     15.8000     17.9000      0
 10     17.0000     20.0000      1 *
```

329

```
H I S T O G R A M
-----------------
                                                   VARIABLE V(21)

MEAN=  8.43750     SIGMA=     5.51214     RANGE= 32.00000     VMIN=     1.00000     VMAX=     33.00000     NV=   32

------------------------------------------------------------------------------------------------------------------------
            RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
  1     1.0000     4.2000     7 *******
  2     4.2000     7.4000     9 *********
  3     7.4000    10.6000     9 *********
  4    10.6000    13.8000     4 ****
  5    13.8000    17.0000     2 **
  6    17.0000    20.2000     0
  7    20.2000    23.4000     0
  8    23.4000    26.6000     0
  9    26.6000    29.8000     0
 10    29.8000    33.0000     1 *
------------------------------------------------------------------------------------------------------------------------
     SCALING FACTOR = 1
------------------------------------------------------------------------------------------------------------------------
```

```
H I S T O G R A M
-----------------
                                                  VARIABLE V( 1)

MEAN=805.44360     SIGMA=     5.17808     RANGE= 19.20020     VMIN=   793.79980     VMAX=   813.00000     NV=   26

---------------------------------------------------------------------------------------------------------------------
            RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1    793.7998    795.7197    3 ***
  2    795.7197    797.6396    0
  3    797.6396    799.5595    0
  4    799.5596    801.4795    1 *
  5    801.4795    803.3994    4 ****
  6    803.3994    805.3193    2 **
  7    805.3193    807.2393    4 ****
  8    807.2393    809.1592    8 ********
  9    809.1592    811.0791    2 **
 10    811.0791    813.0000    2 **
---------------------------------------------------------------------------------------------------------------------
```

```
H I S T O G R A M
-----------------
                                                  VARIABLE V( 2)

MEAN=896.55112     SIGMA=     5.46580     RANGE= 18.89990     VMIN=   885.69995     VMAX=   904.59985     NV=   26

---------------------------------------------------------------------------------------------------------------------
            RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1    885.7000    887.5899    3 ***
  2    887.5898    889.4797    0
  3    889.4797    891.3696    1 *
  4    891.3696    893.2595    1 *
  5    893.2595    895.1494    4 ****
  6    895.1494    897.0393    1 *
  7    897.0393    898.9292    5 *****
  8    898.9292    900.8191    7 *******
  9    900.8191    902.7090    2 **
 10    902.7090    904.5959    2 **
---------------------------------------------------------------------------------------------------------------------
```

331

```
H I S T O G R A M
-----------------
                                                  VARIABLE V( 3)

MEAN=  1.45738     SIGMA=     0.00906     RANGE=  0.03000     VMIN=     1.44400     VMAX=     1.47400     NV=   26

---------------------------------------------------------------------------------------------------------------------
            RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1      1.4440      1.4470    3 ***
  2      1.4470      1.4500    3 ***
  3      1.4500      1.4530    3 ***
  4      1.4530      1.4560    2 **
  5      1.4560      1.4590    5 *****
  6      1.4590      1.4620    3 ***
  7      1.4620      1.4650    1 *
  8      1.4650      1.4680    1 *
  9      1.4680      1.4710    3 ***
```

```
H I S T O G R A M
-----------------
                                                            VARIABLE V( 6)

MEAN=257.54100      SIGMA=      2.26385      RANGE=   7.79991      VMIN=    254.09999      VMAX=    261.89990      NV=    26
----------------------------------------------------------------------------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1    254.1000    254.8800    2 **
  2    254.8800    255.6600    5 *****
  3    255.6600    256.4399    4 ****
  4    256.4399    257.2197    1 *
  5    257.2197    257.9995    4 ****
  6    257.9995    258.7793    0
  7    258.7793    259.5591    5 *****
  8    259.5591    260.3389    2 **
  9    260.3389    261.1187    0
 10    261.1187    261.8999    3 ***
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                            VARIABLE V( 7)

MEAN=274.13037      SIGMA=      2.05165      RANGE=   8.10010      VMIN=    270.89990      VMAX=    279.00000      NV=    26
----------------------------------------------------------------------------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1    270.8999    271.7097    1 *
  2    271.7097    272.5195    8 ********
  3    272.5195    273.3293    3 ***
  4    273.3293    274.1392    2 **
  5    274.1392    274.9490    4 ****
  6    274.9490    275.7588    2 **
  7    275.7588    276.5686    3 ***
  8    276.5686    277.3784    1 *
  9    277.3784    278.1882    0
 10    278.1882    279.0000    2 **
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                            VARIABLE V( 8)

MEAN=  1.49766      SIGMA=      0.00594      RANGE=   0.02600      VMIN=      1.47500      VMAX=      1.50100      NV=    24
----------------------------------------------------------------------------------------------------------------------------
              RANGE             FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1     1.4750      1.4776     1 *
  2     1.4776      1.4802     0
  3     1.4802      1.4828     2 **
  4     1.4828      1.4854     6 ******
  5     1.4854      1.4880     5 *****
  6     1.4880      1.4906     4 ****
  7     1.4906      1.4932     3 ***
  8     1.4932      1.4958     0
  9     1.4958      1.4984     2 **
```

332

```
H I S T O G R A M
-----------------
                                                     VARIAPLE V( 9)

MEAN= 19.19609     SIGMA=     11.48751     RANGE= 29.09000     VMIN=     0.33000     VMAX=     29.42000     NV=     26

-----------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
   1       0.3300      3.2390     9 *********
   2       3.2390      6.1480     0
   3       6.1480      9.0570     0
   4       9.0570     11.9660     0
   5      11.9660     14.8750     0
   6      14.8750     17.7840     0
   7      17.7840     20.6930     0
   8      20.6930     23.6020     4 ****
   9      23.6020     26.5110     8 ********
  10      26.5110     29.4200     6 ******
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                     VARIABLE V(10)

MEAN= 27.27107     SIGMA=     0.75503     RANGE=  3.00000     VMIN=     26.00000     VMAX=     29.00000     NV=     26

-----------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
   1      26.0000     26.3000     1 *
   2      26.3000     26.6000     4 ****
   3      26.6000     26.9000     7 *******
   4      26.9000     27.2000     2 **
   5      27.2000     27.4999     1 *
   6      27.4999     27.7999     4 ****
   7      27.7999     28.0999     3 ***
   8      28.0999     28.3999     2 **
   9      28.3999     28.6999     1 *
  10      28.6999     29.0000     1 *
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                     VARIABLE V(11)

MEAN= 26.58109     SIGMA=     0.64651     RANGE=  2.34001     VMIN=     25.32999     VMAX=     27.67000     NV=     26

-----------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
   1      25.3300     25.5640     2 **
   2      25.5640     25.7980     1 *
   3      25.7980     26.0320     4 ****
   4      26.0320     26.2660     2 **
   5      26.2660     26.5000     2 **
   6      26.5000     26.7339     3 ***
   7      26.7339     26.9679     3 ***
   8      26.9679     27.2019     3 ***
   9      27.2019     27.4359     4 ****
  10      27.4359     27.6700     2 **
```

333

334

```
H I S T O G R A M
-----------------
                                              VARIABLE V(13)

MEAN=   9.26923        SIGMA=      4.15516      RANGE= 15.00000       VMIN=      3.00000      VMAX=    18.00000      NV=    26

------------------------------------------------------------------------------------------------------------------------------------
                 RANGE               FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------------
   1     3.0000       4.5000      3 ***
   2     4.5000       6.0000      5 *****
   3     6.0000       7.5000      2 **
   4     7.5000       9.0000      5 *****
   5     9.0000      10.5000      3 ***
   6    10.5000      12.0000      3 ***
   7    12.0000      13.5000      1 *
   8    13.5000      15.0000      0
   9    15.0000      16.5000      2 **
  10    16.5000      18.0000      2 **
------------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                              VARIABLE V(14)

MEAN=   9.15383        SIGMA=      3.41595      RANGE= 15.00000       VMIN=      3.00000      VMAX=    18.00000      NV=    26

------------------------------------------------------------------------------------------------------------------------------------
                 RANGE               FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------------
   1     3.0000       4.5000      3 ***
   2     4.5000       6.0000      2 **
   3     6.0000       7.5000      3 ***
   4     7.5000       9.0000     10 **********
   5     9.0000      10.5000      0
   6    10.5000      12.0000      3 ***
   7    12.0000      13.5000      2 **
   8    13.5000      15.0000      2 **
   9    15.0000      16.5000      0
  10    16.5000      18.0000      1 *
------------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                              VARIABLE V(15)

MEAN=  14.11537        SIGMA=      5.20598      RANGE= 20.00000       VMIN=      4.00000      VMAX=    24.00000      NV=    26

------------------------------------------------------------------------------------------------------------------------------------
                 RANGE               FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------------
   1     4.0000       6.0000      2 **
   2     6.0000       8.0000      2 **
   3     8.0000      10.0000      3 ***
   4    10.0000      12.0000      6 ******
   5    12.0000      14.0000      3 ***
   6    14.0000      16.0000      1 *
   7    16.0000      18.0000      1 *
   8    18.0000      20.0000      5 *****
   9    20.0000      22.0000      2 **
```

```
H I S T O G R A M
-----------------
                                                      VARIABLE V(16)

MEAN=  1.68181      SIGMA=      5.78701     RANGE= 25.00000     VMIN=   -13.00000      VMAX=     12.00000      NV=    22

-----------------------------------------------------------------------------------------------------------------------------
               RANGE          FREQ.1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95...100
-----------------------------------------------------------------------------------------------------------------------------
  1   -13.0000    -10.5000    2 **
  2   -10.5000     -8.0000    0
  3    -8.0000     -5.5000    0
  4    -5.5000     -3.0000    0
  5    -3.0000     -0.5000    4 ****
  6    -0.5000      2.0000    8 ********
  7     2.0000      4.5000    3 ***
  8     4.5000      7.0000    2 **
  9     7.0000      9.5000    1 *
 10     9.5000     12.0000    2 **
-----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                      VARIABLE V(17)

MEAN= 12.07999      SIGMA=      5.54199     RANGE= 23.00000     VMIN=     2.00000      VMAX=     25.00000      NV=    25

-----------------------------------------------------------------------------------------------------------------------------
               RANGE          FREQ.1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95...100
-----------------------------------------------------------------------------------------------------------------------------
  1     2.0000      4.3000    1 *
  2     4.3000      6.6000    1 *
  3     6.6000      8.9000    6 ******
  4     8.9000     11.2000    7 *******
  5    11.2000     13.5000    3 ***
  6    13.5000     15.8000    2 **
  7    15.8000     18.1000    1 *
  8    18.1000     20.4000    1 *
  9    20.4000     22.7000    0
 10    22.7000     25.0000    3 ***
-----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                      VARIABLE V(18)

MEAN= 13.63999      SIGMA=      5.42500     RANGE= 22.00000     VMIN=     2.00000      VMAX=     24.00000      NV=    25

-----------------------------------------------------------------------------------------------------------------------------
               RANGE          FREQ.1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95...100
-----------------------------------------------------------------------------------------------------------------------------
  1     2.0000      4.2000    1 *
  2     4.2000      6.4000    1 *
  3     6.4000      8.6000    2 **
  4     8.6000     10.8000    3 ***
  5    10.8000     13.0000    7 *******
  6    13.0000     15.2000    2 **
  7    15.2000     17.4000    0
  8    17.4000     19.6000    4 ****
  9    19.6000     21.8000    3 ***
```

```
H I S T O G R A M
-----------------
                                                          VARIABLE V(19)

MEAN=  8.15384        SIGMA=      5.53793      RANGE= 24.00000      VMIN=      1.00000      VMAX=     25.00000       NV=     26

------------------------------------------------------------------------------------------------------------------------------------
              RANGE                FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------------
  1       1.0000       3.4000     3 ***
  2       3.4000       5.8000     8 ********
  3       5.8000       8.2000     4 ****
  4       8.2000      10.6000     4 ****
  5      10.6000      13.0000     1 *
  6      13.0000      15.4000     4 ****
  7      15.4000      17.8000     1 *
  8      17.8000      20.2000     0
  9      20.2000      22.6000     0
 10      22.6000      25.0000     1 *
------------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                          VARIABLE V(20)

MEAN=  5.99999        SIGMA=      2.80110      RANGE= 12.00000      VMIN=      2.00000      VMAX=     14.00000       NV=     26

------------------------------------------------------------------------------------------------------------------------------------
              RANGE                FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------------
  1       2.0000       3.2000     7 *******
  2       3.2000       4.4000     1 *
  3       4.4000       5.6000     1 *
  4       5.6000       6.8000     7 *******
  5       6.8000       8.0000     7 *******
  6       8.0000       9.2000     1 *
  7       9.2000      10.4000     0
  8      10.4000      11.6000     0
  9      11.6000      12.8000     0
 10      12.8000      14.0000     2 **
------------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                          VARIABLE V(21)

MEAN= 17.69228        SIGMA=      4.58904      RANGE= 19.00000      VMIN=      9.00000      VMAX=     28.00000       NV=     26

------------------------------------------------------------------------------------------------------------------------------------
              RANGE                FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------------
  1       9.0000      10.9000     1 *
  2      10.9000      12.8000     3 ***
  3      12.8000      14.7000     4 ****
  4      14.7000      16.6000     3 ***
  5      16.6000      18.5000     5 *****
  6      18.5000      20.4000     2 **
  7      20.4000      22.3000     4 ****
  8      22.3000      24.2000     2 **
  9      24.2000      26.1000     1 *
```

```
H I S T O G R A M
-----------------
                                                    VARIABLE V(22)

MEAN=  4.94444      SIGMA=      6.34475      RANGE= 18.50000       VMIN=      0.50000       VMAX=     19.00000       NV=      9
---------------------------------------------------------------------------------------------------------------------------------
            RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------------
   1      0.5000      2.3500     5 *****
   2      2.3500      4.2000     2 **
   3      4.2000      6.0500     0
   4      6.0500      7.9000     0
   5      7.9000      9.7500     0
   6      9.7500     11.6000     0
   7     11.6000     13.4500     0
   8     13.4500     15.3000     1 *
   9     15.3000     17.1500     0
  10     17.1500     19.0000     1 *
---------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(23)

MEAN=177.35548      SIGMA=      2.95804      RANGE=  9.00000       VMIN=    173.00000       VMAX=    182.00000       NV=      9
---------------------------------------------------------------------------------------------------------------------------------
            RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------------
   1    173.0000    173.9000     1 *
   2    173.9000    174.8000     0
   3    174.8000    175.7000     2 **
   4    175.7000    176.6000     2 **
   5    176.6000    177.5000     0
   6    177.5000    178.4000     1 *
   7    178.4000    179.3000     0
   8    179.3000    180.2000     1 *
   9    180.2000    181.0999     0
  10    181.0999    182.0000     2 **
---------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(24)

MEAN=239.99994      SIGMA=      3.71494      RANGE= 11.00000       VMIN=    234.00000       VMAX=    245.00000       NV=      9
---------------------------------------------------------------------------------------------------------------------------------
            RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------------
   1    234.0000    235.1000     1 *
   2    235.1000    236.2000     0
   3    236.2000    237.3000     2 **
   4    237.3000    238.4000     1 *
   5    238.4000    239.5000     0
   6    239.5000    240.5999     2 **
   7    240.5999    241.6999     0
   8    241.6999    242.7999     0
   9    242.7999    243.8999     0
  10    243.8999    245.0000     3 ***
```

337

```
H I S T O G R A M
-----------------
                                                              VARIABLE V(25)

MEAN=  3.65384      SIGMA=       0.47578     RANGE=  1.00000      VMIN=       3.00000       VMAX=       4.00000       NV=     26
------------------------------------------------------------------------------------------------------------------------------
              RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1      3.0000        3.1000       9 *********
  2      3.1000        3.2000       0
  3      3.2000        3.3000       0
  4      3.3000        3.4000       0
  5      3.4000        3.5000       0
  6      3.5000        3.6000       0
  7      3.6000        3.7000       0
  8      3.7000        3.8000       0
  9      3.8000        3.9000       0
 10      3.9000        4.0000      17 *****************
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                              VARIABLE V(26)

MEAN= 78.63977      SIGMA=      13.44404     RANGE= 34.00000      VMIN=      56.00000       VMAX=      90.00000       NV=     25
------------------------------------------------------------------------------------------------------------------------------
              RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1     56.0000       59.4000       4 ****
  2     59.4000       62.8000       2 **
  3     62.8000       66.2000       1 *
  4     66.2000       69.6000       1 *
  5     69.6000       73.0000       0
  6     73.0000       76.4000       0
  7     76.4000       79.8000       0
  8     79.8000       83.2000       0
  9     83.2000       86.5999      10 **********
 10     86.5999       90.0000       7 *******
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                              VARIABLE V(27)

MEAN= 12.99999      SIGMA=       4.59566     RANGE= 13.00000      VMIN=       1.00000       VMAX=      16.00000       NV=     25
------------------------------------------------------------------------------------------------------------------------------
              RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1      1.0000        2.5000       2 **
  2      2.5000        4.0000       0
  3      4.0000        5.5000       0
  4      5.5000        7.0000       0
  5      7.0000        8.5000       0
  6      8.5000       10.0000       6 ******
  7     10.0000       11.5000       0
  8     11.5000       13.0000       1 *
  9     13.0000       14.5000       0
```

338

```
H I S T O G R A M
-----------------
                                                        VARIABLE V( 1)

MEAN=794.21265     SIGMA=      4.51655     RANGE= 12.09985     VMIN=     789.00000     VMAX=    801.09985     NV=   135

-----------------------------------------------------------------------------------------------------------------------
             RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1    789.0000   790.2100    6 ******
  2    790.2100   791.4199   11 ***********
  3    791.4199   792.6299   19 *******************
  4    792.6299   793.8399   19 *******************
  5    793.8399   795.0498   28 ****************************
  6    795.0498   796.2598   27 ***************************
  7    796.2598   797.4697   16 ****************
  8    797.4697   798.6797    7 *******
  9    798.6797   799.8896    1 *
 10    799.8896   801.0999    1 *
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V( 2)

MEAN=881.90981     SIGMA=      4.24343     RANGE= 12.00000     VMIN=     876.50000     VMAX=    888.50000     NV=   135

-----------------------------------------------------------------------------------------------------------------------
             RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1    876.5000   877.7000    7 *******
  2    877.7000   878.8999   11 ***********
  3    878.8999   880.0999   16 ****************
  4    880.0999   881.2998   19 *******************
  5    881.2998   882.4998   24 ************************
  6    882.4998   883.6997   32 ********************************
  7    883.6997   884.8997   14 **************
  8    884.8997   886.0996    8 ********
  9    886.0996   887.2996    3 ***
 10    887.2996   888.5000    1 *
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V( 3)

MEAN=  1.44835     SIGMA=      0.00648     RANGE=  0.04200     VMIN=       1.43700     VMAX=      1.47900     NV=   134

-----------------------------------------------------------------------------------------------------------------------
             RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1      1.4370     1.4412   13 *************
  2      1.4412     1.4454   29 *****************************
  3      1.4454     1.4496   39 ***************************************
  4      1.4496     1.4538   31 *******************************
  5      1.4538     1.4580   16 ****************
  6      1.4580     1.4622    5 *****
  7      1.4622     1.4664    0
  8      1.4664     1.4706    0
  9      1.4706     1.4748    0
 10      1.4748     1.4790    1 *
```

340

```
H I S T O G R A M
-----------------
                                                VARIABLE V( 6)

MEAN=257.59570      SIGMA=      1.65831      RANGE=  9.79996      VMIN=   253.39999      VMAX=   263.19995      NV=   139

-----------------------------------------------------------------------------------------------------------------------------
             RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1    253.4000    254.3800    3 ***
  2    254.3800    255.3600    3 ***
  3    255.3600    256.3399   24 ************************
  4    256.3398    257.3199   27 ***************************
  5    257.3198    258.2999   40 ****************************************
  6    258.2998    259.2799   26 **************************
  7    259.2798    260.2599   12 ************
  8    260.2598    261.2397    2 **
  9    261.2397    262.2197    1 *
 10    262.2197    263.2000    1 *
-----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                VARIABLE V( 7)

MEAN=274.68799      SIGMA=      2.01556      RANGE=  9.00000      VMIN=   270.19995      VMAX=   279.19995      NV=   139

-----------------------------------------------------------------------------------------------------------------------------
             RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1    270.2000    271.0999    5 *****
  2    271.0999    271.9998    7 *******
  3    271.9998    272.8997   11 ***********
  4    272.8997    273.7996   17 *****************
  5    273.7996    274.6995   28 ****************************
  6    274.6995    275.5994   26 **************************
  7    275.5994    276.4993   23 ***********************
  8    276.4993    277.3992   11 ***********
  9    277.3992    278.2991    8 ********
 10    278.2991    279.2000    3 ***
-----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                VARIABLE V( 8)

MEAN=  1.48907      SIGMA=      0.00793      RANGE=  0.02800      VMIN=     1.48000      VMAX=     1.50800      NV=   130

-----------------------------------------------------------------------------------------------------------------------------
             RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------------
  1      1.4800      1.4828    5 *****
  2      1.4828      1.4856   20 ********************
  3      1.4856      1.4884   39 ***************************************
  4      1.4884      1.4912   31 *******************************
  5      1.4912      1.4940   17 *****************
  6      1.4940      1.4968   10 **********
  7      1.4968      1.4996    6 ******
  8      1.4996      1.5024    1 *
  9      1.5024      1.5052    0
 10      1.5052      1.5080    1 *
```

```
H I S T O G R A M
-----------------
                                                  VARIABLE V( 9)

MEAN= 15.61822      SIGMA=     13.92613      RANGE= 97.00000      VMIN=      0.50000      VMAX=      97.50000      NV=    133

----------------------------------------------------------------------------------------------------------------------------
           RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1      0.5000     10.2000   66 ******************************************************************
  2     10.2000     19.9000    0
  3     19.9000     29.6000   54 ******************************************************
  4     29.6000     39.3000   12 ************
  5     39.3000     49.0000    0
  6     49.0000     58.7000    0
  7     58.7000     68.4000    0
  8     68.4000     78.1000    0
  9     78.1000     87.8000    0
 10     87.8000     97.5000    1 *
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                  VARIABLE V(10)

MEAN= 26.56536      SIGMA=      0.51373      RANGE=  2.67999      VMIN=     25.17000      VMAX=      27.84999      NV=    134

----------------------------------------------------------------------------------------------------------------------------
           RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1     25.1700     25.4380    2 **
  2     25.4380     25.7060    4 ****
  3     25.7060     25.9740    8 ********
  4     25.9740     26.2420   24 ************************
  5     26.2420     26.5099   18 ******************
  6     26.5099     26.7779   25 *************************
  7     26.7779     27.0459   30 ******************************
  8     27.0459     27.3139   13 *************
  9     27.3139     27.5819    9 *********
 10     27.5819     27.8500    1 *
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                  VARIABLE V(11)

MEAN= 26.21875      SIGMA=      0.51254      RANGE=  3.68001      VMIN=     24.82999      VMAX=      28.50999      NV=    132

----------------------------------------------------------------------------------------------------------------------------
           RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1     24.8300     25.1980    2 **
  2     25.1980     25.5660    5 *****
  3     25.5660     25.9340   32 ********************************
  4     25.9340     26.3020   30 ******************************
  5     26.3020     26.6700   38 **************************************
  6     26.6700     27.0380   19 *******************
  7     27.0380     27.4060    5 *****
  8     27.4060     27.7740    0
  9     27.7740     28.1420    0
 10     28.1420     28.5100    1 *
```

341

```
H I S T O G R A M
-----------------
                                                     VARIABLE V(13)

MEAN= 13.20889     SIGMA=     5.65703     RANGE= 23.00000     VMIN=     4.00000     VMAX=     32.00000     NV=  134

---------------------------------------------------------------------------------------------------------------------
               RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1     4.0000      6.8000    11 ***********
  2     6.8000      9.6000    26 **************************
  3     9.6000     12.4000    30 ******************************
  4    12.4000     15.2000    28 ****************************
  5    15.2000     18.0000    11 ***********
  6    18.0000     20.8000    16 ****************
  7    20.8000     23.6000     3 ***
  8    23.6000     26.3999     4 ****
  9    26.3999     29.1999     3 ***
 10    29.1999     32.0000     2 **
---------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                     VARIABLE V(14)

MEAN= 14.45516     SIGMA=     5.11314     RANGE= 30.00000     VMIN=     5.00000     VMAX=     35.00000     NV=  134

---------------------------------------------------------------------------------------------------------------------
               RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1     5.0000      8.0000    15 ***************
  2     8.0000     11.0000    20 ********************
  3    11.0000     14.0000    40 ****************************************
  4    14.0000     17.0000    29 *****************************
  5    17.0000     20.0000    15 ***************
  6    20.0000     23.0000     6 ******
  7    23.0000     26.0000     6 ******
  8    26.0000     29.0000     1 *
  9    29.0000     32.0000     1 *
 10    32.0000     35.0000     1 *
---------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                     VARIABLE V(15)

MEAN= 19.65548     SIGMA=     6.18170     RANGE= 32.00000     VMIN=     6.00000     VMAX=     38.00000     NV=  134

---------------------------------------------------------------------------------------------------------------------
               RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
  1     6.0000      9.2000     6 ******
  2     9.2000     12.4000    15 ***************
  3    12.4000     15.6000    13 *************
  4    15.6000     18.8000    23 ***********************
  5    18.8000     22.0000    27 ***************************
  6    22.0000     25.2000    30 ******************************
  7    25.2000     28.4000    11 ***********
  8    28.4000     31.6000     4 ****
  9    31.6000     34.8000     3 ***
 10    34.8000     38.0000     2 **
```

342

```
H I S T O G R A M
-----------------
                                                        VARIABLE V(16)

MEAN= -0.12871     SIGMA=     5.90291     RANGE= 50.00000     VMIN=  -25.00000     VMAX=    25.00000     NV=   101

----------------------------------------------------------------------------------------------------------------------
          RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------
  1   -25.0000    -20.0000    1 *
  2   -20.0000    -15.0000    0
  3   -15.0000    -10.0000    5 *****
  4   -10.0000     -5.0000   15 ***************
  5    -5.0000      0.0      19 *******************
  6     0.0         5.0000   54 ******************************************************
  7     5.0000     10.0000    6 ******
  8    10.0000     15.0000    0
  9    15.0000     20.0000    0
 10    20.0000     25.0000    1 *
----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V(17)

MEAN= 14.29540     SIGMA=     7.44857     RANGE= 53.00000     VMIN=    1.00000     VMAX=    54.00000     NV=   132

----------------------------------------------------------------------------------------------------------------------
          RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------
  1     1.0000      6.3000    8 ********
  2     6.3000     11.6000   51 ***************************************************
  3    11.6000     16.9000   40 ****************************************
  4    16.9000     22.2000   15 ***************
  5    22.2000     27.5000   12 ************
  6    27.5000     32.8000    2 **
  7    32.8000     38.0999    2 **
  8    38.0999     43.3999    1 *
  9    43.3999     48.6999    0
 10    48.6999     54.0000    1 *
----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V(18)

MEAN= 15.45448     SIGMA=     6.61076     RANGE= 39.00000     VMIN=    5.00000     VMAX=    44.00000     NV=   132

----------------------------------------------------------------------------------------------------------------------
          RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------
  1     5.0000      8.9000    9 *********
  2     8.9000     12.8000   44 ********************************************
  3    12.8000     16.7000   35 ***********************************
  4    16.7000     20.6000   18 ******************
  5    20.6000     24.5000   12 ************
  6    24.5000     28.4000    8 ********
  7    28.4000     32.3000    2 **
  8    32.3000     36.2000    3 ***
  9    36.2000     40.1000    0
```

343

```
H I S T O G R A M
-----------------
                                                        VARIABLE V(19)

MEAN= 11.47278      SIGMA=      6.28540     RANGE= 37.00000      VMIN=      1.00000      VMAX=     38.00000      NV=   129

---------------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
   1     1.0000      4.7000     8 ********
   2     4.7000      8.4000    40 ****************************************
   3     8.4000     12.1000    40 ****************************************
   4    12.1000     15.8000    11 ***********
   5    15.8000     19.5000    16 ****************
   6    19.5000     23.2000     6 ******
   7    23.2000     26.9000     3 ***
   8    26.9000     30.6000     4 ****
   9    30.6000     34.3000     0
  10    34.3000     38.0000     1 *
---------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V(20)

MEAN= 12.65378      SIGMA=      5.16907     RANGE= 28.00000      VMIN=      4.00000      VMAX=     32.00000      NV=   130

---------------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
   1     4.0000      6.8000    10 **********
   2     6.8000      9.6000    29 *****************************
   3     9.6000     12.4000    36 ************************************
   4    12.4000     15.2000    23 ***********************
   5    15.2000     18.0000     9 *********
   6    18.0000     20.8000     9 *********
   7    20.8000     23.6000     9 *********
   8    23.6000     26.3999     4 ****
   9    26.3999     29.1999     0
  10    29.1999     32.0000     1 *
---------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                        VARIABLE V(21)

MEAN= 26.86107      SIGMA=      9.41497     RANGE= 56.00000      VMIN=     11.00000      VMAX=     67.00000      NV=   130

---------------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
   1    11.0000     16.6000    13 *************
   2    16.6000     22.2000    34 **********************************
   3    22.2000     27.8000    33 *********************************
   4    27.8000     33.4000    29 *****************************
   5    33.4000     39.0000     4 ****
   6    39.0000     44.5999     7 *******
   7    44.5999     50.1999     9 *********
   8    50.1999     55.7999     0
   9    55.7999     61.3999     0
  10    61.3999     67.0000     1 *
---------------------------------------------------------------------------------------------------------------------------
```

344

```
H I S T O G R A M
-----------------
                                                    VARIABLE V(22)

MEAN=  2.55618      SIGMA=      3.62631      RANGE= 11.91000      VMIN=     0.09000      VMAX=     12.00000      NV=    21

-----------------------------------------------------------------------------------------------------------------------
               RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1      0.0900      1.2810     13 *************
  2      1.2810      2.4720      1 *
  3      2.4720      3.6630      2 **
  4      3.6630      4.8540      1 *
  5      4.8540      6.0450      0
  6      6.0450      7.2360      0
  7      7.2360      8.4270      2 **
  8      8.4270      9.6180      0
  9      9.6180     10.8090      1 *
 10     10.8090     12.0000      1 *
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(23)

MEAN=173.73795      SIGMA=      4.30025      RANGE= 20.00000      VMIN=   168.00000      VMAX=    188.00000      NV=    21

-----------------------------------------------------------------------------------------------------------------------
               RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1    168.0000    170.0000      5 *****
  2    170.0000    172.0000      3 ***
  3    172.0000    174.0000      6 ******
  4    174.0000    176.0000      3 ***
  5    176.0000    178.0000      3 ***
  6    178.0000    180.0000      0
  7    180.0000    182.0000      0
  8    182.0000    184.0000      0
  9    184.0000    186.0000      0
 10    186.0000    188.0000      1 *
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(24)

MEAN=241.20456      SIGMA=      3.89962      RANGE= 12.00000      VMIN=   236.00000      VMAX=    248.00000      NV=    21

-----------------------------------------------------------------------------------------------------------------------
               RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
  1    236.0000    237.2000      4 ****
  2    237.2000    238.4000      1 *
  3    238.4000    239.6000      1 *
  4    239.6000    240.8000      2 **
  5    240.8000    242.0000      2 **
  6    242.0000    243.2000      3 ***
  7    243.2000    244.4000      1 *
  8    244.4000    245.6000      4 ****
  9    245.6000    246.8000      0
 10    246.8000    248.0000      3 ***
```

```
H I S T O G R A M
-----------------
                                                   VARIABLE V(25)

MEAN=  3.86225     SIGMA=      0.80669     RANGE=  2.00000     VMIN=     3.00000     VMAX=     5.0000C     NV=   139

--------------------------------------------------------------------------------------------------------------------
          RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------
  1     3.0000     3.2000    56 ********************************************************
  2     3.2000     3.4000     0
  3     3.4000     3.6000     C
  4     3.6000     3.8000     0
  5     3.8000     4.0000     0
  6     4.0000     4.2000    46 **********************************************
  7     4.2000     4.4000     0
  8     4.4000     4.6000     C
  9     4.6000     4.8000     0
 10     4.8000     5.0000    37 *************************************
--------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(26)

MEAN= 50.73782     SIGMA=     22.86497     RANGE= 83.00000     VMIN=    27.00000     VMAX=   110.00000     NV=   130

--------------------------------------------------------------------------------------------------------------------
          RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------
  1    27.0000    35.3000    49 *************************************************
  2    35.3000    43.6000     0
  3    43.6000    51.9000    12 ************
  4    51.9000    60.2000    44 ********************************************
  5    60.2000    68.4999     3 ***
  6    68.4999    76.7999     3 ***
  7    76.7999    85.0999     1 *
  8    85.0999    93.3999    10 **********
  9    93.3999   101.6999     0
 10   101.6999   110.0000     8 ********
--------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(27)

MEAN= 11.76920     SIGMA=     10.98825     RANGE= 54.00000     VMIN=     1.00000     VMAX=    55.00000     NV=   117

--------------------------------------------------------------------------------------------------------------------
          RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------
  1     1.0000     6.4000    52 ****************************************************
  2     6.4000    11.8000     2 **
  3    11.8000    17.2000    52 ****************************************************
  4    17.2000    22.6000     0
  5    22.6000    28.0000     2 **
  6    28.0000    33.4000     6 ******
  7    33.4000    38.8000     0
  8    38.8000    44.2000     0
  9    44.2000    49.6000     0
 10    49.6000    55.0000     7 ***
```

```
H I S T O G R A M
-----------------
                                                         VARIABLE V( 1)

MEAN=799.18481      SIGMA=      4.83477     RANGE= 19.39990     VMIN=    788.00000      VMAX=     807.39990        NV=     31

-----------------------------------------------------------------------------------------------------------------------
          RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
 1    788.0000    789.9399    2 **
 2    789.9399    751.8799    0
 3    791.8799    793.8198    1 *
 4    793.8198    795.7598    3 ***
 5    795.7598    757.6997    6 ******
 6    797.6997    799.6396    5 *****
 7    799.6396    801.5796    5 *****
 8    801.5796    803.5195    4 ****
 9    803.5195    805.4595    2 **
10    805.4595    807.3999    3 ***
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                         VARIABLE V( 2)

MEAN=891.12598      SIGMA=      5.26189     RANGE= 23.40015     VMIN=    875.79980      VMAX=     899.19995        NV=     31

-----------------------------------------------------------------------------------------------------------------------
          RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
 1    875.7998    878.1396    1 *
 2    878.1396    880.4795    0
 3    880.4795    882.8193    1 *
 4    882.8193    885.1592    0
 5    885.1592    887.4990    1 *
 6    887.4990    889.8389    9 *********
 7    889.8389    892.1787    6 ******
 8    892.1787    894.5186    6 *****
 9    894.5186    896.8584    3 ***
10    896.8584    899.2000    4 ****
-----------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                         VARIABLE V( 3)

MEAN= 1.44802       SIGMA=      0.00744     RANGE=  0.03000     VMIN=      1.43800      VMAX=       1.46800        NV=     31

-----------------------------------------------------------------------------------------------------------------------
          RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
-----------------------------------------------------------------------------------------------------------------------
 1      1.4380      1.4410    1 *
 2      1.4410      1.4440    4 ****
 3      1.4440      1.4470    6 ******
 4      1.4470      1.4500   15 ***** **********
 5      1.4500      1.4530    2 **
 6      1.4530      1.4560    0
 7      1.4560      1.4590    0
 8      1.4590      1.4620    1 *
 9      1.4620      1.4650    0
```

```
H I S T O G R A M
-----------------
                                                       VARIABLE V( 4)
MEAN=  8.75861      SIGMA=     0.09277     RANGE=  0.40000     VMIN=     8.50000     VMAX=     8.90000     NV=    29
---------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1....5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
   1     8.5000    8.5400    1 *
   2     8.5400    8.5800    0
   3     8.5800    8.6200    3 ***
   4     8.6200    8.6600    0
   5     8.6600    8.7000    6 ******
   6     8.7000    8.7400    0
   7     8.7400    8.7800    0
   8     8.7800    8.8200   16 ****************
   9     8.8200    8.8600    0
  10     8.8600    8.9000    3 ***
---------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                       VARIABLE V( 5)
MEAN=538.86450      SIGMA=     2.37171     RANGE=  9.00000     VMIN=   534.39990     VMAX=   543.39990     NV=    30
---------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1....5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
   1   534.3999  535.2998    1 *
   2   535.2998  536.1997    1 *
   3   536.1997  537.0996    4 ****
   4   537.0996  537.9995    4 ****
   5   537.9995  538.8994    8 ********
   6   538.8994  539.7993    2 **
   7   539.7993  540.6992    3 ***
   8   540.6992  541.5991    3 ***
   9   541.5391  542.4990    3 ***
  10   542.4990  543.3999    1 *
---------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                       VARIABLE V( 6)
MEAN=257.99292      SIGMA=     1.29904     RANGE=  6.19995     VMIN=   255.00000     VMAX=   261.19995     NV=    30
---------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1....5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
   1   255.0000  255.6200    1 *
   2   255.6200  256.2400    1 *
   3   256.2400  256.8599    3 ***
   4   256.8599  257.4797    6 ******
   5   257.4797  258.0996    3 ***
   6   258.0996  258.7195   11 ***********
   7   258.7195  259.3394    2 **
   8   259.3394  259.9592    1 *
   9   259.9592  260.5791    0
```

348

```
H I S T O G R A M
-----------------
                                                                VARIABLE V( 7)

MEAN=276.83594      SIGMA=      1.69558      RANGE=  6.60010      VMIN=    273.29980      VMAX=    279.89990      NV=     30

---------------------------------------------------------------------------------------------------------------------------
             RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
  1    273.2998    273.9557    1 *
  2    273.9597    274.6195    2 **
  3    274.6196    275.2795    3 ***
  4    275.2795    275.9395    4 ****
  5    275.9395    276.5994    1 *
  6    276.5994    277.2593    6 ******
  7    277.2593    277.9192    3 ***
  8    277.9192    278.5791    7 *******
  9    278.5791    279.2390    1 *
 10    279.2390    279.8999    2 **
---------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                                VARIABLE V( 8)

MEAN=  1.47890      SIGMA=      0.00544      RANGE=  0.01800      VMIN=      1.47200      VMAX=      1.49000      NV=     22

---------------------------------------------------------------------------------------------------------------------------
             RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
  1      1.4720      1.4738    2 **
  2      1.4738      1.4756    4 ****
  3      1.4756      1.4774    5 *****
  4      1.4774      1.4792    3 ***
  5      1.4792      1.4810    0
  6      1.4810      1.4828    1 *
  7      1.4828      1.4846    5 *****
  8      1.4846      1.4864    0
  9      1.4864      1.4882    1 *
 10      1.4882      1.4900    1 *
---------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                                VARIABLE V( 9)

MEAN= 49.77405      SIGMA=     23.87721      RANGE= 71.00000      VMIN=      1.00000      VMAX=     72.00000      NV=     31

---------------------------------------------------------------------------------------------------------------------------
             RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
  1      1.0000      8.1000    5 *****
  2      8.1000     15.2000    0
  3     15.2000     22.3000    0
  4     22.3000     29.4000    0
  5     29.4000     36.5000    0
  6     36.5000     43.6000    0
  7     43.6000     50.7000   14 **************
  8     50.7000     57.7999    0
  9     57.7999     64.8999    0
```

```
H I S T O G R A M
-----------------
                                                   VARIABLE V(10)

MEAN= 24.23209       SIGMA=      0.24606      RANGE=  0.84001      VMIN=      23.82999       VMAX=      24.67000       NV=     23

---------------------------------------------------------------------------------------------------------------------------------
             RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------------
  1      23.8300     23.9140    2 **
  2      23.9140     23.9980    0
  3      23.9980     24.0820    5 *****
  4      24.0820     24.1660    0
  5      24.1660     24.2500    5 ******
  6      24.2500     24.3340    4 ****
  7      24.3340     24.4180    0
  8      24.4180     24.5020    4 ****
  9      24.5020     24.5860    0
 10      24.5860     24.6700    2 **
---------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(11)

MEAN= 23.47583       SIGMA=      0.24551      RANGE=  1.00000      VMIN=      23.00000       VMAX=      24.00000       NV=     22

---------------------------------------------------------------------------------------------------------------------------------
             RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------------
  1      23.0000     23.1000    1 *
  2      23.1000     23.2000    2 **
  3      23.2000     23.3000    0
  4      23.3000     23.4000    8 ********
  5      23.4000     23.5000    0
  6      23.5000     23.5999    4 ****
  7      23.5999     23.6999    5 *****
  8      23.6999     23.7999    0
  9      23.7999     23.8999    0
 10      23.8999     24.0000    2 **
---------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(13)

MEAN= 11.47825       SIGMA=      3.80927      RANGE= 14.00000      VMIN=       6.00000       VMAX=      20.00000       NV=     23

---------------------------------------------------------------------------------------------------------------------------------
             RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------------
  1       6.0000      7.4000    3 ***
  2       7.4000      8.8000    4 ****
  3       8.8000     10.2000    4 ****
  4      10.2000     11.6000    1 *
  5      11.6000     13.0000    3 ***
  6      13.0000     14.4000    3 ***
  7      14.4000     15.8000    0
  8      15.8000     17.2000    3 ***
  9      17.2000     18.6000    1 *
 10      18.6000     20.0000    1 *
```

350

```
H I S T O G R A M
-----------------
                                                    VARIABLE V(14)

MEAN= 13.73912      SIGMA=      3.40357     RANGE= 13.00000      VMIN=      8.00000      VMAX=      21.00000       NV=     23
--------------------------------------------------------------------------------------------------------------------------------
            RANGE           FREQ.1....5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------------------
  1      8.0000      9.3000    1 *
  2      9.3000     10.6000    3 ***
  3     10.6000     11.9000    1 *
  4     11.9000     13.2000    9 *********
  5     13.2000     14.5000    2 **
  6     14.5000     15.8000    1 *
  7     15.8000     17.1000    2 **
  8     17.1000     18.4000    1 *
  9     18.4000     19.7000    0
 10     19.7000     21.0000    3 ***
--------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(15)

MEAN= 18.78258      SIGMA=      5.42908     RANGE= 21.00000      VMIN=     11.00000      VMAX=      32.00000       NV=     23
--------------------------------------------------------------------------------------------------------------------------------
            RANGE           FREQ.1....5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------------------
  1     11.0000     13.1000    5 *****
  2     13.1000     15.2000    2 **
  3     15.2000     17.3000    2 **
  4     17.3000     19.4000    3 ***
  5     19.4000     21.5000    6 ******
  6     21.5000     23.6000    2 **
  7     23.6000     25.7000    0
  8     25.7000     27.7999    1 *
  9     27.7999     29.8999    1 *
 10     29.8999     32.0000    1 *
--------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(16)

MEAN=  0.88889      SIGMA=      3.39753     RANGE= 16.00000      VMIN=    -10.00000      VMAX=       6.00000       NV=     18
--------------------------------------------------------------------------------------------------------------------------------
            RANGE           FREQ.1....5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------------------
  1    -10.0000     -8.4000    1 *
  2     -8.4000     -6.8000    0
  3     -6.8000     -5.2000    0
  4     -5.2000     -3.6000    0
  5     -3.6000     -2.0000    0
  6     -2.0000     -0.4000    5 *****
  7     -0.4000      1.2000    1 *
  8      1.2000      2.8000    6 ******
  9      2.8000      4.4000    4 ****
```

```
H I S T O G R A M
                                              VARIABLE V(17)

MEAN= 11.99999      SIGMA=      3.74166      RANGE= 16.00000      VMIN=      5.00000      VMAX=     21.00000      NV=     22

----------------------------------------------------------------------------------------------------------------------------
            RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1      5.0000      6.6000     2 **
  2      6.6000      8.2000     2 **
  3      8.2000      9.8000     1 *
  4      9.8000     11.4000     5 *****
  5     11.4000     13.0000     2 **
  6     13.0000     14.6000     5 *****
  7     14.6000     16.2000     3 ***
  8     16.2000     17.8000     1 *
  9     17.8000     19.4000     0
 10     19.4000     21.0000     1 *
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
                                              VARIABLE V(18)

MEAN= 14.54544      SIGMA=      3.79867      RANGE= 17.00000      VMIN=      5.00000      VMAX=     22.00000      NV=     22

----------------------------------------------------------------------------------------------------------------------------
            RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1      5.0000      6.7000     1 *
  2      6.7000      8.4000     0
  3      8.4000     10.1000     0
  4     10.1000     11.8000     3 ***
  5     11.8000     13.5000     4 ****
  6     13.5000     15.2000     7 *******
  7     15.2000     16.9000     1 *
  8     16.9000     18.6000     2 **
  9     18.6000     20.3000     3 ***
 10     20.3000     22.0000     1 *
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
                                              VARIABLE V(19)

MEAN=  9.90908      SIGMA=      3.57909      RANGE= 14.00000      VMIN=      3.00000      VMAX=     17.00000      NV=     22

----------------------------------------------------------------------------------------------------------------------------
            RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1      3.0000      4.4000     1 *
  2      4.4000      5.8000     0
  3      5.8000      7.2000     4 ****
  4      7.2000      8.6000     4 ****
  5      8.6000     10.0000     2 **
  6     10.0000     11.4000     4 ****
  7     11.4000     12.8000     2 **
  8     12.8000     14.2000     2 **
  9     14.2000     15.6000     1 *
```

352

```
H I S T O G R A M
-----------------
                                                         VARIABLE V(20)

MEAN=  7.68181      SIGMA=      3.15344     RANGE= 12.00000     VMIN=      2.00000      VMAX=      14.00000      NV=     22

------------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ..1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95..100
------------------------------------------------------------------------------------------------------------------------------
  1      2.0000      3.2000    1 *
  2      3.2000      4.4000    2 **
  3      4.4000      5.6000    3 ***
  4      5.6000      6.8000    4 ****
  5      6.8000      8.0000    3 ***
  6      8.0000      9.2000    2 **
  7      9.2000     10.4000    1 *
  8     10.4000     11.6000    2 **
  9     11.6000     12.8000    3 ***
 10     12.8000     14.0000    1 *
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                         VARIABLE V(21)

MEAN= 16.13635      SIGMA=      4.85513     RANGE= 18.00000     VMIN=     10.00000      VMAX=      28.00000      NV=     22

------------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ..1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95..100
------------------------------------------------------------------------------------------------------------------------------
  1     10.0000     11.8000    3 ***
  2     11.8000     13.6000    4 ****
  3     13.6000     15.4000    5 *****
  4     15.4000     17.2000    4 ****
  5     17.2000     19.0000    0
  6     19.0000     20.8000    2 **
  7     20.8000     22.6000    1 *
  8     22.6000     24.3999    1 *
  9     24.3999     26.1999    1 *
 10     26.1999     28.0000    1 *
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                         VARIABLE V(22)

MEAN= 12.85000      SIGMA=      5.34065     RANGE= 16.49998     VMIN=      6.70000      VMAX=      23.20000      NV=      6

------------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ..1....5....10....15....20....25....30....35....40....45....50....55....60....65....70....75....80....85....90....95..100
------------------------------------------------------------------------------------------------------------------------------
  1      6.7000      8.3500    1 *
  2      8.3500     10.0000    1 *
  3     10.0000     11.6500    1 *
  4     11.6500     13.3000    1 *
  5     13.3000     14.9500    0
  6     14.9500     16.6000    1 *
  7     16.6000     18.2500    0
  8     18.2500     19.9000    0
  9     19.9000     21.5500    0
```

```
HISTOGRAM
                                        VARIABLE V(23)
MEAN=157.16563    SIGMA=    2.33937    RANGE=  7.00000    VMIN=   155.00000    VMAX=   162.00000    NV=    6
--------------------------------------------------------------------------------------------------------
          RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------
  1   155.0000   155.7000   2 **
  2   155.7000   156.4000   0
  3   156.4000   157.1000   3 ***
  4   157.1000   157.8000   0
  5   157.8000   158.5000   0
  6   158.5000   159.2000   0
  7   159.2000   159.9000   0
  8   159.9000   160.6000   0
  9   160.6000   161.3000   0
 10   161.3000   162.0000   1 *
--------------------------------------------------------------------------------------------------------

HISTOGRAM
                                        VARIABLE V(24)
MEAN=239.99998    SIGMA=    3.74166    RANGE= 11.00000    VMIN=   237.00000    VMAX=   248.00000    NV=    6
--------------------------------------------------------------------------------------------------------
          RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------
  1   237.0000   238.1000   2 **
  2   238.1000   239.2000   2 **
  3   239.2000   240.3000   1 *
  4   240.3000   241.4000   0
  5   241.4000   242.5000   0
  6   242.5000   243.5999   0
  7   243.5999   244.6999   0
  8   244.6999   245.7999   0
  9   245.7999   246.8999   0
 10   246.8999   248.0000   1 *
--------------------------------------------------------------------------------------------------------

HISTOGRAM
                                        VARIABLE V(28)
MEAN=577.40576    SIGMA=  379.09302    RANGE=*********    VMIN=   105.00000    VMAX=  1650.00000    NV=   27
--------------------------------------------------------------------------------------------------------
          RANGE            FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------
  1   105.0000   259.5000   4 ****
  2   259.5000   414.0000   7 *******
  3   414.0000   568.5000   7 ****** *
  4   568.5000   723.0000   4 ****
  5   723.0000   877.5000   1 *
  6   877.5000  1032.0000   0
  7  1032.0000  1186.5000   1 *
  8  1186.5000  1341.0000   1 *
  9  1341.0000  1495.5000   1 *
```

354

```
H I S T O G R A M
-----------------
                                                      VARIABLE V( 1)

MEAN=787.85156    SIGMA=     4.60977    RANGE= 14.80005    VMIN=   780.29980    VMAX=   795.09985    NV=  109

------------------------------------------------------------------------------------------------------------------------
          RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
  1   780.2998   781.7759    3 ***
  2   781.7798   783.2559    5 *****
  3   783.2598   784.7357   14 **************
  4   784.7397   786.2157    9 *********
  5   786.2197   787.6957   25 *************************
  6   787.6997   789.1757   15 ***************
  7   789.1797   790.6557   14 **************
  8   790.6597   792.1356   13 *************
  9   792.1396   793.6156    6 ******
 10   793.6196   795.0999    5 *****
------------------------------------------------------------------------------------------------------------------------
H I S T O G R A M
-----------------
                                                      VARIABLE V( 2)

MEAN=875.92188    SIGMA=     5.12348    RANGE= 19.40015    VMIN=   868.29980    VMAX=   887.69995    NV=  109

------------------------------------------------------------------------------------------------------------------------
          RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
  1   868.2998   870.2357    4 ****
  2   870.2397   872.1757   11 ***********
  3   872.1797   874.1156   15 ***************
  4   874.1196   876.0596   29 *****************************
  5   876.0596   877.9955   20 ********************
  6   877.9995   879.9395   17 *****************
  7   879.9395   881.8754    8 ********
  8   881.8794   883.8153    4 ****
  9   883.8193   885.7553    0
 10   885.7597   887.7000    1 *
------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                      VARIABLE V( 3)

MEAN=  1.43638    SIGMA=     0.02689    RANGE=  0.11600    VMIN=     1.34300    VMAX=     1.45900    NV=  101

------------------------------------------------------------------------------------------------------------------------
          RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------
  1     1.3430     1.3545    8 ********
  2     1.3546     1.3662    0
  3     1.3662     1.3778    0
  4     1.3778     1.3894    0
  5     1.3894     1.4010    0
  6     1.4010     1.4126    0
  7     1.4126     1.4242    0
  8     1.4242     1.4359    5 *****
  9     1.4358     1.4474   65 *****************************************************************
 10     1.4474     1.4590   23 ***********************
```

355

```
H I S T O G R A M
-----------------
                                                                    VARIABLE V( 5)

MEAN=538.82031     SIGMA=     2.90474     RANGE=  9.10010     VMIN=  533.59985     VMAX=   542.69995     NV=   89

--------------------------------------------------------------------------------------------------------------------------
           RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------------
  1    533.5999    534.5058     4 ****
  2    534.5098    535.4197     3 ***
  3    535.4197    536.3256     2 **
  4    536.3296    537.2395     5 *****
  5    537.2395    538.1494    18 ******************
  6    538.1494    539.0593     6 ******
  7    539.0593    539.9692    23 ***********************
  8    539.9692    540.8792    21 *********************
  9    540.8792    541.7891     3 ***
 10    541.7891    542.7000     4 ****
--------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                                    VARIABLE V( 6)

MEAN=257.74392     SIGMA=     1.56125     RANGE=  9.79991     VMIN=  251.59999     VMAX=   261.39990     NV=   89

--------------------------------------------------------------------------------------------------------------------------
           RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------------
  1    251.6000    252.5800     1 *
  2    252.5900    253.5600     0
  3    253.5600    254.5399     1 *
  4    254.5399    255.5199     4 ****
  5    255.5199    256.4998     6 ******
  6    256.4998    257.4797    25 *************************
  7    257.4797    258.4597    24 ************************
  8    258.4597    259.4397    20 ********************
  9    259.4397    260.4197     5 *****
 10    260.4197    261.3999     3 ***
--------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                                    VARIABLE V( 7)

MEAN=276.87991     SIGMA=     1.71391     RANGE=  9.00000     VMIN=  270.89990     VMAX=   279.89990     NV=   91

--------------------------------------------------------------------------------------------------------------------------
           RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
--------------------------------------------------------------------------------------------------------------------------
  1    270.8999    271.7998     2 **
  2    271.7999    272.6997     0
  3    272.6997    273.5996     1 *
  4    273.5996    274.4995     4 ****
  5    274.4995    275.3994     8 ********
  6    275.3994    276.2993    10 **********
  7    276.2993    277.1992    23 ***********************
  8    277.1992    278.0991    23 ***********************
  9    278.0991    278.9990    13 *************
 10    [illegible]  [illegible]   7 *******
```

356

```
H I S T O G R A M
-----------------
                                                    VARIABLE V( 8)

MEAN=  1.48422       SIGMA=      0.00775      RANGE=  0.02700      VMIN=       1.47300      VMAX=      1.50000      NV=   108
----------------------------------------------------------------------------------------------------------------------------
            RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
   1      1.4730       1.4757      6 ******
   2      1.4757       1.4784     14 **************
   3      1.4784       1.4811     19 *******************
   4      1.4811       1.4838     15 ***************
   5      1.4838       1.4865     15 ***************
   6      1.4865       1.4892     16 ****************
   7      1.4892       1.4919     10 **********
   8      1.4919       1.4946      7 *******
   9      1.4946       1.4973      4 ****
  10      1.4973       1.5000      2 **
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V( 9)

MEAN=  8.51641       SIGMA=      6.34259      RANGE= 23.00000      VMIN=       1.00000      VMAX=     24.00000      NV=    91
----------------------------------------------------------------------------------------------------------------------------
            RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
   1      1.0000       3.3000      1 *
   2      3.3000       5.6000      0
   3      5.6000       7.9000     77 *****************************************************************************
   4      7.9000      10.2000      0
   5     10.2000      12.5000      0
   6     12.5000      14.8000      0
   7     14.8000      17.1000      0
   8     17.1000      19.4000      0
   9     19.4000      21.7000      0
  10     21.7000      24.0000     13 *************
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(10)

MEAN= 23.58395       SIGMA=      0.37630      RANGE=  1.50000      VMIN=      22.82999      VMAX=     24.32999      NV=    89
----------------------------------------------------------------------------------------------------------------------------
            RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
   1     22.8300      22.9800      5 *****
   2     22.9800      23.1300      5 *****
   3     23.1300      23.2800      7 *******
   4     23.2800      23.4300     11 ***********
   5     23.4300      23.5800     15 ***************
   6     23.5800      23.7299     15 ***************
   7     23.7299      23.8799     15 ***************
   8     23.8799      24.0299      6 ******
   9     24.0299      24.1799      8 ********
  10     24.1799      24.3300      2 **
```

357

```
H I S T O G R A M
-----------------
                                                      VARIABLE V(11)

MEAN= 23.26579      SIGMA=       0.33109      RANGE=  1.50000      VMIN=      22.50000      VMAX=      24.00000      NV=   108

------------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1      22.5000      22.6500     1 *
  2      22.6500      22.8000     4 ****
  3      22.8000      22.9500     6 ******
  4      22.9500      23.1000    26 **************************
  5      23.1000      23.2500    20 ********************
  6      23.2500      23.4000    13 *************
  7      23.4000      23.5500    21 *********************
  8      23.5500      23.7000    10 **********
  9      23.7000      23.8499     2 **
 10      23.8499      24.0000     5 *****
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                      VARIABLE V(13)

MEAN= 16.11574      SIGMA=       5.59665      RANGE= 37.00000      VMIN=       4.00000      VMAX=      41.00000      NV=    95

------------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1       4.0000       7.7000     2 **
  2       7.7000      11.4000    13 *************
  3      11.4000      15.1000    29 *****************************
  4      15.1000      18.8000    30 ******************************
  5      18.8000      22.5000    11 ***********
  6      22.5000      26.2000     5 *****
  7      26.2000      29.9000     3 ***
  8      29.9000      33.6000     0
  9      33.6000      37.3000     1 *
 10      37.3000      41.0000     1 *
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                      VARIABLE V(14)

MEAN= 24.04185      SIGMA=       6.91483      RANGE= 35.00000      VMIN=      13.00000      VMAX=      48.00000      NV=    95

------------------------------------------------------------------------------------------------------------------------------
              RANGE          FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1      13.0000      16.5000    11 ***********
  2      16.5000      20.0000    19 *******************
  3      20.0000      23.5000    17 *****************
  4      23.5000      27.0000    35 ***********************************
  5      27.0000      30.5000     3 ***
  6      30.5000      34.0000     2 **
  7      34.0000      37.5000     3 ***
  8      37.5000      41.0000     2 **
  9      41.0000      44.5000     1 *
 10      44.5000      48.0000     3 ***
```

358

```
H I S T O G R A M
-----------------
                                                   VARIABLE V(15)

MEAN= 31.57654     SIGMA=      9.72753     RANGE= 48.00000      VMIN=     14.00000      VMAX=      62.00000      NV=   104

----------------------------------------------------------------------------------------------------------------------------
            RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1     14.0000     18.8000     2 **
  2     18.8000     23.6000    18 ******************
  3     23.6000     29.4000    24 ************************
  4     28.4000     33.2000    27 ***************************
  5     33.2000     37.9999    11 ***********
  6     37.9999     42.7999     9 *********
  7     42.7999     47.5999     5 *****
  8     47.5999     52.3999     4 ****
  9     52.3999     57.1999     1 *
 10     57.1999     62.0000     4 ****
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(16)

MEAN=  8.87062     SIGMA=      5.79244     RANGE= 36.00000      VMIN=     -8.00000      VMAX=      28.00000      NV=   108

----------------------------------------------------------------------------------------------------------------------------
            RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1     -8.0000     -4.4000     1 *
  2     -4.4000     -0.8000     2 **
  3     -0.8000      2.8000     6 ******
  4      2.8000      6.4000    24 ************************
  5      6.4000     10.0000    34 **********************************
  6     10.0000     13.6000    23 ***********************
  7     13.6000     17.2000     9 *********
  8     17.2000     20.8000     2 **
  9     20.8000     24.4000     5 *****
 10     24.4000     28.0000     2 **
----------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(17)

MEAN= 28.09219     SIGMA=     10.66610     RANGE= 61.00000      VMIN=      5.00000      VMAX=      66.00000      NV=   108

----------------------------------------------------------------------------------------------------------------------------
            RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
----------------------------------------------------------------------------------------------------------------------------
  1      5.0000     11.1000     4 ****
  2     11.1000     17.2000     2 **
  3     17.2000     23.3000    35 ***********************************
  4     23.3000     29.4000    31 *******************************
  5     29.4000     35.5000    15 ***************
  6     35.5000     41.6000     5 *****
  7     41.6000     47.7000    10 **********
  8     47.7000     53.7999     3 ***
  9     53.7999     59.8999     2 **
 10     59.8999     66.0000     1 *
```

```
H I S T O G R A M
-----------------
                                                   VARIABLE V(18)

MEAN= 34.29579     SIGMA=     13.69141     RANGE= 71.00000     VMIN=    10.00000     VMAX=    81.00000     NV=    108

---------------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
   1      10.0000      17.1000     6 ******
   2      17.1000      24.2000    15 ***************
   3      24.2000      31.3000    31 *******************************
   4      31.3000      38.4000    29 *****************************
   5      38.4000      45.5000    12 ************
   6      45.5000      52.5999     3 ***
   7      52.5999      59.6999     4 ****
   8      59.6999      66.7999     4 ****
   9      66.7999      73.8999     2 **
  10      73.8999      81.0000     2 **
---------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(19)

MEAN= 31.47174     SIGMA=     15.36811     RANGE= 65.00000     VMIN=    12.00000     VMAX=    77.00000     NV=    108

---------------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
   1      12.0000      18.5000    14 **************
   2      18.5000      25.0000    40 ****************************************
   3      25.0000      31.5000    19 *******************
   4      31.5000      38.0000     9 *********
   5      38.0000      44.5000     4 ****
   6      44.5000      51.0000     8 ********
   7      51.0000      57.5000     5 *****
   8      57.5000      64.0000     2 **
   9      64.0000      70.5000     3 ***
  10      70.5000      77.0000     4 ****
---------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                   VARIABLE V(20)

MEAN= 28.11995     SIGMA=     13.25156     RANGE= 59.00000     VMIN=    10.00000     VMAX=    69.00000     NV=    108

---------------------------------------------------------------------------------------------------------------------------
              RANGE           FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------------
   1      10.0000      15.9000     6 ******
   2      15.9000      21.8000    32 ********************************
   3      21.8000      27.7000    34 **********************************
   4      27.7000      33.6000     8 ********
   5      33.6000      39.5000     6 ******
   6      39.5000      45.4000     9 *********
   7      45.4000      51.3000     5 *****
   8      51.3000      57.2000     1 *
   9      57.2000      63.0999     4 ****
  10      63.0999      69.0000     3 ***
```

360

```
H I S T O G R A M
-----------------
                                                              VARIABLE V(21)

MEAN= 44.84198      SIGMA=      19.36647      RANGE= 81.00000      VMIN=      19.00000      VMAX=    100.00000      NV=   108

------------------------------------------------------------------------------------------------------------------------------
               RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1     19.0000     27.1000     8 ********
  2     27.1000     35.2000    36 ************************************
  3     35.2000     43.3000    22 **********************
  4     43.3000     51.4000    14 **************
  5     51.4000     59.5000     6 ******
  6     59.5000     67.5999     6 ******
  7     67.5999     75.6999     7 *******
  8     75.6999     83.7999     0
  9     83.7999     91.8999     8 ********
 10     91.8999    100.0000     1 *
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                              VARIABLE V(22)

MEAN=  8.08714      SIGMA=      12.08474      RANGE= 29.18999      VMIN=       0.01000      VMAX=     29.20000      NV=     7

------------------------------------------------------------------------------------------------------------------------------
               RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1      0.0100      2.9290     5 *****
  2      2.9290      5.8480     0
  3      5.8480      8.7670     0
  4      8.7670     11.6860     0
  5     11.6860     14.6050     0
  6     14.6050     17.5240     0
  7     17.5240     20.4430     0
  8     20.4430     23.3620     0
  9     23.3620     26.2810     1 *
 10     26.2810     29.2000     1 *
------------------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                              VARIABLE V(23)

MEAN=164.57138      SIGMA=       2.92217      RANGE=  8.00000      VMIN=     161.00000      VMAX=    169.00000      NV=     7

------------------------------------------------------------------------------------------------------------------------------
               RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
------------------------------------------------------------------------------------------------------------------------------
  1    161.0000    161.8000     1 *
  2    161.8000    162.6000     0
  3    162.6000    163.4000     3 ***
  4    163.4000    164.2000     1 *
  5    164.2000    164.9999     0
  6    164.9999    165.7999     0
  7    165.7999    166.5999     0
  8    166.5999    167.3999     0
  9    167.3999    168.1999     0
 10    168.1999    169.0000     2 **
```

```
H I S T O G R A M
-----------------
                                                    VARIABLE V(28)

MEAN=519.83447     SIGMA=   206.37794     RANGE=*********     VMIN=    60.00000     VMAX=  1087.00000     NV=   101

---------------------------------------------------------------------------------------------------------------------
            RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
   1     60.0000    162.7000    1 *
   2    162.7000    265.3999    6 ******
   3    265.3999    368.0999    4 ****
   4    368.0999    470.7998   12 ************
   5    470.7998    573.4999   20 ********************
   6    573.4998    676.1997   15 ***************
   7    676.1997    778.8997   15 ***************
   8    778.8997    881.5996   21 *********************
   9    881.5996    984.2996    3 ***
  10    984.2996   1087.0000    4 ****
---------------------------------------------------------------------------------------------------------------------

H I S T O G R A M
-----------------
                                                    VARIABLE V(24)

MEAN=243.42853     SIGMA=     4.80763     RANGE= 12.00000     VMIN=   239.00000     VMAX=   251.00000     NV=     7

---------------------------------------------------------------------------------------------------------------------
            RANGE              FREQ.1...5...10...15...20...25...30...35...40...45...50...55...60...65...70...75...80...85...90...95..100
---------------------------------------------------------------------------------------------------------------------
   1    239.0000    240.2000    3 ***
   2    240.2000    241.4000    0
   3    241.4000    242.6000    1 *
   4    242.6000    243.8000    0
   5    243.8000    245.0000    1 *
   6    245.0000    246.2000    0
   7    246.2000    247.4000    0
   8    247.4000    248.6000    0
   9    248.6000    249.8000    0
  10    249.8000    251.0000    2 **
---------------------------------------------------------------------------------------------------------------------
      SCALING FACTOR = 1
---------------------------------------------------------------------------------------------------------------------
```

APPENDIX D

Raw Data Listing

RAW DATA LISTING

Presented herein is a listing of the data for the cells constructed during the subject battery builds. This data is listed as it appeared on IBM cards used for the regressions carried out under this contract. The data is in F6.2 format with variable V1 through V12 appearing on the first card, variables V13 through V24 appearing on the second card, and variables V25 through V28 on the third card. The cell serial number and card number is indicated on the extreme right. Card data is read consecutively from left to right.

```
          RAW DATA LISTING                   VARIABLES IN NUMERICAL ORDER

       **********   DATA FOR BATTERY S/N 25A,26A   **********

772.6 859.9 1.45    524.1                         24.85     555-1
  6.0   6.0   7.0                        10.0               555-2
                                                            555-3
771.0 858.8 1.44    520.5                         24.51     556-1
  3.0   3.0   3.0                         6.0               556-2
                                                            556-3
767.2 856.5 1.45    518.7                         24.34     557-1
  3.0   3.0   3.0                                           557-2
                                                            557-3
780.3 867.3 1.44    526.5          1.467          25.51     558-1
  3.0   3.0   6.0                                           558-2
                                                            558-3
758.6 846.6 1.44    520.8                         24.68     559-1
  2.0   2.0   3.0                         5.0               559-2
                                                            559-3
761.6 849.9 1.44    527.5                         24.68     560-1
  4.0   4.0   3.0                         5.0               560-2
                                                            560-3
765.8 853.3 1.44                   1.472          25.85     561-1
  6.0   6.0   7.0                                           561-2
                                                            561-3
760.1 847.0 1.44    525.0                         25.00     562-1
  3.0   3.0   3.0                         5.0               562-2
                                                            562-3
751.7 839.6 1.44    518.3          1.469          25.85     563-1
  2.0   1.0   2.0                                           563-2
                                                            563-3
753.1 840.6 1.44    519.1          1.461          25.17     564-1
  4.0   3.0   4.0                                           564-2
                                                            564-3
764.3 850.9 1.44    529.6          1.483          26.51     565-1
  5.0   5.0   6.0                                           565-2
                                                            565-3
757.8 846.5 1.44    523.3          1.475          25.85     566-1
  3.0   3.0   3.0                                           566-2
                                                            566-3
782.1 869.8 1.44    531.8          1.481          26.00     567-1
  3.0   6.0  10.0                                           567-2
                                                            567-3
777.6 855.4 1.44    527.3          1.475          25.85     568-1
  2.0   5.0   7.0                                           568-2
                                                            568-3
764.5 851.5 1.44    529.8          1.481          26.00     569-1
  5.0   3.0   5.0                                           569-2
                                                            569-3
780.3 867.6 1.44    528.7          1.473          25.51     570-1
  8.0   9.0  12.0                                           570-2
                                                            570-3
763.4 850.3 1.44    523.8                         25.00     571-1
  4.0   3.0   5.0                         8.0               571-2
                                                            571-3
778.4 865.8 1.44    524.8                         24.51     572-1
  3.0   3.0   5.0                         9.0               572-2
                                                            572-3
763.8 850.4 1.44    527.8          1.477          25.85     573-1
  5.0   3.0   5.0                                           573-2
```

							573-3
759.3 6.0	846.5 6.0	1.44 6.0	523.6	1.481		25.34	574-1 574-2 574-3
776.4 4.0	864.5 3.0	1.44 4.0	528.7	1.462		25.17	575-1 575-2 575-3
760.1 4.0	846.8 3.0	1.44 3.0	521.8		8.0	25.00	576-1 576-2 576-3
773.5 7.0	869.9 6.0	1.44 9.0	522.7	1.513		25.34	577-1 577-2 577-3
762.8 3.0	848.8 3.0	1.44 3.0	526.0	1.472		25.51	578-1 578-2 578-3
776.5 5.0	864.0 3.0	1.44 5.0	525.3	1.460		25.34	579-1 579-2 579-3
779.6 6.0	867.3 6.0	1.44 9.0	529.9	1.479		27.17	580-1 580-2 580-3
763.7 5.0	851.7 3.0	1.44 5.0	530.2	1.476		26.51	581-1 581-2 581-3
777.6 5.0	865.3 5.0	1.44 5.0	527.5		11.0	25.00	582-1 582-2 582-3
783.7 4.0	875.2 3.0	1.44 3.0	527.4	1.477		26.17	583-1 583-2 583-3
777.8 3.0	865.2 3.0	1.44 3.0	528.3	1.461		25.34	584-1 584-2 584-3
761.1 3.0	847.8 3.0	1.44 2.0	525.7	1.488		25.68	585-1 585-2 585-3
782.1 4.0	869.7 3.0	1.44 3.0	528.4	1.488		25.34	586-1 586-2 586-3
772.5 4.0	859.9 3.0	1.44 5.0	524.4	1.486		26.17	587-1 587-2 587-3
764.2 3.0	850.8 3.0	1.44 2.0	528.6	1.463		25.34	588-1 588-2 588-3
781.6 4.0	868.0 2.0	1.44 3.0	531.4	1.466		26.85	589-1 589-2 589-3
780.7 3.0	868.0 3.0	1.44 1.0	529.1	1.468		25.17	590-1 590-2 590-3
785.2 5.0	872.0 6.0	1.44 7.0	533.5	1.486		26.34	591-1 591-2 591-3
756.3 3.0	844.1 2.0	1.44 1.0	520.3	1.467		25.17	592-1 592-2 592-3
758.9 3.0	845.2 3.0	1.44 2.0	522.7	1.479		26.17	593-1 593-2 593-3

			1.44	1.469		25.34	594-1
2.0	1.0	1.0					594-2
							594-3
			1.44			25.00	595-1
5.0	5.0	5.0			8.0		595-2
							595-3
			1.44	1.482		26.34	596-1
3.0	2.0	5.0					596-2
							596-3
			1.44	1.477		25.51	597-1
3.0	3.0	3.0					597-2
							597-3
			1.44	1.486		26.00	598-1
7.0	7.0	5.0					598-2
							598-3
			1.44	1.472		26.00	599-1
2.0	3.0	0.0					599-2
							599-3
			1.44			25.00	600-1
6.0	5.0	3.0			11.0		600-2
							600-3
			1.45	1.472		26.00	601-1
7.0	6.0	4.0					601-2
							601-3
			1.44	1.474		26.68	602-1
9.0	7.0	9.0					602-2
							602-3
			1.44	1.477		26.68	603-1
4.0	3.0	3.0					603-2
							603-3
			1.44	1.458		25.17	604-1
4.0	3.0	0.0					604-2
							604-3
			1.45	1.470		25.17	605-1
9.0	6.0	6.0					605-2
							605-3
							606-1
							606-2
							606-3
			1.44			25.00	607-1
2.0	0.0	1.0			8.0		607-2
							607-3
			1.45	1.476		24.51	608-1
7.0	6.0	4.0					608-2
							608-3
			1.45	1.466		24.51	609-1
5.0	5.0	4.0					609-2
							609-3
			1.45	1.474		25.51	610-1
7.0	7.0	4.0					610-2
							610-3
			1.44	1.477		25.17	611-1
0.0	0.0	0.0					611-2
							611-3
			1.44	1.467		25.34	612-1
4.0	3.0	2.0					612-2
							612-3
			1.45	1.489		25.00	613-1
5.0	4.0	3.0					613-2
							613-3
			1.45			24.51	614-1

4.0	3.0	1.0			12.0		614-2
							614-3
			1.45	1.473		25.51	615-1
6.0	6.0	3.0					615-2
							615-3
			1.44	1.468		25.17	616-1
10.0	5.0	4.0					616-2
							616-3
			1.44	1.468		25.34	617-1
6.0	7.0	8.0					617-2
							617-3
			1.45			25.00	618-1
9.0	3.0	3.0			13.0		618-2
							618-3
			1.45	1.488		25.68	619-1
3.0	12.0	10.0					619-2
							619-3
			1.44	1.476		25.85	620-1
5.0	3.0	4.0					620-2
							620-3
			1.44			24.68	621-1
3.0	3.0	5.0			14.0		621-2
							621-3
			1.44			24.85	622-1
3.0	2.0	2.0			10.0		622-2
							622-3
			1.45			24.34	623-1
5.0	3.0	2.0					623-2
							623-3
			1.45	1.465		25.34	624-1
8.0	5.0	2.0					624-2
							624-3
			1.45	1.474		25.51	625-1
6.0	7.0	5.0					625-2
							625-3
			1.44	1.468		26.00	626-1
5.0	5.0	4.0					626-2
							626-3
			1.44			24.51	627-1
5.0	4.0	0.0			8.0		627-2
							627-3
			1.45	1.472		25.51	628-1
5.0	7.0	5.0					628-2
							628-3
			1.44	1.475		25.66	629-1
5.0	5.0	3.0					629-2
							629-3
			1.45			25.00	630-1
4.0	3.0	0.0			7.0		630-2
							630-3
			1.44			24.85	631-1
3.0	2.0	1.0			9.0		631-2
							631-3
			1.45	1.473		26.00	632-1
8.0	6.0	2.0					632-2
							632-3
			1.45	1.471		25.51	633-1
8.0	5.0	3.0					633-2
							633-3
			1.45	1.471		26.17	634-1
6.0	3.0	2.0					634-2

368

					634-3
		1.45	1.463	25.17	635-1
3.0	1.0	0.0			635-2
					635-3
		1.45	1.459	25.17	636-1
5.0	3.0	0.0			636-2
					636-3
		1.45	1.474	26.00	637-1
4.0	2.0	1.0			637-2
					637-3
		1.46	1.482	26.85	638-1
9.0	5.0	2.0			638-2
					638-3
		1.45	1.482	25.68	639-1
11.0	7.0	10.0			639-2
					639-3
		1.45	1.459	25.34	640-1
6.0	3.0	4.0			640-2
					640-3
		1.45	1.465	25.17	641-1
9.0	6.0	7.0			641-2
					641-3
		1.45	1.481	25.68	642-1
7.0	3.0	2.0			642-2
					642-3
		1.46	1.479	25.00	420-1
6.0	5.0	0.0			420-2
					420-3
		1.46	1.467	25.85	421-1
9.0	6.0	4.0			421-2
					421-3
		1.45	1.486	26.17	422-1
7.0	6.0	8.0			422-2
					422-3
		1.45	1.475	25.68	423-1
3.0	2.0	0.0			423-2
					423-3
		1.45	1.472	26.00	424-1
7.0	6.0	2.0			424-2
					424-3
		1.45	1.472	27.00	425-1
4.0	3.0	1.0			425-2
					425-3
		1.46	1.480	25.17	426-1
6.0	5.0	0.0			426-2
					426-3
		1.46	1.478	25.68	427-1
4.0	3.0	0.0			427-2
					427-3
		1.46	1.471	24.85	428-1
7.0	5.0	3.0			428-2
					428-3
					429-1
6.0	4.0	2.0			429-2
					429-3

********** DATA FOR BATTERY S/N 30,31 **********

779.3	868.9	532.5	1.487	26.85	643-1
					643-2
					643-3
780.6	869.6	529.6	1.474	25.00	644-1
					644-2
					644-3
784.1		531.7	1.479	24.85	645-1
					645-2
					645-3
781.3	870.2	530.0	1.489	25.68	646-1
					646-2
					646-3
780.1	865.4	528.7	1.485	25.68	647-1
					647-2
					647-3
782.8	872.1	531.5	1.482	25.34	648-1
					648-2
					648-3
780.4	867.4	528.6	1.485	26.00	649-1
					649-2
					649-3
780.2	869.4	530.4	1.487	26.17	650-1
					650-2
					650-3
781.4	870.8	529.2	1.476	25.00	651-1
					651-2
					651-3
781.6	870.0	531.5	1.484	25.68	652-1
					652-2
					652-3
780.2	870.0	526.0	1.490	25.85	653-1
					653-2
					653-3
780.5	870.0	529.2	1.474	24.68	654-1
					654-2
					654-3
776.5	866.0	525.9	1.492	25.68	655-1
					655-2
					655-3
779.9	868.2	525.3	1.484	25.34	656-1
					656-2
					656-3
780.7	869.8	533.3	1.488	26.17	657-1
					657-2
					657-3
777.6	867.0	527.2	1.476	25.00	658-1
					658-2
					658-3
782.3	871.3	530.7	1.489	26.68	659-1
					659-2
					659-3
785.0	874.2	533.1	1.485	25.68	660-1
					660-2
					660-3
779.0	868.2	527.6	1.485	25.68	661-1
					661-2
					661-3
782.5	871.8	532.4	1.489	26.58	662-1
					662-2
					662-3

370

774.5	863.3	526.9	1.483	25.51	663-1 663-2 663-3
770.7	860.3	519.7	1.475 6.0 8.0	24.34	664-1 664-2 664-3
779.7	869.8	528.9	1.482	26.00	665-1 665-2 665-3
788.8	886.1	537.4	1.479 20.0 33.0	27.34	666-1 666-2 666-3
780.8	870.2	530.5	1.485	25.68	667-1 667-2 667-3
780.9	869.7	529.1	1.477 6.0 12.0	26.85	668-1 668-2 668-3
781.7	870.6	530.4	1.484	25.85	669-1 669-2 669-3
774.8	864.2	522.6	1.486	26.00	670-1 670-2 670-3
779.7	869.0	527.6	1.480	25.17	671-1 671-2 671-3
778.8	868.8	527.9	1.480	25.34	672-1 672-2 672-3
780.1	869.1	532.2	1.477 6.0 3.0	26.68	673-1 673-2 673-3
784.6	874.6	530.8	1.482 6.0 12.0	27.51	674-1 674-2 674-3
776.5	864.3	529.1	1.482	25.51	675-1 675-2 675-3
781.3	870.4	528.9	1.490	25.85	676-1 676-2 676-3
776.6	864.8	526.4	1.484	25.85	677-1 677-2 677-3
783.9	872.2	531.8	1.486	25.85	678-1 678-2 678-3
778.6	863.7	526.8	1.469 8.0 6.0	24.85	679-1 679-2 679-3
778.3	866.7	528.0	1.478	25.17	680-1 680-2 680-3
780.4	869.4	529.6	1.486	25.85	681-1 681-2 681-3
781.1	871.2	531.9	1.479	25.34	682-1 682-2 682-3
779.0	867.0	529.6	1.485	25.85	683-1

					683-2 683-3
783.3	870.7	533.8	1.485	25.85	684-1 684-2 684-3
784.0	873.3	535.2	1.487	26.85	685-1 685-2 685-3
780.1	871.4	530.6	1.476	25.00	686-1 686-2 686-3
783.2	871.2	533.2	1.480	25.68	687-1 687-2 687-3
786.6	875.8	538.1	1.479 5.0 10.0	28.00	688-1 688-2 688-3
786.2	875.7	531.2	1.481	26.68	689-1 689-2 689-3
777.4	866.8	528.6	1.484	26.00	690-1 690-2 690-3
787.8	877.7	534.1	1.480	25.51	691-1 691-2 691-3
777.5	867.0	530.2	1.489	26.17	693-1 693-2 693-3
781.9	871.8	528.9	1.492	25.51	694-1 694-2 694-3
779.7	869.9	530.4	1.486 3.0 10.0	26.68	695-1 695-2 695-3
781.5	870.9	527.8	1.482	25.51	696-1 696-2 696-3
779.2	867.6	530.4	1.481	25.17	697-1 697-2 697-3
776.6	865.8	526.2	1.479	24.68	698-1 698-2 698-3
777.2	866.4	527.3	1.483	25.17	699-1 699-2 699-3
781.2	871.1	531.2	1.483	25.17	700-1 700-2 700-3
785.7	874.9	535.4	1.488	25.85	701-1 701-2 701-3
778.5	869.3	527.7	1.490	25.85	702-1 702-2 702-3
775.2	863.9	523.1	1.476	24.85	703-1 703-2 703-3
786.7	875.4	535.4	1.490	25.85	704-1 704-2

						704-3
783.7	873.8	532.3	1.475		24.85	705-1
						705-2
						705-3
782.0	870.5	531.6	1.477		26.34	706-1
			2.0	7.0		706-2
						706-3
778.0	866.8	527.1	1.479		24.68	707-1
						707-2
						707-3
778.8	907.0	528.9				708-1
						708-2
						708-3
780.7	869.6	530.3	1.479		26.51	709-1
			4.0	9.0		709-2
						709-3
777.4	866.0	526.9	1.489		25.51	710-1
						710-2
						710-3
785.6	874.1	535.5	1.477		26.68	711-1
			10.0	15.0		711-2
						711-3
777.8	866.1	526.9	1.477		25.00	712-1
						712-2
						712-3
781.7	870.5	530.3	1.477		25.00	713-1
						713-2
						713-3
781.3	870.0	531.1	1.439		25.85	714-1
						714-2
						714-3
782.3	873.7	531.3	1.482		26.51	715-1
			6.0	15.0		715-2
						715-3
776.3	865.7	526.5	1.479		26.17	716-1
			3.0	12.0		716-2
						716-3
782.3	870.8	531.7	1.478		24.68	717-1
						717-2
						717-3
781.2	869.8	530.2	1.483		25.85	718-1
						718-2
						718-3
778.4	868.0	523.4	1.478		25.00	719-1
						719-2
						719-3
779.6	868.5	525.9	1.472		25.00	720-1
						720-2
						720-3
778.8	868.9	528.7	1.481		25.34	721-1
						721-2
						721-3
782.7	872.9	527.9	1.488		25.34	722-1
						722-2
						722-3
773.8	862.0	522.3	1.471		24.51	723-1
						723-2
						723-3
775.7	864.1	525.8	1.474		24.68	724-1
						724-2
						724-3

777.3	868.6	526.0	1.476	10.0	11.0	25.85	725-1 725-2 725-3
773.6	862.0	523.7	1.476			24.85	726-1 726-2 726-3
774.5	863.0	523.4	1.474			24.68	727-1 727-2 727-3
776.3	866.3	524.0	1.469	6.0	7.0	24.85	728-1 728-2 728-3
775.7		523.8	1.470			25.00	729-1 729-2 729-3
772.1	889.7	521.4	1.497			25.51	730-1 730-2 730-3
785.2	874.3	533.7	1.472	5.0	8.0	25.85	731-1 731-2 731-3
779.4	869.2	528.5	1.460	6.0	9.0	26.17	732-1 732-2 732-3
774.2	863.6	522.2	1.472			24.85	733-1 733-2 733-3
776.9		523.8	1.480			25.51	734-1 734-2 734-3
779.3	869.0	527.9	1.480			25.34	735-1 735-2 735-3
774.8	863.5	524.1	1.481			25.51	736-1 736-2 736-3
774.4	862.6	523.3	1.476			25.34	737-1 737-2 737-3
778.6	865.8	528.1	1.477			25.34	738-1 738-2 738-3
774.8	870.0	523.9	1.479			25.00	739-1 739-2 739-3
776.2	865.2	524.6	1.467	4.0	6.0	24.85	740-1 740-2 740-3
780.0	869.2	529.7	1.469	0.0	3.0	24.85	741-1 741-2 741-3
774.9		523.2				26.34	742-1 742-2 742-3
780.6	869.8	529.2	1.474	4.0		26.34	743-1 743-2 743-3
770.8	860.0	519.5	1.478			25.00	744-1 744-2 744-3
779.3	[illegible]	527.5	1.483			25.68	745-1

							745-2 745-3
779.8	869.2	528.9	1.472			24.51	746-1 746-2 746-3
781.1	870.5	529.1	1.475	6.0	10.0	26.00	747-1 747-2 747-3
774.1	863.4	523.7	1.470	0.0	0.0	25.17	748-1 748-2 748-3
		525.2					749-1 749-2 749-3
778.9	865.3	529.8	1.472	3.0	5.0	25.85	750-1 750-2 750-3
777.2	868.1	526.6	1.470	2.0	3.0	25.17	751-1 751-2 751-3
784.7	873.5	533.9	1.472	0.0	1.0	25.85	752-1 752-2 752-3
783.8	874.6	533.2	1.471	2.0	4.0	26.00	753-1 753-2 753-3
786.3	875.2	535.0	1.472	5.0	4.0	25.85	754-1 754-2 754-3
779.0		526.4	1.467	1.0	3.0	25.00	755-1 755-2 755-3
784.3	872.9	533.2	1.473	0.0	9.0	26.68	756-1 756-2 756-3
776.9	868.1	524.9	1.471	-1.0	0.0	25.17	757-1 757-2 757-3
782.3	872.5	529.8	1.471	4.0	5.0	26.00	758-1 758-2 758-3
780.7	871.0	528.1	1.483	4.0	7.0	26.68	759-1 759-2 759-3
784.6	874.0	532.5	1.421	6.0		26.34	763-1 763-2 763-3
785.3	873.0	532.4	1.470	4.0	6.0	25.34	764-1 764-2 764-3
782.1	872.7	531.1	1.476	6.0	10.0		765-1 765-2 765-3
784.2	872.2	532.5	1.474	7.0	7.0		766-1 766-2 766-3
798.7		526.2					429-1 429-2 429-3
800.2	891.2	529.5	1.480		9.0	25.51	430-1 430-2

375

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   802.0                    529.9                                         431-1
                                                                          431-2
                                                                          431-3
   801.9 901.6              527.3           1.494             26.00       432-1
                                             11.0  26.0                   432-2
                                                                          432-3
   800.6 890.5              531.1           1.488             25.68       433-1
                                                                          433-2
                                                                          433-3
   801.0 894.1              526.8           1.472             25.00       434-1
                                                   0.0                    434-2
                                                                          434-3
   800.7 893.5              530.2           1.487             26.68       435-1
                                              0.0    8.0                  435-2
                                                                          435-3
   801.9 895.4              529.3           1.481             25.00       436-1
                                                                          436-2
                                                                          436-3
   792.9 886.3              522.6                                         437-1
                                                                          437-2
                                                                          437-3
   800.2 892.2              530.6           1.485             25.51       438-1
                                                                          438-2
                                                                          438-3
   802.3 894.8              527.6           1.485             25.00       439-1
                                                                          439-2
                                                                          439-3
   801.8 894.8              531.4           1.474             26.34       440-1
                                              3.0                         440-2
                                                                          440-3
   805.6 901.8              531.6           1.482             26.00       441-1
                                              5.0   13.0                  441-2
                                                                          441-3
   798.6 888.3              531.2           1.483             25.68       442-1
                                             -3.0    0.0                  442-2
                                                                          442-3
   797.9 890.8              527.4           1.472             24.85       443-1
                                              5.0    6.0                  443-2
                                                                          443-3
   799.6 895.1              523.9           1.475             25.34       444-1
                                              6.0    9.0                  444-2
                                                                          444-3
   804.7 896.3              529.7           1.487                         445-1
                                              0.0                         445-2
                                                                          445-3

       **********   DATA FOR BATTERY S/N 32,33   **********

   789.6 877.1 1.452               257.6 271.6 1.494 26.92 26.34 26.34          820-1
    28.   24.   31.   -3.   13.    19.   17.   18.   27.                        820-2
     3.   54.   15.                                                             820-3
   799.6 887.0 1.452               259.6 279.1 1.489 26.92 26.85 26.67          821-1
    22.   25.   23.    1.   20.    25.   17.   21.   42.    1.00 172.0 245.0    821-2
     3.   45.   24.                                                             821-3
   795.7 893.2 1.459               258.6 274.2 1.490 30.92 27.17 26.34          822-1
    12.   15.   12.    0.    8.     8.    2.    7.   20.                        822-2
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376

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                                                                                            822-3
  3.    29.     2.                         257.1 274.4 1.488  7.00 26.34 26.34              823-1
793.3  881.0  1.443                                                  .09 173.5 238.0       823-2
  9.    13.    21.     0.     16.     19.     8.     13.    28.                             823-3
  3.   109.     0.                         258.4 275.6 1.493  6.75 26.17 26.17              824-1
795.4  883.1  1.440                                                  .10 176.0 237.0       824-2
  7.    12.    18.     5.     37.     33.    24.     22.    45.                             824-3
  3.   109.     0.                         256.5 276.3       30.67 27.00                    825-1
793.5  880.7  1.458                                                                         825-2
 12.    15.    19.                                                                          825-3
  3.    29.     2.                         255.7 275.1 1.493 23.50 26.00 25.50              826-1
795.2  882.9  1.444                                                                         826-2
 11.    14.    17.     9.     26.     25.    19.     16.    31.                             826-3
  3.    87.     0.                         255.4 277.7 1.486 29.75 26.34 25.50              827-1
795.2  882.9  1.455                                                                         827-2
  4.     7.     9.    -6.     12.      7.     2.      4.    14.                             827-3
  3.    29.     2.                         256.1 276.1 1.487 30.10 26.51 25.83              828-1
794.7  882.6  1.455                                                                         828-2
  8.    12.    15.     2.     10.     10.     6.      6.    15.                             828-3
  3.    29.     2.                         255.8 273.2 1.485 29.90 26.51 25.83              829-1
791.5  879.5  1.459                                                                         829-2
  9.    12.    12.    -1.     10.     10.     5.      8.    19.                             829-3
  3.    29.     2.                         258.9 275.9 1.494 29.58 27.34 26.33              830-1
797.4  885.2  1.455                                                                         830-2
 10.    13.    11.    -7.      8.      9.     6.      8.    22.                             830-3
  3.    29.     2.                         257.8 275.4 1.488  6.00 27.17 27.00              831-1
795.4  883.0  1.458                        15.          15.   31.  10.00 173.0 248.0       831-2
 20.    19.    20.    -2.     12.                                                           831-3
  3.    45.    25.                         255.7 273.2                                      832-1
792.2  879.8                                                                                832-2
                                                                                            832-3
  3.    69.                                258.2 277.0 1.485 29.25 26.68 26.00              833-1
797.4  884.9  1.455                                                                         833-2
 17.    18.    17.     0.     11.     11.     9.      9.    19.                             833-3
  3.    29.     2.                         256.9 275.2 1.486 29.42 26.68 26.00              834-1
794.2  881.9  1.456                                                                         834-2
  7.     7.    11.     0.      8.     10.     6.      9.    18.                             834-3
  3.    29.     2.                         257.4 275.1 1.487 29.10 27.17 26.17              835-1
793.9  881.3  1.458                                                                         835-2
 11.    13.    20.    -2.     10.     10.     8.      8.    17.                             835-3
  3.    29.     2.                         256.1 274.6 1.487 25.00 26.85 26.17              836-1
792.0  879.5  1.450                                                                         836-2
  9.    12.    18.     2.     16.     18.    19.     20.    39.                             836-3
  3.    29.     2.                         255.4 276.4 1.487 24.83 26.85 26.00              837-1
794.3  881.1  1.454                                                                         837-2
 16.    16.    23.     3.     14.     15.    10.     10.    22.                             837-3
  3.    29.     2.                         258.3 271.9       24.67 27.34 26.50              838-1
792.0  879.6  1.459                                                                         838-2
 14.    16.    18.     2.     11.     10.                                                   838-3
  3.    29.     2.                         259.1 270.7 1.486 26.83 26.51 26.50              839-1
791.2  878.4  1.454                                                                         839-2
 14.    16.    23.     0.     14.     18.     4.     12.    29.                             839-3
  3.    54.    15.                         255.9 272.7 1.485 26.75 26.34 26.17              840-1
790.4  877.4  1.456                                                                         840-2
 30.    32.    31.     2.     21.     20.    17.     22.    40.                             840-3
  3.    54.    15.                         253.4 274.6 1.490 23.50 26.34 25.67              841-1
790.1  877.7  1.451                                                                         841-2
 19.    17.    27.     3.     15.     15.    12.     10.    24.                             841-3
  3.    29.     2.                         254.6 274.5 1.486 23.33 26.51 25.83              842-1
791.0  878.7  1.451                                                                         842-2
 11.    12.    16.    -7.     10.      7.     6.     10.    26.                             842-3
  3.    29.     2.
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377

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796.9 884.6 1.456                256.1 277.0 1.487 24.17 26.34 25.67              843-1
 13.   13.   19.   -7.   11.      9.    7.    6.   16.                            843-2
  3.   29.    2.                                                                  843-3
794.2 881.8                      256.8 276.0                                      844-1
                                                                                  844-2
  3.  109.                                                                        844-3
790.0 877.5 1.454                255.4 272.6 1.485 27.33 26.68 25.83              845-1
  6.    7.   12.    0.    8.     10.    5.    6.   15.                            845-2
  3.   29.    2.                                                                  845-3
                                 255.7 270.5                                      846-1
                                                                                  846-2
  3.                                                                              846-3
795.0 882.6 1.446                257.1 278.1 1.486  6.00 26.17 26.17              847-1
 13.   12.   14.    2.   14.     16.   16.    9.   21.   .10 177.   245.          847-2
  3.   91.   17.                                                                  847-3
794.7 881.8 1.449                256.6 276.7 1.483 25.33 26.00 26.00              848-1
 20.   24.   25.    0.   17.     18.   17.   12.   25.                            848-2
  3.   67.    2.                                                                  848-3
791.6 878.8 1.448                257.5 273.8 1.486 25.33 26.68 26.50              849-1
 25.   26.   24.    0.   12.     14.    8.   15.   29.                            849-2
  3.   67.    2.                                                                  849-3
797.6 885.3 1.450                258.5 277.9 1.491 27.33 27.17 26.17              850-1
 13.   15.   21.    2.   11.     10.    5.   14.   30.                            850-2
  3.   29.    2.                                                                  850-3
792.2 879.8 1.454                256.6 275.0 1.487 27.50 27.00 26.17              851-1
 13.   14.   23.    2.   13.     13.    9.   11.   24.                            851-2
  3.   29.    2.                                                                  851-3
793.2 881.1 1.447                258.2 273.2 1.492 25.00 26.85 26.83              852-1
 20.   19.   32.   -9.   10.     12.   18.   16.   31.                            852-2
  3.   54.   15.                                                                  852-3
795.8 883.4 1.451                258.1 275.9 1.496 27.50 27.17 26.33              853-1
 13.   15.   18.    2.   13.     13.    8.   11.   27.                            853-2
  3.   29.    2.                                                                  853-3
                                 256.1 273.2                                      854-1
                                                                                  854-2
  3.   29.                                                                        854-3
794.3 881.3 1.444                257.6 273.3 1.498  5.75 26.17 26.17              855-1
 18.   15.   26.    5.   54.     44.   20.   24.   50.   .19 177.0 236.0          855-2
  3.   91.   17.                                                                  855-3
795.2 883.0 1.449                255.1 276.7 1.484 24.83 25.85 25.67              856-1
 12.   14.   17.    2.   14.     13.   11.   11.   24.                            856-2
  5.   55.   15.                                                                  856-3
794.9 882.6 1.453                257.8 275.2 1.489 27.25 26.85 25.83              857-1
 12.   16.   11.    2.    9.     10.    5.   10.   20.                            857-2
  5.   30.    2.                                                                  857-3
801.1 888.5 1.448                259.8 279.2 1.490 27.17 26.85 25.83              858-1
 10.   15.   22.    3.   14.     15.   18.   13.   26.                            858-2
  5.   30.    2.                                                                  858-3
794.6 881.9 1.444                257.6 275.6 1.486  5.67 26.00 26.34              859-1
  9.   12.   21.    0.   24.     24.   14.   12.   24.   .19 174.0 240.0          859-2
  5.   92.   17.                                                                  859-3
793.4 881.1 1.445                258.3 273.5 1.484 23.75 25.85 25.67              860-1
 14.   14.   15.    0.    8.     10.    8.    9.   22.                            860-2
  5.   55.   15.                                                                  860-3
793.1 881.0 1.452                256.4 274.5 1.488 27.10 26.34 25.67              861-1
  5.    3.    7.    4.   13.     14.    7.    6.   16.                            861-2
  5.   30.    2.                                                                  861-3
791.1 876.9 1.450                257.9 271.9 1.484 24.17 26.17 26.00              862-1
 18.   16.   21.    0.   10.     13.   11.   10.   23.                            862-2
  5.   55.   15.                                                                  862-3
790.9 872.5 1.451                256.5 272.5 1.482 27.00 26.85 26.17              863-1
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                                                                                        863-2
   6.     9.    10.     0.    4.    5.     1.     8.    16.                             863-3
   5.    30.     2.                                                                     864-1
 792.9  880.1  1.441               256.2 275.5 1.488  5.33 26.85 25.68                  864-2
   7.     8.    20.     3.   24.   25.    13.    12.    26.     .90 172.0 243.0         864-3
   5.   109.     1.                                                                     865-1
 790.9  878.5  1.446               258.9 272.1 1.488 27.00 27.00 26.50                  865-2
   4.     8.    18.     0.    5.    6.     5.     6.    15.                             865-3
   5.    30.     2.                                                                     866-1
 796.7  884.5  1.459               261.7 273.5 1.497 26.83 25.85 26.40                  866-2
  10.    10.    15.     2.   11.   10.     8.    17.    20.                             866-3
   5.    30.     2.                                                                     867-1
 793.0  880.7  1.441               257.9 275.1 1.487 27.50 27.00 26.33                  867-2
   8.    11.    13.     2.   10.   11.     6.     8.    19.                             867-3
   5.    30.     2.                                                                     868-1
 793.2  881.7  1.445               257.6 275.8 1.486 23.75 26.17 26.17                  868-2
  23.    21.    19.     0.   16.   14.    10.    14.    29.                             868-3
   5.    70.     0.                                                                     869-1
 795.2  883.1  1.448               259.4 276.1 1.487 27.50 27.00 26.00                  869-2
  11.    13.    20.     2.   10.   11.    10.    10.    20.                             869-3
   5.    30.     2.                                                                     870-1
 795.3  883.1  1.449               257.4 276.8 1.485 27.42 26.68 26.00                  870-2
  10.    14.    24.     2.    8.   10.    10.    10.    24.                             870-3
   5.    30.     2.                                                                     871-1
 793.7  881.2  1.447               257.4 274.5 1.484  3.33 26.85 26.00                  871-2
  14.    15.    19.     3.    9.   11.     8.    10.    21.                             871-3
   5.    30.     3.                                                                     872-1
 789.3  877.4  1.449               255.6 271.8 1.489 23.33 26.17 25.83                  872-2
  16.    18.    17.     0.   11.   13.    11.    10.    24.                             872-3
   5.    55.    15.                                                                     873-1
 797.7  884.7  1.448               263.2 272.5 1.496  3.25 27.34 26.33                  873-2
  10.    12.    23.     0.    8.    9.     6.     8.    22.                             873-3
   5.    30.     3.                                                                     874-1
 795.0  882.2  1.442               259.4 273.7 1.489  2.63 27.17 26.17                  874-2
   4.     8.    10.    -1.    6.    7.     5.     6.    17.                             874-3
   5.    30.     3.                                                                     875-1
 797.2  885.6                      257.4 277.3                                          875-2
                                                                                        875-3
   5.    55.                                                                            876-1
 796.6  883.8  1.450               258.7 274.3        5.25 26.00                        876-2
  14.    16.    21.                                                                     876-3
   5.    99.    17.                                                                     877-1
 796.8  884.2  1.443               259.1 274.6 1.492  2.92 27.34 26.33                  877-2
  10.    14.    23.     2.    9.   10.     6.     9.    23.                             877-3
   5.    30.     3.                                                                     878-1
 795.0  882.2  1.439               256.3 275.6 1.486  3.00 26.34 25.50                  878-2
  10.    10.    19.     4.   10.   13.     7.    10.    20.                             878-3
   5.    30.     3.                                                                     879-1
 793.5  881.5  1.446               257.1 274.2 1.482 22.83 26.00 25.83                  879-2
   8.    13.    10.     2.    6.    8.     5.     9.    18.                             879-3
   5.    55.    15.                                                                     880-1
 792.6  880.1  1.444               259.5 271.9 1.495  3.00 27.17 26.50                  880-2
   8.    12.    19.     1.    8.    9.     6.     8.    17.    8.00 169.0 243.0         880-3
   5.    30.     3.                                                                     881-1
 792.1  879.9  1.448               258.5 273.3 1.492  3.17 27.17 26.33                  881-2
  14.    16.    23.     4.   12.   14.     9.    10.    24.                             881-3
   5.    30.     3.                                                                     882-1
 795.2  883.4  1.447               257.4 275.8 1.486 97.50 26.34 25.60                  882-2
   7.     1.    12.     4.   14.   16.    10.    12.    24.     .20 174.0 236.0         882-3
   5.                                                                                   883-1
 792.2  880.5  1.444               258.8 271.8 1.490 26.50 26.51 26.00                  883-2
   9.    12.    16.     8.   21.   21.    15.    14.    28.
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                                                                                     883-3
   5.    78.    10.                                                                  884-1
                                     257.7 273.5 1.486  3.17 26.51 25.67
 791.9 879.6 1.445                                                                   884-2
  10.     7.    12.     1.     6.     7.     4.     8.    15.                        884-3
   5.    30.     3.                                                                  885-1
                                     258.6 274.7 1.489  5.10 26.00 26.17
 795.4 882.3 1.445                                                                   885-2
  13.    13.    19.     2.    24.    24.    14.    12.    24.                        885-3
   5.    92.    17.                                                                  887-1
                                     258.2 276.2 1.486  2.75 26.68 25.83
 796.4 884.0 1.440                                                                   887-2
  13.    14.    15.     3.     9.    10.     5.     8.    16.                        887-3
   5.    30.     3.                                                                  888-1
                                     257.1 275.1 1.491   .50 27.00 26.33
 793.3 880.5 1.452                                                                   
  13.    13.    22.     4.    12.    16.     8.    11.    22.  12.00 168.0 248.0   888-2
                                                                                     888-3
   5.    30.     3.                                                                  889-1
                                     257.2 274.3 1.485 22.58 26.68 26.50
 793.2 880.9 1.447                                                                   889-2
  16.    18.    18.    -1.     9.    10.    20.     8.    17.                        889-3
   5.    68.     2.                                                                  890-1
                                     257.6 276.3 1.486 31.33 26.34 25.83
 795.0 882.6 1.447                                                                   890-2
  14.    15.    14.     0.    15.    15.    10.    13.    29.                        890-3
   5.    55.    15.                                                                  892-1
                                     258.2 275.7 1.490 31.17 26.51 26.33
 796.2 883.3 1.445                                                                   892-2
  16.    19.    21.    -1.    11.    13.    10.    13.    28.                        892-3
   5.    55.    15.                                                                  893-1
                                     256.8 274.4 1.492 30.25 26.51 26.17
 792.3 880.4 1.449                                                                   893-2
  27.    24.    22.     0.    11.    13.    12.    16.    32.                        893-3
   5.    55.    15.                                                                  894-1
                                     259.1 273.8 1.489  4.75 26.17 26.17
 795.8 883.3 1.450                                                                   
  10.    10.    15.     1.    22.    22.    11.     9.    22.   4.16 174.0 241.0   894-2
                                                                                     894-3
   5.   110.     0.                                                                  895-1
                                     257.3 273.9 1.489 30.17 26.34 26.33
 792.1 879.3 1.443                                                                   895-2
  20.    18.    23.    -2.    13.    16.    14.    15.    31.                        895-3
   3.    53.    15.                                                                  896-1
                                     256.7 275.1 1.493 30.00 26.51 26.33
 794.3 881.7 1.439                                                                   896-2
  20.    20.    26.     2.    22.    24.    26.    25.    50.                        896-3
   3.    53.    15.                                                                  898-1
                                     257.4 274.5 1.490  2.67 27.17 26.67
 793.7 880.9 1.445                                                                   
   8.     8.    16.     0.    13.    16.     8.    15.    27.   2.00 169.0 240.0   898-2
                                                                                     898-3
   3.    28.     3.                                                                  899-1
                                     257.0 275.6 1.493  3.58 26.34 26.51
 796.3 884.1 1.447                                                                   899-2
   9.     7.    23.    -1.    42.    33.    21.    18.    39.                        899-3
   3.   108.     0.                                                                  900-1
                                     256.9 276.1 1.492 29.90 26.68 26.50
 795.8 883.1 1.446                                                                   900-2
   9.    10.    11.   -12.     9.    11.     9.    10.    23.                        900-3
   3.    53.    15.                                                                  901-1
                                     258.4 273.5 1.491  2.75 27.17 26.33
 793.7 881.6 1.438                                                                   901-2
   9.     9.    21.     4.    12.    16.    12.    16.    30.                        901-3
   3.    28.     3.                                                                  902-1
                                     260.1 273.2 1.488  3.50 26.68 26.68
 794.6 882.0 1.444                                                                   902-2
   5.     8.    15.    -5.    22.    20.    10.     9.    23.                        902-3
   3.   108.     0.                                                                  903-1
                                     259.3 273.2 1.493 29.67 26.85 26.67
 795.1 882.3 1.448                                                                   903-2
  20.    18.    26.   -10.    20.    23.     2.    20.    44.                        903-3
   3.    53.    15.                                                                  904-1
                                     258.1 270.6 1.486 29.58 26.85 26.67
 791.2 87[illegible] 1.447                                                             904-2
  18.    16.    17.    -9.     9.    12.    10.    14.    29.                        904-3
   3.    53.    15.                                                                  905-1
                                     256.6 272.1 1.486  2.17 27.17 26.33
 790.7 87[illegible].3 1.446                                                           905-2
   9.    11.    1[illegible].     5.     9.    10.     4.     6.    16.               905-3
   3.    28.     3.                                                                  906-1
                                     253.5 275.7 1.491 27.33 25.85 25.34
 797.[illegible] 87[illegible] 1.442                                                   906-2
   5.  [illegible]  [illegible]  2.    19.    17.    12.    10.    22.                906-3
   3.
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                                   258.2 272.8 1.500 23.90 26.85 26.51              907-1
 797.2 886.1 1.443                                                                  907-2
  14.   17.   24.     7.    28.    27.   28.   24.   48.                            907-3
   3.   86.    0.
                                   255.8 274.8 1.484 29.50 25.85 25.67              908-1
 794.3 881.6 1.446                                                                  908-2
  18.   18.   19.     0.    10.    12.    8.   12.   28.                            908-3
   3.   53.   15.
                                   257.1 273.6 1.483  1.90 27.00 26.33              909-1
 793.1 881.6 1.445                                                                  909-2
  13.   12.   16.     0.     9.    10.    8.   10.   21.                            909-3
   3.   28.    3.
                                   256.1 272.4 1.486  1.83 26.85 26.00              910-1
 790.8 879.1 1.441                                                                  910-2
  14.   16.   27.     7.    17.    19.   16.   21.   38.                            910-3
   3.   28.    3.
                                   257.5 274.2 1.487  1.75 27.17 25.83              911-1
 795.0 882.6 1.439                                                                  911-2
  10.   12.   17.    25.    23.    24.   17.   18.   33.    3.00 169.0 245.0        911-3
   3.   28.    3.
                                   254.6 274.2 1.483  4.17 26.17 25.83              912-1
 792.4 880.3 1.446                                                                  912-2
  14.   14.   18.     0.    11.    13.   12.   13.   24.                            912-3
   3.   53.   16.
                                   258.9 274.2 1.487  1.58 27.51 26.50              913-1
 795.5 882.6 1.443                                                                  913-2
   9.    9.   19.     0.     6.     9.    6.    9.   29.                            913-3
   3.   28.    3.
                                   257.2 276.8 1.493  4.00 26.17 26.00              914-1
 796.6 884.5 1.442                                                                  914-2
  19.   20.   25.     2.    28.    34.   38.   32.   67.                            914-3
   3.   53.   16.
                                   257.1 274.9 1.489 27.17 26.34 25.68              915-1
 795.2 883.7 1.442                                                                  915-2
   9.   12.   17.     8.    24.    24.   20.   18.   32.                            915-3
   3.
                                   256.6 278.5 1.489  1.50 27.34 26.50              916-1
 796.3 883.9 1.450                                                                  916-2
  11.   13.   21.     2.     9.    12.    8.    9.   20.                            916-3
   4.   27.    3.
                                   255.5 274.9 1.492 27.17 26.17 25.68              917-1
 791.5 879.7 1.441                                                                  917-2
   9.    8.   10.     3.    10.    10.    8.    9.   17.                            917-3
   4.
                                   257.6 275.4 1.486  1.33 26.51 25.67              918-1
 796.2 883.2 1.448                                                                  918-2
  11.   10.   20.     0.    10.    10.    5.    8.   18.                            918-3
   4.   27.    3.
                                   257.1 274.6 1.482  4.42 27.00 26.00              919-1
 794.5 882.4 1.447                                                                  919-2
   8.   10.   13.     2.     8.    10.    6.    7.   16.                            919-3
   4.   27.    3.
                                   257.3 276.4 1.485  4.50 25.85 25.83              920-1
 796.9 884.9 1.450                                                                  920-2
  14.   14.   26.     0.    16.    20.   17.   16.   30.                            920-3
   4.   52.   16.
                                   255.4 272.6 1.489       26.51 26.00              921-1
 789.2 877.2 1.447                                                                  921-2
   9.   11.   13.     5.    16.    17.   12.   12.   24.                            921-3
   4.
                                   256.1 273.3 1.490  4.33 26.68 26.50              922-1
 793.6 881.4 1.449                                                                  922-2
  16.   18.   21.    -8.     9.    13.    2.   14.   28.                            922-3
   4.   52.   16.
                                   255.5 277.7 1.489  4.17 25.68 25.67              923-1
 796.5 884.6 1.445                                                                  923-2
  24.   24.   30.     3.    24.    30.   27.   23.   44.                            923-3
   4.   52.   16.
                                   259.5 270.5 1.487  3.33 26.34 26.51              924-1
 791.6 879.2 1.451                                                                  924-2
   5.    9.   11.    -2.    15.    17.   10.   11.   22.     .16 178.0 236.0        924-3
   4.   89.   17.
                                   258.7 273.0 1.496  4.17 26.00 25.83              925-1
 793.7 881.6 1.452                                                                  925-2
  11.   13.   25.    -7.     9.    12.   10.    9.   20.                            925-3
   4.   52.   16.
                                   257.8 274.1 1.485  3.00 26.85 25.85              926-1
 794.3 881.7 1.444                                                                  926-2
  11.   11.   15.    -2.    23.    22.    8.    7.   19.     .12 173.0 241.0        926-3
   4.   52.   55.
                                   257.8 276.1 1.484  4.10 26.34 26.17              927-1
 795.4 884.2 1.446
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381

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  12.    14.    20.   -3.    11.    15.     9.    10.    27.                                927-2
   4.    52.    16.                                                                          927-3
 795.9  883.9  1.445                257.6  276.1  1.497   3.90  26.17  26.50                928-1
  28.    23.    33.   -5.    16.    19.    24.    22.    49.                                928-2
   4.    52.    16.                                                                          928-3
 793.7  881.9  1.452                259.8  274.7  1.488   3.83  26.68  26.50                929-1
  12.    13.    19.  -10.     8.    10.     9.    11.    23.                                929-2
   4.    52.    16.                                                                          929-3
 798.5  886.2  1.445                258.3  277.7  1.481   2.75  25.50  25.51                930-1
  13.    13.    25.    4.    23.    22.    10.    16.    32.     .13  172.0  244.0         930-2
   4.    52.    55.                                                                          930-3
 792.1  880.3  1.446                254.2  276.3  1.487  26.67  26.17  25.68                931-1
   9.    10.    17.    5.    15.    15.    10.    10.    22.                                931-2
   4.    75.    10.                                                                          931-3
 790.6  878.2  1.447                257.3  272.1  1.490  26.10  25.85  25.83                932-1
   6.     9.     9.    3.    10.    10.     9.     9.    16.                                932-2
   4.                                                                                        932-3
 795.5  883.0  1.444                258.3  275.7  1.495   3.67  26.68  26.33                933-1
  18.    19.    22.    0.    22.    27.    27.    23.    46.                                933-2
   4.    52.    16.                                                                          933-3
 791.6  879.0  1.451                257.4  272.0  1.487   3.67  26.17  26.17                934-1
  18.    16.    26.   -5.    13.    17.    12.    13.    27.                                934-2
   4.    52.    16.                                                                          934-3
 797.6  885.6  1.452                258.6  278.1  1.494  26.17  27.51  27.00                935-1
  10.     8.     9.    0.     9.    10.     8.     8.    18.                                935-2
   4.                                                                                        935-3
 795.8  883.6  1.447                258.3  276.6  1.492   3.50  26.85  26.50                936-1
  18.    16.    30.   -8.    17.    18.     5.    18.    27.                                936-2
   4.    52.    16.                                                                          936-3
 795.6  883.3  1.451                258.6  274.9  1.485   3.33  26.00  25.83                938-1
  10.    14.    20.   -6.    12.    16.    12.    10.    26.                                938-2
   4.    52.    16.                                                                          938-3
 793.0  881.2  1.439                256.2  276.7  1.483   3.10  26.00  26.00                939-1
  16.    13.    28.   -9.     8.    11.     9.    10.    24.                                939-2
   4.    52.    16.                                                                          939-3
 794.5  882.4  1.437                256.7  275.1                3.00  25.17  24.83                940-1
  14.    17.    28.    1.    15.    11.                                                     940-2
   4.    52.    16.                                                                          940-3
 794.6  882.8  1.446                257.5  274.4  1.484   2.83  25.68  25.67                941-1
  14.    19.    25.    0.    15.    18.    16.    13.    30.                                941-2
   4.    52.    16.                                                                          941-3
 791.8  879.9  1.446                258.9  271.2  1.487   2.42  25.51  26.33                942-1
  16.    21.    23.   -8.    11.    14.     5.     9.    23.                                942-2
   4.    52.    16.                                                                          942-3
 791.2  878.6  1.449                257.6  274.0  1.490   2.33  26.85  26.67                943-1
  18.    17.    25.    0.     8.    10.    10.    10.    23.                                943-2
   4.    52.    16.                                                                          943-3
 794.0  881.5  1.447                258.9  273.7  1.490   2.00  26.68  27.00                944-1
  16.    16.    25.   -2.    11.    14.    14.    16.    28.                                944-2
   4.    52.    16.                                                                          944-3
 795.0  882.6  1.447                257.3  276.9  1.491   1.67  25.85  27.17                945-1
  16.    23.    24.   -3.    12.    15.    10.    16.    31.    8.00  175.0  248.0         945-2
   4.    52.    16.                                                                          945-3
 789.0  876.5  1.444                259.1  270.2  1.480   1.50  26.17  26.50                946-1
  23.     5.     6.  -11.     6.     8.    11.     4.    11.                                946-2
   4.    52.    16.                                                                          946-3
 794.2  882.9  1.441                255.7  277.6  1.486  26.00  25.17  24.83                947-1
  11.    14.    16.    6.    19.    20.    14.    13.    26.                                947-2
   4.                                                                                        947-3
 791.8  879.4  1.455                259.2  274.3  1.490   2.50  25.68  26.67                948-1
  13.    11.    23.   -2.    24.    22.    11.    11.    24.     .18  176.0  239.0         948-2
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                                                                                          948-3
  4.    89.    17.                           258.2 274.5 1.489  1.42 26.34 26.67          949-1
794.1 881.8  1.446                                                                        949-2
  4.    18.    24.      0.    12.    16.     8.    15.    32.    3.00 169.0 245.0         949-3
  4.    52.    16.                           258.3 276.6 1.492  1.33 25.85 26.50          950-1
795.7 883.1  1.445                                                                        950-2
 14.    21.    28.      3.    24.    30.    28.    23.    48.                             950-3
  4.    52.    16.                           260.9 275.4 1.489  2.17 26.34 26.68          951-1
796.0 883.6  1.451                                                                        951-2
 15.    17.    27.     -2.    27.    25.    16.    14.    31.                             951-3
  4.    89.    17.                           257.6 274.8 1.495  1.00 26.85 27.00          952-1
794.2 881.8  1.455                                                                        952-2
 24.    21.    34.      1.    16.    20.    19.    20.    37.                             952-3
  4.    49.    16.                           260.9 274.7 1.496  1.83 27.51 27.34          953-1
797.3 884.7  1.451                                                                        953-2
 17.    16.    24.    -12.    33.    22.    20.    15.    37.                             953-3
  4.   104.     0.                           259.1 274.9 1.499   .67 27.00 27.17          954-1
             1.452                                                                        954-2
 26.    27.    36.      0.    21.    25.    20.    24.    48.                             954-3
  4.    49.    16.                           259.2 274.4 1.490   .50 26.34 27.00          955-1
             1.453                                                                        955-2
 32.    35.    38.     -4.    19.    25.    19.    22.    45.                             955-3
  4.    49.    16.                           259.6 274.5 1.508  1.17 27.17 26.85          956-1
796.0 883.4  1.451                                                                        956-2
 13.    12.    22.      1.    13.    13.    12.     4.    26.                             956-3
  4.    49.    33.                           255.7 278.2 1.499  1.67 27.85 28.51          957-1
794.8 882.6  1.460                                                   .16 188.0 242.0      957-2
 12.     9.    18.    -25.     1.    10.    14.    13.    39.                             957-3
  4.    49.    55.                           259.1 274.2 1.495 25.00 27.00 26.68          958-1
794.1 881.8  1.451                                                                        958-2
 10.    10.    15.      1.    13.    12.    14.    12.    22.                             958-3
  4.    49.    33.                           259.5 274.8 1.498 24.83 26.00 27.17          959-1
796.1 883.2  1.479                                                                        959-2
 15.    17.    24.     -1.    13.    14.    14.    19.    38.                             959-3
  4.    49.    33.                           259.6 275.1 1.496 24.42 26.85 26.68          960-1
797.9 885.5  1.452                                                                        960-2
  9.    12.    18.      1.    11.    12.    12.    10.    22.                             960-3
  4.    49.    33.                           259.1 275.1 1.496 24.33 27.51 27.17          961-1
795.4 883.0  1.451                                                                        961-2
  7.    10.    12.     -2.    12.    12.    14.    15.    30.                             961-3
  4.    49.    33.                           258.8 275.0 1.490 24.10 26.85 26.68          962-1
798.0 885.5  1.450                                                                        962-2
 11.    15.    19.      2.    14.    14.    12.    15.    29.                             962-3
  4.    49.    33.                           256.3 274.5 1.489 23.17 26.51 26.17          461-1
794.8 886.2  1.449                                                  2.40 175.0 240.0      461-2
 10.     9.    19.      4.    14.    24.     5.     6.    21.                             461-3
  3.    90.    16.


810.7 902.5  1.446                           260.2 273.1 1.485 23.42 26.68 26.17          464-1
  6.     6.    10.      2.    11.    12.     4.     7.    18.     .70 175.2 237.0         464-2
  3.    90.    16.                                                                        464-3
795.6 887.0  1.444                           257.3 275.7 1.483 23.58 26.00 25.68          465-1
 10.    11.    22.     12.    18.    22.    15.    13.    25.     .50 173.0 237.0         465-2
  3.    90.    16.                                                                        465-3
803.0 894.3  1.448                           255.0 272.4 1.482 24.17 26.51 26.00          466-1
  8.     7.    12.      6.    23.    20.     6.     3.    15.                             466-2
  3.    90.    16.                                                                        466-3
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806.5 897.2 1.466                      254.5 272.8 1.484  1.83 26.68 25.33             469-1
  6.    9.   11.    0.     8.     8.     4.     5.    15.                            469-2
  3.   60.    9.                                                                    469-3
802.4 893.8 1.457                      255.4 272.5 1.475  1.34 26.85 25.50             470-1
  9.    9.   12.   12.    11.    11.     5.     6.    14.                            470-2
  3.   68.    1.                                                                    470-3
811.4 903.4 1.447                      255.8 278.3 1.487 24.42 26.34 26.00             471-1
  4.    4.    8.    3.    19.    15.     6.     7.    19.                            471-2
  3.   90.   16.                                                                    471-3
802.1 893.4 1.458                      255.1 272.1 1.482  1.50 27.00 25.83             472-1
 13.   14.   12.    5.    10.     9.    13.     7.    15.                            472-2
  3.   60.    9.                                                                    472-3
793.8 885.7 1.446                      255.3 276.2 1.487 24.83 26.85 26.51             473-1
  8.    9.   24.    8.    23.    19.    17.    14.    28.    .80 177.5 240.0         473-2
  3.   90.   16.                                                                    473-3
807.5 899.7 1.459                      261.9 271.9 1.501 25.67 27.68 27.17             475-1
 11.   13.   20.    3.    25.    18.    12.     7.    22.                            475-2
  4.   86.   16.                                                                    475-3
807.7 890.1 1.464                      259.3 272.2 1.496 25.33 27.51 27.34             476-1
 12.   12.   20.    2.    14.    20.    10.     7.    23.   3.30 181.5 234.0         476-2
  4.   86.   16.                                                                    476-3
807.9 897.7 1.468                      261.4 272.8              1.42 28.68 27.33       477-1
 11.   13.   21.  -13.     2.     2.     4.     6.    18.  14.00 180.0 245.0         477-2
  4.   56.    9.                                                                    477-3
808.4 900.7 1.451                      257.4 274.6 1.487 25.92 26.51 26.34             478-1
  4.    4.    6.    2.    10.    12.     2.     3.    14.   1.70 176.0 238.0         478-2
  4.   86.   16.                                                                    478-3
801.1 892.4 1.472                      255.1 272.4              1.17 29.00 27.67       479-1
 18.    6.   14.  -12.     0.     0.     6.     6.    17.  19.00 182.0 245.0         479-2
  4.   56.    9.                                                                    479-3
809.7 901.7 1.455                      259.8 271.9 1.486 26.25 27.34 27.00             480-1
  6.    9.   12.    2.    11.    14.     6.     4.    14.                            480-2
  4.   86.   16.                                                                    480-3
809.0 900.8 1.461                      261.4 272.9 1.498 26.50 27.68 27.34             481-1
  5.    8.   10.   -1.     8.    12.     4.     3.    14.                            481-2
  4.   86.   16.                                                                    481-3
808.3 899.7 1.455                      257.8 276.1 1.485 27.00 26.68 26.34             482-1
  3.    3.    4.    0.     8.     9.     2.     3.     9.                            482-2
  4.   86.   16.                                                                    482-3
804.9 896.3 1.456                      259.3 270.9 1.486 26.67 27.17 26.85             483-1
  7.    7.   10.    2.    12.    11.     4.     3.    12.                            483-2
  4.   86.   16.                                                                    483-3
805.2 897.4 1.451                      256.4 273.9 1.493 27.25 28.00 27.51             484-1
  5.    9.   15.   -1.     9.    18.    13.     7.    24.                            484-2
  4.   86.   16.                                                                    484-3
801.7 893.5 1.456                      254.1 274.4 1.492 28.67 28.17 26.85             485-1
  9.    8.   12.   -2.     7.    12.    10.     6.    22.                            485-2
  4.   86.   16.                                                                    485-3
808.5 900.0 1.460                      256.5 275.7 1.483 29.00 26.68 26.00             487-1
 10.    9.    9.    2.    13.     9.     1.     3.    12.                            487-2
  4.   86.   16.                                                                    487-3
813.0 904.6 1.457                      257.6 279.0 1.484 22.67 26.35 26.51             488-1
  7.    7.   14.    2.     8.    18.     9.     6.    19.   2.10 176.0 244.0         488-2
  4.                                                                                488-3
808.3 [illegible] 1.470                258.8 274.4 1.491  1.00 26.00 26.83             489-1
 16.   14.   20.    0.     8.     8.    10.     7.    13.                            489-2
  4.   56.    9.                                                                    489-3
807.0 899.1 1.470                      258.9 274.1 1.490   .58 27.68 26.50             491-1
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384

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  18.    18.    20.     0.    11.    12.    25.     8.    10.                                        491-3
   4.    56.     9.                                                                                  493-1
 806.2  897.1  1.452                  256.0  276.5  1.488 29.42 27.83 27.34                          493-2
   9.     9.    14.     1.    13.    20.    15.     9.    22.                                        493-3
   4.    90.    13.                                                                                  494-1
 806.9  898.2  1.474                  259.5  272.1  1.490   .33 28.17 27.00                          494-2
  16.    12.    17.    -2.     6.     6.     4.     2.    12.                                        494-3
   4.    64.     1.

    **********   DATA FOR BATTERY S/N 34,35   **********

                                                                                                     1478-1
 787.4  875.5  1.445          540.6  259.8  277.2  1.481  24.00  24.00  23.83                        1478-2
  18.    25.    33.      9.    22.    38.    23.    22.    37.                                       1478-3
                       334.                                                                          1479-1
 781.0  868.8  1.442          536.6  257.0  275.7  1.482  24.00  23.83  23.67                        1479-2
  16.    25.    34.     10.    22.    39.    27.    25.    42.                                       1479-3
                       168.                                                                          1480-1
 783.8  871.8  1.442          538.6  258.1  276.5  1.482  24.00  24.00  23.33                        1480-2
  14.    23.    24.     12.    24.    52.    22.    22.    32.                                       1480-3
                       385.                                                                          1481-1
 782.9  871.1  1.443          537.6  256.9  276.7  1.483  24.00  24.17  23.67                        1481-2
  18.    23.    26.     10.    22.    33.    22.    22.    35.                                       1481-3
                       260.                                                                          1482-1
 784.1  872.1  1.444          534.4  256.9  273.7  1.480  24.00  24.17  23.67                        1482-2
  16.    21.    26.     10.    18.    31.    20.    19.    30.                                       1482-3
                        60.                                                                          1483-1
 783.2  871.6  1.443          537.3  256.8  276.7  1.479  24.00  24.00  23.50                        1483-2
  10.    14.    17.      6.    18.    30.    16.    16.    26.                                       1483-3
                       352.                                                                          1484-1
 786.9  875.1  1.442          539.8  257.2  278.7  1.480  24.00  23.83  23.50                        1484-2
  15.    20.    21.      8.    20.    45.    19.    18.    30.                                       1484-3
                       435.                                                                          1485-1
 784.5  872.8  1.440          539.1  257.6  277.6  1.483  24.00  24.17  23.50                        1485-2
  16.    23.    32.     18.    38.    60.    37.    36.    52.                                       1485-3
                       260.                                                                          1486-1
 787.2  875.2  1.442          540.3  257.9  278.5  1.481  24.00  24.17  23.67                        1486-2
  16.    20.    26.      8.    21.    33.    21.    21.    35.                                       1486-3
                       478.                                                                          1487-1
 785.6  873.2  1.443          539.8  256.3  279.4  1.484  24.00  23.67  23.17                        1487-2
  17.    25.    32.      9.    35.    37.    26.    22.    38.                                       1487-3
                         0.                                                                          1488-1
 783.4  871.3  1.446          533.6  257.0  273.0  1.479  24.00  24.17  23.67                        1488-2
  17.    23.    29.      8.    23.    40.    22.    20.    35.                                       1488-3
                       457.                                                                          1489-1
 787.7  875.6  1.445          537.2  256.8  276.5  1.481  24.00  23.83  23.50                        1489-2
  14.    18.    22.     10.    23.    34.    20.    21.    28.                                       1489-3
                         0.                                                                          1490-1
 781.9  869.8  1.452          535.0  256.4  274.6  1.481  24.00  23.67  23.17                        1490-2
  13.    17.    20.     10.    32.    33.    23.    19.    33.                                       1490-3
                         0.                                                                          1491-1
 783.9  870.8  1.443          535.8  255.3  276.6  1.475   6.00  23.50  23.17                        1491-2
  13.    24.    29.      7.    21.    26.    18.    16.    29.                                       1491-3
                       488.                                                                          1492-1
 787.5  878.7  1.441          542.1  259.3  278.8  1.488   6.00  24.00  23.50                        1492-2
  18.    26.    38.      2.    46.    70.    46.    42.    62.                                       1492-3
                       464.                                                                          1493-1
 786.3  874.4  1.446          539.8  258.6  271.1  1.491   6.00  23.83  23.00
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 16.   27.   34.    7.   32.   34.   24.   22.   36.                            1493-2
                  515.                                                          1493-3
784.6 872.4 1.347                         1.494              23.17              1494-1
                   10.   29.   38.   48.   40.   64.                            1494-2
                  815.                                                          1494-3
784.8 873.0 1.446       535.4 256.6 275.1 1.481 6.00  23.83 23.17               1495-1
 19.   26.   31.   10.   35.   34.   26.   16.   36.                            1495-2
                  565.                                                          1495-3
787.5 875.2 1.441       538.3 256.8 277.6 1.492 6.00  23.33 23.00               1496-1
 14.   23.   27.    7.   29.   27.   32.   28.   43.                            1496-2
                  507.                                                          1496-3
791.6 878.2 1.448       538.0 257.3 276.7 1.491 6.00  23.17 22.83               1497-1
 19.   23.   34.    7.   26.   22.   24.   23.   34.                            1497-2
                  753.                                                          1497-3
789.9 877.8 1.443       540.0 256.2 279.9 1.481 6.00  23.50 23.17               1498-1
  9.   26.   27.    5.   24.   27.   20.   19.   34.                            1498-2
                  788.                                                          1498-3
781.3 869.1 1.348                         1.490              23.34              1499-1
                    6.   22.   28.   36.   20.   50.                            1499-2
                  828.                                                          1499-3
784.7 872.8 1.438       536.7 257.5 275.3 1.492 6.00  23.50 23.00               1500-1
 17.   22.   42.   21.   29.   58.   54.   50.   70.   .10  163.0 242.0         1500-2
                  485.                                                          1500-3
786.3 874.4 1.442       539.3 258.0 277.3 1.485 6.00  23.67 23.17               1501-1
 16.   24.   35.    7.   30.   31.   22.   18.   35.                            1501-2
                  616.                                                          1501-3
785.4 872.9 1.440       539.4 257.9 277.6 1.482 6.00  23.83 23.33               1502-1
 16.   25.   28.   12.   42.   42.   31.   28.   44.                            1502-2
                  440.                                                          1502-3
786.9 875.2 1.444       540.1 258.3 277.8 1.480 6.00  24.17 24.00               1503-1
 11.   24.   31.    7.   20.   32.   22.   22.   36.                            1503-2
                  735.                                                          1503-3
786.6 874.5 1.444       537.6 251.6 276.0 1.483 6.00  23.67 23.17               1504-1
  4.   14.   24.    3.   28.   24.   14.   10.   25.                            1504-2
                  375.                                                          1504-3
786.3 874.2 1.457       539.5 259.6 275.7       1.00                            1505-1
                                                                                1505-2
                  1008.                                                         1505-3
787.1 875.3 1.448       542.5 261.4 277.1 1.483 6.00  24.33 24.00               1506-1
 21.   24.   28.    9.   24.   39.   25.   24.   38.                            1506-2
                  714.                                                          1506-3
786.8 875.5 1.446       538.9 255.6 279.2 1.485 6.00  23.00 23.00               1507-1
  9.   16.   19.   0.01  13.   13.   12.   12.   24.                            1507-2
                  682.                                                          1507-3
783.7 871.9 1.439       540.2 258.0 277.9 1.490 6.00  23.50 23.00               1508-1
 16.   23.   26.   12.   34.   41.   36.   30.   43.                            1508-2
                  500.                                                          1508-3
788.4 876.9 1.436       541.6 260.5 270.9 1.500 6.00  24.33 24.00               1509-1
 28.   38.   43.   22.   46.   81.   66.   58.   85.                            1509-2
                  470.                                                          1509-3
786.5 875.0 1.443       540.7 257.9 278.6 1.498 6.00  23.33 22.83               1510-1
 23.   35.   44.   14.   44.   44.   61.   51.   85.                            1510-2
                  465.                                                          1510-3
780.3 868.3 1.436       535.8 254.6 277.2 1.477 6.00  22.83 22.50               1511-1
 13.   18.   24.   16.   41.   39.   35.   34.   42.                            1511-2
                  491.                                                          1511-3
784.6 872.6 1.442       541.3 260.0 277.5 1.482 6.00  23.83 23.50               1512-1
 14.   20.   20.    5.   28.   29.   23.   22.   36.                            1512-2
                  646.                                                          1512-3
787.3 875.6 1.440       538.7 257.7 277.0 1.484 6.00  23.83 23.17               1513-1
 16.   22.   21.    7.   52.   56.   48.   43.   59.                            1513-2
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386

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                         615.                                                                    1514-1
791.6 879.9 1.437              540.6 258.1 278.5 1.492   6.00 24.17 23.85                       1514-2
 28.   48.   53.         10.    9.    30.   54.   46.    74.                                     1514-3
                         771.                                                                    1515-1
787.9 876.2 1.439              540.4 258.9 277.8 1.484   6.00 23.83 23.17                       1515-2
 16.   25.   36.         13.    44.   44.   32.   27.    49.                                     1515-3
                         568.                                                                    1516-1
783.7 871.7 1.444              540.2 259.1 277.1 1.488   6.00 23.67 23.00                       1516-2
 19.   26.   27.         10.    34.   34.   26.   23.    36.                                     1516-3
                         669.                                                                    1517-1
786.9 874.7 1.349                                1.490              23.51                       1517-2
                          8.    24.   32.   41.   36.    55.                                     1517-3
                         811.                                                                    1518-1
785.8 874.0 1.441              540.8 257.6 279.2 1.490   6.00 23.83 23.00                       1518-2
 27.   42.   48.         25.    66.   68.   67.   58.    84.                                     1518-3
                         432.                                                                    1519-1
784.4 872.7 1.445              535.3 256.4 274.8 1.486   6.00 23.67 23.00                       1519-2
 20.   25.   30.          8.    24.   30.   24.   22.    35.                                     1519-3
                         599.                                                                    1520-1
787.4 875.2 1.444              539.8 260.8 275.1 1.483   6.00 24.00 23.67                       1520-2
 21.   28.   31.         10.    30.   50.   30.   27.    45.                                     1520-3
                         425.                                                                    1521-1
783.2 871.0 1.438              537.4 258.4 275.2 1.494   6.00 23.67 23.33                       1521-2
 22.   32.   50.         24.    54.   64.   72.   64.    90.    1.20 164.0 244.0                 1521-3
                         547.                                                                    1522-1
788.1 876.1 1.453              539.1 258.2 276.9 1.489   6.00 23.67 22.83                       1522-2
 22.   23.   31.         10.    37.   38.   29.   27.    41.                                     1522-3
                         686.                                                                    1523-1
792.6 880.3 1.437              542.7 259.0 279.0 1.495   6.00 23.50 23.17                       1523-2
 20.   29.   42.         22.    52.   61.   75.   66.    90.                                     1523-3
                         409.                                                                    1524-1
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 11.   15.   20.          4.    22.   20.   24.   22.    35.                                     1524-3
                         843.                                                                    1525-1
789.0 876.7 1.444              539.9 257.6 278.1 1.476   6.00 23.33 23.17                       1525-2
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                         712.                                                                    1526-1
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 26.   47.   51.         14.    24.   38.   69.   62.   100.                                     1526-3
                         223.                                                                    1527-1
788.3 876.2 1.435              540.0 257.2 278.6 1.489   6.00 23.00 22.83                       1527-2
 12.   21.   24.          8.    28.   27.   31.   28.    45.                                     1527-3
                         605.                                                                    1528-1
790.6 878.1 1.439              539.6 257.4 278.0 1.488   6.00 23.33 23.17                       1528-2
 18.   27.   42.         17.    40.   37.   50.   42.    71.                                     1528-3
                         516.                                                                    1529-1
786.8 875.4 1.453              539.3 257.3 277.9 1.486   6.00 23.83 23.50                       1529-2
 34.   34.   38.          9.    51.   80.   57.   50.    72.     .01 163.0 239.0                 1529-3
                         585.                                                                    1530-1
787.2 875.2 1.455              539.7 257.8 277.9 1.478   6.00 23.83 23.50                       1530-2
 21.   26.   31.          9.    24.   45.   28.   26.    23.                                     1530-3
                         607.                                                                    1531-1
794.0 881.4 1.430              540.2 257.3 278.9 1.489   6.00 23.17 23.51                       1531-2
 24.   36.   56.         -8.    26.   26.   46.   40.    68.                                     1531-3
                         277.                                                                    1532-1
791.2 879.2 1.435              540.0 258.6 277.3 1.484   6.00 23.50 23.00                       1532-2
 10.   16.   22.         18.    43.   52.   49.   45.    67.                                     1532-3
                         478.                                                                    1533-1
792.7 880.3 1.432              540.1 258.9 277.0 1.487   6.00 23.17 22.67                       1533-2
 16.   41.   44.         15.    42.   55.   75.   63.    90.     .10 163.0 239.0                 1533-3
                         226.
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387

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  786.9 875.0 1.440        539.1 259.3 275.9 1.485  6.00 23.67 23.33        1534-1
   16.   23.   33.   12.    32.   38.   30.   24.   34.                     1534-2
                    566.                                                    1534-3
  788.8 876.4 1.439        540.6 259.4 277.3 1.482  6.00 22.83 23.34        1535-1
   24.   35.   43.   10.    28.   34.   29.   25.   44.                     1535-2
                    566.                                                    1535-3
  790.2 878.3 1.439        537.6 257.3 276.3 1.488  6.00 23.00 22.67        1536-1
   10.   21.   38.   14.    42.   41.   49.   43.   62.                     1536-2
                    535.                                                    1536-3
  784.3 872.6                                1.490              23.50        1537-1
                      8.    25.   35.   46.   39.   64.                     1537-2
                    794.                                                    1537-3
  786.4 874.6 1.440        539.2 259.3 275.9 1.488  6.00 23.83 23.00        1538-1
   12.   20.   26.    5.    28.   27.   23.   22.   34.                     1538-2
                    522.                                                    1538-3
  785.4 873.2 1.442        537.9 257.2 276.6 1.496  6.00 23.50 22.67        1539-1
   26.   25.   38.   24.    54.   64.   77.   69.   90.  1.00  169.0 239.0  1539-2
                    247.                                                    1539-3
  788.8 876.8 1.441        539.1 257.5 277.6 1.477  6.00 23.67 23.50        1540-1
   13.   18.   27.    8.    24.   29.   23.   22.   34.                     1540-2
                    807.                                                    1540-3
  784.8 872.9 1.452                    276.6 1.479  6.00 24.00 23.67        1541-1
   21.   27.   30.   11.    25.   38.   23.   24.   36.                     1541-2
                    709.                                                    1541-3
  788.9 876.7 1.441        539.2 259.2 276.0 1.481  6.00 23.50 23.50        1542-1
   15.   26.   36.   10.    30.   36.   30.   26.   46.                     1542-2
                    494.                                                    1542-3
  790.7 878.8 1.440        539.3 257.2 278.0 1.479  6.00 23.33 23.17        1543-1
   12.   24.   33.    3.    20.   18.   23.   20.   35.                     1543-2
                    776.                                                    1543-3
  789.8 877.7 1.437        540.1 259.3 276.9 1.488  6.00 23.50 23.00        1544-1
    8.   17.   20.    8.    27.   34.   31.   29.   46.                     1544-2
                    570.                                                    1544-3
  793.9 882.0 1.440        538.0 257.6 276.6 1.477  6.00 23.50 23.17        1545-1
   13.   26.   32.    6.    24.   30.   25.   20.   38.                     1545-2
                    669.                                                    1545-3
  784.0 871.7                                1.491              23.51        1546-1
               58.    5.    21.   28.   40.   36.   58.                     1546-2
                    790.                                                    1546-3
  786.8 874.7 1.442        540.0 258.1 277.6 1.477  6.00 23.33 23.17        1547-1
   13.   22.   29.    2.    19.   18.   20.   17.   33.                     1547-2
                    831.                                                    1547-3
  790.9 878.8 1.438        539.4 257.1 278.3 1.478  6.00 22.83 23.00        1548-1
   13.   25.   37.    7.    23.   28.   20.   18.   31.                     1548-2
                    610.                                                    1548-3
  791.5 879.2                          276.7 1.477  6.00       23.17        1549-1
   12.   25.   35.    6.    22.   28.   24.   21.   33.                     1549-2
                    710.                                                    1549-3
  789.3 877.2 1.443        537.3 255.6 277.7 1.484  6.00 23.33 22.83        1550-1
   12.   22.   32.    5.    18.   19.   22.   21.   32.                     1550-2
                    728.                                                    1550-3
  788.8 876.7 1.443        542.0 259.8 277.8 1.487  6.00 23.00 23.00        1551-1
   16.   25.   29.    5.    26.   26.   35.   31.   52.                     1551-2
                    615.                                                    1551-3
  790.7 878.5 1.442        537.6 257.6 275.6 1.486  6.00 23.17 23.00        1552-1
   17.   24.   36.    5.    26.   26.   29.   26.   44.                     1552-2
                    718.                                                    1552-3
  793.0 880.8 1.442        541.4 259.2 278.2 1.480  6.00 23.67 23.00        1553-1
   18.   28.   32.    6.    33.   34.   30.   24.   46.                     1553-2
                    644.                                                    1553-3
  785.3 873.4 1.448        537.7 255.5 278.2 1.488  6.00 23.17 23.00        1554-1
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388

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 41.   45.   58.   16.   46.   56.   54.   48.   75.                          1554-3
                   368.                                                        1555-1
                        540.0 258.9 276.9 1.497  6.00 23.17 23.00
789.6 877.7 1.444                                                              1555-2
 18.   18.   39.   15.   43.   41.   61.   52.   89.                           1555-3
                   377.                                                        1556-1
                        537.3 255.1 278.2 1.482  6.00 22.83 22.67
788.2 876.7 1.449                                                              1556-2
 15.   20.   26.   15.   21.   21.   22.   20.   33.                           1556-3
                   705.                                                        1557-1
                                                                               1557-2
                                                                               1557-3
                                                                               1558-1
                                                                               1558-2
                                                                               1558-3
                                                    1.482           23.68      1559-1
790.2 878.1 1.445                                                              1559-2
             27.   0.01  9.    13.   17.   16.   29.                           1559-3
                   695.                                                        1560-1
                        540.8 256.9 279.8 1.474  6.00 23.33 23.50
790.2 877.8 1.452                                                              1560-2
 12.   20.   28.   7.    19.   23.   18.   18.   28.                           1560-3
                   811.                                                        1561-1
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784.4 872.8 1.446                                                              1561-2
 14.   25.   26.   5.    21.   22.   26.   24.   38.                           1561-3
                   490.                                                        1562-1
                        540.6 258.7 277.7 1.483  6.00 23.50 23.00
794.3 882.0 1.453                                                              1562-2
 13.   24.   28.   8.    24.   30.   24.   22.   37.                           1562-3
                   868.                                                        1563-1
                        539.3 256.7 278.3 1.477  6.00 23.33 23.33
788.2 876.0 1.449                                                              1563-2
 18.   27.   32.   4.    21.   21.   26.   22.   41.                           1563-3
                   599.                                                        1564-1
                        534.2 254.2 275.5 1.487  6.00 22.83 23.00
787.3 875.0 1.446                                                              1564-2
 7.    15.   14.   3.    19.   21.   23.   20.   35.                           1564-3
                   598.                                                        1565-1
                        540.4 258.6 277.5 1.476  6.00 23.50 23.33
793.2 880.8 1.448                                                              1565-2
 13.   16.   20.   5.    19.   23.   18.   15.   48.                           1565-3
                   559.                                                        1566-1
                        536.4 256.9 275.3 1.475  6.00 23.17 23.17
782.6 871.1 1.453                                                              1566-2
 12.   18.   27.   4.    19.   20.   20.   17.   34.                           1566-3
                   862.                                                        1567-1
                        539.8 258.4 277.1 1.477  6.00 23.83 23.67
788.7 877.0 1.452                                                              1567-2
 9.    13.   20.   4.    23.   26.   16.   16.   28.                           1567-3
                   863.                                                        1568-1
                                                                               1568-2
                                                                               1568-3
                        538.0 259.2 274.4 1.475  6.00 23.50 23.33              1569-1
789.5 877.2 1.448                                                              1569-2
 17.   26.   30.   10.   27.   32.   24.   22.   38.                           1569-3
                   852.                                                        1570-1
                        539.4 258.9 276.8 1.479  6.00 23.83 23.00
795.1 882.8 1.450                                                              1570-2
 17.   26.   32.   9.    35.   33.   27.   22.   39.                           1570-3
                   800.                                                        1571-1
                        537.8 258.7 274.8 1.477  6.00 23.67 23.00
791.5 880.0 1.458                                     25.00 161.0 251.0        1571-2
 13.   17.   19.   8.    25.   24.   17.   16.   25.                           1571-3
                   1087.                                                       1572-1
                        537.5 258.3 279.1 1.478  6.00 23.50 23.00
791.6 879.4 1.443                                                              1572-2
 10.   16.   22.   9.    22.   26.   19.   20.   28.                           1572-3
                   947.                                                        1573-1
                        539.5 258.9 276.0 1.484  6.00 24.17 24.00
789.8 878.1 1.458                                                              1573-2
 10.   16.   22.   9.    23.   38.   22.   21.   29.                           1573-3
                   1022.                                                       1574-1
                                                                               1574-2
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  792.1  879.8  1.454         538.0  257.7  276.8  1.485   6.00  23.67  23.17         1575-
    10.    27.    30.     8.    33.    31.    22.    22.    31.                      1575-
                  1050.                                                              1575-
  791.7  879.3  1.445         537.8  258.3  275.4  1.480   6.00  23.67  23.50         1576-
    16.    26.    27.    10.    38.    38.    32.    29.    47.                      1576-
                   576.                                                              1576-
  790.6  878.1  1.459         538.3  257.0  277.1  1.486   6.00  23.67  23.00         1577-
    14.    20.    22.     8.    27.    25.    18.    18.    28.  29.20  169.0  250.0 1577-
                   973.                                                              1577-
  789.6  877.7  1.447         538.1  257.1  277.0  1.487   6.00  23.50  23.83         1578-1
    18.    22.    30.    11.    28.    32.    26.    24.    40.                      1578-2
                   788.                                                              1578-3

  785.0  872.6  1.444                              1.483                23.68         1580-1
                  21.    -3.     6.    10.    14.    13.    22.                      1580-2
                   683.                                                              1580-3
  790.8  878.8  1.447                              1.479                23.51         1581-1
                  20.    -4.     5.    10.    12.    10.    19.                      1581-2
                   954.                                                              1581-3
  790.2  877.8                                     1.475                23.51         1582-1
    13.    18.    19.     8.    25.    32.    18.    17.    28.                      1582-2
                                                                                     1582-3
  786.6  874.5                                     1.483                22.85         1583-1
    11.    15.    21.     8.    22.    26.    22.    20.    33.                      1583-2
                                                                                     1583-3
  792.2  881.0                                     1.477                23.34         1584-1
    16.    24.    33.     8.    30.    28.    24.    24.    36.                      1584-2
                                                                                     1584-3
  794.3  882.6                                     1.479                23.34         1585-1
    14.    16.    22.     7.    25.    25.    24.    23.    38.                      1585-2
                                                                                     1585-3
  789.6  887.7                                     1.473                23.00         1586-1
    14.    18.    24.   0.01    23.    21.    16.    14.    25.                      1586-2
                                                                                     1586-3
  786.9  875.3  1.343                              1.488                23.17         1587-1
                  62.    10.    31.    38.    52.    44.    68.                      1587-2
                   820.                                                              1587-3
  789.1  877.6  1.350                              1.491                23.51         1588-1
                  50.     5.    21.    28.    43.    37.    62.                      1588-2
                   795.                                                              1588-3
  786.2  874.6  1.347                              1.493                23.51         1589-1
                  41.     6.    21.    28.    39.    43.    52.                      1589-2
                   810.                                                              1589-3
  791.4  879.5  1.348                              1.490                23.34         1590-1
                  30.     6.    19.    26.    34.    30.    46.                      1590-2
                   824.                                                              1590-3
  792.4  880.5  1.353                              1.487                23.34         1591-1
                  47.     2.    12.    17.    20.    18.    31.                      1591-2
                   784.                                                              1591-3
  804.7  896.1  1.447    8.7  540.8  258.6  278.2  1.483  48.00  24.67  23.68          495-1
    10.    13.    21.     0.     8.    11.    16.     5.    13.                       495-2
                   565.                                                               495-3
  801.7  890.1  1.446    8.9  540.9  258.9  278.0         48.00                       496-1
                                                                  9.00  157.0  237.0  496-2
                   372.                                                               496-3
  795.4  887.7  1.448    8.8  536.1  257.4  274.4  1.481  48.00  24.50  23.68          497-1
    11.    13.    19.     2.    10.    12.     9.     6.    14.                       497-2
                   323.                                                               497-3
```

390

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                                                                            498-1
799.5 891.8 1.446   8.7   537.1 257.3 275.3 1.475 48.00 24.17 23.34         498-2
  6.   12.   14.   -1.     12.   12.    8.    7.   14.                      498-3
                  375.                                                      499-1
800.5 892.3 1.448   8.8   538.4 257.8 276.7 1.487 48.00 24.17 23.34         499-2
 10.   12.   20.    0.     16.   14.   11.   10.   28.                      499-3
                  410.                                                      500-1
801.0 892.8 1.450   8.5   540.5 258.2 278.2       48.00 15.30 155.0 237.0   500-2
                                                                            500-3
                 1090.                                                      502-1
795.2 888.8 1.448   8.8   537.6 256.4 277.1 1.483 48.00 24.00 23.34         502-2
 14.   16.   19.    2.     12.   16.   14.   12.   20.  23.20 162.0 248.0   502-3
                  145.                                                      503-1
798.6 891.6 1.450   8.6   539.7 258.9 276.8       48.00 10.60 155.0 239.0   503-2
                                                                            503-3
                    0.                                                      504-1
796.8 889.8 1.449   8.9   536.2 257.4 274.8 1.477 48.00 24.33 23.68         504-2
  8.   10.   12.   -2.      6.   22.    6.    4.   11.                      504-3
                  655.                                                      505-1
806.4 898.6 1.448   8.7   542.1 258.6 279.9 1.475 48.00 24.17 23.33         505-2
  8.   10.   17.   -2.     14.   14.    8.    5.   14.                      505-3
                  633.                                                      506-1
798.5 890.6 1.447   8.6   538.5 258.7 275.4 1.483 48.00 24.33 24.00         506-2
  8.   10.   12.    0.      8.   14.    6.    6.   10.                      506-3
                  752.                                                      507-1
788.0 875.8 1.448         536.9 257.2 275.9        2.00  6.70 157.0 239.0   507-2
                                                                            507-3
                  587.                                                      508-1
797.6 889.8 1.447   8.8   537.4 258.7 274.9 1.490 48.00 24.50 23.51         508-2
 10.   12.   14.    2.     10.   12.    9.    6.   14.                      508-3
                  352.                                                      510-1
796.5 888.5 1.445   8.7   538.9 256.1 278.3 1.483 48.00 23.83 23.34         510-2
  8.   11.   17.    0.     11.   11.   10.    9.   17.                      510-3
                  340.                                                      511-1
797.3 889.5 1.443   8.8   537.0 255.0 277.9 1.472 48.00 24.00 23.34         511-2
  6.    8.   11.  -10.      5.    5.    3.    2.   10.                      511-3
                  442.                                                      512-1
799.2 891.9 1.445   8.8   538.5 256.4 278.1 1.477 72.00 24.00 23.51         512-2
 18.   20.   32.    6.     21.   14.   17.   14.   26.                      512-3
                  555.                                                      513-1
801.1 892.9 1.468   8.8   538.6 257.8 276.9        1.00                     513-2
                                                                            513-3
                 1650.                                                      514-1
802.3 894.8 1.448   8.8   538.3 257.6 276.8       72.00 24.50               514-2
 16.   13.   23.                                                            514-3
                  550.                                                      515-1
795.9 888.1 1.447   8.8   538.8 258.4 276.4 1.476 72.00 24.00 23.17         515-2
 13.   15.   21.   -1.     13.   17.    8.    7.   13.                      515-3
                  550.                                                      516-1
795.7 887.7 1.461   8.8   536.7 258.4 274.0        1.00                     516-2
                                                                            516-3
                 1328.                                                      517-1
793.3 885.3 1.447   8.7   534.4 257.0 273.3 1.479 72.00 24.17 23.33         517-2
 12.   14.   13.   -1.      9.   11.    6.    5.   12.                      517-3
                  305.                                                      518-1
806.5 898.3 1.446   8.8   542.2 260.7 277.6 1.479 72.00 24.67 23.68         518-2
 14.   20.   20.    3.     16.   18.   12.   11.   21.                      518-3
                  190.                                                      519-1
800.6 892.5 1.441   8.9   540.7 259.6 277.0 1.483 72.00 24.33 24.00         519-2
  9.   12.   21.    1.     10.   20.   12.   12.   17.                      519-3
                  230.                                                      520-1
798.2 890.5 1.441   8.8   540.2 256.9 279.2 1.477 72.00 24.17 23.33
```

```
    12.    13.    22.     2.    13.    15.    10.     7.    16.                               520-
                          0.                                                                  520-
 805.2  897.8  1.446    8.8  541.8  258.6  279.4  1.475  72.00  24.00  23.17                  521-
    16.    17.    29.     4.    16.    20.    14.    11.    20.                               521-2
                        460.                                                                  521-
 800.2  892.2  1.448    8.8  538.0  258.3  275.7  1.472  72.00  23.83  23.00                  522-
     7.    12.    11.     2.    10.    13.     6.     4.    12.                               522-
                        550.                                                                  522-
 801.8  894.4  1.448    8.8  543.4  261.2  278.0  1.479  72.00  24.33  23.51                  523-
    16.    18.    18.     2.    14.    14.     8.     6.    14.                               523-2
                          0.                                                                  523-
 803.2  895.2  1.465    8.8  538.4  256.7  277.7          1.00                                524-
                                                                                              524-2
                       1466.                                                                  524-3
 807.4  899.2  1.441    8.6  540.2  258.4  278.0  1.474  72.00  24.17  23.51                  525-1
    12.    14.    20.     3.    13.    15.    10.     8.    16.                               525-2
                          0.                                                                  525-3
 797.2  889.6  1.438    8.7  537.7  258.6  275.2  1.476  72.00  24.50  23.68                  526-1
    20.    21.    26.     4.    17.    20.    15.    12.    23.                               526-2
                        105.                                                                  526-3
 788.8  880.8  1.449                                      2.00                                527-1
                                                                12.30  157.0  240.0           527-2
                        610.                                                                  527-3

 111.11
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APPENDIX E

Summary of Test Results in Spare Nickel-Cadmium Cells From OAO A-2 Flight Batteries

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Engineering Physics Division
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X-761-71-228

SUMMARY OF TEST RESULTS ON SPARE NICKEL-CADMIUM CELLS FROM OAO-A-2 FLIGHT BATTERIES

Floyd E. Ford

April 1971

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

394

SUMMARY OF TEST RESULTS ON SPARE NICKEL-CADMIUM CELLS FROM OAO-A-2 FLIGHT BATTERIES

Floyd Ford
Engineering Physics Division

ABSTRACT

Five cells from the production lot for OAO flight batteries for the A-2 spacecraft were subjected to 6091 orbital cycles simulating some of the various electrical conditions the spacecraft battery experiences in flight. It was shown that the undervoltage cut-off of 1.18 volts per cell would yield over 85% of the battery's ampere-hour capacity to 1.00 volts average when new, but provided less than 65% after extended periods of orbital cycling. The loss of discharge voltage with cycling is attributed to the onset of a "double plateau" effect observed after extended periods of repetitive cycling. Partial improvement in the discharge voltage was obtained by allowing the battery to "run down" in ampere-hour capacity; however, the voltage was enhanced only to the depth-of-discharge the battery experienced during the "run down." A like "new" discharge voltage profile can be obtained only if the deep discharge is conducted to 1.0 volts per cell average, or below the voltage exhibited on the lower plateau.

Low temperature (0°C) tests conducted at various cycle intervals revealed an increase in each cell voltage of approximately 0.020 volts. One cell exhibited an abnormal voltage increase (above 1.55 volts) and was shown to be generating hydrogen gas during the overcharge test. After reverse charging the cell to remove 3.0 ampere-hours of precharge, the overcharge voltage decreased to the values exhibited by the other four cells. All cells operated satisfactorily after 450 days of test and delivered 23.0 ampere-hours after completing 6091 cycles.

The test results have demonstrated that cells with apparently "normal" characteristics when new may exhibit "abnormal" changes in overcharge characteristics with cycling. Change in overcharge voltage for one cell is attributed to excessive precharge combined with the effects of "negative capacity fading" with cycling. The importance of rigid controls during the manufacturing of nickel-cadmium aerospace cells is shown through correlation of cell test results to the manufacturing process.

395

CONTENTS

ILLUSTRATIONS

396

ILLUSTRATIONS (Continued)

397

ILLUSTRATIONS (Continued)

TABLES

398

SUMMARY OF TEST RESULTS ON SPARE NICKEL-CADMIUM CELLS FROM OAO-A-2 FLIGHT BATTERIES

INTRODUCTION

Five cells from the group of cells manufactured by Gulton Industries for Orbiting Astronomical Observatory (OAO) battery assemblies 25A and 26A were tested at Goddard Space Flight Center from September 16, 1968 to December 12, 1969. These cells are identified by the serial numbers 424A, 602, 588, 603, and 639. These cells were tested as a 5-cell pack. The exact details of each test sequence and cycle condition are beyond the scope of this document; however, the general test conditions are as follows:

Cycle: 90 minutes (60-minute charge, 30-minute discharge)

Depth of Discharge: 15%

Charge Rate: 5 and 8 amperes

Temperature: 0°C, 15°C, and 32°C (two test conditions at 40°C)

The temperature was 15°C or lower for over 70% of the total test period (6091 90-minute cycles during 450 days). To observe changes in overcharge voltage, the pack was subjected to a C/20 (1.0 amperes) overcharge at 0°C after various cycle conditions. The effects of continuous cycling on battery discharge voltage and capacity were also observed. Findings and observations from the test on the A2 flight cells are summarized below.

CYCLING TESTS

Figure 1 is a summary of the results obtained while cycling with various voltage limits as controls. Charge rates of 5 amperes (lower curve) and 8.0 amperes (upper curve) were used throughout the series of tests. The test temperatures were 0°C, 15°C, and 32°C. Also shown (along the ordinate) are the minimum values for percent recharge at these temperatures. It is noted that, using the nominal battery voltage limit system (BVLS), level four, the percent recharge increases with decreasing temperature. Because of the slope of the BVLS curves, the battery overcharge exceeds the minimum requirements at low temperatures in order to meet the minimum requirements at high temperatures. This design characteristic was implemented to minimize the possibility of thermal run-a-way.

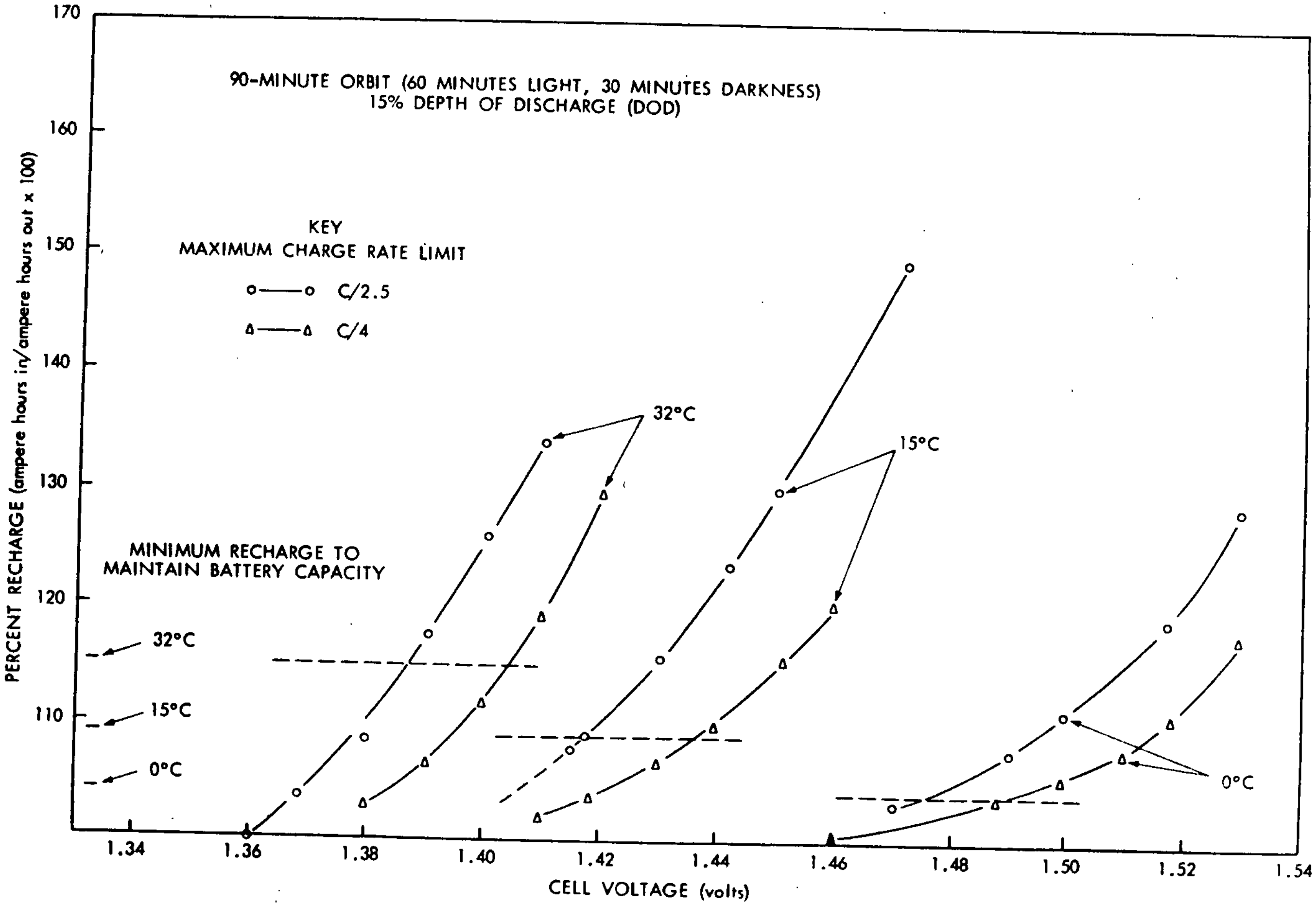

Figure 1. Recharge Percentage for Voltage-Limit Charging of OAO-A-2 Flight Cells

400

At various intervals during the cycling test, the pack was discharged to determine the cell ampere-hour capacity and to observe the effects of continuous cycling on the discharge voltage. Note that on some data sheets and/or curves two cycle numbers are given. The larger number is the number of accumulative charge-discharge cycles, while the smaller one is the number of charge-discharge cycles completed since the previous capacity discharge of the pack.

Figure 2 is a comparison of the ampere-hour capacity from pre-cycling test with the capacity after 627 continuous cycles (1437 total cycles). The 627 continuous cycles were completed at the three test temperatures previously given and under conditions simulating the various BVLS limits. The characteristic observed on discharge after 627 continuous cycles, where the voltage decreases from approximately 1.16 volts per cell to just above 1.0 volts per cell, is observed throughout the test program on these cells.

Figure 3 illustrates the voltage for a 6-ampere discharge after varying numbers of uninterrupted cycles. Curve 1 is used as the reference for discussion because it represents 1636 continuous cycles. It is from this data that the "double" or "two-plateau" voltage can be positively identified for the first time during this test. It is noted that for curve 1 after 1636 continuous cycles at 15% depth of discharge, the end of dark voltage is 1.22 volts/cell (25.62 volts for 21 cells). This value was consistent with the end of dark voltage from several previous cycles. The first stable plateau on discharge occurs at approximately 1.18 to 1.19 volts/cell (24.78 to 24.99 volts for 21 cells), which is very close to URG (undervoltage restabilization generator) level for the A-2 spacecraft. The reason for the change in voltage from the upper plateau to the lower plateau is not fully understood. This change is sometimes referred to as "memory." The maximum and minimum cell voltage during the transition between voltage plateaus is shown to illustrate that all cells do not respond identically. It is noted that on this pack the first cell to decrease in voltage to the lower plateau is the highest capacity cell in terms of ampere-hours to 1.0 volt per cell.

Following the discharge shown by curve 1, the battery was returned to cycling for recharge. After 28 cycles, a capacity discharge was made to assess any change in the discharge voltage characteristics. It is readily apparent from Figure 3 that the discharge voltage (curve 2) is significantly improved by the previous discharge illustrated by curve 1. A comparison of ampere-hours to a specific discharge voltage for cycles 3074 and 3101 is given in Table 1.

The ampere-hour capacity to 1.0 volts is greater after extended cycling than after the discharge following the capacity cycle. Contrary to this finding, the capacity to other voltages listed is always greater on the discharge following the capacity cycle shown in curve 1. It is obvious that the ampere-hour limitation of a battery after extended cycling is primarily dependent on the definition

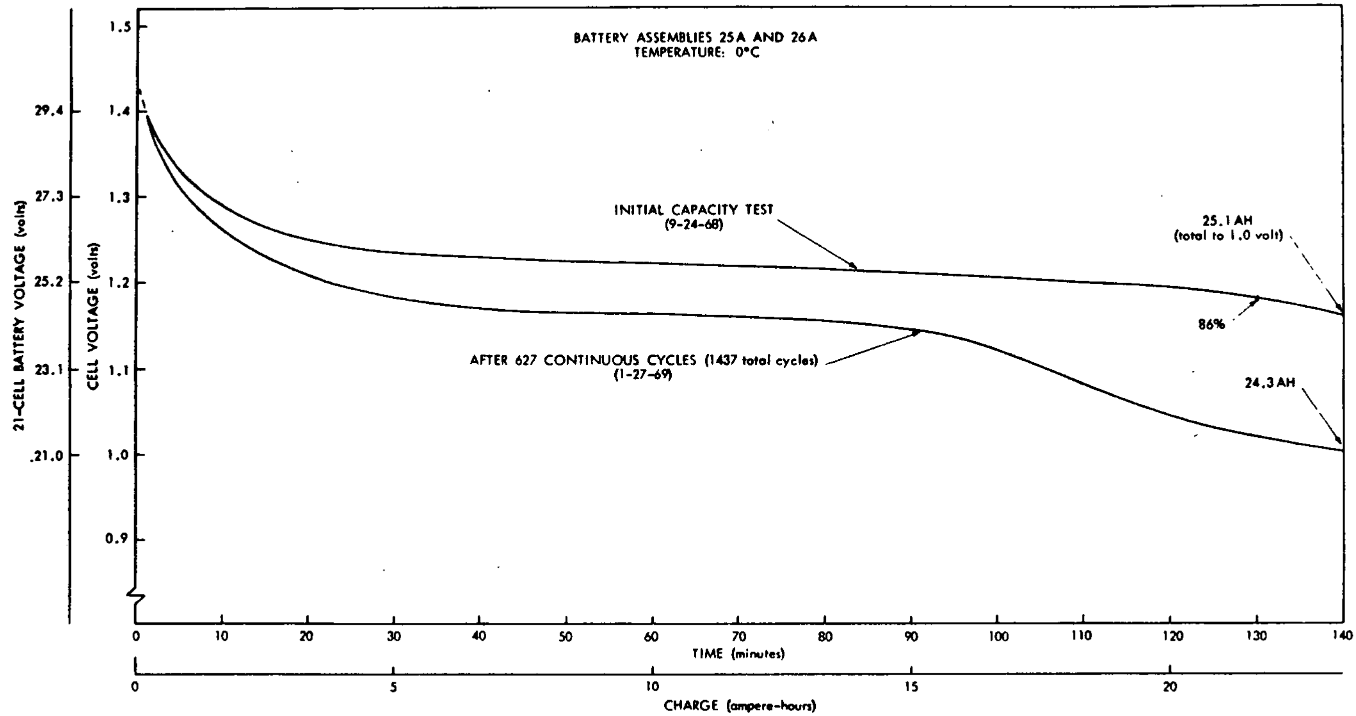

Figure 2. Voltage Profile for 10-Ampere Discharge

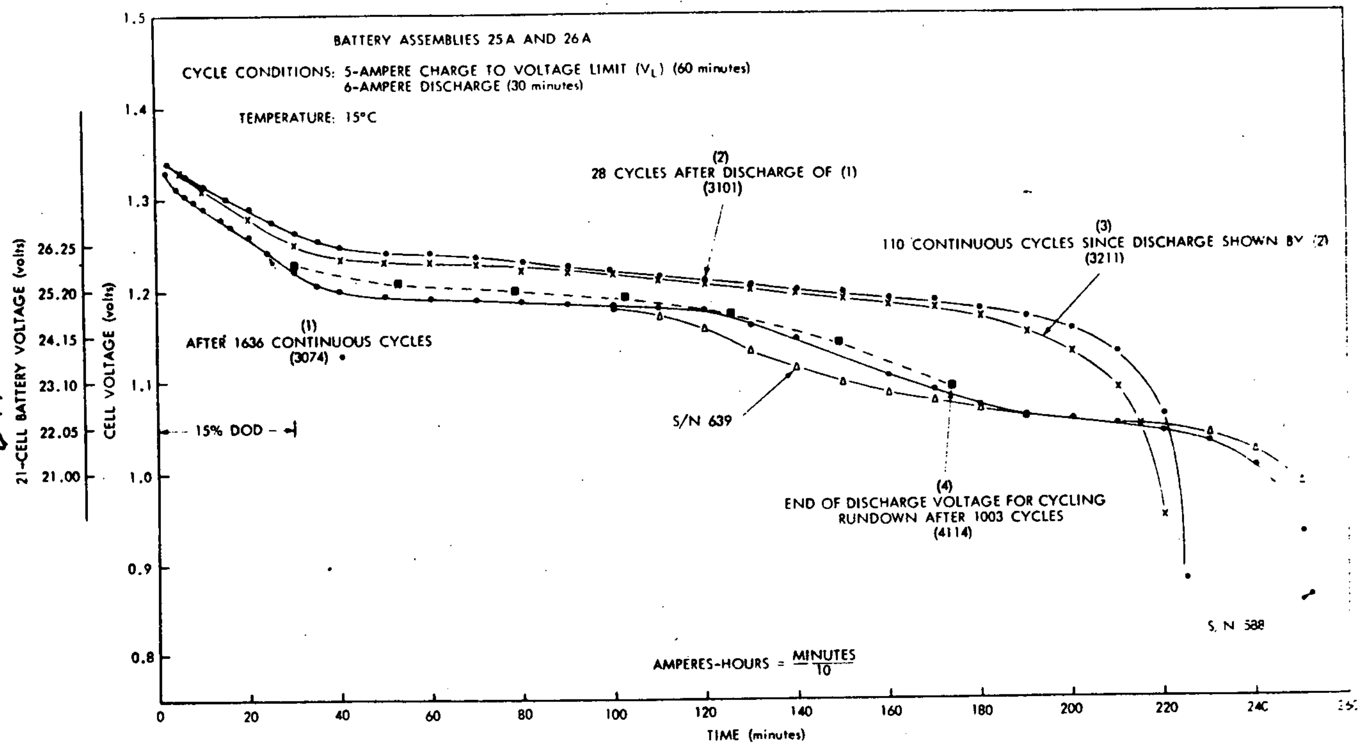

Figure 3. Voltage Profile for 6-Ampere Discharge After Various Numbers of Consecutive Cycles

Table 1

Comparison of Discharge Voltage to Capacity for Two Cycles

Discharge Voltage per Cell	Voltage for 21 Cells	Voltage for 22 Cells	Ampere-Hour Capacity	
			Cycle 3074	Cycle 3101
1.00	21.00	22.00	24.3	22.3
1.10	23.10	24.20	15.5	21.5
1.15	24.15	25.30	13.0	20.3
1.20	25.20	26.40	4.0	14.0

of undervoltage. It can be concluded that a safe undervoltage cut-off (1.10 to 1.15 volts/cell) for "new" or reconditioned batteries will result in a severe capacity penalty for batteries that have experienced extended cycling under the OAO cycle conditions. Data taken after 110 cycles (curve 3) show that the discharge voltage has decreased slightly below that for the previous discharge (curve 2). The steady-state percent recharge for the 110 cycles prior to the discharge shown in curve 3 was 107%.

Because actual use of the battery in orbit does not provide for continuous discharge as performed in the preceding test, it was decided to simulate a "run-down" in battery capacity such as would be caused by reduction of the available charging current during the sunlit portion of the orbit. A total of 1003 cycles was accumulated before the run-down was initiated. Curve 4 of Figure 3 illustrates the results. The depth of discharge was 15% (3.0 ampere-hours per shadow period) and the recharge was 0.8 ampere-hours per sunlit period, causing a loss of approximately 2.2 ampere-hours per orbit. The similarity of the voltage profile of curve 1 for the constant current discharge, and curve 4 for the cyclic run-down, leads to the conclusion that the double-plateau voltage has reappeared. The voltage profile obtained for the cyclic run-down was very similar to that for the constant current discharge. Following the cyclic run-down, the pack was allowed to recharge for 13 cycles by increasing the charge rate to 5.0 amperes. The pack was again discharged by using a constant current (6.0 amperes). Data for this discharge are illustrated in Figure 4 for comparison with previous discharge data.

The voltage profile for this discharge (cycle 4134) is very significant in that it reveals two distinct characteristics: (1) The discharge voltage, up to 140

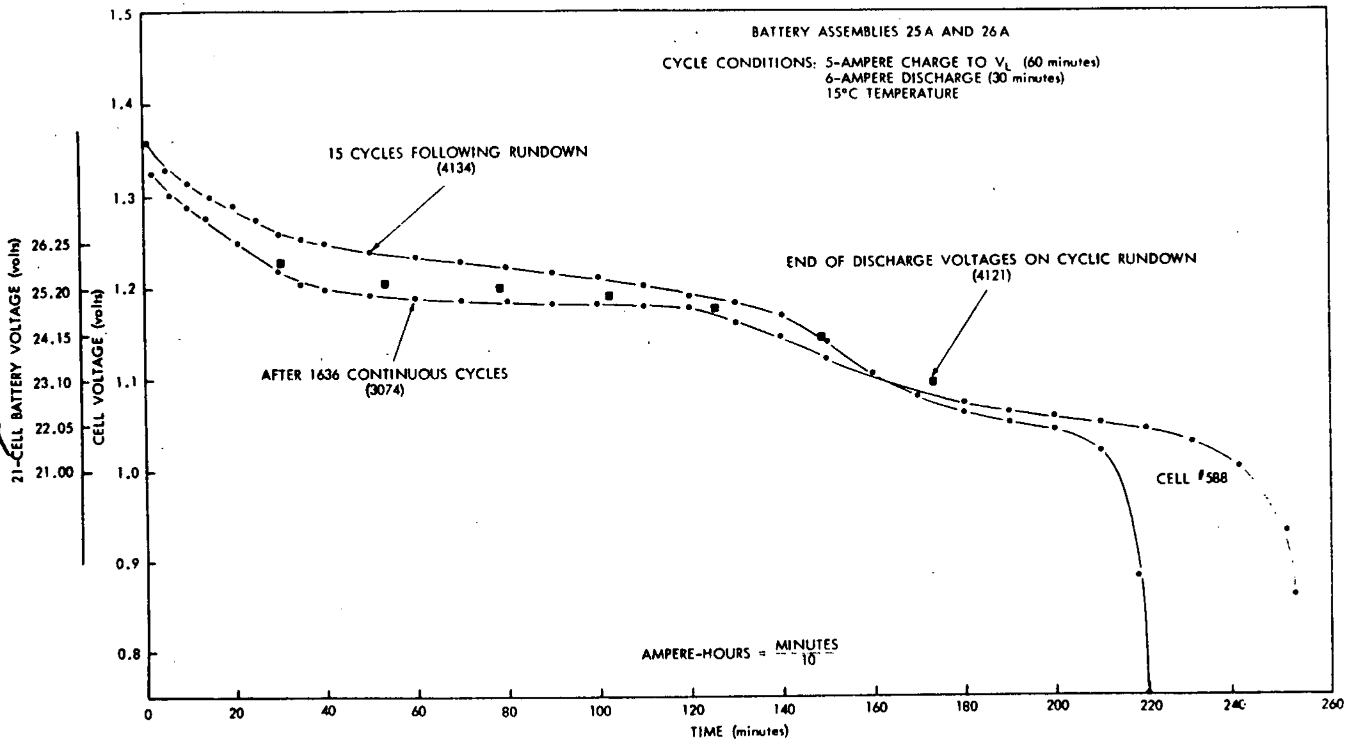

Figure 4. Voltage Profile for 6-Ampere Discharge, Showing the Effect of Continuous Cycling

minutes of discharge, is higher than that obtained during the same period in a cyclic run-down, and (2) The two-plateau effect was not eliminated by the cyclic run-down to 1.1 volts per cell. It is noted that the increase in capacity to 1.18 volts per cell after cyclic run-down is approximately 1.5 ampere-hours.

A comparison of discharge voltage vs. state-of-charge for three conditions reveals the following:

Condition	Percent of total capacity* to 1.18 volts/cell
Prior to Cycling	86% (10.0 amperes)
After 1636 Continuous Cycles	62% (6.0 amperes)
Post Cycling Capacity (after cyclic recharge)	96% (6.0 amperes)

*Total capacity is that obtained for discharge to 1.0 volt per cell.

It is noted that the capacity obtained when discharging the pack at 15°C or 0°C to 1.0 volts/cell was always greater than the rated value of 20 ampere-hours. The final discharge after 6091 cycles resulted in 23.1 ampere-hours. It can be concluded that the capacity obtained to any voltage between 1.30 and 1.0 is very dependent on the cycle history of the cells or battery. The present URG level of 1.18 volts per cell yields over 85% of the battery's total capacity when new, but provides less than 65% after extended periods of orbital use. It has been further demonstrated that allowing the battery to run down to URG in orbit provides for only a slight improvement in battery discharge voltage. To improve effectively the discharge voltage to near "new" condition, a discharge well into the second voltage plateau is required.

Additional work is needed to determine the exact cause of the two-plateau voltage and just how it can be prevented. One solution that seems feasible is to require the manufacturer to use more electrolyte (KOH) in the cells. An examination of components from cell #588 of this test group revealed two problems: the cell was extremely dry, and cadmium migration had taken its toll on the separator. The components from this cell were compared with the components of a cell from three-year storage. There was no apparent degradation of the cell taken from storage. Just how great an increase in KOH is necessary above the amount now used is not known for the 20 ampere-hour cell. Tests at GSFC on the Gulton 6.0 ampere-hour cell revealed that up to 20% increase in KOH quantity did not cause any significant increase in cell pressure. The long-term effect was not determined because of separator contamination. A proposed test to investigate the addition of KOH to OAO cells is currently underway.

406

OVERCHARGE TESTS

One reason for conducting the extended cycling test on these cells was to determine if any change in voltage characteristics occurred during the life of the cell. Because the cell voltage is sensitive to temperature, the test was conducted at 0°C, using a C/20 charge rate. The data obtained at various intervals during the 6091 cycles were compared with those measured by the manufacturer at 5°C using the C/20 charge rate. The lower temperature of 0°C was used because all previous overcharge tests at GSFC had been conducted at this temperature.

Table 2 summarizes the results. The first overcharge test was conducted after 2538 cycles. The voltage of each cell at this time was slightly higher than the voltage obtained during test by the manufacturer and may be attributed to the 5°C difference in temperature. Cell #424 exhibited slightly higher voltage than the other four cells. During the overcharge test after 4577 cycles, all cells exhibited an increase in voltage; however, cell #424 showed a significant increase when compared with the other four cells. It was at this point that the trend of increasing voltage was established on cell #424. During the overcharge test following cycle 5438, the voltage of cell #424 was approximately 50 millivolts higher than that of any other cell.

During cycle 5595 (1.51 volts/cell limit), a gas sample was extracted from cell #424 and analyzed. Of the 38 PSIG pressure, 70% was hydrogen and 30% was oxygen. Cycling was continued, and the pressure trend was observed. By cycle 5642, the end of charge pressure was at 37 PSIG (increased from 32 PSIG after the sample of cycle 5595 was extracted), while the end of charge pressure of the other four cells remained stable during this period. Data for a typical cycle (5642) are shown in Figure 5, illustrating the cell voltage divergence during charge. The voltage of cell #424 never reached 1.55 volts during the cycling test.

Immediately following cycle 5642, the overcharge test was repeated. Results from this test are illustrated in Figure 6. After two hours at C/20 (0°C), the current was reduced to 0.5 amperes to bring the voltage of cell #424 below 1.55 volts. The voltage of cell #424 was allowed to exceed the 1.55 volt limit for just over 75 minutes in order to observe the cell pressure change. During the two-hour period, the pressure increased from 37 to 43 PSIG.

The condition of this cell prohibited further cycling and overcharge tests at 0°C, and it was decided to adjust the pre-charge on the cadmium plates. Upon discharging the pack, cell #424 was reverse-charged at 2.0 amperes for 90 minutes. During the 3.0 ampere-hour reverse-charge, a gas sample was taken to determine the gas content of this cell. (The cell had been evacuated before reverse-charging.) The sample, which contained more than 97% hydrogen,

Table 2

Overcharge Voltages for A-2 Flight Cells

Test Date	Cycles* Completed	Serial Numbers					Comments**
		424	602	588	603	639	
		Voltage					
9-9-68	—	1.472	1.474	1.463	1.477	1.482	Test conducted by manufacturer 4° C @ C/20
4-8-69	2538	1.491	1.485	1.482	1.486	1.483	
8-15-69	4577	1.543	1.500	1.512	1.504	1.497	
10-28-69	5438	1.546	1.500	1.510	1.497	1.499	
11-7-69	5595	—	—	—	—	—	Gas Sample: 70% Hydrogen, 30% Oxygen
11-10-69	5642	1.576	1.503	1.530	1.506	1.506	Test terminated after 2 hours
11-12-69	—	—	—	—	—	—	Capacity discharge: Cell #424 reversed charge @ C/10 - 3.0 AH
11-14-69	5687	1.519	1.537	1.532	1.536	1.516	
11-21-69	5792	1.518	1.508	1.506	1.509	1.495	
12-5-69	6014	1.513	1.512	1.503	1.523	1.503	

*The test was terminated after 6091 cycles.

**All GSFC overcharge tests were conducted at 0°C, with 1.0 ampere charge rate.

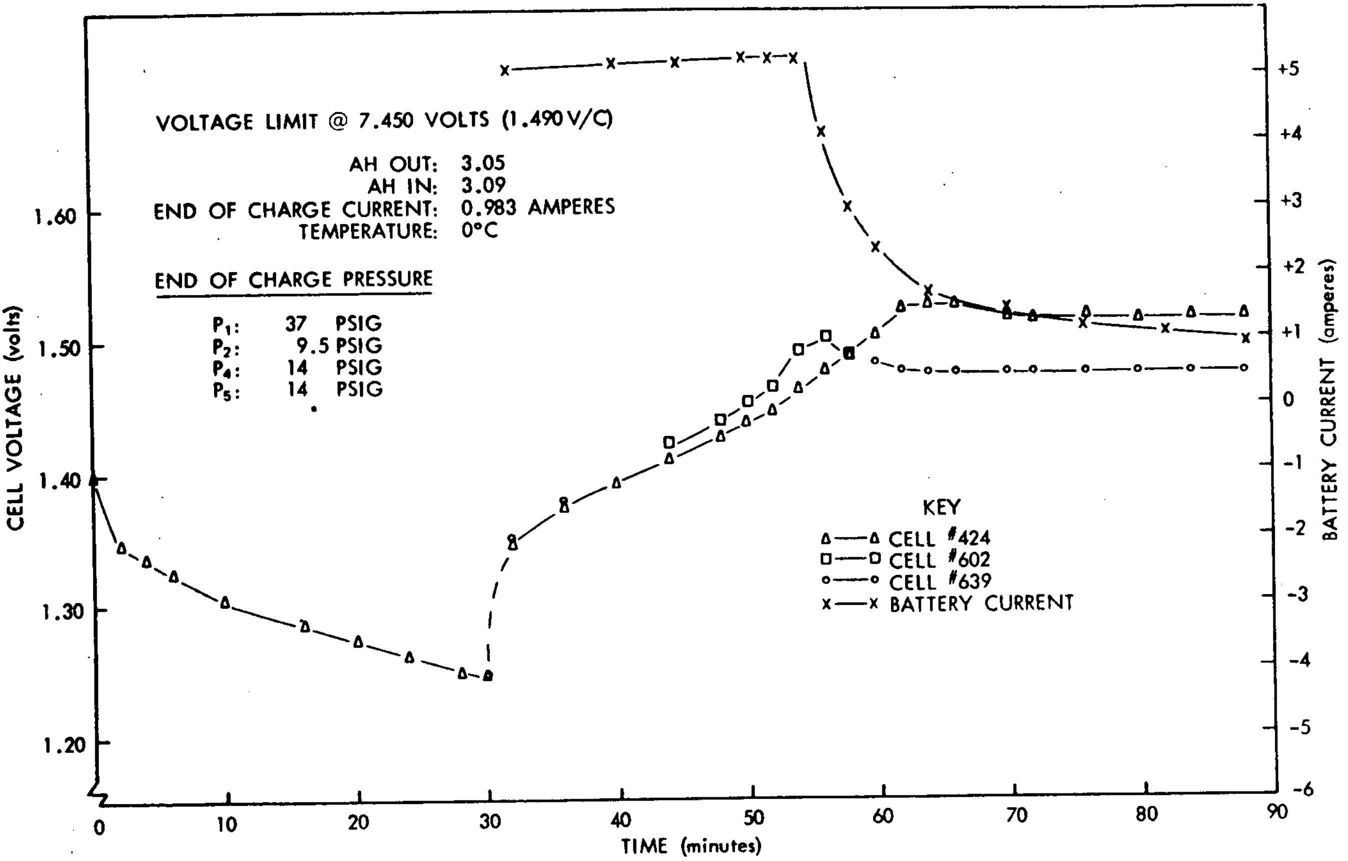

Figure 5. Voltage Profile for Cycle 5642

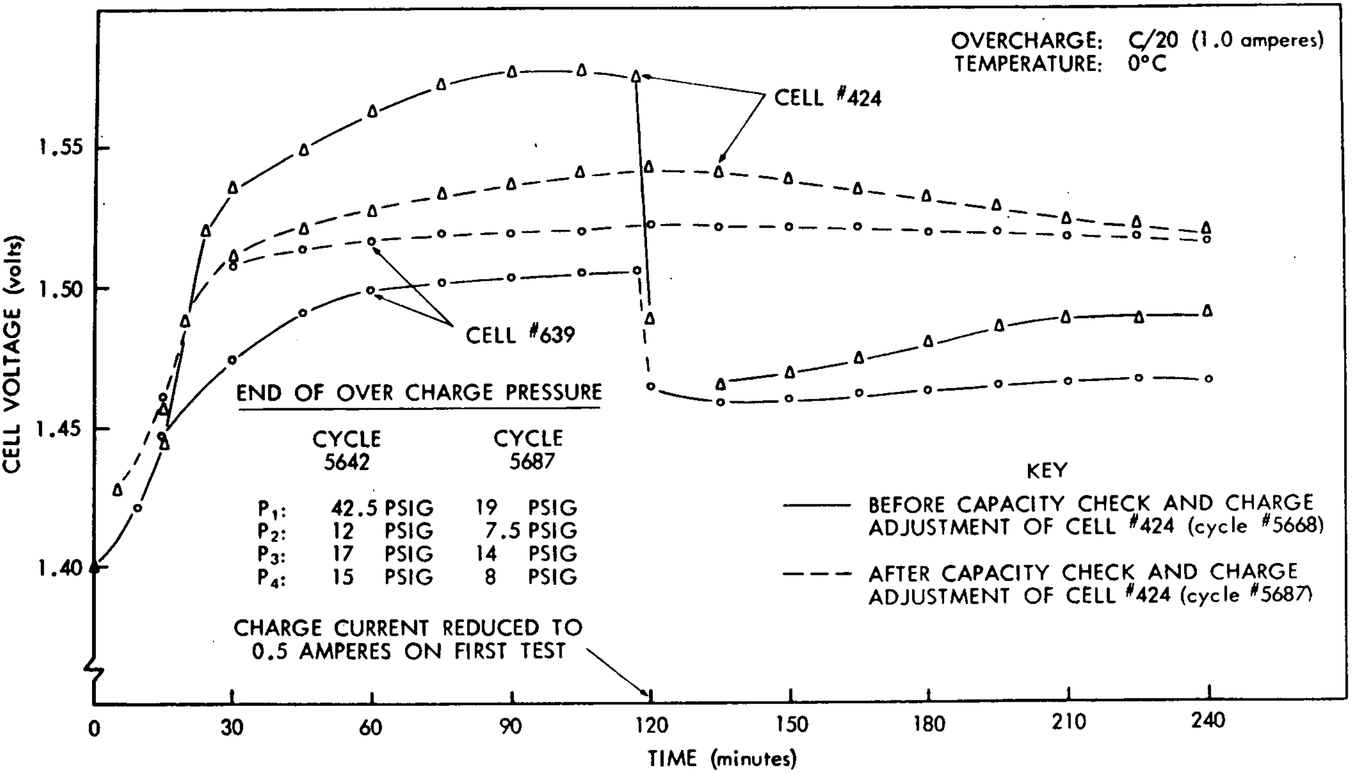

Figure 6. Voltage Profile During Overcharge Test

410

verified that this cell was positive (limited on discharge—the normal condition). The pressure at the 2.0 ampere rate was observed to increase at approximately 2.5 PSI per minute.

Upon recharging the pack and completing 19 cycles, the overcharge test was repeated. The voltages at the end of 4 hours are listed in Table 2. Voltage data for the four hours of overcharge are shown in Figure 6, and are compared with the voltages obtained from the test prior to the charge adjustment on cell #424. Two facts are obvious: (1) The overcharge voltage of cell #424 was decreased by the charge adjustment of the negative electrode, and (2) the overcharge voltages of all other cells were slightly higher than those obtained on previous tests. This latter result is attributed to the cell's having been completely discharged only 19 cycles before the overcharge test was conducted.

The voltage data for cycle 5687 (19 cycles after charge adjustment) are shown in Figure 7. Cell divergence still exists but is less than 0.030 volts, as compared with cycle 5642 where the divergence was greater than 0.050 volts. Even though the control voltage for the two cycles was the same, there is a difference in end-of-light current of over 0.2 amperes.

Additional overcharge tests were conducted prior to terminating the test on this pack. Cell #603 approached, but never exceeded, the 1.55 volt limit. All cells were operating satisfactorily when the pack was subjected to the final capacity discharge, at which time a total energy of 23.0 ampere-hours was measured. The total test time was 450 days. Cells completed the open circuit voltage (OCV) test with the following results:

Cell #	OCV (after 450 days)
424	1.179
602	1.191
588	1.181
603	1.193
639	1.192

DISCUSSION OF RESULTS

From the information presented about the overcharge tests, two conclusions can be drawn: (1) The overcharge voltage during the 450 days of test increased

411

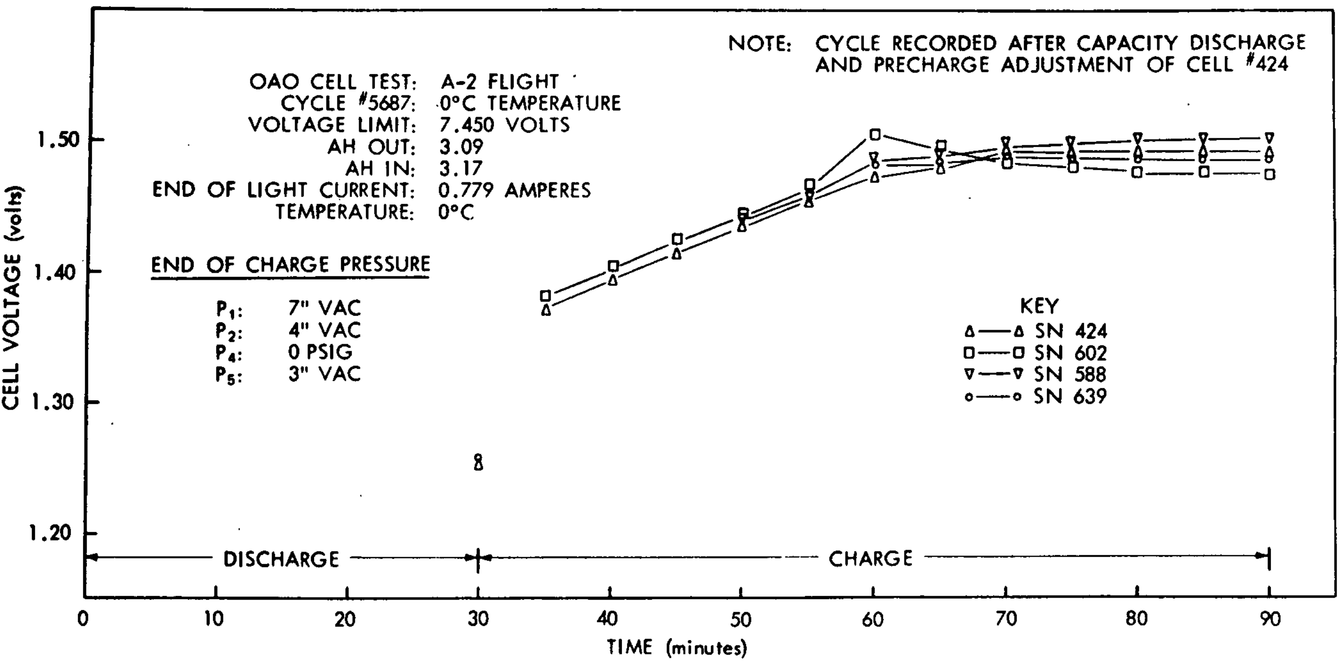

Figure 7. Voltage Profile for Cycle 5687

by over 0.020 volts on all cells, and (2) The overcharge voltage of one cell increased to an intolerable degree that could have resulted in cell failure due to overpressure. It was further shown that discharging the cadmium plates of cell #424 by 3.0 ampere-hours could reduce the cell voltage to that of the other test cells.

To understand the problem encountered during the cycling test of the A-2 cells, it is necessary to examine other data on these cells and also on cells from battery assemblies 30 and 31. Cells from the A-2 production lot (includes assemblies 25A, 26A, 30, and 31) were found to have pre-charges of 3.5 to 6.1 ampere-hours. The pre-charge was measured by oxygen recombination methods, and the results are as follows (Table 3):

Table 3

Pre-Charges of A-2 Cells

Cell #	OAO Battery #	Pre-Charge (ampere-hours)	Comments
603	25A & 26A	5.4	Cell had completed 529 cycles
639	25A & 26A	3.5	Cell had completed 529 cycles
666	30 & 31	6.1	Completed cell selection for battery
668	30 & 31	3.4	Completed cell selection for battery
674	30 & 31	4.0	Completed cell selection for battery
762	30 & 31	1.0	KOH added at GSFC
429	30 & 31	1.3	Charge adjustment not made by manufacturer

Negative-to-positive capacity ratios for the production lot of cells for batteries 25A and 26A were 1.22 to 1.39. During formation of the cells by the manufacturer, some cells were found with positive plate capacities of up to 30 ampere-hours (those over 30 were rejected). With a required ratio of 1.30, the minimum negative plate capacity had to be 35.1 ampere-hours. Since the manufacturer destroys the integrity of cells after formation and mixes the positive plates as well as the negative plates, it is possible that a cell can be assembled with high capacity positive plates and low capacity negative plates. Such a cell would have

413

a difference between positive and negative capacity of 5.1 (35.1 - 30.0) ampere-hours. It is apparent that 5.4 ampere-hours (cell #603) of pre-charge would result in a negative limited cell. This situation would be "worst case" and not very likely. The concern is with cells that have high pre-charge which could result in high cell voltage with cycling, and are not found by the 5°C overcharge test required in the battery specification. Cell #424 is apparently such a cell. The fact that the overcharge voltage did not increase significantly until more than 4,000 test cycles were completed typifies the problem with nickel-cadmium batteries, and illustrates the need for very rigid controls by the manufacturer when making sealed cells.

CONCLUSIONS

From the test results reported herein and from recent tests at Naval Ammunition Depot (NAD)-Crane on cells with known pre-charge levels, it has been demonstrated that cells with perfectly normal characteristics when new may show up deficient after extended cycling. In both cases (GSFC and NAD-Crane) an increase in overcharge voltage at 0°C was directly attributed to excessive pre-charge level. In both cases the overcharge voltage was decreased by reducing the pre-charge. These results illustrate the effects of "negative capacity fading" during the life of the cell, and the impact on cell operation. The importance of rigid controls at the manufacturer's facility is emphasized. Extended testing, such as was completed on these cells, is not only impossible on flight batteries, but it is not feasible from a cell lifetime consideration.

RECOMMENDATIONS

The results of this test should have no immediate impact on the use of the A-2 flight batteries since the cycle regime for the test cells has been somewhat more rigorous than the orbital conditions experienced by the batteries in the A-2 spacecraft. Based on the results of more than a year of testing on the flight cells, it is predicted that some change in battery characteristics will be experienced. The magnitude of this change, and the rate of its occurrence, are not predictable. An increase in the overcharge voltage for cells in the flight battery will effectively reduce the percent of recharge per orbit for a given battery voltage control level. Also, the third electrode will show a decrease in the end-of-light readings. In all probability, it will be required to increase the battery voltage control level above that used early in the flight. One point should be emphasized - the increase in overcharge voltage on the test cells was determined at 0°C. The spacecraft battery temperature is approximately 10° to 15°C above this temperature. Consequently the change should be less significant, and not obvious as early in the battery life as it was during the cell tests.

To overcome the problem of increasing over-charge voltage with cycling as identified during this test, two solutions are recommended: (1) Impose a requirement on the manufacturer to control pre-charge on each cell, and (2) Increase the negative-to-positive ratio requirement from 1.30 to a minimum of 1.50.

It is recommended that 30 to 35% of the 50-percent excess negative capacity be utilized as pre-charge. It is noted that although zero pre-charge is thought to be undesirable, tests on OAO cells at NAD-Crane with zero pre-charge have not shown any degradation relative to cells with pre-charge. The consequence of excessive pre-charge in flight cells can be premature battery failure, either during ground test or in flight. Spacecraft batteries are usually made of many series-connected cells. Each cell is a distinct and separate unit; consequently, a battery is only as good as any single cell.

Cycling tests on the A-2 cells were terminated after 6091 cycles. Cells were removed from the pack for physical and chemical analysis, including extraction of KOH, measurement of pre-charge after cycling, and analysis of the separator material.

Test results and data related to the analysis are given in the appendices.

APPENDIX A

SEQUENCE OF EVENTS IN PRECHARGE TEST

Date	Event	Ampere-Hour Equivalent	
		Cell # 603	Cell # 639
Nov. 1968	Backfilled with O_2 to remove precharge.	5.3	3.6
	Vented O_2 to restore precharge.	2.6	2.8
Feb. 1970	Backfilled with O_2 to measure precharge (completion of electrical test).	5.1	5.2

4-16

APPENDIX B

CHEMICAL ANALYSIS OF CELL #602

During the soxhlet extractor washing procedure, a precipitate of grey particles was washed off the 20 AH plate stack from OAO Cell 602 and deposited in the extractor. The wash water became cloudy.

The solid precipitate was filtered from the water, which became quite clear. The solid was enmeshed in the filter paper and no attempt was made to scrape it off because filter paper can be used as a sample matrix. The grey solid was then analyzed in its filter paper matrix by X-ray fluorescence. The analysis indicated that Cd, Ni, Mn, Fe, Co, Cu, Ba and Cl were present. Note: C, H and O, although not detectable by X-rays, could be present (and probably are) in combination with the metals that were detected (as $CO_3^=$, OH^- or oxides).

The sample (in its filter paper matrix) was also analyzed by X-ray diffraction. (Fluorescence determines the component elements; diffraction determines the crystal structure, and therefore compounds or molecules). Because of a sample-mounting difficulty, the results of this analysis were somewhat difficult to interpret, but evidence was rather strong that $Cd(OH)_2$ was present. Somewhat less reliably indicated were nickel metal (Ni^0), cadmium carbonate ($CdCO_3$), gamma ferric oxide (γFE_2O_3), and barium metal (Ba^0).

These two X-ray analyses were qualitative, but gave a rough indication of the relative amounts of the component substances. Apparently a preponderance of Cd(OH) is indicated in the diffraction pattern. In the fluorescence plotout, the Ba $L\alpha$, Fe $K\alpha$, Ni $K\alpha$ & $K\beta$, Cu $K\alpha$, and Cd $K\alpha$ peaks all went off scale (2×10^5 counts per minute full scale), and this probably means that Fe, Ni, Cu, Cd and Ba are present in more than trace amounts.

APPENDIX C

PHYSICAL DESCRIPTION OF CELL #477 AFTER RATIO TEST

BRIEF HISTORY

Cell #477 was manufactured by Gulton Industries for OAO battery assemblies 32 and 33. The cell completed all phases of the Gulton process as per specification AV-252CS-89A and was subjected to the cell selection procedure of specification AV-252CS-26D. The cell met all requirements and was then tested to determine the total negative-to-positive capacity ratio.

During the ratio test, the cell received a 10-ampere discharge from full charged condition to a reverse voltage of -1.5 volts. Prior to the full charge, the cell was reverse charged from 0.0 volts to -1.5 volts to measure the precharge of the cadmium electrodes. The total time of reversal was over two hours. The main difference between this cell and those of batteries 30 and 31 is that during the reverse charge the cell is flooded with electrolyte. This cell, along with five flight quality cells, was delivered to GSFC late in November 1969.

ANALYSIS AND DESCRIPTION

On January 12, 1970, the cell was opened and extracted from the case for examination. Even though this cell was flooded by Gulton for the ratio test, no residual KOH was found in the cell case. The separator material was found to be saturated with KOH. When the nylon cover for the cell plate stack was removed from the case, reddish brown residue was found between the cell case and the nylon cover. An analysis (X-ray fluorescence) revealed that the residue consisted primarily of iron oxide, with some nickel. Figures C-1 and C-2 show the nylon liner.

Photographs were taken of the cell as it was disassembled. Figure C-3 shows the cell, with the third electrode attached, as removed from the case. Figure C-4 shows the same cell at a 45° angle. In general, the condition of the plates was from good to excellent. Some localized dark spots, observed on the separator, may be attributed to blisters. A close examination of the positive plates revealed only a slight indication of blistering. Few if any pimples were found on the plates. Figure C-5 shows the separator with the first negative plate lifted. The dark spot in the lower left portion of the plate was caused by the positive plate next to the separator. This is better illustrated in Figure C-6, where the separator has been folded away from the plate. The area immediately under the dark spot can best be described as a hole that had apparently emitted a solution - probably due to gassing. This could not be classified as a blister

Figure C-1. Nylon Cover for Plate and Third Electrode Assembly of Cell #477 as Removed from Case. Discoloration is Brownish-Red, and was in Liquid Form when Removed.

Figure C-2. Opposite Side of Nylon Cover Shown in Figure C-1.

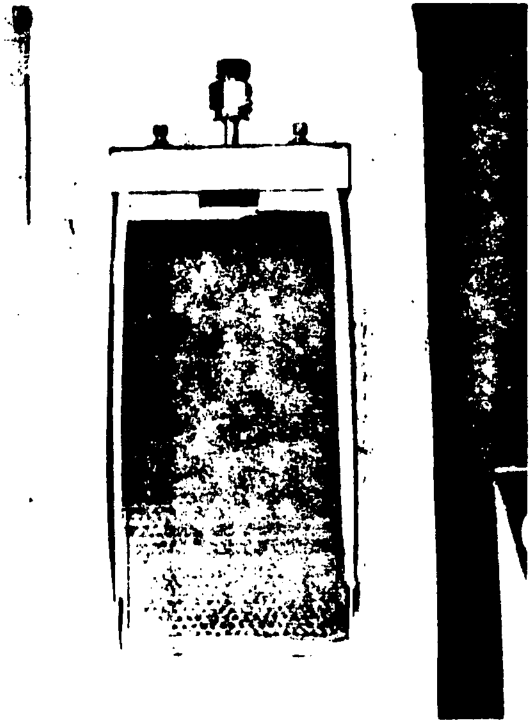

Figure C-3. View of Cell #477 as Removed from Cell Case.

Figure C-4. View of Cell #477 as Removed from Cell Case (45° View).

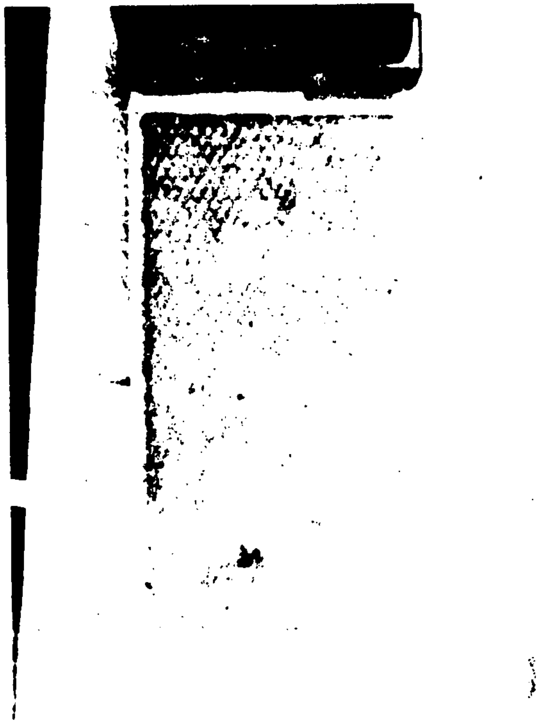

Figure C-5. View of Cell with First Negative Plate Lifted.

Figure C-6. Separator Removed from First Positive Plate. Note Dark Discoloration Spot on Separator.

421

since no material was found in the area or imbedded in the separator. Figure C-7 shows a larger pinhole, similar to that described previously. There was also a darkening of the separator material over this hole. Figure C-8 shows another area where the separator was darkened although there was no hole in the plate under the dark spots.

It is my conclusion that this cell showed no physical deterioration that could be related to the 10-ampere reverse charging. Features found in this cell were no worse than would be expected on other cells that had received similar electrical tests (not reversed). It is noted that there was no apparent degradation of separator material. It was very easy to remove the separators from the negative as well as from the positive plates.

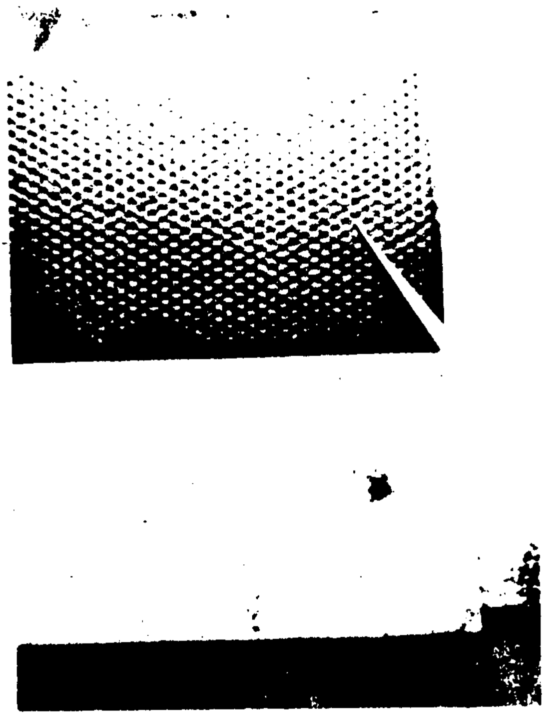

Figure C-7. Positive Plate, Showing Small Pinhole. Dark Spot on Separator Resulted from Pinhole Area.

Figure C-8. Dark Spots in Separator Resulting from Positive Plates.

APPENDIX D

PHYSICAL DESCRIPTION OF CELL #588 AFTER CYCLING TEST

BRIEF HISTORY

Cell #588 was a flight spare cell for the OAO A-2 batteries. It was activated with KOH by Gulton in August 1968, and received at GSFC for test in early September 1968. The cell completed over 6,000 cycles as part of GSFC's five-cell test pack (designated A-2 Flight Pack 2). Total test time was 15 months. Although the temperature range extended from 0° to 32°C, over 70% of the 15 months of testing was conducted at 15°C and below. Just before the end of testing on this cell, the pack delivered 23.0 ampere-hours. Upon completion of the discharge, an open circuit stand test was conducted, and cell #588 recovered to 1.18 volts. This cell showed no unusual characteristics during the 15 months of testing.

ANALYSIS

On January 13, 1970, this cell was opened for physical examination. There were no signs of leaking around the positive terminal. A photograph of the cell plate stack as removed from the cell case is shown in Figure D-1. Because this cell had only one ceramic seal, particular attention was given the ceramic portion of the seal. As can be seen from Figures D-2 and D-3, there is no evidence of silver migration or other discoloration on the ceramic.

The effects of the 15 months of testing became evident upon lifting the first negative plate. Figure D-4 shows the separator under the outermost plate (negative) after this plate was lifted. The grayish-black material is a form of cadmium. Figure D-5 shows a close-up of the top portion of the separator. Note the fibers that were pulled from the separator as they adhered to the negative plate. It was observed that a gray dust could very easily be rubbed off the negative plate or separator. In all cases where the separator touched the negative plates, an effort was required to remove the separator. This resulted in the tearing and pulling of separator fibers as they adhered to the negative plate. Figure D-6 illustrates a typical condition. Figure D-7 shows the brown discoloration found around the positive plate tabs of the top of the separator. Several layers of separator had the spot around the positive tabs. The probable cause is excessive heat, from either a short circuit (burnt open) or overheating of terminals during soldering.

Another observation made during this inspection was the dryness of the separator. When it was squeezed between the thumb and forefinger, no evidence of

Figure D-1. View of Cell #588 as Removed from Case.

Figure D-2. Close-Up of Seal, Showing Condition of Ceramic.

Figure D-3. Close-Up of Seal, Showing Condition of Ceramic.

Figure D-4. View Showing Separator Under First Negative Plate.

Figure D-5. Close-Up View of Separator Under First Negative Plate. Note Fibers Between Separator and Negative Plate.

Figure D-6. Negative Plate, with Separator Fibers Adhered to Surface.

Figure D-7. Separator Area from around Positive Plate Tab (Top), Showing Discoloration (Brown).

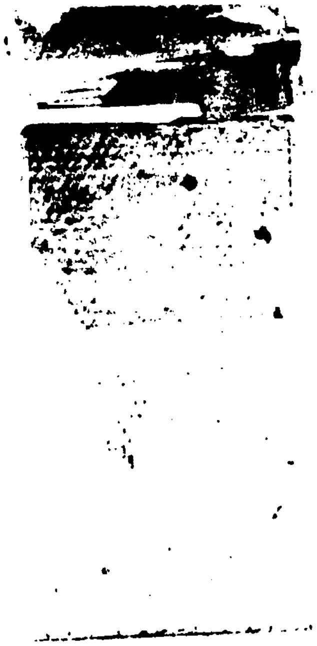

Figure D-8. Postive Plate with Dark Spots.

moisture was found. The significance of this finding is that the 65 to 70 cc of KOH used by the manufacturer is based on optimizing the parameters on a new cell. In every case experienced by the writer, this quantity of KOH appears to be much less than the amount the cell should have for long life performance. Other cells from the test pack will be subjected to more detailed analysis.

Of particular interest were the small blisters (or pimples) found on the positive plates. Some plates were in worse condition than others, but all positive plates had some blisters. Figure D-8 shows a typical positive plate with the separator folded away. It is noted that the dark spots on the positive plate resulted in similar dark spots on the separator. The exact cause of these spots is not known, but it is suspected that they are caused by the bursting of blisters (caused by gas escaping from below the surface). Figure D-9 shows a close-up of a positive plate and reveals small blisters (more like pimples) distributed over the surface of the plate, with large concentrations at the left edge. Figure D-10 shows another positive plate with blistering along the top portion. Figure D-11 shows the only case observed where flaking had occurred on the positive plate. The small piece of material at the top corner is active positive material.

In conclusion, the most significant observance of deterioration in this cell was due to migration of cadmium into the separator. Considering the length and conditions of the test, this migration was more severe than had been expected. The ceramic seal was in good condition, with practically no signs of silver migration. Separator material <u>outside</u> the areas between the plates appeared to be in very good condition. There was no tendency for the separator to adhere to the positive plates, only to the negative plates. There were blisters or pimples, to varying degrees, on each positive plate. It was observed that the blistering was concentrated around the edges of the positive plates, with few blisters distributed across the plate surface.

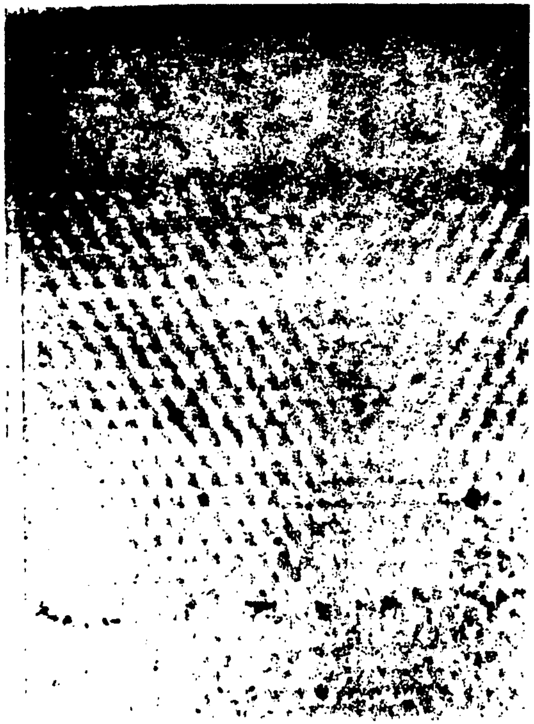

Figure D-9. Close-Up of Positive Plate, Showing Small Blisters and Dark Spots.

Figure D-10. Positive Plate, Showing Small Pimples or Blisters Around Top Edge of Plate.

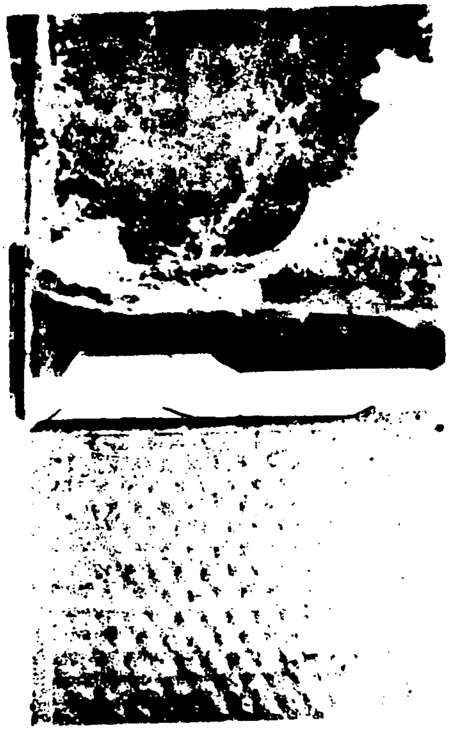

Figure D-11. Positive Plate, Showing Flaking of Material Around Edge of Plate. Negative Plate (Top) with Separator Fibers Adhered to Surface.

431

APPENDIX E

PHYSICAL PROPERTIES OF SEPARATOR MATERIAL*

Pellon Type 2505 (Formerly 2505ML)

PELLON 1605 SEPARATOR MATERIAL

The separator material used in the OAO-A-2 cells was tested to determine its wetting- and physical characteristics. The Pellon 16015 separator material was removed from the cell plates with difficulty, and it retained considerable cadmium metal. Part of the sample was washed according to the following schedule: De-ionized (D.I.) H_2O, 1/2 hour; 5% HOAc, 2 hours; D.I. H_2O, 1 hour; 3% NH_4OH, 1 hour, followed by three 1-hour washes with D.I. H_2O. A final, 15-hour water wash was followed by vacuum drying at ambient temperature. Tests on the wetting- and physical properties of washed, unwashed and stock materials in 31% KOH were run concurrently, and the resulting data are given in Table E-1.

Table E-1

Properties of Pellon 16015 Separator Material

Test	Unwashed Material (Cell # 602)	Washed Material (Cell # 602)	Stock Material
Wicking			
min/cm	20	230	211
Wet-out time (min)	1.5	45	26 (Visual)
A.C. Resistance			
cm height @ ____ min	7.55 @ 150	6.25 @ 1440	6.35 @ 1440
Ω-cm	1.7	1.7	1.1
Ω-cm^2	0.020	0.021	0.016 (Repeat)
Dry Tensile Strength	195	195	225
Time to pass 300cc air (sec)	1.73	2.58	2.14
Thickness (inch x 10^3)	11.8	12.1	14.0 0.036cm

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*In its original form, the material in this Appendix was transmitted by Mr. S. Orenstein of ESB, Inc., Yardley, Pa., in a letter to Mr. T. Hennigan, Space Power Technology Branch, GSFC, in 1970. This work was done under NASA Contract NAS5-10418.

432

Thickness measurements reflect adhesion of the separator material to the negative plate. The observed changes in specific resistance and tensile strength are slight, and the latter can be attributed to damage resulting from "peeling" the material from the negative plates, but the 10% decrease in viscosity molecular weight indicates degraded material. The increase in specific resistance is apparently real.

Ratio of viscoisty molecular weight (15 mg/cc sample in m-cresol):

$$\frac{\text{Washed}}{\text{Stock}} = 0.92$$

Migration of metallic cadmium, though detrimental to cycle life, seems to offer greatly enhanced wettability. This conclusion is based on the assumption that cadmium is the only KOH-wettable material removed in the wash cycle.

PELLON 2505 SEPARATOR MATERIAL

Additional tests were performed on Pellon 2505 separator material. The results of these tests are given in Table E-1. For quick reference, a copy of Table 4 of the ESB, Inc., 5th Quarterly Report (NAS 5-10418) is also given (Table E-2).

Sufficient material to perform all tests on lot 16015 in both 31 percent- and 34 percent KOH was not available. However, the A.C. resistance of sample 16015B in 34 percent KOH was determined, and is shown below along with the wet thickness.

A.C. Resistance	1.80 Ω-cm
	0.066 Ω-cm^2
Wet Thickness	36.6 x 10^{-3} cm.
	14.4 x 10^{-3} inch

These data agree well with previously reported data on sample 16015B in 34 percent KOH. Furthermore, the data for lots #14000 and 12777 in 31 percent KOH are comparable to those reported in 34 percent KOH, allowing for variations in the material and experimental technic. Note that the 31 percent KOH wicking tests for the latter two materials were done open to the atmosphere.

This same configuration was used during the fifth quarter*. The only significant difference between the data of the fifth quarter and those measured recently is the thickness of lot #12777. At present, the only explanation is a typographical error in Table 4 of the Fifth Quarterly Report.

In view of these tests, we can safely say that our previous conclusions about wettability and molecular weight are valid. The extraordinary wettability of the unwashed 16015 sample can best be explained by the presence of cadmium metal. This explanation is supported by the superior wicking ability of the used, unwashed material over the original separator. Note also that the 8 percent loss of viscosity molecular weight is accompanied by a 13 percent loss in tensile strength.

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*Fifth Quarter Report, Contract NAS5-10418.

434

Table E-2

Properties* of Separator Material

Test	From Cell #602		Tested During Fifth Quarter**		
	Unwashed**	Washed**			
	16015†	16015†	16015†	14000†	12777†
Wicking††					
height at 30 min (mm)	45	1.5	11.5	80	41
Maximum height at - min (mm)	75.5 @ 150	62.5 @ 1440	63.5 @ 1440	80 @ 30	76 @ 240
Rate to maximum height (min/mm)	2.0	23.0	22.7	3.16	
Wet-out Time (min)	1.52	44.73	26.38	0.9	10.5
A.C. Resistance					
Ω-cm	1.73	1.70	1.13	1.81	6.41
Ω-cm^2	0.052	0.052	0.040	0.062	0.103
Dry Tensile Strength (psi)	195	193	225	—	—
Time to pass 300 cc of air (sec)	1.73	2.58	2.14	—	—
Thickness in 31% KOH inches x 10^3	11.8	12.1	14.0	14.5	6.4

*All tests used 31% KOH.

**Origin

†Lot No.

††Wicking tests for 16015 samples were conducted in closed chambers, while those for 14000 and 12777 samples were performed in the open atmosphere.

APPENDIX F

1) Listing, Battery Model
2) Flow Charts, Battery Model

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C      THIS MODEL IS DESIGNED FOR USE ON A 360/67 MACHINE
C      IT IS PRESENTLY CONFIGURED FOR ON-LINE TIME-SHARING
C      OPERATION
C      ORBITAL PARAMETERS (BVLS LEVEL,CHARGE AND DISCHARGE RATE,
C      BATTERY TEMPERATURE, FTC...) ARE READ IN VIA THE KEYBOARD.
C      INSTANTANEOUS ORBITAL PARAMETERS (BATTERY VOLTAGE, CURRENT,
C      STATE-OF-CHARGE, ETC...) ARE THEN PRINTED ONTO PAPER OR
C      THE DISK, VIA OPERATOR OPTION.
       COMMON NSUNT,LTORB,ITIME,NSTD,LT,NXSYS,NRITE,NTORB,NORB
      1,IREG,MODE,VREG,BTVL,BTCR,NFLAG,IFLAG
      2,BPCAP,BCEL,BSOC,BTEMP,BVLS,BTOL,CFK,CFCR,RAD,K,IDSK,NDK
   920 FORMAT(20H TODAY'S DATE  (3I2))
   921 FORMAT(3I2)
   922 FORMAT(19H NRITE,NTORB  (2I3))
   923 FORMAT(2I3)
   924 FORMAT(45H NSUNT,LTORB,BPCAP,BCEL,MODE  (2I5,2F10.0,I5))
   925 FORMAT(2I5,2F10.0,I5)
   926 FORMAT(41H BSOC,BVLS,BTEMP,BTOL,CNEG,CPOS  (6F10.0))
   927 FORMAT(6F10.0)
   940 FORMAT(1H1)
   942 FORMAT(///)
   950 FORMAT(10H TODAY IS ,I2,1H/,I2,1H/,I2)
   952 FORMAT(7H ORBIT ,I2,4H OF ,I2)
   954 FORMAT(49H NSUNT,LTORB,BPCAP,BCEL,BSOC,BVLS,BTEMP,BTOL,MODE/2I4,
      12F8.1,F8.3,3F8.1,I4)
   970 FORMAT(47H WHAT NEXTO STOP,LOOP,START AGAIN (0,1,2)  (I2))
   972 FORMAT(I2)
C      READ IN BATTERY CHARACTERISTICS
       CALL BTR(0,0)
C      ENTER INITIALIZATION DATA
       WRITE(6,920)
       READ(5,921)IONTH,IDAY,IYEAR
   104 CONTINUE
   188 CONTINUE
       WRITE(6,924)
    89 READ(5,925)NSUNT,LTORB,BPCAP,BCEL,MODE
   100 CONTINUE
       WRITE(6,926)
       READ(5,927)BSOC,BVLS,BTEMP,BTOL,CNEG,CPOS
       WRITE(6,940)
       WRITE(6,942)
       WRITE(6,950)IONTH,IDAY,IYEAR
C      CHECK TO SEE IF OPERATOR ENTERED DATA PROPERLY
       WRITE(6,988)
   988 FORMAT(2X,'ARE ALL VALUES OK  YES=1,NO=0 (I1)')
       READ(5,987)NTEST
   987 FORMAT(I1)
       IF(NTEST-1)188,150,150
   150 CONTINUE
       WRITE(6,922)
       READ(5,923)NRITE,NTORB
C      SPECIFY IF YOU WANT DATA WRITTEN ONTO THE DISK AND THE INTERVAL
       IF(NRITE.EQ.0)GO TO 8444
       WRITE(6,801)
   801 FORMAT(2X,'DO YOU WANT THE DATA WRITTEN ONTO THE DISK ')
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437

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      WRITE(5,802)                                                      BAT00560
 802  FORMAT(2X,'WRITE 1=YES,0=NO  (I1)')                               BAT00570
      READ(5,804)IDSK                                                   BAT00580
 804  FORMAT(I1)                                                        BAT00590
      IF(IDSK.EQ.0) GO TO 659                                           BAT00600
      WRITE(6,977)                                                      BAT00610
977   FORMAT(2X,'DATA WRITTEN ONTO DISK EVERY K MINUTES')               BAT00620
      WRITE(6,976)                                                      BAT00630
976   FORMAT(2X,'SPECIFY K    (I2)')                                    BAT00640
      READ(5,975)NDK                                                    BAT00650
975   FORMAT(I2)                                                        BAT00660
659   CONTINUE                                                          BAT00670
      WRITE(6,986)                                                      BAT00680
 986  FORMAT(2X,'DATA PRINTED EVERY  I  MINUTES. SPECIFY  I ')          BAT00690
      WRITE(6,985)                                                      BAT00700
 985  FORMAT(2X,' I =     (I2)')                                        BAT00710
      READ(5,984)K                                                      BAT00720
  984 FORMAT(I2)                                                        BAT00730
C     START TO PROCESS THE DATA                                         BAT00740
8444  DO 600 NTO=1,NTORB                                                BAT00750
C     INITIALIZE THE START OF THE ECLIPSE PORTION                       BAT00760
      NORB=NTO                                                          BAT00770
      NFLAG=0                                                           BAT00780
      IFLAG=0                                                           BAT00790
      ITIME=0                                                           BAT00800
      LT=0                                                              BAT00810
      IREG=0                                                            BAT00820
      WRITE(6,942)                                                      BAT00830
      WRITE(6,952)NORB,NTORB                                            BAT00840
      WRITE(6,954)NSUNT,LTORB,BPCAP,BCEL,BSOC,BVLS,BTEMP,BTOL,MODE      BAT00850
      WRITE(6,942)                                                      BAT00860
      DO 500 LL=1,LTORB                                                 BAT00870
C     INCREMENT TIME BY ONE MINUTE                                      BAT00880
      ITIME=ITIME+1                                                     BAT00890
C     DETERMINE THE TOTAL ECLIPSE PERIOD                                BAT00900
      NSTD=LTORB-NSUNT                                                  BAT00910
C     DETERMINE THE TIME REMAINING IN DARK PORTION                      BAT00920
      LT=ITIME-NSTD                                                     BAT00930
C     DETERMINE IF IT IS THE FIRST MINUTE OF THE ORBIT                  BAT00940
      IF(ITIME-1)1000,210,220                                           BAT00950
C     IF IT IS THE FIRST MINUTE BEGIN BY SETTING THE DISCHARGE          BAT00960
C     FLAG, I.E.-NXSYS=1                                                BAT00970
  210 NXSYS=1                                                           BAT00980
      GO TO 250                                                         BAT00990
C     CHECK IF IT IS THE FIRST MINUTE OF CHARGE, IF SO THEN             BAT01000
C     SET THE CHARGE FLAG, I.E.-NXSYS=2                                 BAT01010
  220 IF(ITIME-(NSTD+1))250,230,250                                     BAT01020
  230 NXSYS=2                                                           BAT01030
  250 CONTINUE                                                          BAT01040
C     INITIALIZE BATTERY AND ORBIT PARAMETERS,CALCULATE THEORETICAL     BAT01050
C     CAPACITY AND VOLTAGE LIMIT AS A FUNCTION OF TEMPERATURE IN        BAT01060
C     THIS SUBROUTINE                                                   BAT01070
      CALL BTR(1,1)                                                     BAT01080
C     CHECK IF STILL IN DISCHARGE                                       BAT01090
  300 IF(NXSYS-1)310,310,330                                            BAT01100
```

```
C     SET DISCHARGE CURRENT EQUAL TO CNEG
  310 BTCR=CNEG
C     CALCULATE BATTERY VOLTAGE
      BTVL=CFK
      GO TO 390
C     CALCULATE FACTOR FOR STEP CHARGE CURRENT
  330 XSYS=NXSYS-2
C     IS THE REGULATOR ON   IF SO. WHAT METHOD OF REDUCED CHARGE
      IF(IREG*MODE)340.340.360
C     CALCULATE CURRENT AND UPDATE BATTERY VOLTAGE
  340 BTCR=(.50**XSYS)*CPOS
      BTVL=CFK+BTCR*CFCR
C     HAS THE BATTERY VOLTAGE REACHED THE VOLTAGE LIMIT
      IF(BTVL-VREG)390.350.350
C     IF SO. THEN INCREMENT NXSYS BY ONE
  350 NXSYS=NXSYS+1
C     TURN ON THE REGULATOR
      IREG=1
C     IF TAPER CHARGE THEN LOCK THE BATTERY VOLTAGE AT THE
C     VOLTAGE LIMIT AND CALCULATE THE NEW CURRENT  IF STEP CHARGE
C     THEN GO TO STATEMENT LABEL 330
      IF(MODE)330.330.360
  360 BTVL=VREG
      BTCR=(BTVL-CFK)/CFCR
  390 CONTINUE
C     CALCULATE CHARGE OR OVERCHARGE PARAMETERS
      CALL BTR(1.2)
C     CHECK TO SEE IF IT IS THE LAST MINUTE OF THE ORBIT
      IF(ITIME-LTORB)420.410.420
C     IF IT IS THE LAST MINUTE OF THE ORBIT THEN CALL BTR(1.3)
C     THIS ROUTINE WILL CALCULATE THE EFFICIENCY AND THERMAL
C     PARAMETERS
  410 CALL BTR(1.3)
  420 CONTINUE
  500 CONTINUE
  600 CONTINUE
C     REQUEST FROM OPERATOR TO STOP PROGRAM OR DO MORE ORBITS
      WRITE(6.970)
      READ(5.972)IGOTO
      IF(IGOTO-1)1000.150.100
 1000 STOP
      END
      SUBROUTINE BTR(ISERT.ITEST)
      DIMENSION RFOUT(6).RFVLD(6).RFRLD(6).RFIN(5).RFVLC(5.3).RFRLC(5.3)
     1.RFSE(16).RFEP(16.4)
     2.RFVL(2).RFRL(2).RFV(2).EP(4)
      COMMON NSUNT.LTORB.ITIME.NSTD.LT.NXSYS.NRITF.NTORB.NORB
     1.IREG.MODE.VREG.BTVL.BTCR.NFLAG.IFLAG
     2.BPCAP.BCEL.BSOC.BTEMP.BVLS.BTOL.CFK.CFCR.RAD.K.IDSK.NDK
  900 FORMAT(3F10.6)
  901 FORMAT(3F10.6)
  902 FORMAT(F10.1.2F10.3.2F10.1)
  906 FORMAT(5F10.0)
  909 FORMAT(5F10.6)
  952 FORMAT(1X.I3.I2.F8.4.F6.2.F6.3.2F7.1.F6.3.F7.1
```

```
     1,F6.3,1X,F5.2,F6.2)
 980  FORMAT(//,' EODV    EOLV    EOLC    EOLEFF    CRTN    AMINT    AMDL
     1AMFIN WMD  WMIN')
  990 FORMAT(1H010X,4F10.2)
 982  FORMAT(2F6.2,2F6.3,F7.2,F7.1,4F8.1)
      IF(ISERT)1000,1000,1500
C READING SUBSECTION
 1000 CONTINUE
      READ(2,900)(RFOUT(KD),RFVLD(KD),RFRLD(KD),KD=1,6)
      READ(2,906)(RFIN(KC),(RFVLC(KC,JC),RFRLC(KC,JC),JC=1,2),KC=1,5)
      READ(2,906)(RFSE(JE),(RFEP(JE,KE),KE=1,4),JE=1,16)
      GO TO 9000
 1500 GO TO (2000,3000,4000),ITEST
C INITIALIZE BATTERIES
 2000 CONTINUE
C      IF WE ARE IN THE SUN THEN GO TO LABEL 2300
      IF(LT)2200,2200,2300
C      IF WE ARE IN THE FIRST MINUTE OF THE ORBIT THEN INITIALIZE
C      PARAMETERS, CALCULATE THEORETICAL CAPACITY AND VOLTAGE
C      LIMIT AS A FUNCTION OF TEMPERATURE
 2200 IF(ITIME-1)9000,2210,2300
 2210 TSUN=NSUNT
      AM100=BPCAP*(80.-.045*(EXP((BTEMP-40.)/9.0185)-1.))
      VREG=(1.04464-2.6E-5*BTEMP)*(1./(3.02373E-2+4.61445E-5*BTEMP))
     1+(BVLS-4.)*1.22560*(1./(4.13556+9.86667E-3*BTEMP))
      VREG=(BCEL/22.)*VREG
      CTOT=BSOC*AM100
      AMINT=CTOT
      CTHR=0.
      WATOT=0.
      WDCHG=0.
      IF(NORB-1)9000,2215,2220
 2215 BATVL=VREG
 2220 CONTINUE
C      IF WE ARE IN THE FIRST MINUTE OF LIGHT THEN UPDATE THE
C      PARAMETERS FROM THE END OF THE DARK PERIOD
 2300 IF((NSTD+1)-ITIME)2400,2310,2400
 2310 CONTINUE
      AMDL=CTOT
      WMOUT=WATOT
      EDBV=BTVL
      CTHR=0.
      WATOT=0.
 2320 CONTINUE
 2400 CONTINUE
C
C          COEFFICIENT CALCULATION
C      CHECK IF WE ARE IN CHARGE OR DISCHARGE
      IF(NXSYS-1)300,300,400
C      BEGIN DISCHARGE MODEL SECTION
  300 RBOUT=.045*((AMINT/AM100)-1.)+(1.+((AM100-AMINT)/AMAX1
     1(9.*BPCAP,ABS(CTHR))))*(CTHR/(60.*BPCAP))
      DO 310 NX=1,5
      NXSOC=NX
      IF(RBOUT+RFOUT(NX+1))310,320,320
```

```
  310 CONTINUE
  320 RDSOC=(-RBOUT-RFOUT(NXSOC))/(RFOUT(NXSOC+1)-RFOUT(NXSOC))
      RFVD=(1.-RDSOC)*RFVLD(NXSOC)+RDSOC*RFVLD(NXSOC+1)
      RFRD=(1.-RDSOC)*RFRLD(NXSOC)+RDSOC*RFRLD(NXSOC+1)
      CFK=(1.+.003*BTOL)*(BCEL*RFVD+BATVL*RFRD)
      CFCR=0.
      GO TO 2800
C     BEGIN CHARGE MODEL SECTION
  400 RBSDL=.300*.43429*ALOG(AMAX1(((AM100-AMDL)/(9.*BPCAP)),
     1(10.-9.*(AMDL/(AM100-9.*BPCAP)))))
      RBIN=CTHR/(AM100-AMDL+.5*(AMINT-AMIN1(AM100,(AMINT/.950))))
      NXSOC=5
      IF(RBIN-(RFIN(NXSOC)+RBSDL))500,500,600
500   DO 510 NX=1,4
      NXSOC=NX
      IF(RBIN-(RFIN(NX+1)+RBSDL))520,520,510
  510 CONTINUE
  520 RCSOC=(RBIN-(RFIN(NXSOC)+RBSDL))/(RFIN(NXSOC+1)-RFIN(NXSOC))
      DO 530 NCR=1,2
      RFVL(NCR)=(1.-RCSOC)*RFVLC(NXSOC,NCR)+RCSOC*RFVLC(NXSOC+1,NCR)
      RFRL(NCR)=(1.-RCSOC)*RFRLC(NXSOC,NCR)+RCSOC*RFRLC(NXSOC+1,NCR)
      RFV(NCR)=BCEL*RFVL(NCR)+BATVL*RFRL(NCR)
  530 CONTINUE
      CFCR=(RFV(1)-RFV(2))/(BPCAP/4.)
      CFK=(1.-.003*BTOL)*(RFV(2)-(BPCAP/4.)*CFCR)
      GO TO 2800
C     BEGIN OVERCHARGE MODEL SECTION
  600 CONTINUE
      CFCR1=((BCEL*RFVLC(NXSOC,1)+BATVL*RFRLC(NXSOC,1))-
     1(BCEL*RFVLC(NXSOC,2)+BATVL*RFRLC(NXSOC,2)))/(BPCAP/4.)
      CFK1=(1.-.003*BTOL)*((BCEL*RFVLC(NXSOC,2)+BATVL*RFRLC(NXSOC,2))
     1-(BPCAP/4.)*CFCR1)
      VEOCL=BCEL*(8.060872-.43429*ALOG(BTEMP))/4.471236
      VEOCH=BCEL*(7.397980-.43429*ALOG(BTEMP))/3.842047
      CFCR2=(10./BPCAP)*((VEOCH-VEOCL)/(.43429*ALOG(4.)))*(4.**((VEOCH-
     1BATVL)/(VEOCH-VEOCL)))
      CFK2=(1.-(.015381*.43429*ALOG(BTEMP)-.023575)*BTOL)*
     1(BATVL-((VEOCH-VEOCL)/(.43429*ALOG(4.))))
      PCRTN=(1.+.013*BTOL)*(.923263+.222928*(20./BPCAP)*
     1((BATVL-CFK2)/CFCR2))
      RSO=((CTOT/AM100)**4.)*((RBIN-(RFIN(NXSOC)+RBSDL))/
     1(PCRTN-(RFIN(NXSOC)+RBSDL)))
      CFCR=(1.-RSO)*CFCR1+RSO*CFCR2
      CFK=(1.-RSO)*CFK1+RSO*CFK2
 2800 CONTINUE
 2900 CONTINUE
      GO TO 9000
C
C DETERMINE EFFICIENCY
 3000 CONTINUE
      EFFC=1.
      IF(BTCR)3200,3200,3110
 3110 CADD=100.*((CTOT-AMDL)/(AM100-AMDL))
      PNPR=CADD
      ITP=10.*BTEMP
```

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      KT=1+4*(ITP/551)+4*(ITP/701)                                      BAT02760
      RTE=(BTEMP-RFSE(KT))/(RFSE(KT+4)-RFSE(KT))                        BAT02770
      IBTCR=100.*(20./BPCAP)*BTCR                                       BAT02780
      KTC=KT+(IBTCR/201)-((IBTCR-201)/201)+(IBTCR/501)-((IBTCR-501)/501)BAT02790
      RCE=((20./BPCAP)*BTCR*RFSE(KT)-RFSE(KTC))/(RFSE(KTC+1)-RFSE(KTC)) BAT02800
      DO 3120 IEP=1,4                                                   BAT02810
      FP(IEP)=(1.-RTE)*((1.-RCE)*RFEP(KTC,IEP)+RCF*RFEP(KTC+1,IEP))     BAT02820
     1+RTE*((1.-RCE)*RFEP(KTC+4,IEP)+RCE*RFEP(KTC+5,IEP))               BAT02830
 3120 CONTINUE                                                          BAT02840
      C2=((EP(3)/EP(4))-1.)/ALOG(1.-(EP(2)/EP(1)))                      BAT02850
      C1=(1.-(EP(2)/EP(1)))*EXP(-EP(3)/(C2*EP(4)))                      BAT02860
      EFFC=EP(1)*(1.-C1*(EXP(PNPR/(C2*EP(4)))-1.))                      BAT02870
      EFMAX=RFEP(KT+3,1)                                                BAT02880
      EFMIN=.01-.0001*CADD                                              BAT02890
      IF(EFFC-EFMAX)3160,3160,3150                                      BAT02900
 3150 EFFC=EFMAX                                                        BAT02910
 3160 IF(EFFC-EFMIN)3170,3200,3200                                      BAT02920
 3170 EFFC=EFMIN                                                        BAT02930
 3200 CONTINUE                                                          BAT02940
C                                                                       BAT02950
C     UPDATE PARAMETERS FOR START OF LIGHT PORTION                      BAT02960
      CTHR=CTHR+BTCR                                                    BAT02970
      CTOT=CTOT+BTCR*EFFC                                               BAT02980
      BSOC=CTOT/AM100                                                   BAT02990
      WATOT=WATOT+ABS(BTCR)*BTVL                                        BAT03000
      WDCHG=WDCHG+(1.-EFFC)*BTCR*BTVL                                   BAT03010
C     DETERMINE IF THE PARAMETERS SHOULD BE WRITTEN OUT NOW             BAT03020
      IF(NORB*NRITE-NTORB)3420,3410,3410                                BAT03030
C     ARE WE ON CHARGE OR DISCHARGE                                     BAT03040
 3410 IF(NXSYS-1)3412,3412,3414                                         BAT03050
 3412 RBOI=RBOUT                                                        BAT03060
      GO TO 3416                                                        BAT03070
 3414 RBOI=RBIN                                                         BAT03080
 3416 CONTINUE                                                          BAT03090
      NFLAG=NFLAG+1                                                     BAT03100
      IFLAG=IFLAG+1                                                     BAT03110
C     CHECK IF THE DATA IS TO WRITTEN ONTO THE DISK                     BAT03120
      IF(IDSK)1000,826,541                                              BAT03130
  541 CONTINUE                                                          BAT03140
      IF(NFLAG.NE.NDK) GO TO 826                                        BAT03150
      WRITE(1,942)ITIME,EFFC,BSOC,BTVL,BTCR                             BAT03160
      NFLAG=0                                                           BAT03170
  942 FORMAT(I3,4F10.3)                                                 BAT03180
  826 CONTINUE                                                          BAT03190
      IF(IFLAG.EQ.K.OR.ITIME.EQ.NSTD.OR.ITIME.EQ.1.OR.ITIME.EQ.LTORB.OR BAT03200
     1.ITIME.EQ.(NSTD+1)) GO TO 444                                     BAT03210
 3420 CONTINUE                                                          BAT03220
      GO TO 9000                                                        BAT03230
C     PRINT EACH MINUTE ORBITAL PARAMETERS                              BAT03240
  444 WRITE(6,952)ITIME,IREG,RBOI,CFK,CFCR,CTHR,WATOT,EFFC,CTOT,BSOC,   BAT03250
     1BTVL,BTCR                                                         BAT03260
      IFLAG=0                                                           BAT03270
      GO TO 9000                                                        BAT03280
C                                                                       BAT03290
 4000 CONTINUE                                                          BAT03300
```
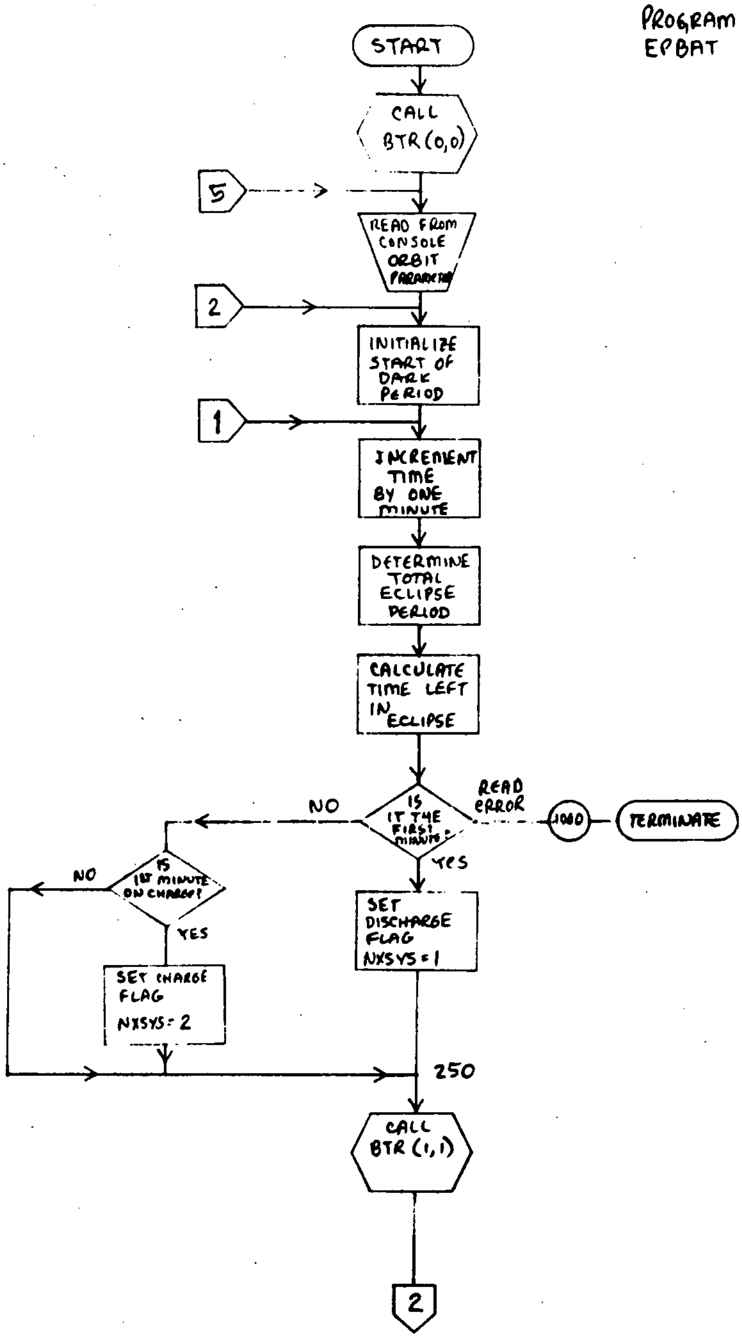
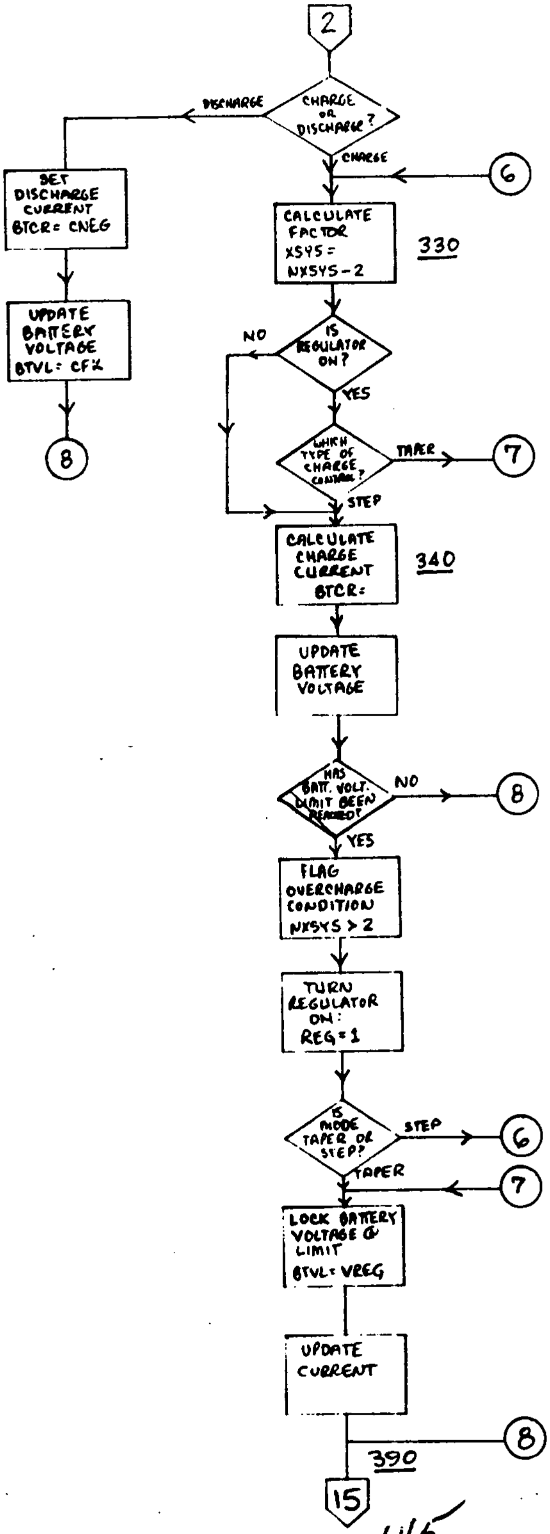
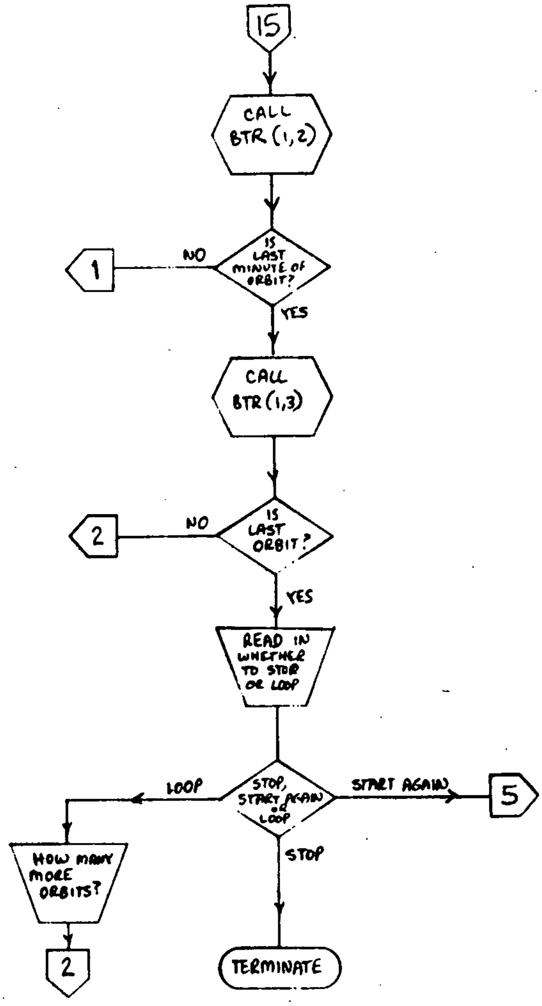

```
      WRITE(6.980)                                                      BAT03310
      TORB=LTORB                                                        BAT03320
      WMIN=WATOT                                                        BAT03330
      AMFIN=CTOT                                                        BAT03340
C     CALCULATE THE PER-CENT CAPACITY RETURNED                          BAT03350
      BCRTN=100.*(CTHR/(AMINT-AMDL))                                    BAT03360
C     PRINT THE END-OF-ORBIT PARAMETERS                                 BAT03370
      WRITE(6.982)EDBV.BTVL.BTCR.EFFC.BCRTN.AMINT.AMDL.AMFIN.WMOUT.WMIN BAT03380
C                                                                       BAT03390
C     CALCULATE THE THERMAL COEFFICIENTS USING TWO DIFFERENT            BAT03400
C     HEAT GENERATION MODELS THEN AVERAGE THE TWO                       BAT03410
C                                                                       BAT03420
      BHGM1=((WMIN-WMOUT)+(AMINT-AMFIN)*BCEL*1.48)/TORB                 BAT03430
      BHGM2=(.13*WMOUT+WDCHG)/TORB                                      BAT03440
      BHGM=(BHGM1+BHGM2)/2.0                                            BAT03450
      QBAY=0.                                                           BAT03460
C     PRINT THE END-OF-ORBIT HEAT GENERATION                            BAT03470
      WRITE(6.990)BHGM1.BHGM2.BHGM.QBAY                                 BAT03480
      RAD=BCRTN                                                         BAT03490
 9000 CONTINUE                                                          BAT03500
      RETURN                                                            BAT03510
      END                                                               BAT03520
      FUNCTION AMAX1(A.B)                                               BAT03530
      IF(A-B)10.20.20                                                   BAT03540
   10 AMAX1=B                                                           BAT03550
      RETURN                                                            BAT03560
   20 AMAX1=A                                                           BAT03570
      RETURN                                                            BAT03580
      END                                                               BAT03590
      FUNCTION AMIN1(A.B)                                               BAT03600
      IF(A-B)10.20.20                                                   BAT03610
   10 AMIN1=A                                                           BAT03620
      RETURN                                                            BAT03630
   20 AMIN1=B                                                           BAT03640
      RETURN                                                            BAT03650
      END                                                               BAT03660
```

PROGRAM
EPBAT (MAIN)

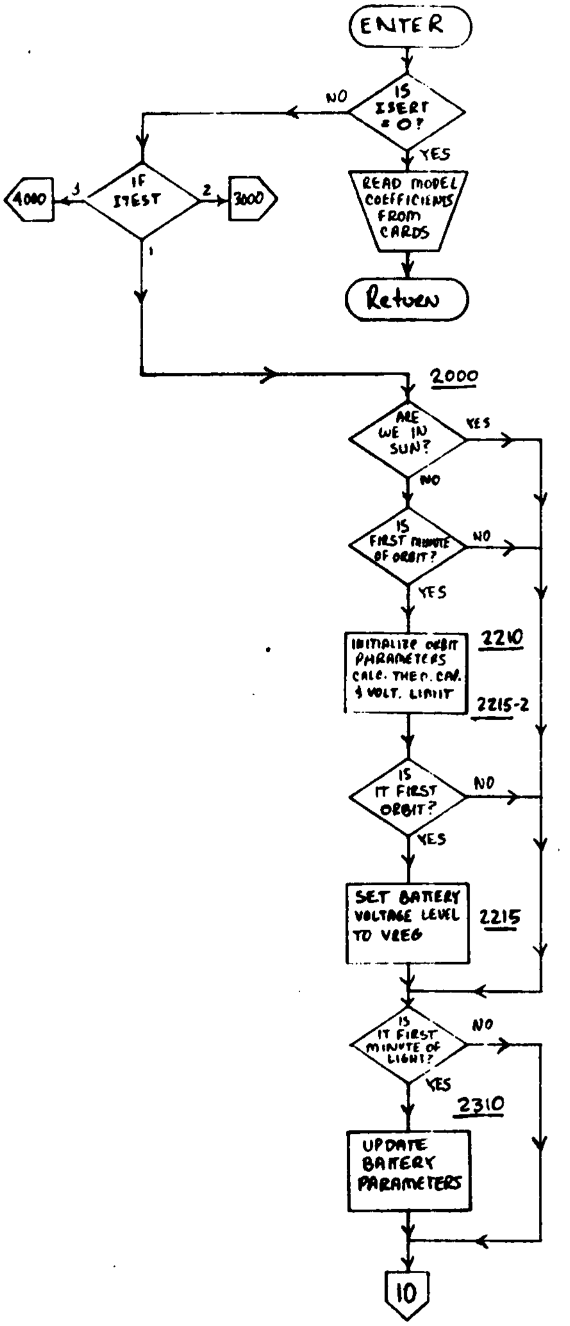


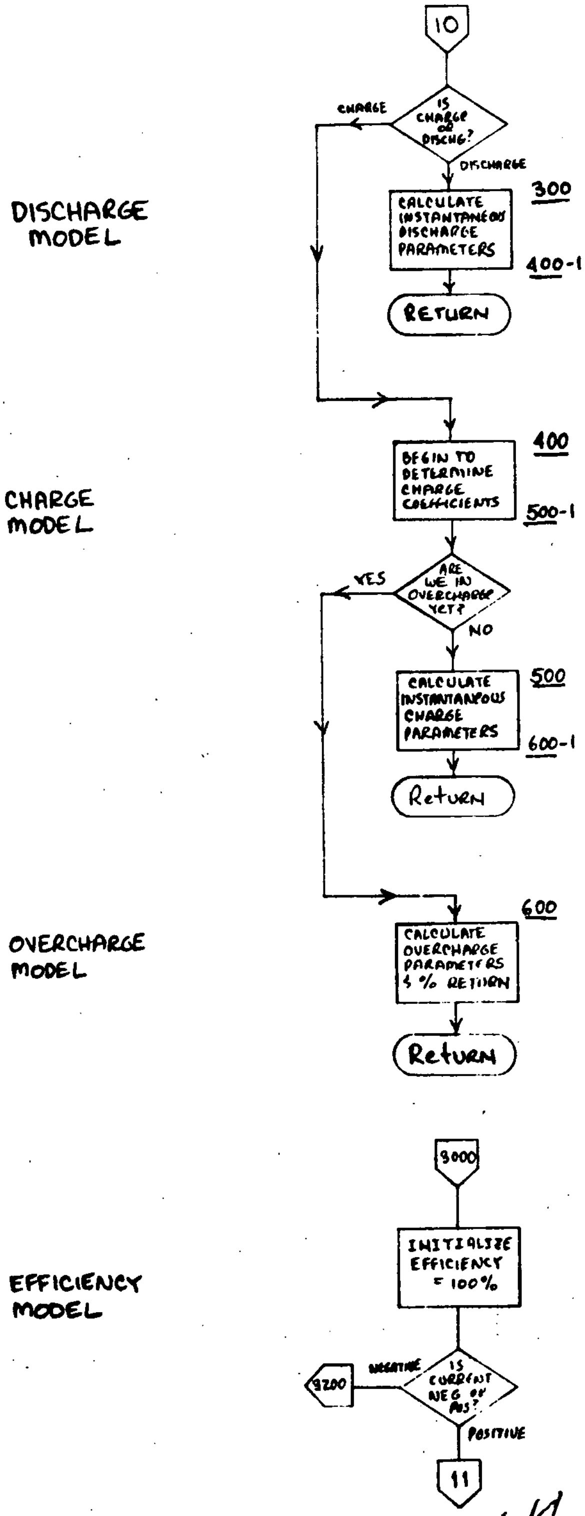

2
CHARGE OR DISCHARGE?
DISCHARGE
CHARGE
SET DISCHARGE CURRENT BTCR= CNEG
UPDATE BATTERY VOLTAGE BTVL= CF%
8
6
CALCULATE FACTOR XSYS = NXSYS-2
330
IS REGULATOR ON?
NO
YES
WHICH TYPE OF CHARGE CONTROL?
TAPER
7
STEP
CALCULATE CHARGE CURRENT BTCR=
340
UPDATE BATTERY VOLTAGE
HAS BATT. VOLT. LIMIT BEEN REACHED?
NO
8
YES
FLAG OVERCHARGE CONDITION NXSYS > 2
TURN REGULATOR ON: REG=1
IS MODE TAPER OR STEP?
STEP
6
TAPER
7
LOCK BATTERY VOLTAGE @ LIMIT BTVL= VREG
UPDATE CURRENT
8
390
15

445


15
CALL BTR (1,2)
IS LAST MINUTE OF ORBIT?
NO
1
YES
CALL BTR (1,3)
IS LAST ORBIT?
NO
2
YES
READ IN WHETHER TO STOP OR LOOP
STOP, START AGAIN OR LOOP
LOOP
START AGAIN
5
STOP
HOW MANY MORE ORBITS?
2
TERMINATE

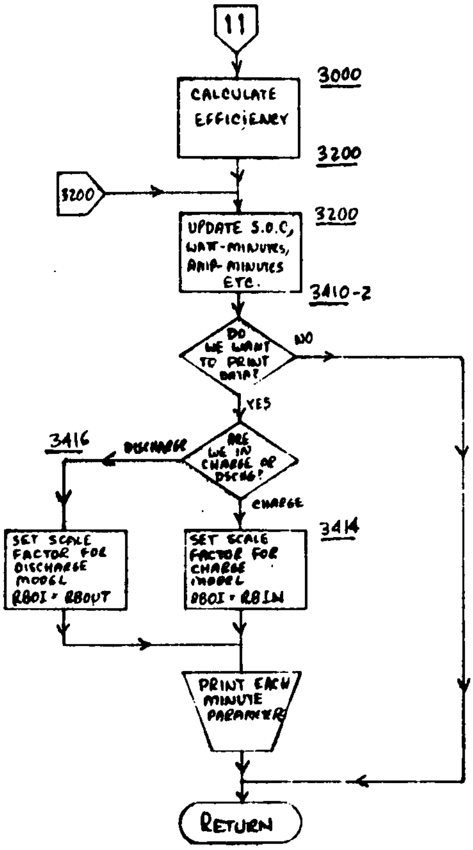
Subroutine BTR (ISERT, ITEST)



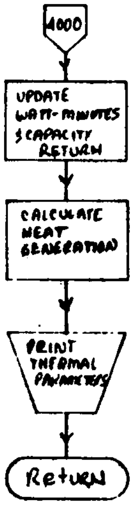

10
CHARGE
IS CHARGE OR DISCHG?
DISCHARGE
DISCHARGE MODEL
CALCULATE INSTANTANEOUS DISCHARGE PARAMETERS
300
400-1
RETURN
CHARGE MODEL
BEGIN TO DETERMINE CHARGE COEFFICIENTS
400
500-1
YES
ARE WE IN OVERCHARGE YET?
NO
CALCULATE INSTANTANEOUS CHARGE PARAMETERS
500
600-1
Return
OVERCHARGE MODEL
CALCULATE OVERCHARGE PARAMETERS & % RETURN
600
Return
9000
EFFICIENCY MODEL
INITIALIZE EFFICIENCY = 100%
9200
NEGATIVE
IS CURRENT NEG OR POS?
POSITIVE
11

EFFICIENCY

OUTPUT

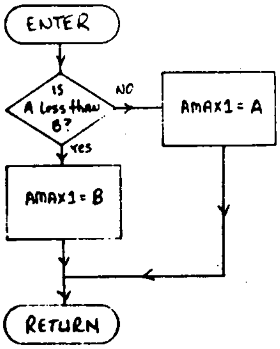


THERMAL

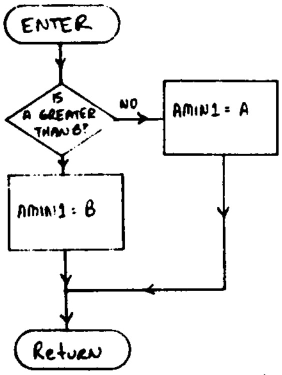


449

FUNCTIO. AMAX1 (A,B)



FUNCTION AMIN1 (A,B)



450