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THIRTEENTH ANNUAL REPORT OF CYCLE LIFE TEST

prepared for
GODDARD SPACE FLIGHT CENTER

Contract S-53742AG

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NASA STI FACILITY

PREPARED BY

WEAPONS QUALITY ENGINEERING CENTER

NAVAL WEAPONS SUPPORT CENTER, CRANE, INDIANA

DEPARTMENT OF THE NAVY
NAVAL WEAPONS SUPPORT CENTER
WEAPONS QUALITY ENGINEERING CENTER
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EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

THIRTEENTH ANNUAL REPORT OF CYCLE LIFE TEST

WQEC/C 77-87 10 MARCH 1977

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REPORT BRIEF

CYCLE LIFE TEST OF SECONDARY SPACECRAFT CELLS

Ref: (a) NASA Purchase Order Number S-53742AG
(b) NASA ltr BRA/VBK/pad of 25 Sep 1961 w/BUWEPS first end FQ-1:WSK of 2 Oct 1961 to CO NAD Crane
(c) Preliminary Work Statement for Battery Evaluation Program of 16 Sep 1974
(d) NAD Crane report QE/C 70-687 of 20 Sep 1970

I. TEST ASSIGNMENT

A. In compliance with references (a) and (b), evaluation of secondary spacecraft cells was begun according to the program outline of reference (c). This thirteenth annual report covers the cycle life test of the evaluation program of secondary spacecraft cells, through 15 December 1976. The acceptance tests and general performance tests of the evaluation program were reported earlier where applicable. The purpose of the acceptance tests is to insure that all cells put into the life cycle program meet the specifications outlined in the respective purchase contracts. A sample number of cells of each type (usually five) are subjected to the general performance tests to determine the limit of their actual capabilities. All reports may be obtained from National Aeronautics and Space Administration, Scientific and Technical Information Division (Code US), Washington, D.C.

B. This evaluation program gathers statistical information concerning cell performance characteristics and limitations which is used by spacecraft power systems planners, designers, and integration teams. Weaknesses discovered in cell design are reported and aid in research and development efforts toward improving the reliability of space batteries. Battery weaknesses encountered in satellite programs such as IMP, NIMBUS, OGO, OAO, SAS, and TETR have been studied and remedied through special tests performed at NAVWPNSUPPCEN Crane.

II. TEST OUTLINE

A. On 5 December 1963 this activity began the cycle life test on 660 sealed, nickel-cadmium cells purchased by NASA. The cells were from four manufacturers, and consisted of seven sample classifications ranging from 3.0 to 20 ampere-hours. Since then 1300

nickel-cadmium, 183 silver-cadmium and 125 silver-zinc cells from several manufacturers have been added to the program, excluding synchronous orbit and accelerated test packs. The capacities of the nickel-cadmium cells ranged from 1.25 to 50 ampere-hours; and that of the silver-cadmium cells ranged from 3.0 to 12.0 ampere-hours; and that of the silver-zinc cells ranged from 5 to 40 ampere-hours. The purpose of the cycle life program is to determine the cycling performance capabilities of packs of cells (5 or 10 cell packs) under different load, charge control and temperature conditions. The load conditions include cycle length (orbit periods) of 1.5 to 24 hours; and depth of discharge ranging from 10 to 75 percent. The charge control methods used are voltage limit, auxiliary electrode, coulometer, stabistor, a two-step regulator, thermistor controlled voltage limit, and the Sherfey upside-down cycling regime. Specially constructed cells to apply internal pressure against the fact of the plate stack, and a type to permit high charge rates were also tested. Environmental conditions include ambient temperatures of -20°C, 0°C, 10°C, 20°C, 40°C, 50°C, and a cycling temperature of 0°C to 40°C within a period of 48 hours. A "Summary in Brief of Test Parameters" is listed in page iv.

III. TEST RESULTS

A. Life cycling data shows that nickel-cadmium cells tested at 0°C give longer cycle life, higher end-of-discharge voltages and less degradation of ampere-hour capacities than cells tested at 25°C or 40°C. Overall performance decreases with increase in the depth of discharge at all test temperatures. Cell cycle life is extended when the amount of recharge is limited to the following amounts: 105 percent at 0°C, 115 percent at 25°C and 125 percent at 40°C. Operating performance can also be improved by recharging at rates between c/2 and c/10 with the amount of recharge controlled by auxiliary electrodes or cadmium-cadmium coulometers. A statistical analysis of the life cycle prediction and cause of failure versus test conditions are given in reference (d).

B. Cycle life data is more limited on silver-cadmium cells. However the silver-cadmium data leads to the following generalizations:

1. Depth of Discharge: Longest life is found at 18 to 25 percent depth of discharge, while 40 to 50 percent depth shortens life.

2. Temperature: Cells giving longest life have operated at 0° to 25°C. Temperatures of 40°C are detrimental. Only one of five packs operating at 40°C (33C) has exceeded 400 days of cycling. Limited data at -20°C indicates short life at this temperature. This is exemplified in pack 85B which cycled 148 days.

3. Orbit Period: The orbit period for silver-cadmium cells is predominately 8 or 24 hours. The failures are not common to either regime until the packs exceed 660 days (approximately 2 years) of testing. Failures prior to this time on test are randomly distributed between the orbit regimes. Four of five packs (57D, 77B, 33B and 113B) exceeding 660 days have operated under a 24-hour orbit regime. Thus the longevity of the silver-cadmium cells is favored by the 24-hour orbit period.

C. The silver-zinc packs were predominantly 24-hour orbit, 40 percent depth of discharge at 25°C. Thus comparison of operational characteristics of the cells at different parameters is not possible. The basic conclusion is that silver-zinc has very short life under these conditions ranging from 32 to 325 days of cycling--the average being 120 days.

D. Cell failure analyses of nickel-cadmium cells have shown several failure modes such as little or no insulation around tabs and busses/comb, ceramic shorts across the terminals, and leaks around the terminals which since have been corrected. A better separator material is still needed to extend cycle life of cells. Battery quality control programs in the manufacturers' plants would do much to eliminate or minimize failure due to misaligned separator material, blistering of positive plates, ragged plate edges, and extraneous material, both active and foreign.

E. Carbonate analyses of a limited number of nickel-cadmium separator tests have revealed extremely high percentages (equivalence) of carbonate. The average is slightly over 60 percent of the total equivalence. Analyses are performed using GSFC's "Procedure for Analysis of Nickel-Cadmium Cell Material," Report No. X-711-74-79 and Addendum, of October 1974.

F. All active and completed packs are listed on pages viii through xxi. The symbols used are explained on pages v through vii.

SUMMARY IN BRIEF OF TEST PARAMETERS

MANUFACTURER	CAPACITIES TESTED	ORBIT PERIOD	PERCENT DEPTH OF DISCHARGE	TEST TEMPERATURES	SPECIAL CHARGE CONTROL	TOTAL NO. OF CELLS
			NICKEL-CADMIUM			
GE	3.0, 5.0, 6.0 6.0, 8.0, 12.0 15.0, 20.0	1.5, 1.92 2.16, 3.0 24.0 Sync	15, 21, 25, 40, 50, 60, 80	0°, 10°, 20° 25°, 40°, 50° 40°, *	AE, AE14, AE14 THER, COUL	423
Gould	3.5, 20.0	1.5, 3.0	15, 25, 40	0°, 25°, 50°-40°		180
Gulton	1.25, 3.5, 3.6, 4.0, 5.0, 5.6, 6.0, 9.0, 10.0, 12.0,15.0,20.0,50.0	1.5, 1.6, 3.0, 24.0 Sync	10, 15, 21, 25, 40, 50, 60	-20°, 0°, 10°, 10°, 20°, 25°, 50°-40°, 40°,*	AE, CLM, MULTI THER	724
Heliotek	20.0	1.5	40	20°	CLM	5
NIFE	3.9	1.5	25	0°, 25°		10
Sonotone	3.0, 3.5, 5.0, 20.0	1.5, 3.0	15, 25, 40, 75	-20°, 0°, 20° 25°, 50°-40°, 40°	ST, AE, IPD	305
Eagle-Picher	3.0, 6.0	1.5, Sync	25, 60	0°, 20°	AE	82
			SILVER-CADMIUM			
ESB	8.0	8.0	25	25°	AE	5
Yardney	3.0, 5.0, 10.0, 11.0, 12.0, 24.0	1.5, 8.0 24.0	16, 20, 27, 30, 40, 43	-20°, 0°, 20°, 25°, 40°	AE-GE (12.0 AH only)	169
Electromite	7.0	8.0	30	20°		3
			SILVER-ZINC			
Delco	25.0, 40.0	3.0, 24.0	25, 40	25°	2SR	45
McDonnell-Douglas	5.0, 40.0	1.5, 4.0, 12.0, Sync	25, 60	0°, 20°, 40°		60
Yardney	5.0, 12.0, 16.0, 21.0	24.0, Sync	31, 42, 60	20°, 25°	2SR	20

EXPLANATION OF SYMBOLS

1. Temperature:

   * Ambient temperature which varies sinusoidally from 0° to 40°C once per 48-hour period.

2. Special Symbols:

   AE: Auxiliary electrode cells.

   (AE): Atmospheric Explorer.

   AE-GE: General Electric type.

   AE-GU: Gulton type.

   AE13: General Electric type AB13.

   AE14: General Electric type AB14.

   ASTRO: Astropower Laboratory, McDonnell-Douglas.

   ATS: Application Technology Satellite.

   CC: Commercial cells.

   CHSP: "Chemsorb" separator.

   CLM: Coulometer in series with cells to effect charge control.

   CO-NI: Nickel-cadmium cells with cobalt additive to nickel-plate.

   CPSP: Cellophane separator.

   C3SP: C3 separator.

   ERTS: Earth Resources Technology Satellite.

   FRS: Folded, vulcanized neoprene, terminal to cover seal.

   GOES: Geostationary Operational Environmental Satellite.

   GSFC: Goddard Space Flight Center, Greenbelt, Maryland

   HCMM: Heat Capacity Mapping Mission

   IM: Cells with improved material and methods used in construction.

   IME: International Magnetosphere Explorer (now known as ISEE).

IMP: Interplanetary Monitoring Platform.

IPD: Cells containing an internal pressure device.

ITOS: Improved TIROS Operational Satellite.

ISEE: International Sun Earth Explorer (was known as IME).

IUE: International Ultraviolet Explorer.

meq: Milliequivalents.

MULTI: Pack contains coulometer and cell with and without auxiliary electrodes.

MULTI*: Pack contains cells with and without auxiliary electrodes.

NA: Not Applicable.

NB: NIMBUS cells.

NBPT: NIMBUS cells with pressure transducers.

pp: Polypropylene.

OAO: Orbiting Astronomical Observatory.

OGO: Orbiting Geophysical Observatory.

OSO: Orbiting Solar Observatory.

PE: Planetary Explorer.

PLSP: Pellon separator.

PS: Polymerized neoprene terminal to cover seal.

RAE: Radio Astronomy Explorer.

RC-AE: Recombination and auxiliary electrodes.

RCPSP: Radiated cellophane separator.

RS: Vulcanized neoprene terminal to cover seal.

SAS: Small Astronomy Satellite.

SMS: Synchronous Meteorological Satellite.

ST: Stabistors used for charge control of cells.

SYNC: Synchronous Orbit.

TETR: Test and training satellite.

THER: Thermistor controlled voltage limit.

WNSP: Woven nylon separator.

2SR: Two-step regulator used for charge control of cells.

3S: Triple seal between terminals and cover (ceramic between glass).

3. Date Completed:

D: Discontinued.

F: Failed.

4. Note: / indicates a change in test parameters (start of test/ present parameters).
+ indicates those packs, or cells, of that type which have been chemically analyzed.

5. Annual Last Graphed: Indicates last annual which contained that pack's life-cycling graph. If nothing is entered then that pack's graph is contained in this annual. The annuals referenced to are listed as follows:

Annual	Report Number	Date	Address
2nd	QE/C 66-304	13 May 1966	NAD Crane, IN
3rd	QE/C 67-685	3 November 1967	NAD Crane, IN
4th	QE/C 68-138	14 May 1968	NAD Crane, IN
5th	QE/C 69-244	7 April 1969	NAD Crane, IN
6th	QE/C 70-173	6 March 1970	NAD Crane, IN
7th	QE/C 71-1	29 January 1971	NAD Crane, IN
8th	QEEL/C 72-1	9 February 1972	NAD Crane, IN
9th	QEEL/C 73-4	22 May 1973	NAD Crane, IN
10th	QEEL/C 74-34	15 February 1974	NAD Crane, IN
11th	WQEC/C 75-2	10 January 1975	NAD Crane, IN
12th	WQEC/C 76-5	11 February 1976	NAVWPNSUPPCEN Crane, IN

ACTIVE AND COMPLETED PACKS

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	ANNUAL LAST GRAPHED
NICD	3.00	Sync	60%	20°	EP		227A	0.50	1.50	5	9-5-73	54 Days	10-29-73 D	NA
NICD	3.00	Sync	60%	20°	EP		227B	0.15	1.50	5	4-10-74	920 Days		
NICD	3.00	Sync	60%	20°	EP		277C	0.15	1.50	5	4-14-76	230 Days		
NICD	6.00	1.5	25%	20°	EP	AE	2D	1.00	3.00	6	2-15-71	376	3-23-71 D	8
NICD	6.00	1.5	25%	20°	EP	AE	14E+	1.00	3.00	6	2-15-71	997	4-10-71 D	8
NICD	6.00	1.5	25%	20°	EP	AE	26D	1.00	3.00	6	2-15-71	25	3-07-71 D	8
NICD	6.00	1.5	25%	20°	EP	AE	22C+	1.00	3.00	6	2-16-71	5,950	3-22-72 D	9
NICD	6.00	1.5	25%	20°	EP	AE	25D+	1.00	3.00	8	2-17-71	5,950	3-22-72 D	9
NICD	6.00	1.5	25%	20°	EP	AE	31C+	1.00	3.00	6	2-17-71	5,936	3-22-72 D	9
NICD	6.00	1.5	25%	20°	EP	AE	30F+	1.00	3.00	6	2-17-71	5,903	3-22-72 D	9
NICD	6.00	1.5	25%	20°	EP	AE	46C+	1.00	3.00	6	2-17-71	5,000	3-22-72 D	9
NICD	6.00	1.5	25%	20°	EP	AE	49B+	1.00	3.00	6	2-17-71	5,905	3-22-72 D	9
NICD	6.00	1.5	25%	20°	EP	AE	2E+	1.65	3.00	5	5-2-71	5,001	6-7-72 D	9
NICD	6.00	1.5	25%	25°	EP		9F+	3.00	3.00	7	11-14-74	10,530		
NICD	6.00	1.5	25%	25°	EP		9J+	3.00	3.00	4	10-29-74	6,167	1-19-76 D	
NICD	6.00	1.5	25%	25°	EP		9K+	3.00	3.00	5	10-10-74	6,270	1-11-76 D	
NICD	6.00	1.5	25%	25°	EP		9L+	3.00	3.00	6	10-2-74	6,391	1-11-76 D	
NICD	6.00	1.5	25%	25°	EP		9M+	3.00	3.00	6	10-2-74	6,306	1-11-76 D	
NICD	6.00	1.5	25%	25°	EP		9O+	3.00	3.00	5	10-10-74	4,001	8-11-75 D	12
NICD	6.00	1.5	25%	25°	EP		9P+	3.00	3.00	6	10-29-74	6,332	1-11-76 D	
NICD	6.00	1.5	25%	25°	EP		9Q+	3.00	3.00	6	10-29-74	6,031	1-11-76 D	
NICD	6.00	1.5	25%	25°	EP		9R+	3.00	3.00	5	11-14-74	6,139	1-19-76 D	
NICD	6.00	1.5	25%	25°	EP		9S+	3.00	3.00	6	11-14-74	10,476		
NICD	6.00	1.5	25%	25°	EP		9T+	3.00	3.00	6	4-1-75	4,002	9-5-75 D	12
NICD	6.00	1.5	40%	40°	EP	AE	42D	4.00	4.00	5	9-1-71	95	9-13-71 D	9
NICD	6.00	1.5	40%	20°	EP	AE	65C	4.00	4.00	5	9-1-71	4,227	5-24-72 F	9
NICD	6.00	1.5	40%	0°	EP	AE	53C	4.00	4.00	5	9-1-71	10,325	9-6-73 D	10
NICD	12.0	Sync	60%	20°	EP		221A	1.20	6.00	5	11-7-72	1975 Days		

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	ANNUAL LAST GRAPHED
NICD	12.0	Sync	60%	10°	EP		222A	1.20	6.00	5	11-23-72	1975 Days		
NICD	12.0	Sync	60%	0°	EP		223A	1.20	6.00	5	11-3-72	1975 Days		
NICD	3.00	1.5	15%	0°	GE		63A	0.52	0.90	10	12-6-63	22,923	2-15-68 D	5
NICD	3.00	3.0	15%	0°	GE		67A	0.21	0.90	10	12-20-63	11,532	2-15-68 D	5
NICD	3.00	1.5	25%	0°	GE		64A	0.86	1.50	10	12-5-63	23,441	2-14-68 D	5
NICD	3.00	3.0	25%	0°	GE		68A	0.34	1.50	10	12-20-63	11,740	2-13-68 D	5
NICD	3.00	1.5	25%	25°	GE		15A	0.94	1.50	10	12-6-63	10,382	11-6-65 F	
NICD	3.00	3.0	25%	25°	GE		19A	0.38	1.50	10	12-20-63	10,768	2-12-68 D	5
NICD	3.00	1.5	40%	25°	GE		16A	1.50	2.40	10	12-5-63	5,014	11-18-64 F	
NICD	3.00	3.0	40%	25°	GE		20A	0.60	2.40	10	12-20-63	5,410	1-8-66 F	3
NICD	3.00	1.5	15%	40°	GE		39A	0.72	0.90	10	12-12-63	8,109	6-19-65 F	7
NICD	3.00	3.0	15%	40°	GE		43A	0.29	0.90	10	12-20-63	2,656	12-26-64 F	2
NICD	3.00	1.5	25%	40°	GE		40A	1.20	1.50	10	12-12-63	2,511	7-9-64 F	2
NICD	3.00	3.0	25%	40°	GE		44A	0.48	1.50	10	12-20-63	4,487	9-14-65 F	2
NICD	4.50	1.5	13%	20°	GE	NB	26E	1.10	1.20	10	2-23-72	8,423	9-17-73 D	10
NICD	5.00	1.5	15%	0°	GE	NB	103A	0.83	1.50	5	4-24-65	62,905		
NICD	5.00	1.5	25%	0°	GE	NBPT	107A	1.38	2.50	5	6-5-65	39,775	6-14-72 D	9
NICD	5.00	1.5	15%	25°	GE	NB	106A	0.90	1.50	5	4-24-65	26,013	12-31-69 F	7
NICD	5.00	1.5	25%	25°	GE	NBPT	104B	1.50	2.50	5	6-10-65	13,149	11-15-67 F	4
NICD	5.00	1.5	15%	40°	GE	NB	113A	0.98	1.50	5	4-24-65	4,998	3-15-66 D	3
NICD	5.00	1.5	25%	40°	GE	NBPT	114A	1.63	2.50	5	6-12-65	8,273	12-19-66 F	3
NICD	6.00	Sync	40%	40°	GE		201A+	0.20	2.00	5	7-18-67	1948 Days	11-19-72 D	NA
NICD	6.00	Sync	40%	25°	GE		202A+	0.20	2.00	5	7-18-67	3407 Days		
NICD	6.00	Sync	40%	0°	GE		203A+	0.20	2.00	5	7-18-67	3407 Days		
NICD	6.00	Sync	40%	-20°	GE		204A	0.20	2.00	5	7-18-67	200 Days	2-5-68 F	NA

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETE	ANNUAL LAST GRAPHEDD
NICD	6.00	Sync	40%	-20°	GE	COUL	204B	0.20	2.00	5	8-2-68	2198 Days	8-28-74 D	NA
NICD	6.00	Sync	60%	0°	GE	COUL	205A+	0.30	3.00	5	7-18-67	3407 Days		
NICD	6.00	Sync	80%	0°	GE	COUL	206A+	0.40	4.00	5	7-18-67	3407 Days		
NICD	6.00	1.5	25%	0°	GE	AE-13	52C	3.00	3.00	5	6-3-68	9,954	2-25-70 F	7
NICD	6.00	1.5	25%	0°	GE	AE-14	50B	3.00	3.00	5	5-20-68	29,206	7-3-73 F	10
NICD	6.00	1.5	25%	25°	GE	AE-13	5B	3.00	3.00	5	5-20-68	13,254	11-3-70 D	7
NICD	6.00	1.5	25%	25°	GE	AE-14	17B	3.00	3.00	5	5-20-68	15,938	2-21-71 F	8
NICD	6.00	1.5	25%	40°	GE	AE-13	6C	3.00	3.00	5	6-3-68	8,072	11-10-69 F	6
NICD	6.00	1.5	25%	40°	GE	AE-14	42C	3.00	3.00	5	5-20-68	9,047	1-16-70 D	7
NICD	6.00	1.5	25%	*/20°	GE	AE-13	62B	3.00	3.00	5	7-3-68	14,406	6-15-73 F	10
NICD	6.00	1.5	25%	*	GE	AE-14	65B	3.00	3.00	5	7-3-68	14,392	1-31-71 D	7
NICD	6.00	1.5	15%	0°	GE	AE	53B	1.80	1.80	5	7-18-68	9,230	2-23-70 F	7
NICD	6.00	1.5	15%	25°	GE	AE	28C	1.80	1.80	5	7-18-68	9,987	4-8-70 F	7
NICD	6.00	1.5	15%	40°	GE	AE	47C	1.80	1.80	5	7-18-68	5,842	7-28-69 D	6
NICD	6.00	1.5	25%	40°	GE	CHSP	9G	4.80	4.80	5	11-7-68	143	11-21-68 F	5
NICD	6.00	1.5	25%	40°	GE	PLSP	27C	4.80	4.80	5	11-7-68	559	12-16-68 D	5
NICD	6.00	1.5	21%	25°	GE	SAS B	1C+	3.50	2.50	8	7-22-70	24,064	1-26-75 D	12
NICD	6.00	2.16/1.5	20%	10°	GE	MULTI*	2F	1.50	1.90	5	12-11-73	13,681		
NICD	6.00	2.16/1.5	20%	20°	GE	MULTI*	2G	1.50	1.90	5	12-11-73	13,512		
NICD	6.00	2.16/1.5	20%	0°	GE	MULTI*	2H	1.50	1.90	5	12-11-73	13,387		
NICD	6.00	1.5	25%	-20°	GE		81B	3.00	3.00	5	3-14-71	17,189	8-29-74 D	11
NICD	6.00	1.5	25%	20°	GE		95B	3.00	3.00	5	3-14-71	30,073		
NICD	6.00	1.5	25%	0°	GE		92B	3.00	3.00	5	3-14-71	29,194		
NICD	6.00	1.5	25%	40°	GE		106B	3.00	3.00	5	3-14-71	7,538	7-2-72 F	9
NICD	6.00	1.92	29%	20°	GE		7D+	1.45	3.75	5	5-5-75	6,099		
NICD	6.00	24.0	60%	40°	GE		91B	0.30	3.60	5	3-18-71	792	6-23-73 D	10
NICD	6.00	24.0	60%	20°	GE		109B+	0.30	3.60	5	3-18-71	1,914		

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	ANNUAL LAST GRAPHED
NICD	6.00	24.0	60%	0°	GE		123B+	0.30	3.60	5	3-18-71	1,876		
NICD	6.00	24.0	60%	-20°/10°	GE		75E+	0.30	3.60	5	3-18-71	1,928		
NICD	6.00	1.5	40%	40°	GE	RC-AE	6D	4.80	4.80	5	4-25-71	2,268	10-11-71 F	8
NICD	6.00	1.5	40%	20°	GE	RC-AE	64B	4.80	4.80	5	4-25-71	2,712	6-29-72 D	9
NICD	6.00	1.5	40%	0°	GE	RC-AE	30C	4.80	4.80	5	4-25-71	4,129	6-29-72 D	9
NICD	8.00	1.5	25%	20°	GE	AE	18E	4.00	4.00	10	3-6-74	13,912		
NICD	8.00	1.5	25%	20°	GE	AE	18F	4.00	4.00	10	3-6-74	13,948		
NICD	12.00	1.5	15%	0°	GE		110A	2.07	3.60	5	1-4-64	68,319		
NICD	12.00	3.0	15%	0°	GE		111A	0.83	3.60	5	1-4-64	34,553		
NICD	12.00	1.5	25%	0°	GE		124A	3.45	6.00	5	1-4-64	34,343	11-5-69 F	6
NICD	12.00	3.0	25%	0°	GE		125A	1.38	6.00	5	1-4-64	34,920		
NICD	12.00	1.5	25%	25°	GE		82A	3.75	6.00	5	1-4-64	10,878	12-30-65 F	2
NICD	12.00	3.0	25%	25°	GE		83A	1.50	6.00	5	1-4-64	13,897	1-24-69 F	6
NICD	12.00	1.5	40%	25°	GE		96A	6.00	9.60	5	1-4-64	4,020	10-2-64 F	2
NICD	12.00	3.0	40%	25°	GE		97A	2.40	9.60	5	1-4-64	5,002	11-8-65 F	2
NICD	12.00	1.5	15%	40°	GE		85A	2.88	3.60	5	1-9-64	9,710	11-8-65 F	2
NICD	12.00	3.0	15%	40°	GE		86A	1.15	3.60	5	1-4-64	10,661	1-2-68 F	5
NICD	12.00	1.5	25%	40°	GE		99A	4.80	6.00	5	1-9-64	4,853	1-5-65 F	2
NICD	12.00	3.0	25%	40°	GE		100A	1.92	6.00	5	1-4-64	4,424	9-24-65 F	2
NICD	12.00	24.0	50%	25°	GE		93A	0.52	6.00	5	3-23-64	349	4-28-65 D	3
NICD	12.00	1.5	25%	0°	GE	AE	60A	6.00	6.00	5	10-6-65	5,650	10-20-66 D	3
NICD	12.00	1.5	25%	25°	GE	AE	12A	6.00	6.00	5	7-20-65	1,698	12-1-65 D	3
NICD	12.00	1.5	40%	25°	GE	AE	24A	9.60	9.60	5	10-2-65	665	11-19-65 D	3
NICD	12.00	1.5	40%	0°	GE	AE	48A	9.60	9.60	5	10-12-65	5,110	2-10-67 D	3
NICD	12.00	1.5	25%	0°	GE	AE	58A	6.00	6.00	5	1-20-67	136	2-10-67 D	NA
NICD	12.00	1.5	40%	0°	GE	AE	72A	6.00	9.60	5	1-20-67	304	2-2-67 D	NA

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
NICD	12.00	1.5	25%	25°	GE	AE	12B	6.00	6.00	5	1-6-67	404	2-10-67	D	NA
NICD	12.00	1.5	40%	25°	GE	AE	24B	6.00	9.60	5	1-5-67	38	2-10-67	D	NA
NICD	12.00	1.5	25%	40°	GE	AE	36A	6.00	6.00	5	1-27-67	75	2-3-67	D	NA
NICD	12.00	1.5	40%	40°	GE	AE	34A	6.00	9.60	5	1-27-67	65	2-3-67	D	NA
NICD	12.00	1.6	16%	10°	GE	MULTI*	7C	3.20	3.20	5	12-11-73	13,894			
NICD	12.00	24.0	50%	0°	GE	AE	8C	1.20	6.00	5	10-8-74	705			
NICD	12.00	24.0	50%	10°	GE	AE	8D	1.20	6.00	5	10-8-74	722			
NICD	12.00	24.0	50%	20°	GE	AE	8E	1.20	6.00	4	10-8-74	687			
NICD	12.00	1.5	25%	20°	GE	AE	8F	6.00	6.00	5	3-7-76	3,643			
NICD	12.00	1.5	40%	0°	GE	AE	8G	9.60	9.60	5	3-3-76	3,792			
NICD	12.00	24.0	50%	20°	GE	AE	8H	1.20	1.20	5	3-15-76	232			
NICD	12.00	Sync	80%	20°	GE	AE	228A	1.20	1.20	5	4-26-76	235 Days			
NICD	12.00	Sync	60%	0°	GE	AE	207A	3.00	6.00	5	3-22-69	2786 Days			
NICD	12.00	Sync	80%	0°	GE	AE	208A	3.00	8.00	5	3-22-69	2786 Days			
NICD	12.00	Sync	60%	20°	GE	AE	209A	3.00	6.00	5	3-22-69	2786 Days			
NICD	12.00	Sync	80%	20°	GE	AE	210A	3.00	8.00	5	3-22-69	2786 Days			
NICD	12.00	Sync	60%	40°	GE	AE	211A	3.00	6.00	5	3-22-69	793 Days	5-26-71	D	NA
NICD	12.00	Sync	80%	-20°	GE	AE	212A+	3.00	8.00	5	3-22-69	1962 Days	8-28-74	D	NA
NICD	20.00	1.5	15%	0°	GE	AE	7B	8.00	6.00	5	2-27-70	12,652	5-6-72	D	9
NICD	20.00	1.5	15%	0°	GE	AE	67B	8.00	6.00	5	2-27-70	12,634	5-6-72	D	9
NICD	20.00	1.5	25%	20°	GE	AE	1G	10.00	10.00	5	9-17-74	11,025			
NICD	20.00	1.5	40%	0°	GE	AE	1H	10.00	10.00	5	9-17-74	11,065			
NICD	20.00	1.5	25%	20°	GE	AE	1I	16.00	16.00	5	9-17-74	10,966			
NICD	20.00	1.5	40%	0°	GE	AE	1J	16.00	16.00	5	9-17-74	11,000			
NICD	3.50	1.5	15%	0°	GOULD		51A	0.60	1.05	10	12-5-63	22,364	2-15-68	D	5
NICD	3.50	3.0	15%	0°	GOULD		55A	0.24	1.05	10	12-20-63	11,546	2-15-68	D	5
NICD	3.50	1.5	25%	0°	GOULD		52A	1.00	1.75	10	12-5-63	13,730	6-11-60	F	3
NICD	3.50	3.0	25%	0°	GOULD		56A	0.40	1.75	10	12-20-63	11,897	2-15-68	D	5

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	ANNUAL LAST GRAPHED
NICD	3.50	1.5	25%	25°	GOULD		3A	1.09	1.75	10	12-6-63	4,751	10-31-64 F	2
NICD	3.50	3.0	25%	25°	GOULD		7A	0.44	1.75	10	12-20-63	4,173	7-26-65 F	2
NICD	3.50	1.5	40%	25°	GOULD		4A	1.75	2.80	10	12-5-63	3,164	7-9-64 F	2
NICD	3.50	3.0	40%	25°	GOULD		8A	0.70	2.80	10	12-20-63	2,494	11-29-64 F	2
NICD	3.50	1.5	15%	40°	GOULD		27A	0.84	1.05	10	12-12-63	4,485	11-6-64 F	2
NICD	3.50	3.0	15%	40°	GOULD		31A	0.34	1.05	10	12-20-63	2,517	1-3-65 F	2
NICD	3.50	1.5	25%	40°	GOULD		28A	1.40	1.75	10	12-12-63	1,811	5-29-64 F	2
NICD	3.50	3.0	25%	40°	GOULD		32A	0.56	1.75	10	12-20-63	975	6-10-64 F	2
NICD	20.00	1.5	15%	0°	GOULD		84A	3.45	6.00	5	1-16-64	22,448	2-13-68 D	5
NICD	20.00	3.0	15%	0°	GOULD		80A	1.38	6.00	5	1-21-64	11,378	2-13-68 D	5
NICD	20.00	1.5	25%	0°	GOULD		98A	5.75	10.00	5	1-21-64	10,641	1-14-66 F	3
NICD	20.00	3.0	25%	0°	GOULD		94A	2.30	10.00	5	1-24-64	11,162	2-13-68 D	5
NICD	20.00	1.5	25%	25°	GOULD		104A	6.25	10.00	5	1-16-64	2,980	8-20-64 F	2
NICD	20.00	3.0	25%	25°	GOULD		105A	2.50	10.00	5	1-21-64	5,690	3-17-66 F	3
NICD	20.00	1.5	40%	25°	GOULD		118A	10.00	16.00	5	2-1-64	2,937	9-7-64 F	2
NICD	20.00	3.0	40%	25°	GOULD		119A	4.00	16.00	5	2-1-64	1,793	9-27-64 F	2
NICD	20.00	1.5	15%	40°	GOULD		112A	4.80	6.00	5	1-16-64	5,213	2-15-65 F	2
NICD	20.00	3.0	15%	40°	GOULD		108A	1.92	6.00	5	1-24-64	4,237	8-31-65 F	2
NICD	20.00	1.5	25%	40°	GOULD		126A	8.00	10.00	5	1-16-64	1,574	5-23-64 F	2
NICD	20.00	3.0	25%	40°	GOULD		122A	3.20	10.00	5	1-24-64	983	7-2-64 F	2
NICD	1.25	1.5	25%	-20°	GULTON		74B	1.00	0.63	5	3-3-66	33,878	6-2-72 D	9
NICD	1.25	1.5	60%	-20°	GULTON		88D	1.00	0.63	5	3-3-66	32,144	3-30-72 F	9
NICD	1.25	1.5	25%	0°	GULTON		108B	1.25	0.63	5	3-4-66	33,063	4-5-72 D	9
NICD	1.25	1.5	60%	0°	GULTON		98B	1.25	1.50	5	3-4-66	12,247	5-28-68 F	5
NICD	3.50	1.5	25%	-20°	GULTON	PS	89C	0.96	1.75	5	12-24-66	23,832	3-13-71 F	8
NICD	3.50	1.5	40%	-20°	GULTON	PS	75D	1.54	2.80	5	12-24-66	14,197	9-28-69 F	6
NICD	3.50	1.5	25%	0°	GULTON	PS	122C	1.01	1.75	5	12-24-66	37,578	5-12-72 D	9
NICD	3.50	1.5	40%	0°	GULTON	PS	99C	1.61	2.80	5	12-24-66	31,769	7-30-72 F	9

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
NICD	3.50	1.5	25%	25°	GULTON	PS	87C	1.09	1.75	5	12-23-66	20,866	9-2-70	F	7
NICD	3.50	1.5	25%	40°	GULTON	PS	112C	1.40	1.75	5	1-2-67	11,155	1-3-69	F	6
NICD	3.50	1.5	40%	25°	GULTON	PS	73C	1.75	2.80	5	12-23-66	9,978	10-28-68	F	5
NICD	3.60	1.5	40%	25°	GULTON	CLM	39B	3.60	2.88	10	11-11-65	5,399	12-6-66	F	3
NICD	4.00	1.5	15%	0°	GULTON	CC	115B	0.69	1.20	5	7-25-64	41,641	4-5-72	D	9
NICD	4.00	1.5	25%	0°	GULTON	CC	126B	1.15	2.00	5	7-25-64	42,234	1-10-72	F	9
NICD	4.00	1.5	25%	25°	GULTON	CC	4B	1.25	2.00	5	8-4-64	35,111	10-13-70	F	7
NICD	4.00	1.5	40%	25°	GULTON	CC	14B	2.00	3.20	5	8-4-64	8,474	3-19-66	F	3
NICD	4.00	1.5	15%	40°	GULTON	CC	28B	0.96	1.20	5	8-4-64	20,227	7-6-68	F	5
NICD	4.00	1.5	25%	40°	GULTON	CC	40B	1.60	2.00	5	8-4-64	10,360	6-22-66	F	3
NICD	4.00	1.5	25%	-20°	GULTON	CLM	40C	2.00	2.00	5	3-4-67	2	3-4-67	F	NA
NICD	4.00	1.5	25%	0°	GULTON	CLM	52B	2.00	2.00	5	3-3-67	5,685	3-5-68	F	5
NICD	4.00	1.5	15%	25°	GULTON	CLM	26C	1.20	1.20	5	2-18-67	11,455	2-28-69	F	6
NICD	4.00	1.5	25%	25°	GULTON	CLM	14C	2.00	2.00	5	3-3-67	2,428	8-8-67	F	4
NICD	4.00	1.5	40%	25°	GULTON	CLM	37C	4.80	4.80	5	3-4-67	790	5-5-67	F	NA
NICD	4.00	1.5	60%	25°	GULTON	CLM	38D	3.20	3.20	5	2-18-67	1.927	6-25-67	F	4
NICD	4.00	1.5	25%	40°	GULTON	CLM	39C	2.00	2.00	5	3-3-67	1,508	6-20-67	F	4
NICD	5.00	1.5	15%	0°	GULTON	NB	117A	0.83	1.50	5	5-8-65	38,767	3-29-72	D	9
NICD	5.00	1.5	25%	0°	GULTON	NBPT	121A	1.38	2.50	5	6-5-65	20,861	3-5-69	F	5
NICD	5.00	1.5	15%	25°	GULTON	NB	120A	0.90	1.50	5	5-2-65	29,753	11-03-70	F	7
NICD	5.00	1.5	25%	25°	GULTON	NBPT	118B	1.50	2.50	5	6-10-65	8,108	11-22-66	F	3
NICD	5.00	1.5	15%	40°	GULTON	NB	127A	0.98	1.50	5	4-29-65	10,638	5-24-67	F	4
NICD	5.00	1.5	25%	40°	GULTON	NBPT	128A	1.63	2.50	5	6-21-65	6,345	8-18-66	F	3
NICD	5.00	1.5	25%	0°	GULTON	CO-NI	21E	1.4	2.50	10	9-2-70	32,714			
NICD	5.00	1.5	25%	25°	GULTON	CO-NI	45E+	1.40	2.50	10	9-2-70	30,225	5-19-76	F	
NICD	5.00	1.5	40%	25°	GULTON	CO-NI	69C+	2.20	4.00	10	9-2-70	16,196	8-14-73	D	9

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
NICD	5.00	1.5	25%	40°	GULTON	CO-NI	9H+	1.40	2.50	10	9-2-70	16,098	8-11-73	D	9
NICD	5.00	1.5	40%	40°	GULTON	CO-NI	33D	2.20	4.00	10	9-2-70	4,523	6-18-71	D	8
NICD	5.60	1.5	25%	-20°	GULTON	FRS	44B	1.61	2.80	5	1-2-66	31,907	8-30-71	F	8
NICD	5.60	1.5	25%	-20°	GULTON	RS	32B	1.61	2.80	5	1-2-66	23,303	3-4-70	F	7
NICD	5.60	1.5	25%	0°	GULTON	FRS	100B	1.61	2.80	5	12-17-65	28,758	2-5-71	F	8
NICD	5.60	1.5	25%	0°	GULTON	RS	90C	1.61	2.80	5	12-17-65	31,623	7-20-71	F	8
NICD	5.60	1.5	25%	25°	GULTON	FRS	76B	1.75	2.80	5	12-10-65	11,158	1-2-68	F	5
NICD	5.60	1.5	25%	25°	GULTON	RS	96C	1.75	2.80	5	12-10-65	9,791	9-19-67	F	4
NICD	5.60	1.5	25%	40°	GULTON	FRS	42B	2.24	2.80	5	12-3-65	3,798	9-10-66	F	3
NICD	5.60	1.5	25%	40°	GULTON	RS	30B	2.24	2.80	5	12-3-65	1,275	3-8-66	F	3
NICD	6.00	1.5	15%	0°	GULTON		61A	1.04	1.80	10	12-31-63	10,146	12-17-65	F	2
NICD	6.00	3.0	15%	0°	GULTON		65A	0.41	1.80	10	12-31-63	11,208	2-15-68	D	5
NICD	6.00	1.5	25%	0°	GULTON		62A	1.72	3.00	10	12-30-63	22,779	2-15-68	D	5
NICD	6.00	3.0	25%	0°	GULTON		66A	0.69	3.00	10	12-31-63	4,414	8-31-65	F	2
NICD	6.00	1.5	25%	25°	GULTON		13A	1.88	3.00	10	12-31-63	4,021	11-11-64	F	2
NICD	6.00	3.0	25%	25°	GULTON		17A	0.75	3.00	10	12-20-63	2,885	1-31-65	F	2
NICD	6.00	1.5	25%	25°	GUTLON		14A	3.00	4.80	10	12-30-63	2,086	6-9-64	F	2
NICD	6.00	3.00	40%	25°	GULTON		18A	1.20	4.80	10	12-31-63	1,500	8-18-64	F	2
NICD	6.00	1.5	15%	40°	GULTON		37A	1.44	1.80	10	12-31-63	6,064	4-14-65	F	2
NICD	6.00	3.0	15%	40°	GULTON		41A	0.58	1.80	10	12-31-63	1,689	9-14-64	F	2
NICD	6.00	1.5	25%	40°	GULTON		38A	2.40	3.00	10	12-30-63	1,377	5-22-64	F	2
NICD	6.00	3.0	25%	40°	GULTON		42A	0.96	3.00	10	12-31-63	4,133	8-23-65	F	2
NICD	6.00	24.0	50%	25°	GULTON		79A	0.20	3.00	5	3-28-64	545	10-13-65	F	3
NICD	6.00	1.5	25%	0°	GULTON	IM	13B	1.73	3.00	5	2-22-65	37,650	10-27-71	F	8
NICD	6.00	1.5	40%	25°	GULTON	IM	18B	3.00	4.80	5	2-22-65	7,577	7-21-66	F	3
NICD	6.00	1.5	25%	40°	GULTON	IM	38B	2.40	3.00	5	2-22-65	5,766	3-31-66	F	3

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
NICD	6.00	1.5	10%	0°	GULTON		61B	0.66	1.20	10	6-7-67	27,536	6-2-72	D	9
NICD	6.00	1.5	25%	0°	GULTON	AE	59A	3.00	3.00	5	4-15-65	14,863	2-28-69	F	5
NICD	6.00	1.5	40%	0°	GULTON	AE	71A	4.80	4.80	5	4-15-65	5,753	5-18-66	F	3
NICD	6.00	1.5	25%	25°	GULTON	AE	23A	3.00	3.00	5	2-5-65	15,713	1-24-68	F	5
NICD	6.00	1.5	40%	25°	GULTON	AE	11A	4.80	4.80	5	2-5-65	7,743	7-9-66	F	3
NICD	6.00	1.5	15%	40°	GULTON	AE	35A	1.80	1.80	5	6-28-65	12,511	11-30-67	F	4
NICD	6.00	1.5	25%	40°	GULTON	AE	47A	3.00	3.00	5	5-16-65	5,502	5-11-66	F	3
NICD	6.00	1.5	15%	*/20°	GULTON	AE	60B	1.80	1.80	5	4-25-67	32,625	12-21-72	D	10
NICD	6.00	1.5	25%	*	GULTON	AE	24C	3.00	3.00	5	4-25-67	17,328	5-24-70	F	7
NICD	6.00	1.5	40%	*	GULTON	AE	40B	4.80	4.80	5	4-25-67	6,156	6-27-68	F	5
NICD	6.00	3.0	25%	-20°	GULTON	CLM	41B	3.00	3.00	5	11-18-66	15,132	7-23-72	F	9
NICD	6.00	3.0	25%	0°	GULTON	CLM	66B	3.00	3.00	5	11-18-66	13,396	8-9-71	F	8
NICD	6.00	3.0	25%	25°	GULTON	CLM	18C	3.00	3.00	5	11-18-66	9,633	6-3-70	F	7
NICD	6.00	3.0	25%	40°	GULTON	CLM	29B	3.00	3.00	5	11-18-66	7,941	9-17-69	F	6
NICD	6.00	1.5	15%	*/20°	GULTON	AE	36D	1.80	1.80	5	1-8-69	41,471			
NICD	6.00	1.5	25%	*/20°	GULTON	AE	58D	3.00	3.00	5	1-8-69	41,756			
NICD	6.00	1.5	0.8%	20°	GULTON	TETR	51B	0.30	0.10	10	2-26-69	21,193	11-13-72	D	9
NICD	6.00	1.5	50%/40%	-20°	GULTON	CLM	39D	6.00	6.00	5	9-21-70	1,376	5-10-71	F	8
NICD	6.00	1.5	50%/40%	0°	GULTON	CLM	63B+	6.00	6.00	5	9-21-70	23,121	3-26-75	F	12
NICD	6.00	1.5	50%/40%	20°	GULTON	CLM	3C+	6.00	6.00	5	9-21-70	26,829	10-31-75	F	12
NICD	6.00	1.5	50%/40%	40°	GULTON	CLM	27D	6.00	6.00	5	9-21-70	6,808	11-6-71	F	8
NICD	6.00	1.5	21%	25°	GULTON	SAS A	18D+	3.50	2.50	8	7-22-70	23,230	11-17-74	D	11
NICD	6.00	1.5	25%	20°	GULTON	AE	28D	3.00	3.00	5	6-9-70	10,804	5-4-72	D	9
NICD	6.00	1.5	25%	20°	GULTON	AE	40D	3.00	3.00	5	6-9-70	10,846	5-4-72	D	9
NICD	6.00	1.5	25%	20°	GULTON	AE	52D	3.00	3.00	5	6-9-70	10,446	5-4-72	D	9
NICD	6.00	1.5	25%	20°	GULTON		6M	3.00	3.00	10	9-25-74	5,504	10-3-75	D	12
NICD	9.00	1.5	25%	20°	GULTON	AE	18G	4.50	4.50	10	4-4-75	8,139			

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
NICD	10.00	1.5	25%	0°	GULTON	AE	20B	5.00	5.00	5	1-15-69	2	1-15-69	F	NA
NICD	10.00	1.5	25%	25°	GULTON	AE	0B	5.00	5.00	5	11-27-67	2,414	5-6-68	F	5
NICD	10.00	1.5	25%	40°	GULTON	AE	6B	5.00	5.00	5	11-27-67	602	3-14-68	F	5
NICD	12.00	1.5	15%	0°	GULTON		16B+	2.07	3.60	5	2-20-65	51,727	4-29-74	F	11
NICD	12.00	1.5	25%	0°	GULTON		101B	3.45	6.00	5	12-19-64	30,110	10-5-71	F	8
NICD	12.00	1.5	25%	25°	GULTON		27B	3.75	6.00	5	1-28-65	14,255	9-5-67	F	4
NICD	12.00	1.5	40%	25°	GULTON		95B	6.00	9.00	5	12-2-64	5,192	11-3-69	F	3
NICD	12.00	1.5	15%	40°	GULTON		78A	2.00	3.60	5	12-22-64	11,071	1-4-65	F	3
NICD	12.00	1.5	25%	40°	GULTON		93B	8.00	10.00	5	12-5-64	5,184	11-10-65	F	3
NICD	12.00	1.5	25%	0°	GULTON	AE	78A	6.00	6.00	5	2-10-67	53,760			
NICD	12.00	1.5	40%	0°	GULTON	AE	71B	6.00	9.00	5	1-6-67	15,275	10-6-69	F	6
NICD	12.00	1.5	40%	25°	GULTON	AE	11B	6.00	9.00	5	10-17-66	11,933	12-31-72	F	5
NICD	12.00	1.5	25%	40°	GULTON	AE	47B	6.00	6.00	5	1-5-67	6,537	6-13-72	F	5
NICD	15.00	Sync	50%	20°	GULTON		226A	1.50	6.25	5	3-5-73	1310 Days			
NICD	15.00	Sync	50%	20°	GULTON		226B	1.50	6.25	5	5-9-74	840 Days			
NICD	20.00	1.5	15%	0°	GULTON		101A	3.45	6.00	5	1-16-64	3,629	9-20-64	F	2
NICD	20.00	3.0	15%	0°	GULTON		132A	1.00	6.00	5	1-31-64	11,212	8-13-80	D	5
NICD	20.00	1.5	15%	10°	GULTON		22B	8.00	6.00	10	2-4-71	12,[illegible]	11-6-73	D	10
NICD	20.00	1.5	15%	10°	GULTON	AE-PT	35B	8.00	6.00	5	2-4-71	10,249	11-28-72	D	8
NICD	20.00	1.5	15%	10°	GULTON	AE	4C	8.00	6.00	9	5-14-72	28,864			
NICD	20.00	1.5	25%	0°	GULTON		115A	5.75	10.00	5	1-16-64	2,031	6-24-64	F	2
NICD	20.00	3.0	25%	0°	GULTON		116A	2.30	10.00	5	2-11-64	10,971	2-13-80	D	5
NICD	20.00	1.5	25%	25°	GULTON		73A	6.25	10.00	5	1-16-64	7,768	6-30-69	F	2
NICD	20.00	3.0	25%	25°	GULTON		74A	2.50	10.00	5	1-21-64	1,754	9-27-64	F	2
NICD	20.00	1.5	40%	25°	GULTON		87A	10.00	16.00	5	2-1-64	627	4-7-64	F	2
NICD	20.00	3.0	40%	25°	GULTON		82A	4.00	16.00	5	2-1-64	330	3-21-64	F	2

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	ANNUAL LAST GRAPHED
NICD	20.00	1.5	15%	40°	GULTON		76A	4.00	6.00	5	1-18-64	9,348	10-15-65 F	
NICD	20.00	3.0	15%	40°	GULTON		77A	1.92	6.00	5	1-21-64	6,032	4-28-65 F	3
NICD	20.00	1.5	25%	40°	GULTON		90A	8.00	10.00	5	1-18-64	4,045	11-12-64 F	2
NICD	20.00	3.0	25%	40°	GULTON		91A	3.20	10.00	5	1-24-64	4,480	10-14-65 F	2
NICD	20.00	1.5	15%	0°	GULTON	AE	59B	5.00	6.00	5	4-8-67	4,026	1-25-68 D	5
NICD	20.00	1.5	15%	25°	GULTON	AE	12C	5.00	6.00	5	3-9-67	4,934	1-25-68 D	5
NICD	20.00	1.5	15%	40°	GULTON	AE	36B	5.00	6.00	5	3-11-67	2,740	9-5-67 D	4
NICD	20.00	1.5	15%	*	GULTON	MULTI	12D	10.00	6.00	5	2-8-68	7,262	5-13-69 D	6
NICD	20.00	1.5	25%	*	GULTON	MULTI	36C	10.00	10.00	5	2-8-68	966	8-14-68 F	5
NICD	20.00	1.5	40%	*	GULTON	MULTI	59C	10.00	16.00	5	2-8-68	131	3-2-68 F	5
NICD	20.00	1.5	15%	0°	GULTON	AE	54B	8.00	6.00	5	3-23-68	46,915		
NICD	20.00	1.5	15%	25°	GULTON	AE	19B	8.00	6.00	5	3-23-68	24,625	7-2-72 D	9
NICD	20.00	1.5	15%	40°	GULTON	AE	38E	8.00	6.00	5	3-23-68	4,943	2-12-69 D	6
NICD	20.00	1.5	25%	*	GULTON	MULTI	48C	10.00	10.00	6	5-26-69	1.948	3-24-70 F	7
NICD	20.00	1.5	25%	20°	GULTON	MULTI*	48D	10.00	10.00	6	7-9-70	13,968	1-12-73 F	10
NICD	20.00	1.5	15%	20°	GULTON	MULTI*	12E	8.00	6.00	5	5-13-70	34,461		
NICD	20.00	1.5	15%	0°	GULTON	MULTI*	68B	8.00	6.00	5	10-18-70	32,102		
NICD	20.00	1.5	25%	20°	GULTON	AE	1D+	10.00	10.00	5	10-15-73	15,403		
NICD	20.00	1.5	25%	20°	GULTON	AE	1E+	10.00	10.00	5	10-15-73	15,329		
NICD	20.00	1.5	25%	20°	GULTON	AE	1F+	10.00	10.00	5	10-15-73	13,977		
NICD	20.00	1.6	25%	10°	GULTON	MULTI*	4D	8.00	5.00	5	9-19-73	14,410		
NICD	20.00	1.5	25%	10°	GULTON	MULTI*	4E+	8.00	6.00	5	10-22-73	15,363		
NICD	20.00	1.5	25%	10°	GULTON	MULTI*	4F+	9.00	6.00	5	10-24-73	15,410		
NICD	20.00	1.5	25%	10°	GULTON	MULTI*	4G+	8.00	6.00	5	10-22-73	15,154		
NICD	50.00	1.5	25%	0°	GULTON		95A	14.38	25.00	5	6-8-64	3,227	2-9-65 F	3

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
NICD	50.00	1.5	15%	40°	GULTON		123A	12.00	15.00	5	6-8-64	1.873	11-11-64	F	3
NICD	20.00	1.5	40%	20°	HELIOTEK		34D	16.00	16.00	5	3-14-72	2,903	10-15-72	F	9
NICD	3.90	1.5	25%	0°	NIFE		97C	1.07	2.00	5	9-29-67	20.009	4-6-71	F	8
NICD	3.90	1.5	25%	25°	NIFE		85C	1.07	2.00	5	9-29-67	9,356	6-19-69	F	6
NICD	3.00	1.5	15%	0°	SONOTONE	3S	43B	0.52	0.90	5	6-24-65	37,969	4-19-72	D	9
NICD	3.00	1.5	25%	0°	SONOTONE	3S	31B	0.86	1.50	5	6-24-65	28.074	8-10-70	F	7
NICD	3.00	1.5	25%	25°	SONOTONE	3S	3B	0.94	1.50	5	6-25-65	11.726	8-23-67	F	4
NICD	3.00	1.5	40%	25°	SONOTONE	3S	2B	1.50	2.40	5	7-10-65	5,399	7-26-66	F	3
NICD	3.00	1.5	15%	40°	SONOTONE	3S	26B	0.72	0.90	5	7-10-65	6,289	10-4-66	F	3
NICD	3.00	1.5	25%	40°	SONOTONE	3S	37B	1.20	1.50	5	7-10-65	5,625	8-4-66	F	3
NICD	3.50	1.5	10%	0°	SONOTONE		15B	0.39	0.70	10	6-7-67	26,353	6-2-72	D	9
NICD	5.00	1.5	15%	0°	SONOTONE		49A	0.86	1.50	10	12-31-63	23,112	2-15-68	D	5
NICD	5.00	3.0	15%	0°	SONOTONE		53A	0.35	1.50	10	12-31-63	11,427	2-13-68	D	5
NICD	5.00	1.5	25%	0°	SONOTONE		50A	1.44	2.50	10	12-17-63	22,525	2-15-68	D	5
NICD	5.00	3.0	25%	0°	SONOTONE		54A	0.58	2.50	10	12-31-63	11,331	2-7-68	D	5
NICD	5.00	1.5	25%	25°	SONOTONE		1A	1.56	2.50	10	12-17-63	11,745	2-27-66	F	3
NICD	5.00	3.0	25%	25°	SONOTONE		5A	0.62	2.50	10	12-31-63	11,092	2-12-68	D	5
NICD	5.00	1.5	40%	25°	SONOTONE		2A	2.50	4.00	10	12-17-63	6,671	4-24-65	F	2
NICD	5.00	3.0	40%	25°	SONOTONE		6A	1.00	4.00	10	1-2-64	5,211	12-13-65	F	2
NICD	5.00	1.5	15%	40°	SONOTONE		25A	1.20	1.50	10	12-17-63	9,328	10-31-65	F	2
NICD	5.00	3.0	15%	40°	SONOTONE		29A	0.48	1.50	10	12-31-63	5,975	4-17-66	F	3
NICD	5.00	1.5	25%	40°	SONOTONE		26A	2.00	2.50	10	12-17-63	3,625	10-15-64	F	2
NICD	5.00	3.0	25%	40°	SONOTONE		30A	0.80	2.50	10	12-31-63	4,141	8-7-65	F	2
NICD	5.00	1.5	25%	-20°	SONOTONE	ST	75C	5.00	2.50	5	10-24-65	2,145	4-5-66	F	3
NICD	5.00	1.5	40%	-20°	SONOTONE	ST	89B	5.00	4.00	5	10-24-65	1.530	2-26-66	F	3
NICD	5.00	1.5	25%	0°	SONOTONE	ST	92A	5.00	2.50	5	9-5-65	8,774	5-10-67	F	4

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
NICD	5.00	1.5	40%	0°	SONOTONE	ST	122B	5.00	4.00	5	9-9-65	5,190	9-24-66	F	3
NICD	5.00	1.5	25%	25°	SONOTONE	ST	73B	5.00	2.00	5	8-12-65	3,742	4-15-66	F	3
NICD	5.00	1.5	40%	25°	SONOTONE	ST	87B	5.00	4.00	5	8-12-65	2,392	1-27-66	F	3
NICD	5.00	1.5	25%	40°	SONOTONE	ST	99B	5.00	2.50	5	8-23-65	4,383	7-9-66	F	3
NICD	5.00	1.5	15%	40°	SONOTONE	ST	112B	5.00	1.50	5	8-23-65	3,294	4-1-66	F	3
NICD	5.00	1.5	25%	25°	SONOTONE	AE	14D	2.50	1.47	5	11-7-67	1,179	2-7-69	F	5
NICD	20.00	1.5	25%	25°	SONOTONE	IPD	22A	20.00	10.00	10	9-20-67	6,664	10-7-69	D	6
NICD	20.00	1.5	25%	25°	SONOTONE	IPD	10A	7.00	10.00	10	9-20-67	7,180	10-7-69	D	6
NICD	20.00	1.5	40%	25°	SONOTONE	IPD	34B	20.00	16.00	10	9-20-67	5,634	7-3-69	F	6
NICD	20.00	3.0	40%	25°	SONOTONE	IPD	46A	20.00	16.00	10	9-20-67	3,501	10-7-69	D	6
NICD	20.00	1.5	75%	25°	SONOTONE	IPD	72B	20.00	30.00	10	9-20-67	1,143	4-5-69	F	6
NICD	20.00	1.5	25%	20°	SONOTONE	IPD*	10B	7.00	10.00	10	5-13-70	13,964	10-30-72	F	9
NICD	20.00	1.5	25%	20°	SONOTONE	IPD*	22B	15.00	10.00	10	5-13-70	3,419	11-23-70	D	7
NICD	20.00	1.5	40%	20°	SONOTONE	IPD*	34C	15.00	16.00	10	5-13-70	8,357	11-2-71	F	8
NICD	20.00	3.0	40%	20°	SONOTONE	IPD*	46B	15.00	16.00	10	5-13-70	686	11-23-70	D	7
NICD	20.00	1.5	75%	20°	SONOTONE	IPD*	72C	20.00	30.00	10	5-13-70	4,381	2-22-71	F	8
AGCD	7.00	8.0	30%	20°	ELECTROMITE		104C	0.40	2.10	3	12-23-70	1,380	3-29-72	D	9
AGCD	8.00	8.0	25%	25°	ESB	AE	1B	0.50	2.00	5	9-9-66	3,875	6-8-70	F	7
AGCD	3.00	1.5	16%	25°	YARDNEY		2C	1.30	1.00	9	9-16-66	7,039	12-12-67	F	4
AGCD	5.00	24.0	20%	0°	YARDNEY	C3SP	57B	0.30	1.00	5	9-17-65	267	6-17-66	F	3
AGCD	5.00	24.0	20%	25°	YARDNEY	C3SP	21A	0.30	1.00	5	9-17-65	98	12-25-65	F	3
AGCD	5.00	24.0	20%	40°	YARDNEY	C3SP	45A	0.30	1.00	5	9-27-65	61	11-16-65	F	3
AGCD	5.00	24.0	20%	25°	YARDNEY	RCPSP	9C	0.30	1.00	10	10-27-65	34	12-1-65	D	2
AGCD	5.00	24.0	20%	25°	YARDNEY	CPSP	33B	0.30	1.00	5	10-17-65	720	11-4-67	F	4
AGCD	5.00	24.0	20%	25°	YARDNEY	PLSP	69A	0.30	1.00	5	10-27-65	595	7-17-67	F	4
AGCD	5.00	24.0	20%	0°	YARDNEY		113B	0.30	1.00	5	1-22-67	2,542	2-19-71	F	8

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	ANNUAL LAST GRAPHED
AGCD	5.00	24.0	20%	25°	YARDNEY		77B	0.30	1.00	5	1-12-67	661	11-12-68 F	5
AGCD	5.00	24.0	20%	25°	YARDNEY		105B	0.30	1.00	5	1-12-67	77	4-19-67 F	4
AGCD	5.00	24.0	20%	40°	YARDNEY		128B	0.30	1.00	5	1-19-67	269	11-4-67 F	4
AGCD	5.00	8.00	20%	0°	YARDNEY	PLCPSP	114B	0.30	1.00	5	1-22-67	1,496	6-25-68 F	5
AGCD	5.00	8.0	20%	25°	YARDNEY	PLCPSP	118C	0.30	1.00	5	1-17-67	1,505	7-9-68 F	5
AGCD	10.00	8.0	30%	25°	YARDNEY		45D	0.50	3.00	5	5-3-67	1,759	11-19-68 F	5
AGCD	10.00	8.0/12.0	25%	20°	YARDNEY		57E	0.50	2.50	5	8-19-73	1,124	11-27-75 D	12
AGCD	11.00	24.0	40%	0°	YARDNEY		45B	0.30	4.40	10	11-5-66	121	3-13-67 F	4
AGCD	11.00	24.0	40%	25°	YARDNEY		21B	0.30	4.40	10	11-5-66	69	1-13-67 F	NA
AGCD	11.00	8.0	27%	25°	YARDNEY	PLSP	21C	0.50	3.00	5	3-28-67	37	4-9-67 F	NA
AGCD	11.00	8.0	27%	25°	YARDNEY	WNSP	45C	0.50	3.00	5	3-28-67	70	4-22-67 F	NA
AGCD	11.00	24.0	18%	0°	YARDNEY	AE-GU	57D	0.25	2.00	5	2-14-68	1,740	1-7-73 F	10
AGCD	11.00	24.0	18%	25°	YARDNEY	AE-GU	69B	0.25	2.00	5	2-14-68	507	7-13-69 F	6
AGCD	11.00	24.0	18%	40°	YARDNEY	AE-GU	33C	0.25	2.00	5	2-14-68	447	5-15-69 F	6
AGCD	12.00	24.0	50%	0°	YARDNEY		57A	0.60	6.00	10	2-14-64	168	9-3-64 F	2
AGCD	12.00	24.0	50%	40°	YARDNEY		33A	0.60	6.00	10	2-14-64	210	9-20-64 F	2
AGCD	12.00	1.5	25%	-20°	YARDNEY		85B	3.90	6.00	5	1-19-66	2,375	3-25-67 F	4
AGCD	12.00	1.5	25%	0°	YARDNEY		97B	3.90	6.00	5	1-19-66	4,481	3-15-67 F	4
AGCD	12.00	1.5	25%	25°	YARDNEY		82B	3.90	6.00	5	1-17-66	4,559	11-27-66 F	3
AGCD	12.00	24.0	43%	0°	YARDNEY	AE-GE	21D	0.50	5.20	5	6-16-67	60	8-13-67 F	NA
AGCD	12.00	24.0	43%	40°	YARDNEY	AE-GE	9F	0.50	5.20	5	6-16-67	310	5-28-68 F	5
AGZN	5.00	1.5	25%	20°	ASTRO		25B	1.60	2.50	10	12-4-69	681	2-1-70 F	7
AGZN	5.00	12.0	25%	20°	ASTRO		25C	9.35	2.50	10	2-8-70	567	11-27-70 F	7
AGZN	5.00	12.0	25%	40°	ASTRO		37D	0.35	2.50	10	2-8-70	391	9-4-70 F	7
AGZN	5.00	1.5	25%	40°	ASTRO		47D	1.60	2.50	10	12-4-69	2,013	4-19-70 F	7
AGZN	5.00	Sync	60%	25°	ASTRO		213A	0.35	2.50	10	1-21-70	425 Days	3-24-71 D	NA

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TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	CHARGE CURRENT	DISCHARGE CURRENT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED		ANNUAL LAST GRAPHED
AGZN	5.00	Sync	60%	40°	ASTRO		214A	0.35	2.50	10	1-21-70	425 Days	3-24-71	D	NA
AGZN	40.00	4.0	20%	20°	ASTRO		20C	3.00	5.00	10	10-25-71	519	2-7-72	D	9
AGZN	40.00	4.0	20%	20°	ASTRO		33E	3.00	5.00	10	10-25-71	502	5-8-72	D	9
AGZN	40.00	Sync	60%	0°	ASTRO		218A	1.50	20.00	10	4-27-71	389 Days	7-15-72	F	NA
AGZN	40.00	Sync	60%	20°	ASTRO		219A	1.50	20.00	10	5-3-71	389 Days	7-15-72	F	NA
AGZN	40.00	Sync	60%	40°	ASTRO		220A	1.50	20.00	10	5-3-71	228 Days	2-8-72	F	NA
AGZN	25.00	24.0	40%	25°	DELCO-REMY		89A	15.00	10.00	5	9-18-64	80	12-8-64	D	2
AGZN	25.00	24.0	40%	25°	DELCO-REMY		75A	15.00	10.00	5	8-18-64	32	9-18-64	F	2
AGZN	25.00	3.0	40%	25°	DELCO-REMY		88B	15.00	20.00	5	3-1-65	120	3-16-65	D	2
AGZN	25.00	3.0	40%	25°	DELCO-REMY		88C	15.00	20.00	5	3-26-65	325	5-6-65	D	2
AGZN	25.00	24.0	40%	25°	DELCO-REMY		9D	1.00	10.00	10	12-13-65	121	4-18-66	D	3
AGZN	25.00	24.0	40%	25°	DELCO-REMY	2SR	9E	1.00	10.00	10	10-5-66	90	1-4-67	D	NA
AGZN	40.00	24.0	25%	25°	DELCO-REMY		75B	25.00	10.00	5	10-28-64	139	3-15-65	D	2
AGZN	5.00	Sync	60%	20°	YARDNEY		224A	0.40	2.50	10	1-15-73	113 Days	5-8-73	D	NA
AGZN	5.00	Sync	60%	20°	YARDNEY		224B	0.40	2.50	6	8-18-73	48 Days	10-5-73	D	NA
AGZN	5.00	Sync	60%	20°	YARDNEY		224C	0.40	2.50	6	8-18-73	392 Days	10-2-74	D	NA
AGZN	12.00	24.0	42%	25°	YARDNEY		9A	0.50	5.00	10	5-7-65	58	7-7-65	D	2
AGZN	16.00	24.0	31%	25°	YARDNEY	2SR	57C	0.50	5.00	10	12-2-66	281	8-30-67	D	4
AGZN	21.00	Sync	60%	20°	YARDNEY		225A	1.20	10.50	10	1-15-73	739 Days	3-18-75	D	NA

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INTRODUCTION

Considerable research is being done to find more efficient and reliable means of storing electrical energy for orbiting satellites. Rechargeable cells offer one such means. The test program at NAVWPNSUPPCEN Crane has been established in order to further the evaluation of certain types of cells and to obtain performance and failure data as an aid to their continued improvement.

This thirteenth annual report covers the cycle life test, the third phase of the evaluation program of secondary spacecraft cells, through 15 December 1976. The purpose of the cycle program is to determine the cycling performance capabilities of packs of cells under different load and temperature conditions. The acceptance tests and general performance tests, the first and second phases of the evaluation program, were reported earlier.

A summary of the results of the life cycling program is given in this report. Complete data and graphs are available upon application via NASA Technical Officer. The application will include information on exactly what data is required; the use to which the data will be put; application details including orbital description, charge control methods, load requirements, etc., as appropriate; name and address of the activity that stands to benefit; name and telephone number of the responsible individual concerned; and the affiliation with any Government agency as contractual arrangement.

During December 1963, this activity began the cycle test on 660 sealed, nickel-cadmium cells purchased by NASA. The cells were from four manufacturers, and consisted of seven sample classifications ranging from 3.0 to 20 ampere-hours. Since then 1300 nickel-cadmium, 183 silver-cadmium and 125 silver-zinc sealed cells, excluding synchronous orbit and accelerated test packs, from several manufacturers have been added to the program. The capacities of the nickel-cadmium cells ranged from 1.25 to 50.0 ampere-hours; that of the silver-cadmium ranged from 3.0 to 12.0 ampere-hours; and that of the silver-zinc cells ranged from 5.0 to 40.0 ampere-hours. These cells are cycled under different load, charge control and temperature conditions. The load conditions include cycle length (orbit periods) of 1.5 to 24 hours; and depths of discharge ranging from 10 to 75 percent. Unless otherwise specified, all cell packs are recharged by using a pack voltage limit as given in the pack's test program. All charging is constant current until the voltage limit is reached; at this time the charge current is automatically reduced to protect the cells during overcharge.

The time at which voltage limiting occurs varies slightly with cycling. Thus the percent of recharge is not constant from cycle to cycle as illustrated in graphs accompanying such voltage limited packs. Other charge control methods used are auxiliary electrode, coulometer, stabistor, two-step regulator, thermistor controlled voltage limit, and Sherfey upside-down cycling regime. Specially constructed cells to apply internal pressure against the face of the plate stack, and a type to permit high charge rates were also tested. Environmental conditions include ambient temperatures of -20°, 0°, 10°, 20°, 25°, 40°, 50° C; and a sinusoidal cycling temperature of 0° to 40° C within a period of 48 hours.

The ampere-hour capacity of each pack, at its specified test temperature, is measured initially and every 88 days of continuous cycling unless otherwise specified. Each pack being checked is discharged immediately after the end of the regular cycle charge period, at the c/2 rate (c being the manufacturer's rated capacity) to a cutoff of 1.0 volt per cell average, or to a low of 0.5 volt on any one cell, or a combination of the two. The pack is then recharged at the c/10 rate for 16 hours and then discharged again as above. Before being returned to regular cycling, the pack is given a 16-hour charge (48-hour prior to 14 December 1969) at the c/10 rate, with the regular on-charge cycling voltage limit. The summary of the capacity check results will list only the amount obtained on the second discharge (Disch #2) unless otherwise noted. All other capacity checks not noted this way receive only one discharge which is run at the cycle rate to 1.0 volt per cell or 0.5 volt on any one cell, or a combination of the two, and then recharged at the regular cycle rate prior to being returned to automatic cycling. By direction of Goddard Space Flight Center capacities to 1.20 and 1.10 volts per cell average have been interpolated from existing data. This has been done for five packs (24C, 48B, 60B, 78A and 101B; see Figures 1 and 2). The first three packs (Figure 1) were 6.0 ampere-hour nickel-cadmium cells in a temperature cycling regime. The other cells were 12 ampere-hour nickel-cadmium cells operating at 40° and 0°C respectively. All these cells were manufactured by Gulton. (See report brief, pages viii through xxi for further information on parameters.) All of these packs have failed or been discontinued.

A cell is considered a failure when its terminal voltage drops below 0.5 volt at any time during a regular discharge-charge cycle. It is removed from the pack upon completion of a recorded cycle unless otherwise specified. The remaining cells continue cycling until they either fail or are discontinued. This is a change, in that, prior to 1972 a pack was considered as having failed when 60 percent of its cells had failed. By direction of Goddard Space Flight Center cell failure analysis is performed at NAVWPNSUPPCEN Crane and a complete chemical analysis may be performed if designated by GSFC. The manufacturer is invited to participate as an observer in the analysis of his cells.

In order to clarify the discussion that follows, all failure terms are defined (see page 8) according to their use in this report. These are our definitions, and they may differ somewhat from usage elsewhere.

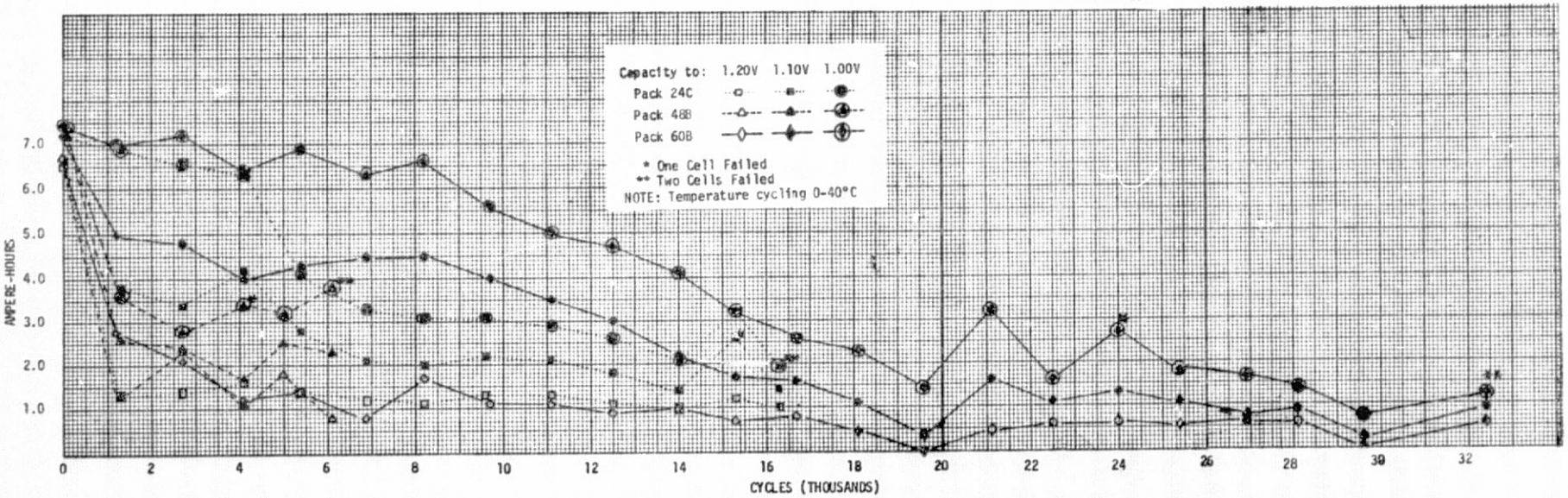
On 31 August 1972, the first battery pack was placed on the new Automatic Data Acquisition and Control System (ADACS) for test. The conversion of the battery packs from the old "Tally" system to ADACS was completed 27 November 1972.

Data is recorded by the new system and consists of individual cell voltage, individual cell temperature, total voltage, current and ambient temperature. Also when appropriate, data is recorded on auxiliary electrode voltage, gas recombination electrode voltage, coulometer voltage, and pressure transducer voltage. It is then converted to absolute values and stored on magnetic tape for data analysis and future reference. Data is read and recorded normally every 2.4 minutes for packs cycling on a *1.48, 3.0 and 24.0 hour orbits. Packs undergoing synchronous orbit testing are recorded every 2.4 minutes during their shadow period and every 8.0 hours during their sun/float period.

All graphs are computer printed with cycle numbers automatically scaled and "staggered" (to allow room for printing) at the bottom of each graph. They are printed in multiples of 10 or 100 depending on the total cycles and room available. Thus the computer is programmed to round as follows:

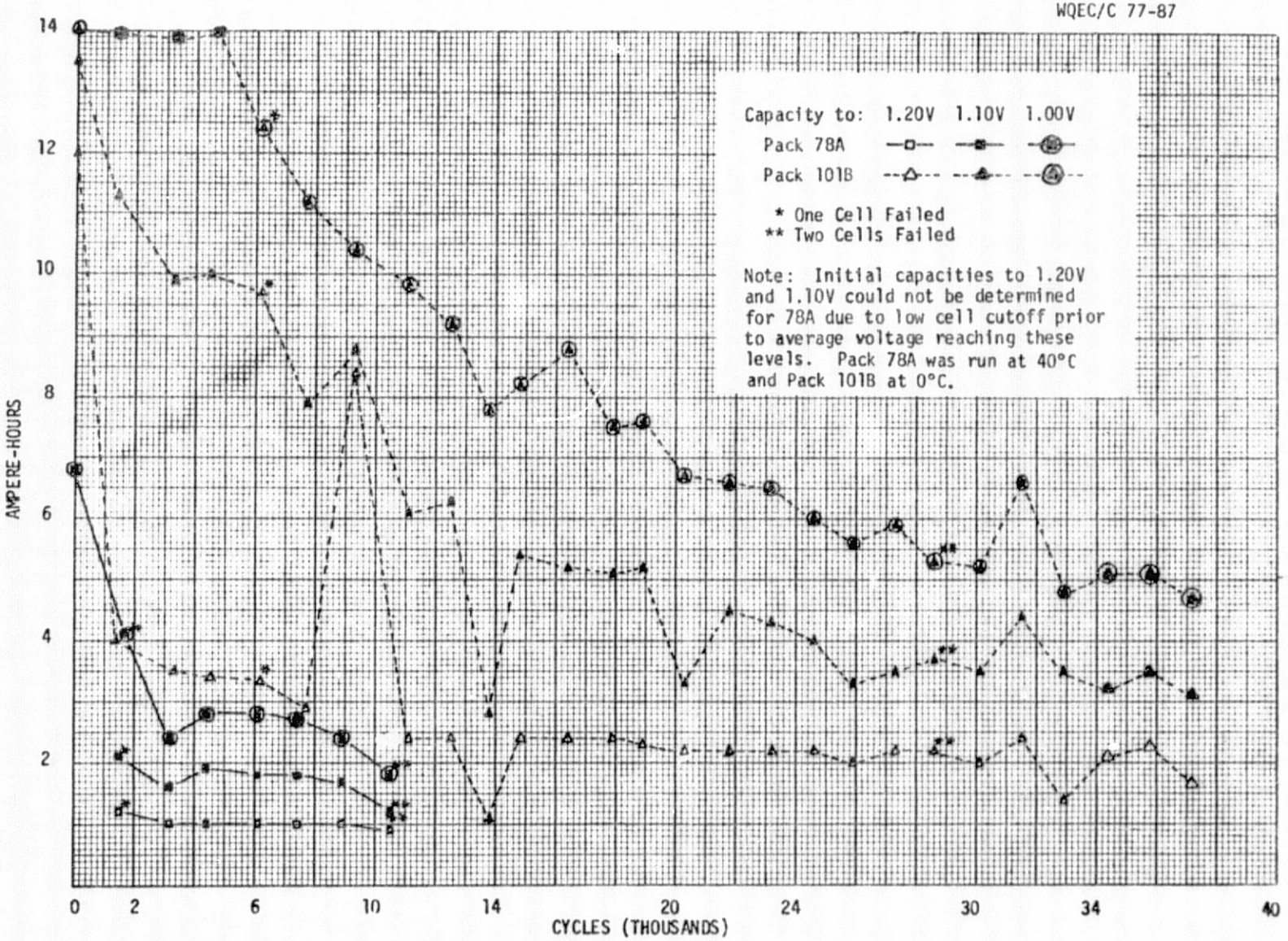
Multiples of 10	Multiples of 100
0-4 Cycles, 0	0-49 Cycles, 0
5-14 Cycles, 1	50-149 Cycles, 1
15-24 Cycles, 2	150-249 Cycles, 2
25-34 Cycles, 3	250-349 Cycles, 3

*The 1.5 hour orbit period was changed to 1.48 hours in which the battery pack now receives a discharge time of .48 hour instead of .50 hour.



CAPACITY, AT CYCLE RATE, TO 1.20, 1.10 AND 1.00 VOLTS

FIGURE 1



CAPACITY, AT CYCLE RATE, TO 1.20, 1.10 AND 1.00 VOLTS

FIGURE 2

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DIVERSE TESTS IN ADDITION TO LIFE CYCLING TESTS

The following tests have been, or are being performed at NAVWPNSUPPCEN Crane. These tests are not reported in this annual; but the results are reported by Crane unless otherwise specified and copies of data are available on request to the NASA Technical Officer or corresponding Program Officer.

A. Acceptance Testing: These tests are conducted on cells ranging in capacity from 1.25 to 100 ampere-hours. The tests consist of: (1) general inspection, weighing and leak checks, (2) three capacity checks, (3) charge retention test, (4) internal short test, (5) charge efficiency test, (6) overcharge test, 0°C and 35°C, (7) internal resistance test, and (8) pressure versus capacity test.

B. Separator Testing: Separator tests are conducted on all types of separators including nylon, cellophane, polyprophylene, various materials by RAI, and ceramic material. The tests are performed in three modes: (1) constant current charge, (2) constant potential charge, and (3) 30-day stand while in a charged state. To date these tests have been limited to silver-zinc and silver-cadmium cells of the various manufacturers. The cells undergoing separator tests are reported by Goddard Space Flight Center.

C. General Performance Testing: General performance testing has been conducted on cells ranging in capacity from 1.25 to 20 ampere-hours. To date these tests have been limited to nickel-cadmium cells. All major manufacturers have been represented. The test consists of: (1) random vibration, (2) sinusoidal vibration, (3) mechanical shock, (4) acceleration, (5) charge at varying rates from c/10 to 2c with discharge rate constant at c/2, (6) charge at constant rate previously determined to give maximum capacity at individual temperatures ranging from -20° to 40° C with discharge rate varying from c/20 to 2c, and (7) overcharge test.

D. Synchronous Orbit Testing: These tests have been performed on 3, 6, 12 and 15 ampere-hour nickel-cadmium cells and on 5, 21 and 40 ampere-hour silver-zinc cells. The test has a 180-day cycle consisting of 140 days of trickle charge and 40 days of discharge-charge. The discharge time is 12 minutes the first day, increasing 3 to 4 minutes each succeeding day, reaching its maximum of 72 minutes on the 18th day which is maintained each day through the 25th. Beginning with the 26th day the discharge time is decreased 3 to 4 minutes per day until it has returned to the 12-minute minimum on the 40th day.

E. Interplanetary Monitoring Platform (IMP) Testing: These tests were performed on batteries identical to the flight batteries aboard the IMP satellites E, F, G and I. The test conditions simulate those aboard the respective satellites and are basically a 12-hour orbit. The cells making up the batteries are silver-cadmium varying in capacity from 3 to 10 ampere-hours. Summary reports have been written by Goddard Space Flight Center.

F. Jet Propulsion Laboratory (JPL) Testing: These tests involve silver-zinc and silver-cadmium cells and consist of three distinct programs.

1. Program involving storage at different temperatures: This series of tests include: (a) capacity check upon receipt, (b) recharge and storage at temperatures ranging from -51° to +49° C, (c) discharge following removal from storage and temperature stabilization at room temperature (25° C), and (d) life cycling at room temperature.

2. Program involving life cycling only: This series of tests included: (a) general inspection, weighing and leak test, (b) measurement of internal resistance, (c) capacity tests, and (d) automatic cycling.

3. Program involving sustained high g-levels: This test consists of subjecting silver-zinc cells of varying capacity to charge-discharge cycles while being subjected to high g-levels. The tests are conducted on both the sealed and vented types of cells. Further the testing is performed on cells that are starved and also on those containing normal amounts of electrolyte. Sustained g-levels applied to the cells during charge-discharge are 1.0g, 10g, 20g, 30g, 50g and 75g.

G. Accelerated Testing: The purpose of this program is to develop: (1) a tool for spacecraft projects and other battery users to determine the life capability of sealed, nickel-cadmium cells, (2) a method of evaluating the effect of design and component changes in cells, and (3) a means of reducing the time and cost of cell testing.

1. The program will consist of 94 test batteries (547 cells).

2. An outline of this program is contained in NASA, GSFC Report X-761-73-183.

3. Interim report, WQEC/C 76-8 of 13 February 1976, includes tests completed through December 1975.

H. NAVSEC Testing (Project 40 - Design Variations): These tests involve silver-zinc, 40-50 ampere-hour cells for evaluation of inorganic separator material. Cells are cycles at 30 and 100 percent DOD test regimes.

I. USAF Aero Propulsion Laboratory: Evaluation of 50 ah nickel-cadmium cells, with nylon and polypropolene separators, on a synchronous type orbit.

DEFINITIONS

Weight Loss: The weight loss in grams between the weight at the time of acceptance and that at the time of failure. Gains or losses of less than one gram are not considered (slight gains may occur from traces of solder left on the cell terminals).

Deposits: Carbonate deposits, at a point of leakage such as at a terminal or seam; or corrosive deposits located under the top portion of the cell case around the seam and the terminal tabs. Deposits are removed prior to weighing as of 14 December 1969.

High Pressure: Signified by a bulged cell case or by a hissing of escaped gas when cell is opened. It may not be present at the time the cell is opened although the bulge indicates its presence at some earlier time.

Concave Sides: Refers to rectangular cells only. The sides of the can are made permanently concave by the higher pressure of neighboring cells in the pack. This sometimes causes a short between the case and internal elements.

Weak Weld: An inadequate weld, as determined by the mechanical strength of the bond. The pieces separate, without tearing of the metal, when pulled apart by the fingers. This may be at a tab-to-plate connection, a tab-to-cell case connection, or a tab-to-terminal connection.

Loosened Active Material: Positive plate active material which separates from the grid in large intact pieces. This condition is often noticed in cylindrical cells due to the fact that the plates are unrolled during failure analysis. However rectangular plates often show the positive material to flake off at the edges or be extremely brittle and crumbly.

Extraneous Active Material: Pieces of loose active material found pressed between the plates. These are thought to have crumbled off the plate edges when the cell was being assembled, since there are no holes or bare spots on the plate itself. These pieces put pressure on the separator material and often cause a short circuit between the plates at that point.

Pierced Separator: Refers to short circuits between plates, which may be caused by plates having rough edges, foreign material between the plates, a grid wire or a tab at the tab-to-plate connection piercing the separator and contacting the adjacent plate.

Excess Scoring: Indentations of the cell case which may put increased pressure on the plates and separators which may cause a short circuit between the case and plates.

Positive Tab Deterioration: The positive tab, above the plates, may be corroded, burned and sometimes broken. The broken tab may fall against the case and cause a short circuit. At times the corrosion is such that the tab crumbles when the cell is opened, so that its prior configuration cannot be determined. A burned positive tab has been attributed to an insufficient area of welding between the tab and the positive terminal, causing a high-resistance contact.

Short Separator: Related to a burned positive tab. The separator material just below the burned tab has pulled back, apparently from the heat generated, so that the plates are exposed. Usually a short between adjacent plates results.

Ceramic Short: It is a dark colored, conducting deposit which causes an electrical short across the ceramic insulator at the terminal, and is a result of silver brazing used in the cells' manufacture. It is determined by measuring the resistance between the insulated material and the cell case after the plates have been cut off the buses. Its presence is fairly well defined, the measured resistance being on the order of 20 ohms or less.

Migration: Active material deposited on the surface of the separator, appearing as a uniform dark coating on the separator material. In severe cases of migration, the separator material may stick to the negative plate. In small areas the plate material may penetrate completely through the separator and be visible as small, dark spots on the positive plate side, usually resulting in a high-resistance short circuit. Where this condition is more pronounced there are burned spots on the separator at the point of penetration. Migration is always by the negative plate material except in two very advanced cases, where there was also slight migration from the positive plate. Migration is accelerated at points of localized pressure on the separator, especially around the edge of the pressure area. For example in the round cells, where a pressure area is produced by a piece of tape covering the tab-to-plate connection, there is no migration at the taped area but a very dark line of migrated material outlines the tape's location. In addition, there may be brownish spots of discoloration around the edge of the tape and usually a small hole in the center of each spot. A similar situation, due to the scoring of the Sonotone 3.5 ampere-hour cell case, also occurs.

Blisters: Raised areas of active material, which have pulled away from the grid. Typically, they ranged from pinhead size to 3/8 inch in diameter, and were invariably found on the positive plates. While blistering has not been shown to have a direct bearing on cell failures, it is included here because is was common in some cell types, but rare or absent in others, and because in at least two cases the separator was burned slightly where blisters had compressed the separator material.

Separator Deterioration: Decomposition of the separator material, exclusive of visible burned spots. Deteriorated separator material, as defined here, is decidedly thinner than normal, adheres to the negative plate, and has lost virtually all tensile strength.

SECTION I

CELLS CURRENTLY ON TEST PROGRAM

I. CELLS CURRENTLY ON TEST PROGRAM

Because of the continuing effort to extend the performance life, new cells, with modifications such as nickel plating the silver braze area or new type seals, are added to the program for evaluation. New cells are also added to the cycle program for evaluation under new environmental conditions such as cycling at -20° C, or cycling during temperature cycling. Each pack is cycled until at least 60 percent of the cells have failed unless instructed otherwise by the Goddard Space Flight Center at Greenbelt, Maryland.

A. General Description:

1. Cells:

a. The majority of the nickel-cadmium cells tested for use in space, or related programs are of one basic type. They are rectangular with stainless steel containers and covers, both terminals are insulated from the cover by a ceramic seal and protrude through the cover as a solder-type terminals. Where auxiliary electrodes are present, the terminal is a stainless steel tab welded to the cell cover. Any cells differing from this description are separately described as they are encountered in the following paragraphs.

2. Charge Control Methods:

a. As a continued effort to improve cells and cell life, various types of charge control methods and devices are being developed. Charge control methods and devices that have been, or are being used for testing at NAVWPNSUPPCEN Crane are as follows: constant current, voltage limiting, high overcharge current capabilities, auxiliary electrode, thermistor, voltage limit dependent upon auxiliary electrode signal, coulometer, the twostep regulator and internal mechanical pressure devices. Sherfey upsidedown cycling and stabistor charge control methods have also been used in the past.

B. Nickel-Cadmium Types:

1. GE 5.0 ah (NIMBUS), Six 5-cell Packs:

a. Cell Description: These cells are cylindrical with a convex base. A threaded stud is fastened to the base to facilitate heat sink mounting. The cell container and the cell cover are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as the contacts for the negative terminal. The positive terminal is insulated from the cell cover by a ceramic bushing and protrudes through the bushing with a solder tab welded to the terminal. Three cells have pressure transducers mounted on the cell to read internal pressure in pounds per square inch absolute. These cells were manufactured to NIMBUS specifications. Acceptance test results are contained in NAD Crane report QE/C 64-459.

b. Parameters and Capacity Checks:

Orbit			1.5-hour			
Temperature	0°	0°	25°	25°	40°	40°
Depth of Discharge	15%	25%	15%	25%	15%	25%
Pack Number	103A	107A*	106A	104B*	113A	114A*
Precycling Capacity	5.42	5.21	4.67	5.58	3.67	3.83
88 Days Disch #2	5.08	5.50	4.00	3.58	2.42	2.25
264 Days Disch #2	5.58	5.33	3.50	1.75	1.83 F	1.63
440 Days Disch #2	5.54	5.42	3.08	2.00		1.00 F
616 Days Disch #2	4.75	4.58	3.25	1.83 F		
792 Days Disch #2	5.08	5.25	3.13			
968 Days Disch #2	5.17	4.46	2.92			
1144 Days Disch #2	5.08	4.21	2.58			
1320 Days Disch #2	4.75	4.42	2.46			
1496 Days Disch #2	4.67	4.37	1.21 F			
1672 Days Disch #2	4.29	4.21				

*One cell in each pack is equipped with a pressure transducer.
F - Failed.
D - Discontinued.

Orbit			1.5-hour			
Temperature		0°	0°	25°	25°	40°	40°
Depth of Discharge		15%	25%	15%	25%	15%	25%
Pack Number		103A	107A*	106A	104B*	113A	114A*
1848 Days	Disch #2	4.42	1.33				
2024 Days	Disch #2	4.33	3.58				
2200 Days	Disch #2	4.75	2.70				
2376 Days	Disch #2	4.21	2.83 D				
2606 Days	Disch #2	3.96					
2782 Days	Disch #2	NA					
2958 Days	Disch #2	3.50					
3104 Days	Disch #2	3.60					
3351 Days	Disch #2	3.00					
3530 Days	Disch #2	3.61					
3706 Days	Disch #2	3.55					

*One cell in each pack is equipped with a pressure transducer.
F - Failed.
D - Discontinued.

c. Test Results:

(1) Performance on Cycling: (Figure 3) Cycling was started in May 1965. Pack 103A has completed 62,905 cycles with one cell failure on cycle 59,281. Pack 107A was discontinued in June 1972 at the request of Goddard Space Flight Center after completing 39,755 cycles. Packs 106A, 104B, 113A and 114A failed on cycles 26,148; 13,149; 4988 and 8273, respectively.

(2) Failure Analysis: Analysis of the 14 failed cells (Pack 103A's failed cell sent to GSFC) showed the major cause of failure to be separator deterioration and migration of the negative plate material. Other conditions found were high internal pressure, electrolyte leakage, pierced separator by the negative tab, blistering on the positive plates and corrosive deposits internally at the positive terminals. In addition to the above failures one pack of five cells was destroyed by thermal runaway caused by the shorting of the positive tab to the top edge of the negative plate. This happened because the insulating material wrapped around the positive tab came loose. In order to prevent a recurrence of this problem in the flight battery a piece of insulating tubing was used to cover the positive tab.

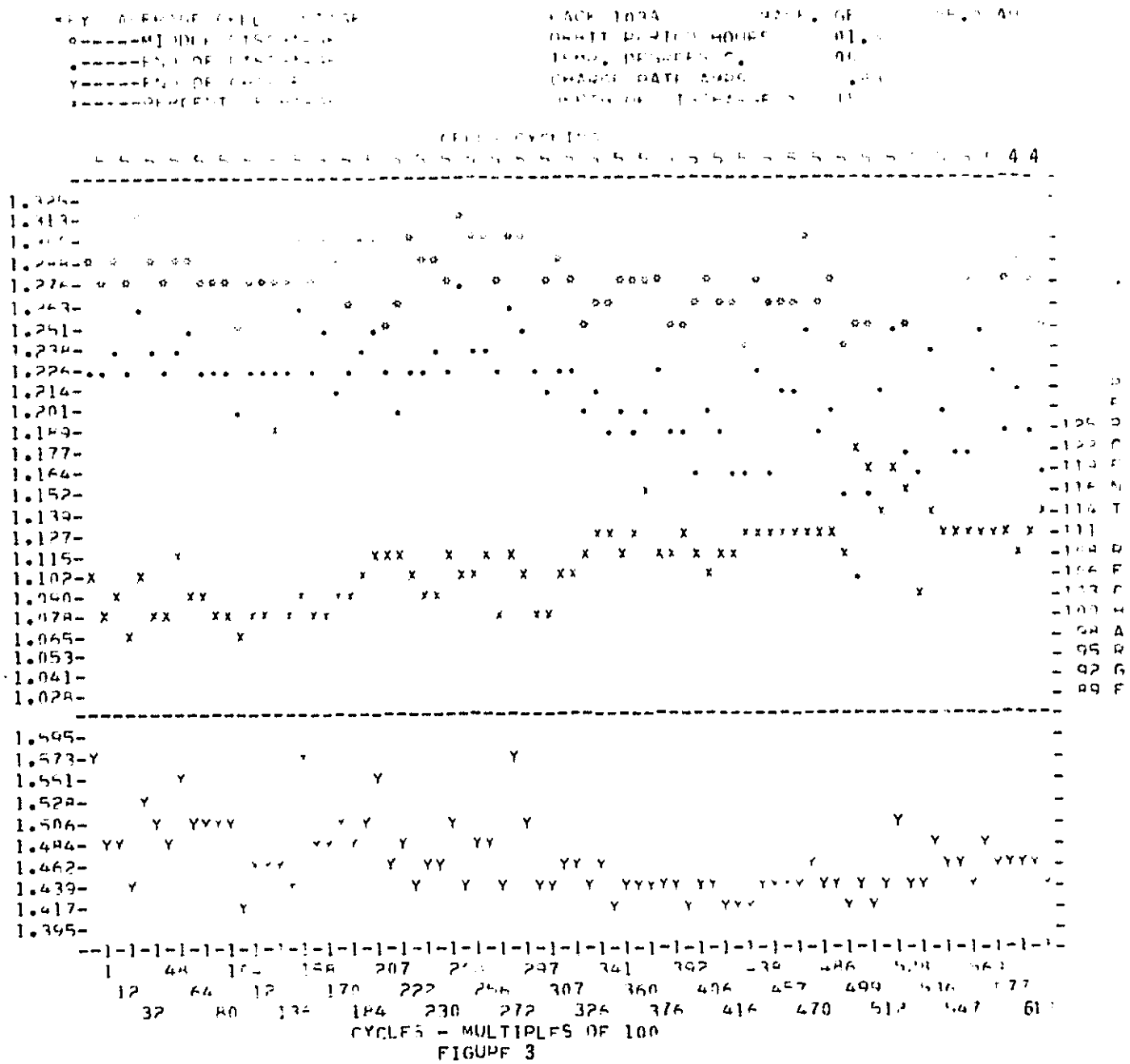

FIGURE 3

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2. Gulton 5.0 ah (Cobalt Additive with Nylon or Polypropylene Separator), Five 10-cell Packs:

a. Cell Description: These cells are rectangular. The cell containers and covers are made of stainless steel. The positive terminal is insulated from the cell cover by a ceramic seal. The negative terminal is welded to the cover. Both terminals protrude through the cover as solder type terminals. Twenty-five cells contain positive plates with cobalt additive; 25 cells are without the cobalt additive and are designated as control cells. Twenty-four cells contain nylon separator and 26 cells contain a polypropylene separator (PPL). The cells are V05 HSB type cells and acceptance test results are contained in NAD Crane report QE/C 70-692. The cells were divided into packs as indicated in the table below.

Pack Number	Type and Number of Cells per Pack			
	Cobalt-Nylon	Control-Nylon	Cobalt-PPL (FT 2140)	Control-PPl (FT 2140)
21E	5 (cells 1 to 5)	5 (cells 6-10)		
45E	2 (cells 1 & 2)	2 (cells 6 & 7)	3 (cells 3 to 5)	3 (cells 8 to 10)
69C	5 (cells 1 to 5	5 (cells 6 to 10)		
9H			5 (cells 1 to 5)	5 (cells 6 to 10)
33D			5 (cells 1 to 5)	5 (cells 6 to 10)

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour				
Temperature	0°	25°	25°	40°	40°
Depth of Discharge	25%	25%	40%	25%	40%
Pack Number	21E	45E	69C	9H	33D
Precycling Capacity	4.83	5.70	5.70	3.33	3.30
88 Days	5.08	2.75	3.52	2.38	3.92 F
264 Days	5.08	2.93	3.08	3.50	
440 Days	5.00	2.80	4.72	2.88	
616 Days	5.08	3.00	3.07	2.63	
792 Days	NA	NA	NA	NA D	
983 Days	5.10	3.63	2.27 D		
1170 Days	5.53	2.78			
1350 Days	4.71	1.75			
1527 Days	4.87	1.31			
1705 Days	4.39	3.07			
1882 Days	3.61	2.53 D			

c. Test Results:

(1) Performance on Cycling: (Figure 4) Cycling was started in June 1970. Pack 21E has completed 32,714 cycles without a cell failure. Packs 33D and 45E failed on cycles 4523 and 30,225, respectively. Packs 69C and 9H were discontinued because of low capacity after 16,196 cycles and 16,098 cycles, respectively, with pack 9H having six cell failures and pack 69C, eight cell failures. The following table indicates the cycle number that the cells either failed or were discontinued on.

	CELLS									
Pack	1	2	3	4	5	6	7	8	9	10
45E	16521 D	26813 F	16521 D	30225 D	30225 F	17221 F	23600 F	24578 F	29909 F	21527 F
69C	14116 F	13174 F	13200 F	16196 D	16196 D	9395 F	9714 F	11432 F	9195 F	10589 F
9H	16098 D	16098 D	14363 F	13067 F	16098 F	10970 F	11739 F	16098 D	15681 F	16098 D

F - Failure
D - Discontinued

(2) Failure Analysis: One cell from 69C, three cells from 45E, and two cells from 9H were analyzed for carbonates following their discontinuation or failure. The other cells from packs 9H, 33D and 69C were returned to NASA Lewis. The failed cells seven from pack 45E had pitting of the positive plates, severe migration was present in the PPL type cells and separator deterioration (one cell shorted) in the nylon separator type cells. The results of the carbonate analysis were tabulated as follows:

AVERAGE ANALYSIS OF EXTRACTED ELECTROLYTE

	69C SN 1874	45E SN 1875	45E SN 1890	45E SN 1892	9H SN 1880	9H SN 1913
Cell No.	5	1	3	5	1	10
Total meq K_2CO_3*	85.17	73.74	82.59	96.13	77.21	74.21
Total meq KOH	59.39	68.91	58.09	61.23	62.23	63.29

AVERAGE ANALYSIS OF EXTRACTED SEPARATOR PATCHES

	69C SN 1874	45E SN 1875	45E SN 1890	45E SN 1892	9H SN 1880	9H SN 1913
Cell No.	5	1	3	5	1	10
Wet Wt.**	0.2099	0.4194	0.8360	0.7316	0.7795	0.4780
Dry Wt.**	0.0894	0.1435	0.5936	0.6340	0.5768	0.3904
cc Sample	0.737	1.153	1.039	1.1090	1.020	1.176
meq K_2CO_3***	0.4332	0.7049	0.6263	0.5760	0.8259	0.3503
meq KOH***	0.1498	0.3992	0.4261	0.2350	0.4844	0.1592

*meq is the abbreviation of milliequivalent.
**Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.
***The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the middle, and one from the last third.

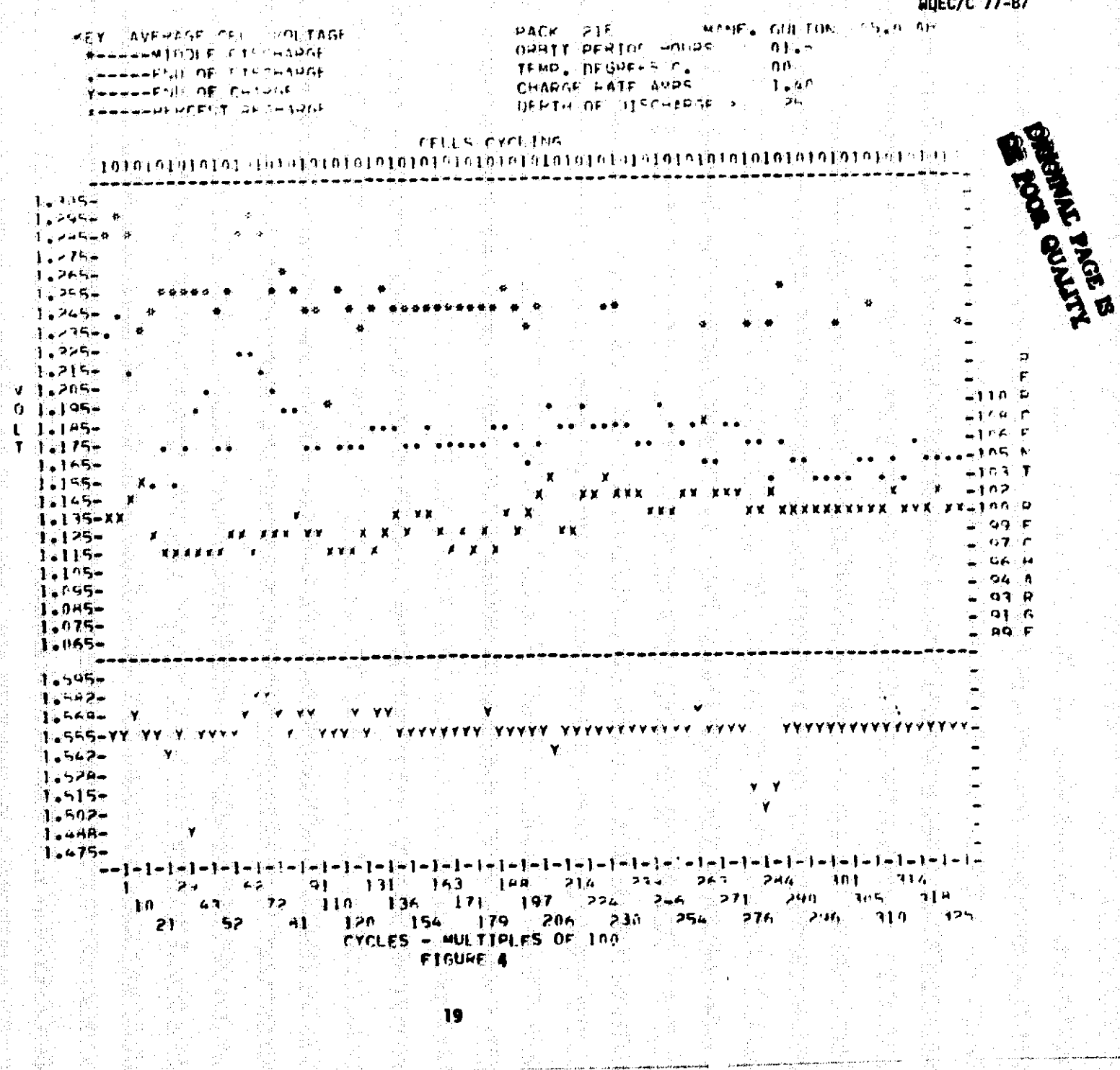

FIGURE 4

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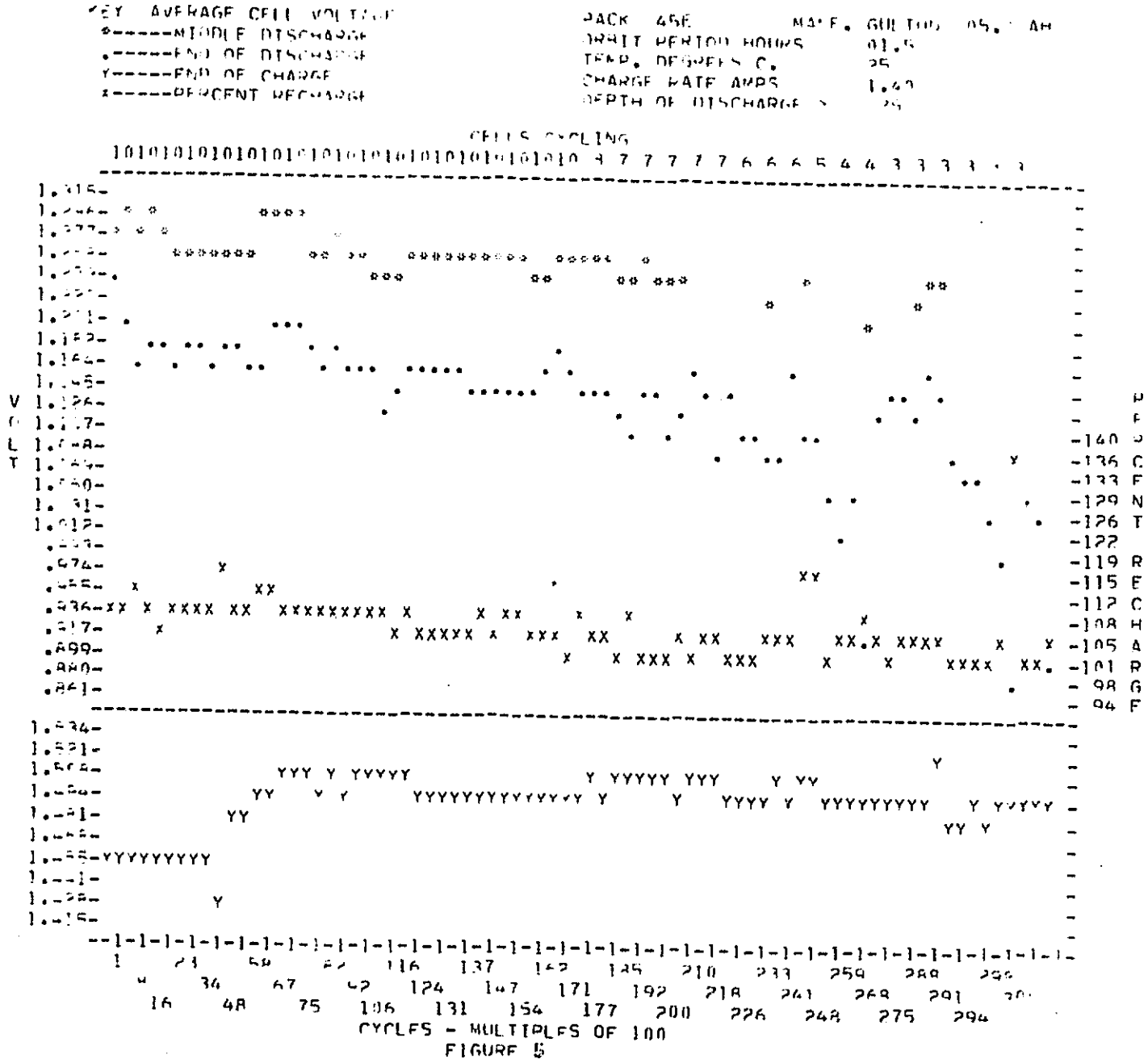

FIGURE 5

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3. EP 6.0 ah (Separator Evaluation), 11 Packs:

a. Cell Description: See Paragraph I.A., page 12. Cells were manufactured for NASA, GSFC, according to GSFC's specification number S-716-P-6 under NASA contract number NAS-5-17806. They are RSN-6B type cells with auxiliary electrodes; but the electrodes are not being evaluated, therefore no test data is being taken on them, nor is there an auxiliary electrode resistor. Nylon and polypropylene are the types of separator material being evaluated in these cells. Initial evaluation test results and detailed cell descriptions are contained in NAD Crane Report WQEC/C 75-32 except for Pack 9T.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour										
Temperature (°C)	25°										
Depth of Discharge (%)	25%										
Type of Separator*	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Pack Number	9L	9M	9K	9O	9P	9Q	9J	9R	9F	9S	9T
Precycling Capacity	5.1	5.6	5.2	5.7	6.6	7.0	6.3	7.5	7.4	6.6	6.3
2000 Cycles	2.1	1.5	2.0	1.4	5.3	2.5	2.2	5.8	4.8	3.2	3.1
4000 Cycles	2.2	1.7	1.4	1.9	5.0	3.0	2.5	4.9	4.7	4.0	D
6000 Cycles	4.1 D	1.7 D	2.1 D	D	4.3 D	5.4 D	2.5 D	4.4 D	4.7	2.9	
8000 Cycles									4.1	2.9	
10000 Cycles									4.3	3.1	

c. Test Results:

(1) Performance on Cycling: (Figures 6 through 14) Cycling began in September and October 1974 and in April 1975 (Pack 9T). Packs 9O and 9T were discontinued after completing 4001 and 2004 cycles respectively, in which 9O had three cell failures and 9T had four. Packs 9K and 9M each had one cell failure following the 2000 cycle capacity test, due to failure to recharge and low capacity, respectively. All the other packs except 9F and 9S were discontinued following their capacity test at 6000 cycles because GSFC had obtained all the information they required, at that time, of those type separators. The packs have completed the following cycles:

*(1) Grace, 3073, pp.
(2) Grace, 3073-35, pp.
(3) Grace, 3074-18, pp.
(4) Grace, 1972-31W, pp.
(5) Grace, 3073-32W, pp.
(6) RAI, WEX 1242, pp.
(7) Hercules, 2711-55, pp.
(8) Canadian, WEX-ISIS, pp.
(9) Pellon, 2505 (control), nylon
(10) Grace, Extracted, nylon
(11) Potassium Titanate

Pack Number	9L	9M	9K	9O	9P	9Q	9J	9R	9F	9S	9T
Cycle Completed	6391 D	6386 D	6270 D	4001 D	6332 D	6091 D	6167 D	6139 D	10530	10476	2004 D

D - Discontinued.

The voltage limit is 1.42 v/c for all packs except 9O and 9Q, in which high pressure necessitated a change to 1.40 and 1.41 v/c after completion of 103 and 617 cycles respectively.

(2) Failure Analysis: The five failed cells, from Packs 9K, 9M and 9O, had severe migration, uncoined positive plates, loosened active material, and weak tabs. The separators of the four failed cells of Pack 9T were like a white paste, in which the compression of the plate stack would allow the inside edges of the plates to short out. Visual analysis of the cells, following extractor analysis, showed excessive migration in which the separator stuck to the negative plates; except for packs 9Q, 9R and 9P, in which the separator was extremely darkened.

(3) One cell, with each type separator material, was subjected to chemical analysis following initial evaluation testing. Also, a cell was removed from each pack for analysis at 2000-cycle intervals. The following table shows the results of the chemical analysis of extracted electrolyte (soxhlet) from individual cell stacks, and from sample patches of the separator material:

Pack Number	Cycles Completed	Total meq** KOH per extract (avg)	Total meq K_2CO_3 per extract (avg)	Meq KOH per Separator patch***	Meq K_2CO_3 per Separator patch	Total Volume (cc) per patch	Wet Weight (g)****	Dry Weight (g)****
9L	3	127.419	70.423	1.536	1.185	0.7070	0.6060	0.1923
9L	2023	124.879	69.513	1.516	1.169	0.7069	0.6060	0.1923
9L	4002	104.547	83.412	0.830	0.966	0.7661	0.4720	0.1925
9L	6351	110.711	98.309	0.965	1.264	0.8538	0.6239	0.2700
9M	3	145.209	68.342	1.392	0.998	0.4890	0.4892	0.1210
9M	2007	67.489	35.672	1.214	0.784	0.5545	0.4533	0.1299
9M	4021	69.294	50.498	1.231	0.709	0.5007	0.4126	0.1253
9M	6386	119.347	79.283	0.875	0 893	0.6251	0.3763	0.1366
9K	3	161.019	64.582	1.973	0.992	0.6270	0.5461	0.1000
9K	2008	169.442	59.453	1.520	0.625	0.0853	0.5488	0.2959
9K	4001	164.605	55.115	0.769	0.381	0.6788	0.3930	0.2237
9K	6270	155.125	68.829	1.003	0.864	0.6870	0.4018	0.1265
90	3	138.026	79.822	1.383	0.994	0.9030	0.6301	0.2872
90	2012	143.896	64.418	1.266	0.515	0.8813	0.4393	0.2537
90	4001	140.540	58.312	1.142	0.676	0.9580	0.5959	0.2979
9P	3	128.557	92.840	1.109	1.743	0.8857	0.5733	0.1717
9P	2018	112.471	70.364	1.168	0.967	0.8517	0.5245	0.1853
9P	4005	99.722	73.467	1.037	1.198	0.8158	0.5814	0.2025
9P	6332	110.743	72.790	0.610	0.6747	0.7895	0.3852	0.1950
9Q	3	133.428	82.369	0.930	1.407	0.7283	0.5577	0.2342
9Q	1997	118.318	67.816	0.873	0.729	0.9131	0.5325	0.2556
9Q	4019	112.805	57.779	0.325	0.330	0.7416	0.3522	0.2594
9Q	6091	104.737	69.868	0.396	0.580	1.0299	0.4115	0.2656
9J	3	127.419	70.423	1.536	1.185	0.7070	0.6060	0.1923
9J	2003	143.897	90.225	1.439	0.902	0.8235	0.5300	0.1667

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Pack Number	Cycles Completed	Total meq** KOH per extract (avg)	Total meq K_2CO_3 per extract (avg)	Meq KOH per Separator patch***	Meq K_2CO_3 per Separator patch	Total Volume (cc) per patch	Wet Weight (g)****	Dry Weight (g)****
9J	4001	124.675	77.137	0.860	0.802	NA	0.4749	0.2103
9J	6167	123.503	83.049	0.915	1.023	1.1137	0.7052	0.4008
9R	3	99.863	46.044	1.222	0.447	1.4489	0.5008	0.2520
9R	1995	112.700	48.673	1.973	1.659	1.0179	0.8314	0.2435
9R	4014	97.828	61.508	0.238	0.283	1.1652	0.3966	0.3011
9R	6139	86.199	68.050	0.299	0.502	0.9018	0.4507	0.3215
9F	3	131.970	55.730	1.975	0.580	1.2840	0.6362	0.2205
9F	1994	112.242	58.146	0.257	0.346	0.9729	0.3304	0.2472
9F	4002	88.237	55.292	1.000	0.924	1.2151	0.6711	0.3046
9F	6177	106.360	73.699	0.965	1.312	1.2026	0.7112	0.3085
9F	8001	76.233	59.400	0.359	0.692	1.9289	0.4495	0.2503
9F	10044	113.579	67.737	1.1385	0.864	1.5614	0.7722	0.4108
9S	3	155.527	75.014	1.368	0.768	0.9895	0.9294	0.2641
9S	1995	109.988	75.133	0.803	0.770	1.3470	0.4878	0.2254
9S	4011	92.796	76.664	0.974	1.456	1.3537	0.7822	0.3394
9S	6129	102.237	96.296	0.9000	1.5636	1.3367	0.7937	0.4000
9S	8002	103.800	93.067	0.8053	1.0626	NA	0.5451	0.2280
9S	10020	104.061	84.419	0.7346	1.2895	1.2040	0.6500	0.3478
9T	3	133.860	71.296	1.349	1.168	*	0.6478	0.2863
9T	630	*	*	*	*	*	*	*
9T	2004	111.118	79.150	1.122	1.372	*	*	*

*could not obtain measureable data.
**meq is the abbreviation of milliequivalents.
***The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the center, and one from the last third.
****Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.
NA - not available.

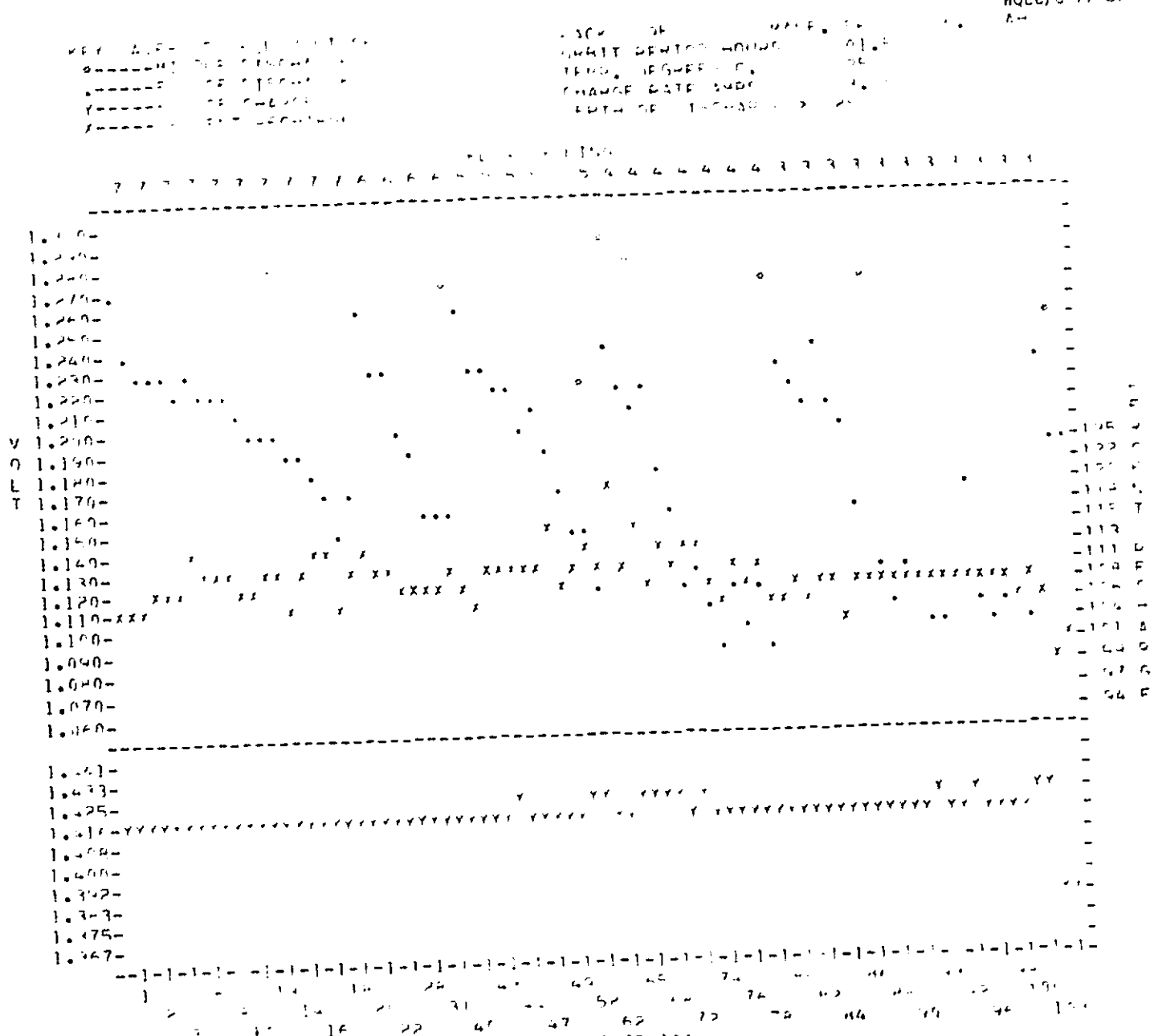

FIGURE 6

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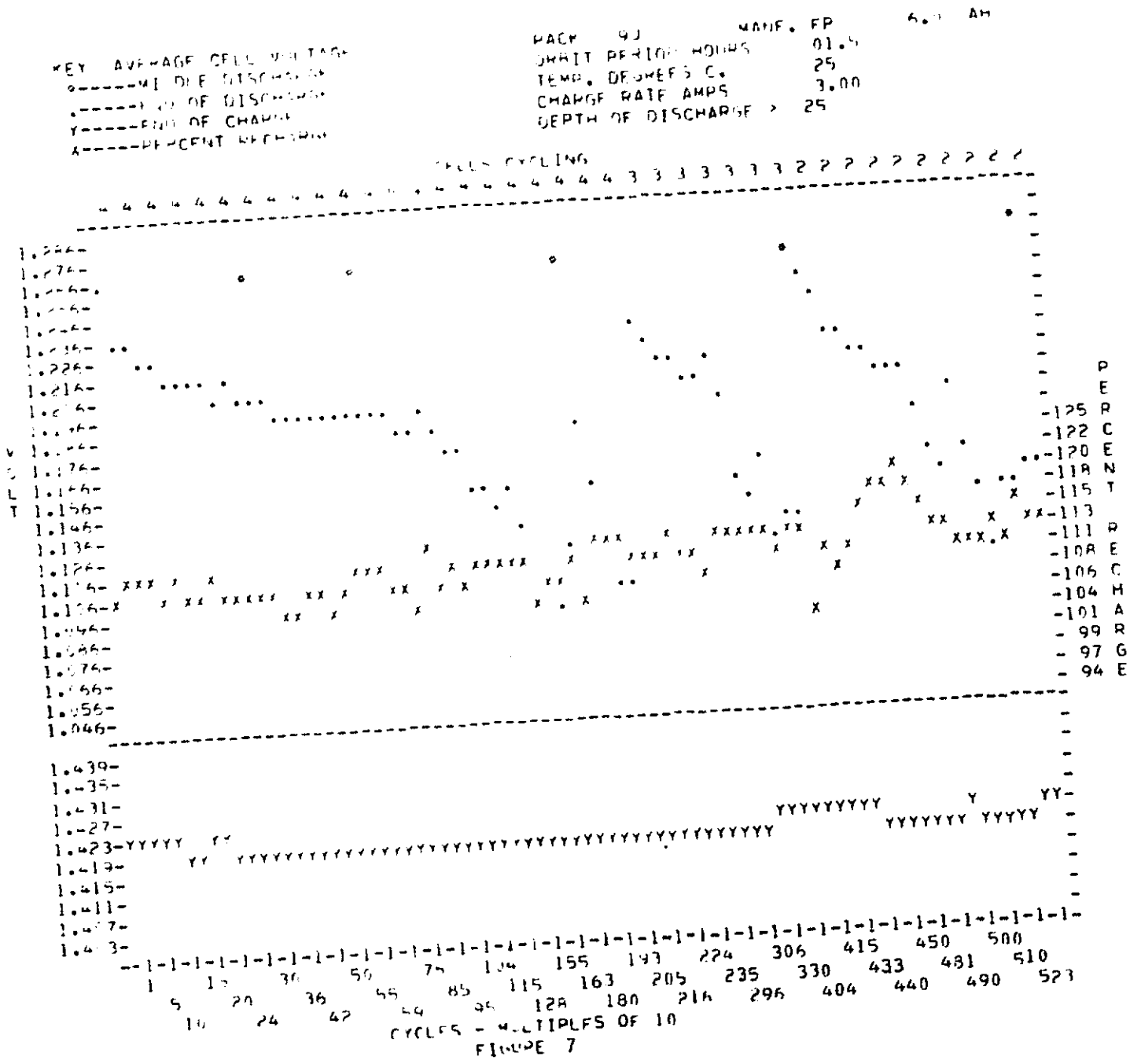
KEY AVERAGE CELL VOLTAGE
MIDDLE DISCHARGE
END OF DISCHARGE
END OF CHARGE
PERCENT RECHARGE
PACK 90
MANF. FP
6.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE > 25
CELLS CYCLING
VOLT
PERCENT RECHARGE
CYCLES - MULTIPLES OF 10

FIGURE 7

KEY AVERAGE CELL VOLTAGE
o------MIDDLE OF DISCHARGE
.------END OF DISCHARGE
Y------END OF CHARGE
X------PERCENT RECHARGE

PACK 9K MANF. FP 6.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE > 25

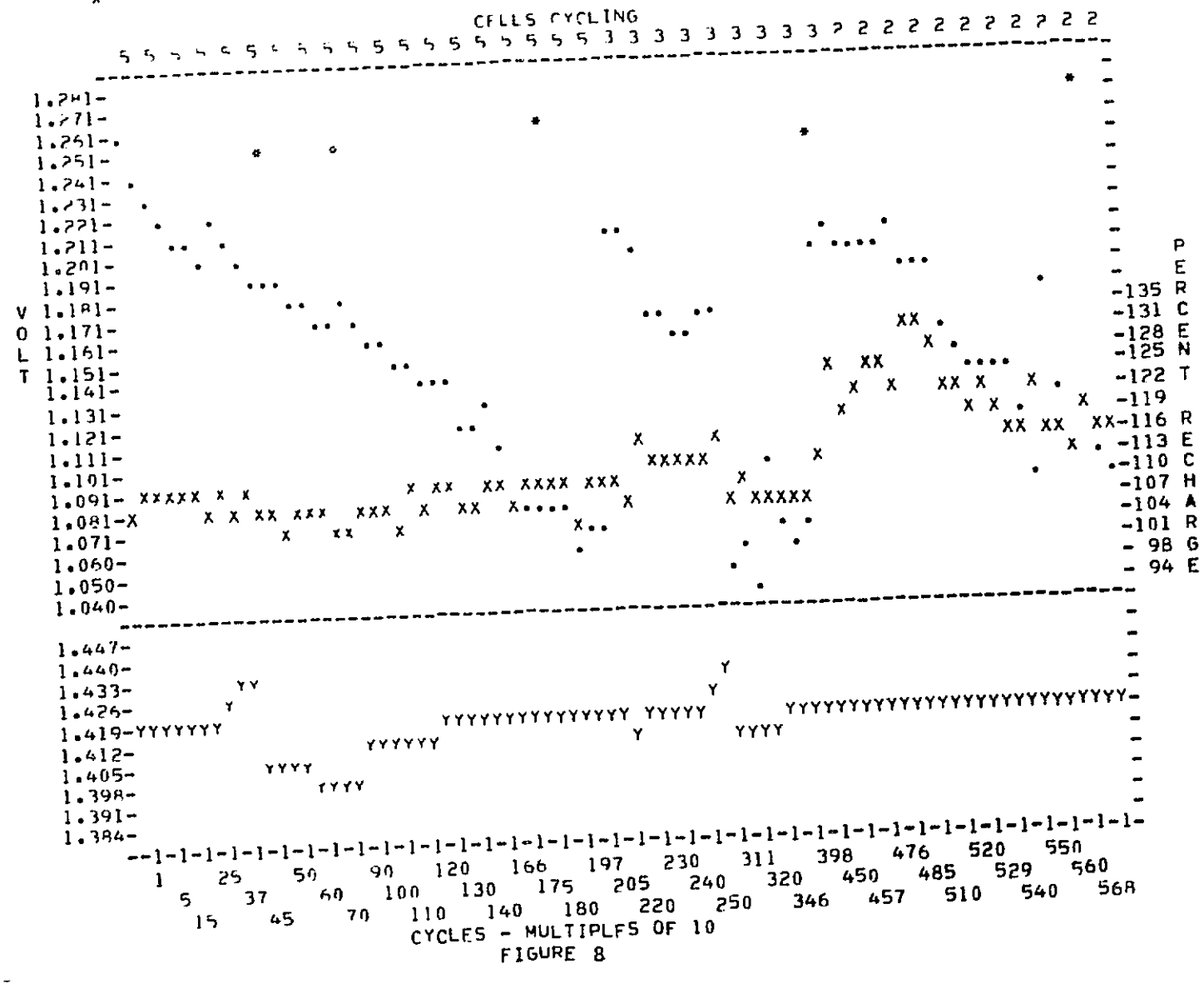

FIGURE 8

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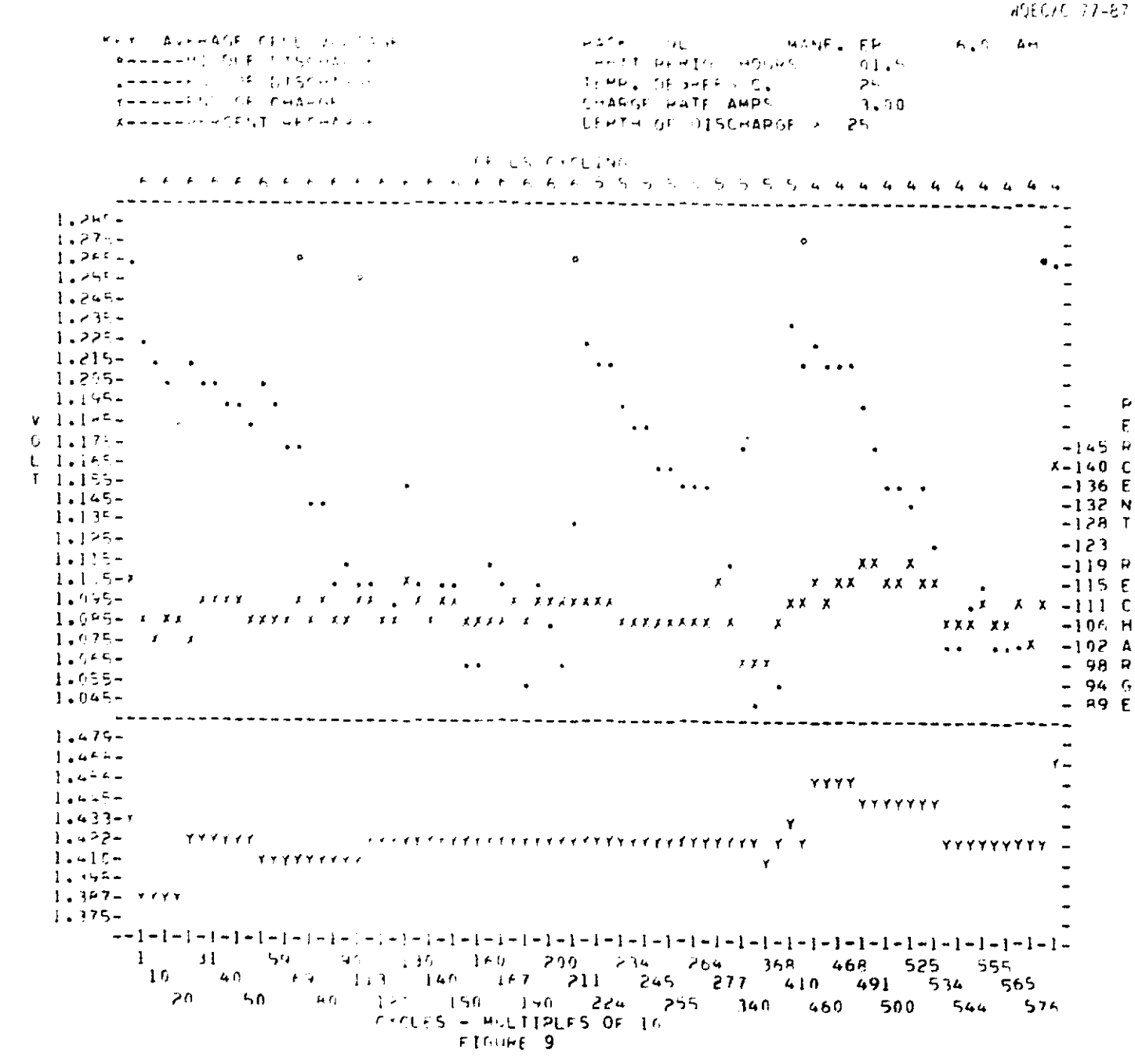

FIGURE 9

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE

PACK 94 MANF. EP 6.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE > 25

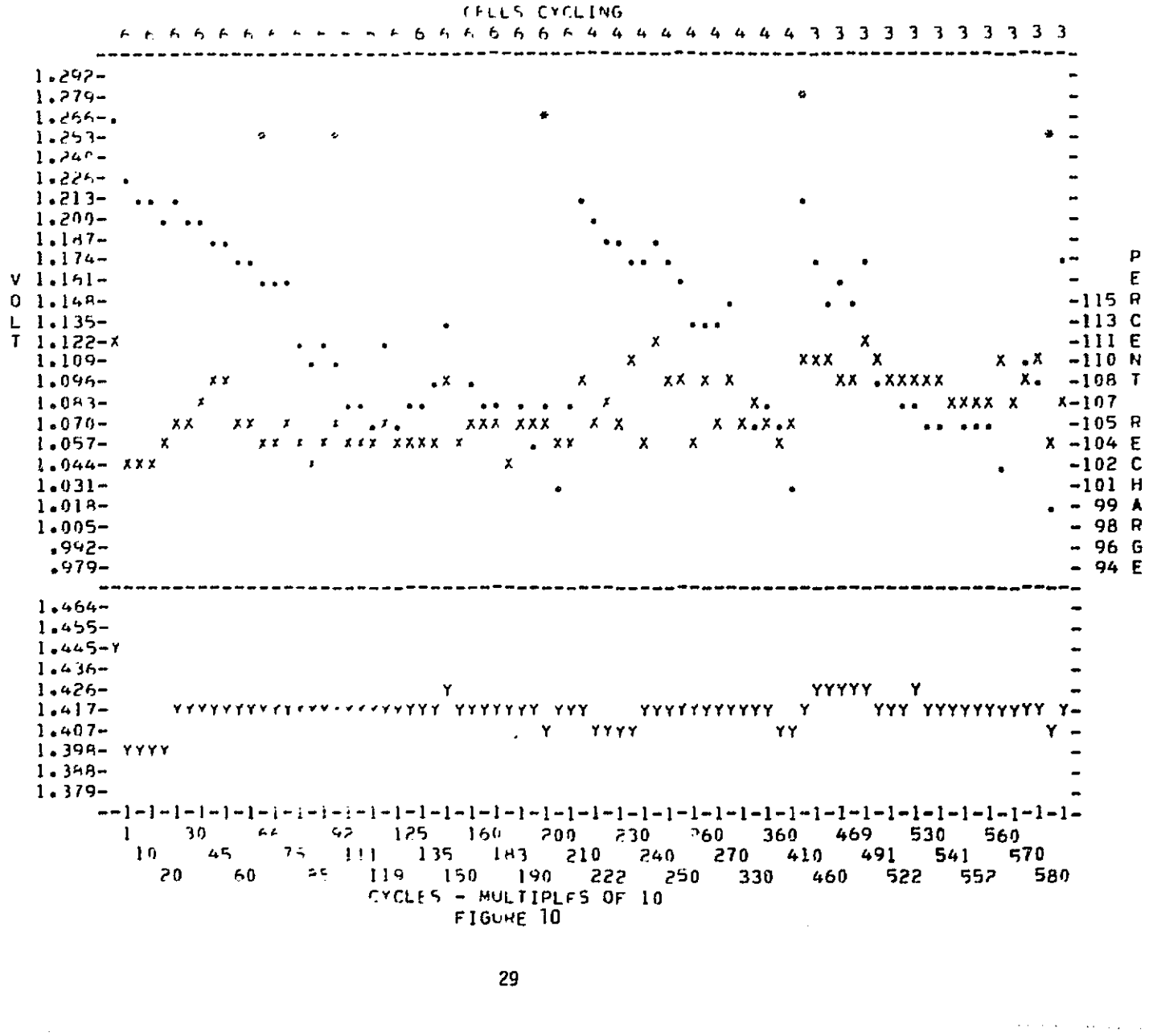

FIGURE 10

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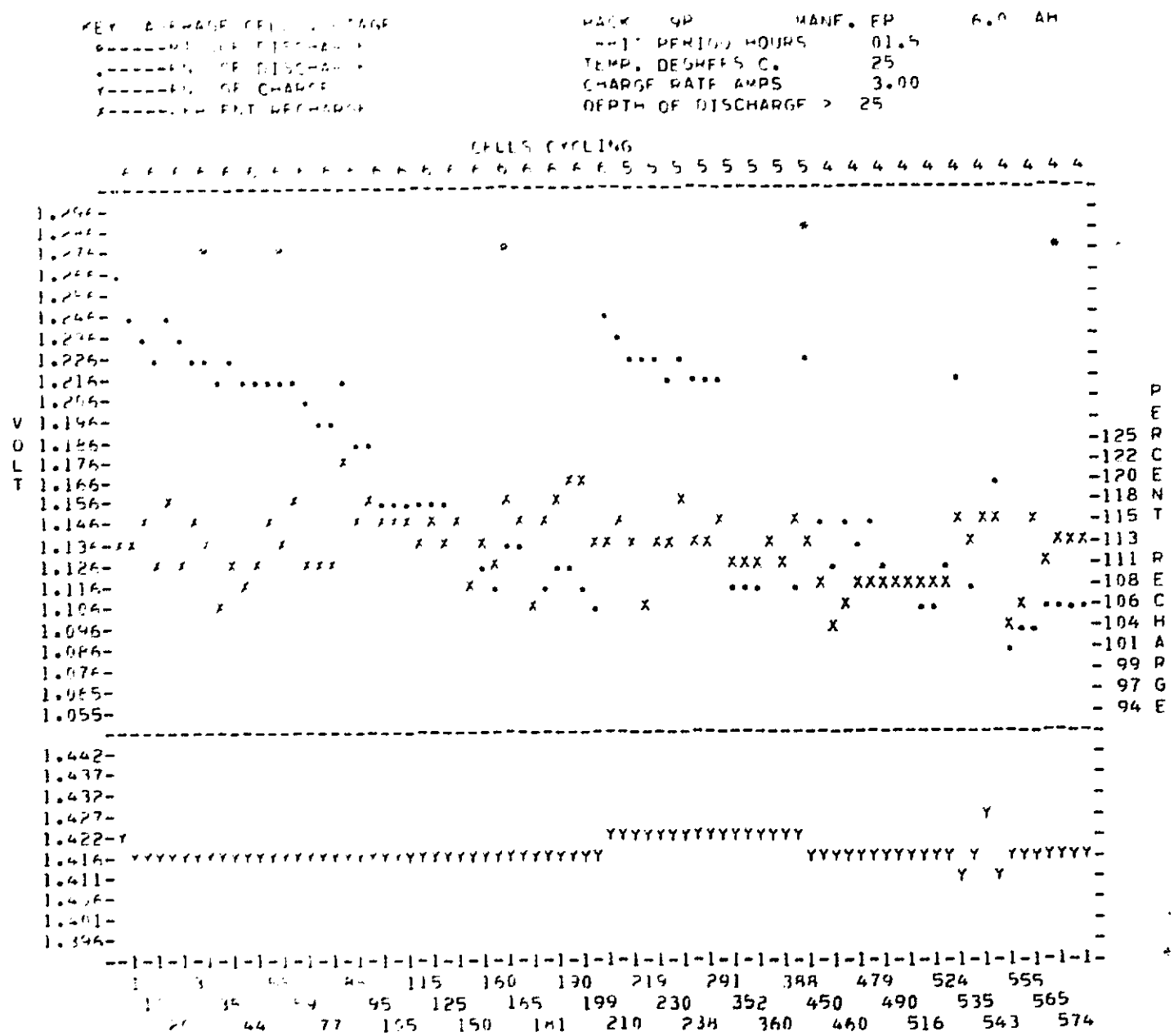
KEY
PACK 9P MANF. EP 6.0 AH
PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE > 25
CELLS CYCLING
VOLT
PERCENT RECHARGE
CYCLES - MULTIPLES OF 10

FIGURE 11

KEY AVERAGE CELL VOLTAGE
*------ DISCHARGE
.------ DISCHARGE
Y------ CHARGE
X------ RECHARGE

PACK 90 MANF. EP 6.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE > 25

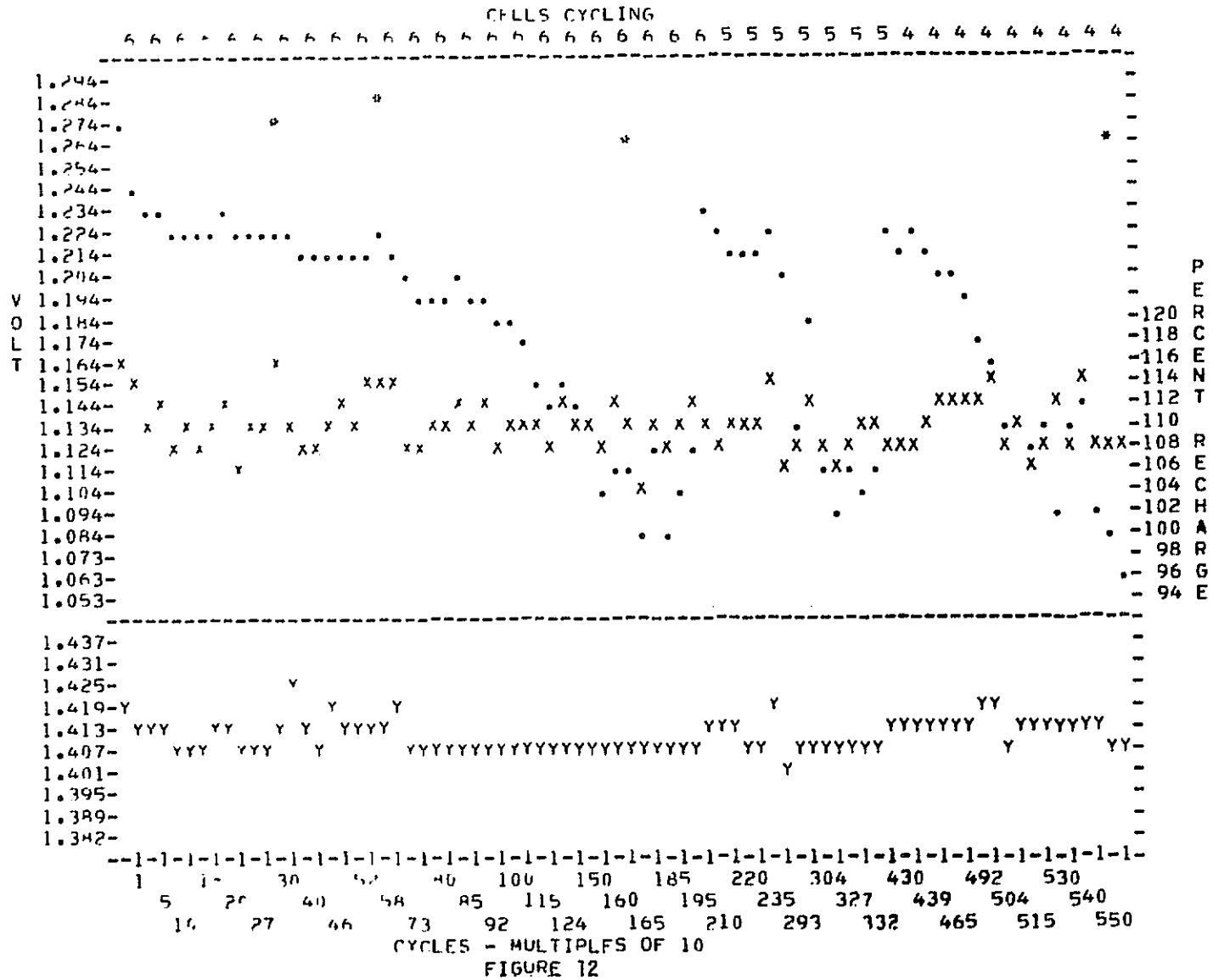

FIGURE 12

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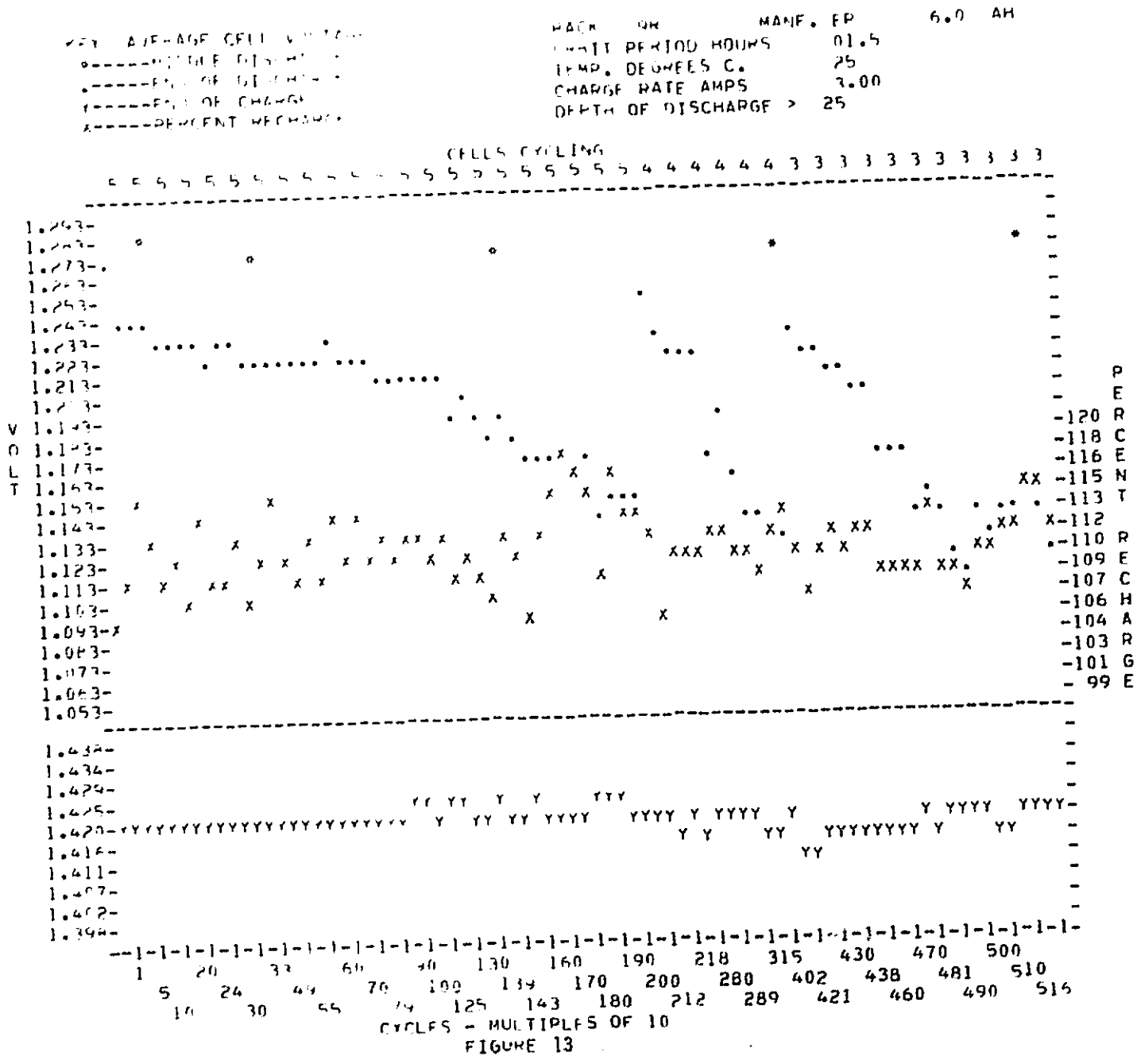
PACK OR MANF. EP 6.0 AH
REST PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE > 25
CELLS CYCLING
VOLT
PERCENT CHARGE
CYCLES - MULTIPLES OF 10

FIGURE 13

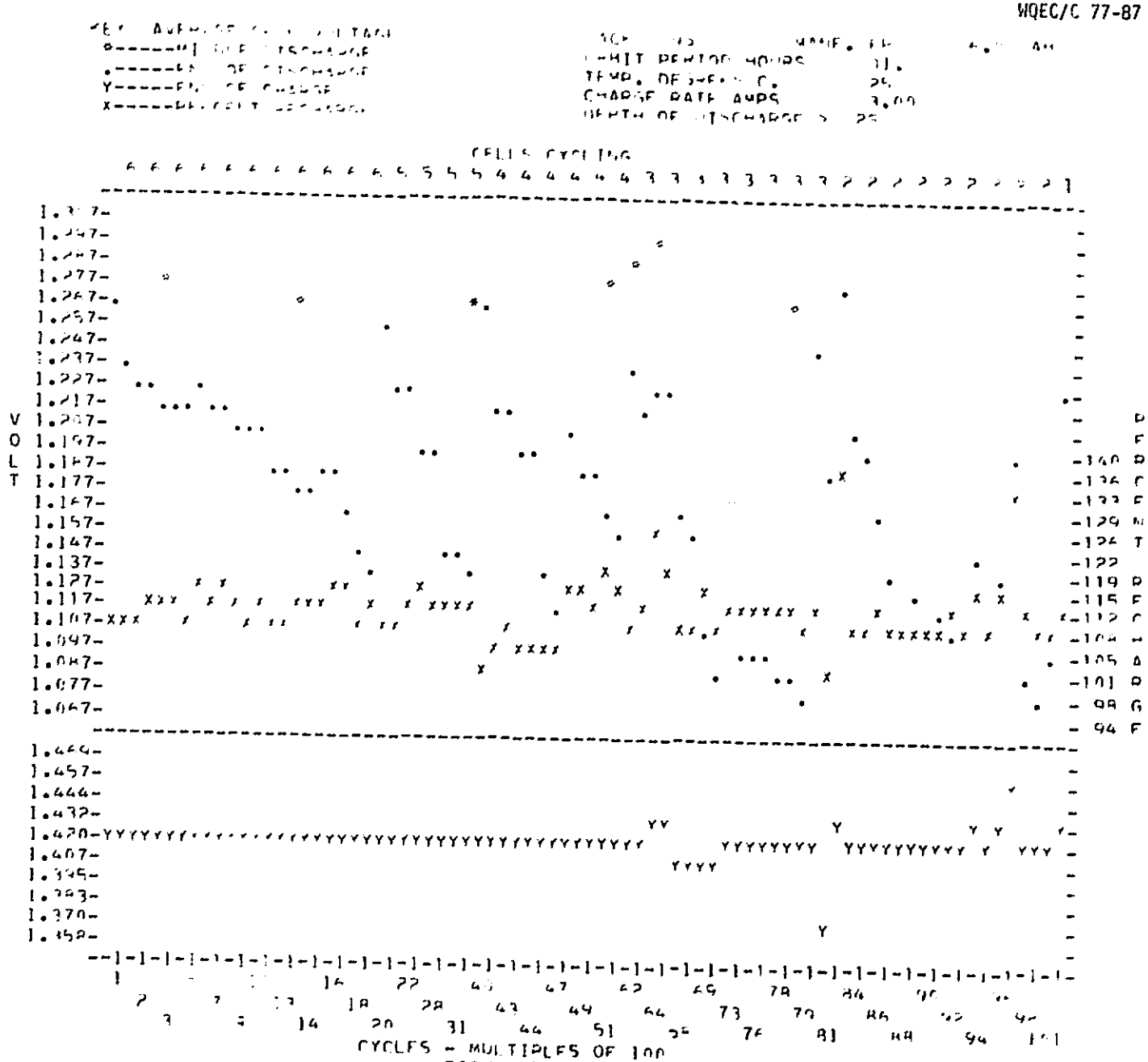

FIGURE 14

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4. General Electric 6.0 ah (AE-C and D, Atmospheric Explorer, C and D), three 5-cell Packs:

a. Cell Description: These cells are rectangular, the containers and covers are made of stainless steel, and the terminals are insulated from the cell cover by double ceramic seals and protrude through the cover as solder-type terminals. The auxiliary electrode is a teflon-coated, sintered, nickel plaque located along one side of the narrow edge of the cell. Physical dimensions are 1.25 inches by 0.065 inch and has a bag-type enclosure of pellon 2506K4 nylon material. Five cells are identified by RCA lot number 19722-94-1 and the seven auxiliary electrode cells have the RCA lot number 19722-94-2. The cells were purchased by RCA under contract number G6F015-0204-00-F23. The remaining three cells were purchased by GSFC under contract number NAS 5-18496, and were identified by General Electric catalog number 42B006AB37-64. Initial evaluation test results and detailed cell descriptions are contained in NAD Crane Report QEEL/C 74-1.

b. Parameters and Capacity Checks:

Orbit Period*		2.16-hours	
Temperature	10°	20°	0°
Depth of Discharge*	20.3%	20.3%	20.3%
Trip Voltage (mv)	.53V	.56V	.48V
Auxiliary Electrode Resistor (ohms)	2000	2000	2000
Pack Number	2F	2G	2H
Precycling Capacity	7.00	7.29	6.79
120 Days	5.81	7.01	5.52
230 Days	6.11	6.82	7.14
450 Days	6.49	7.03	7.18
547 Days	6.31	6.86	6.77
730 Days	6.33	6.60	6.82

*Orbit period 1.5 hour after 2970 cycles with 15.8% DOD and then 20% DOD after 5800 cycles. Packs on voltage limit control after 8800 cycles.

c. Test Results:

(1) Performance on Cycling: (Figures 15 through 17) Cycling was started in December 1973 and packs 2F, 2G and 2H have completed 13,681, 13,512 and 13,387 cycles respectively, without a cell failure.

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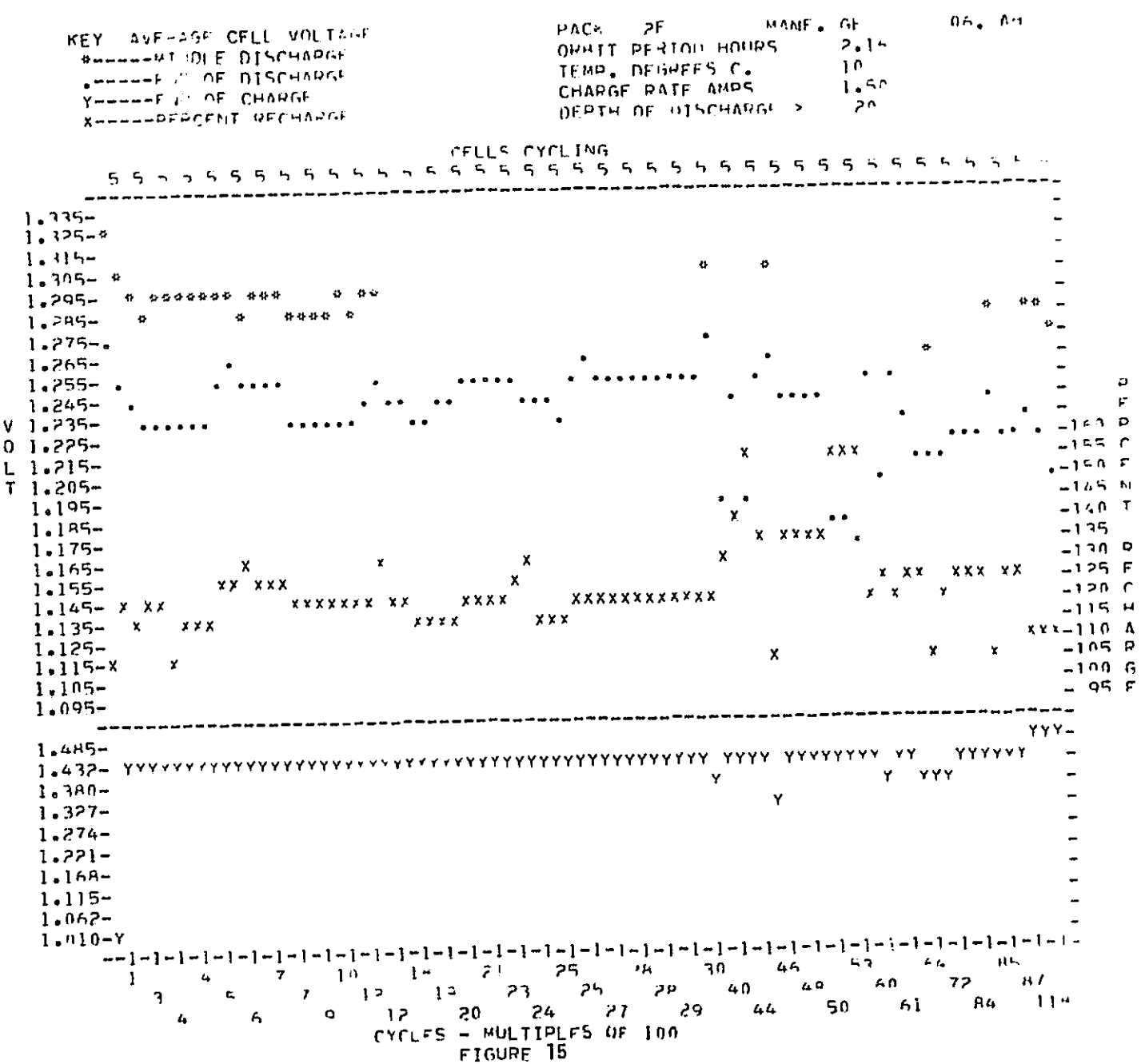

FIGURE 15

NOTE: Orbit period changed to 1.5 hours with 15.8% DOD after 2989 cycles; 20% DOD after 5907 cycles; voltage limit control after 8800 cycles.

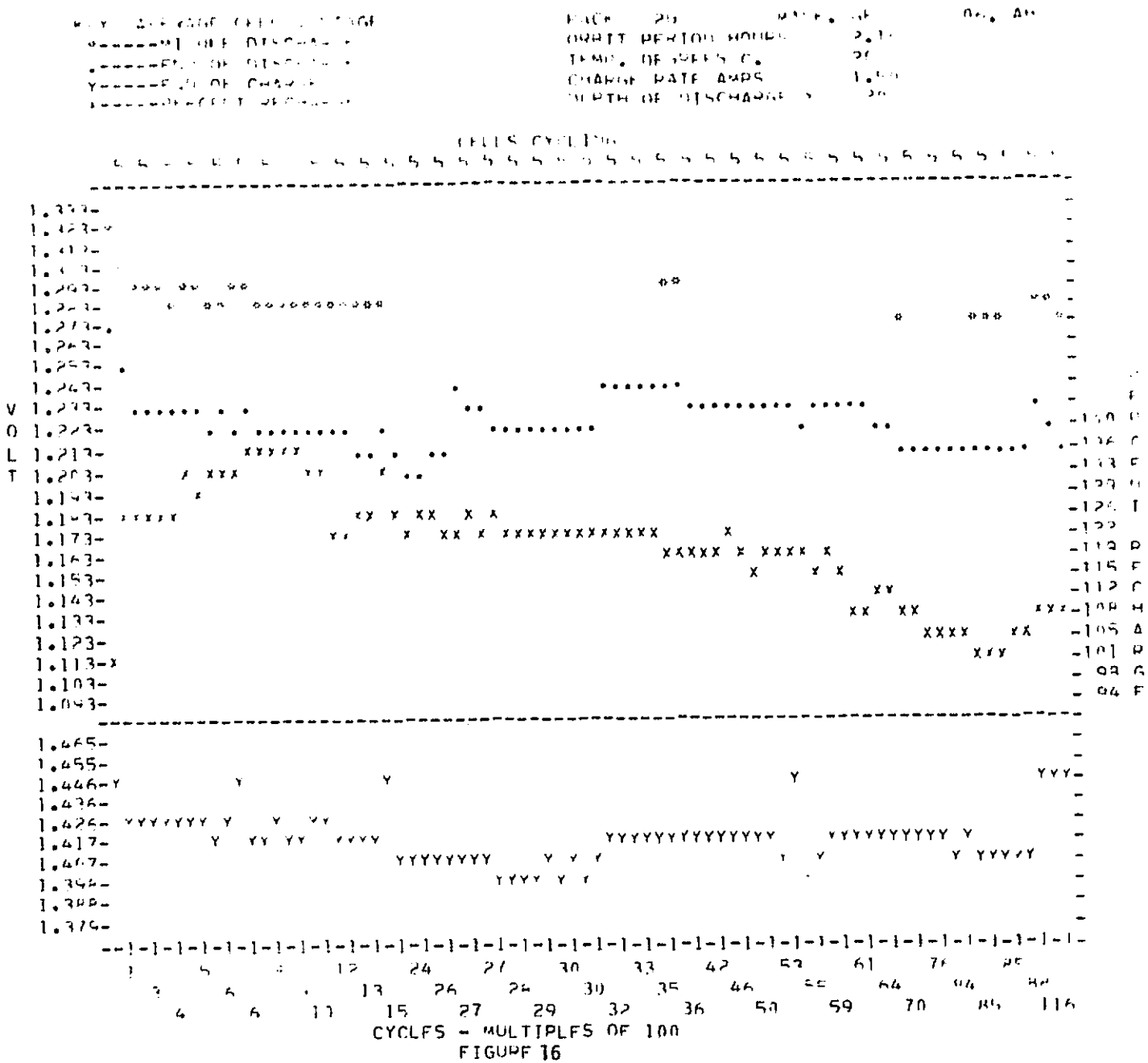

FIGURE 16

NOTE: Orbit period changed to 1.5 hours with 15.8% after 3049 cycles; 20% DOD after 6025 cycles; and voltage limit control after 8800 cycles.

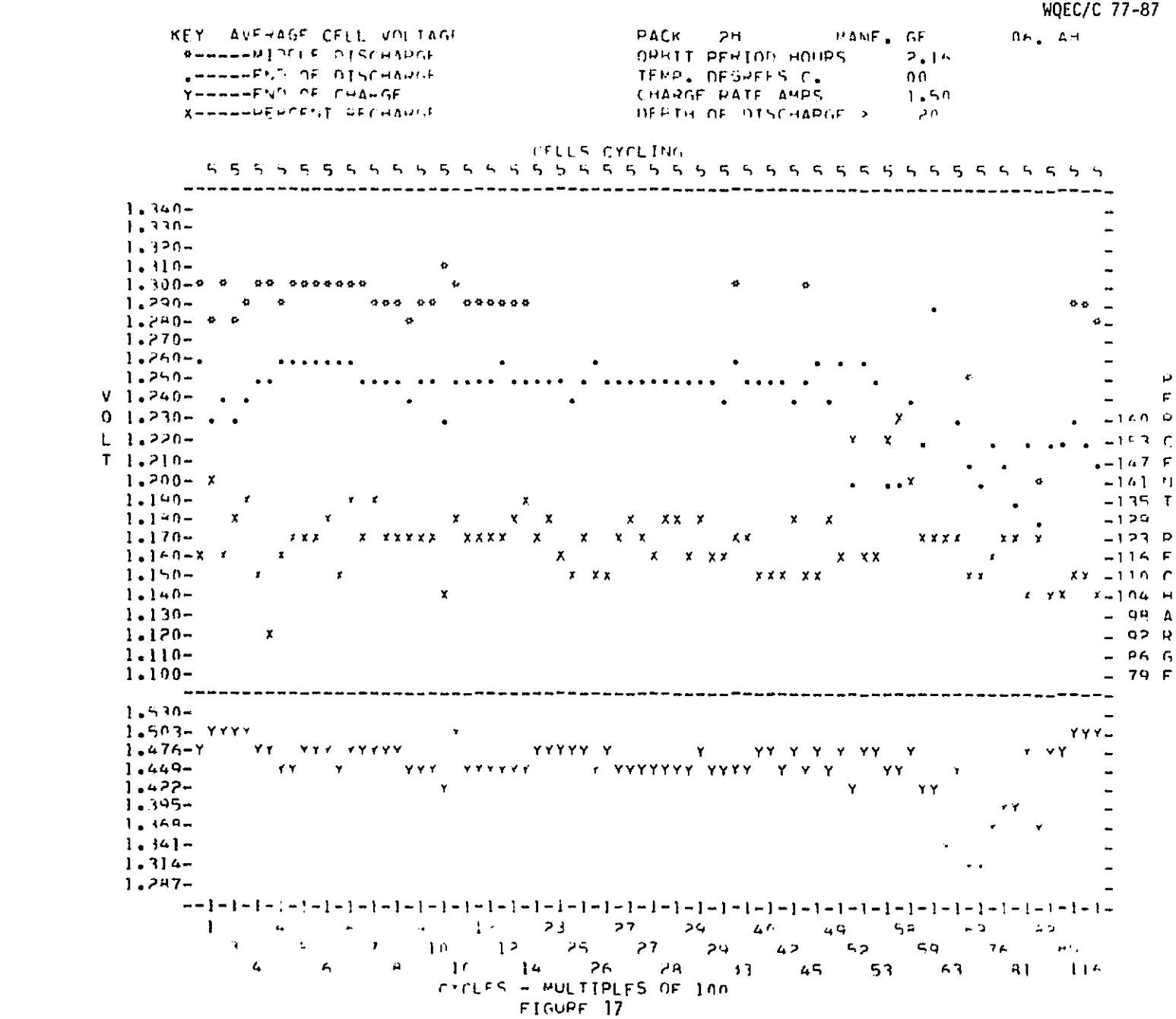

FIGURE 17

NOTE: Orbit period changed to 1.5 hours with 15% DOD after 2974 cycles; 20% DOD after 5876 cycles; and voltage limit control after 8800 cycles.

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5. GE, 6.0 ah (Nickel-Braze), Eight 5-cell Packs:

a. Cell Description: The cell case fits the description of all nickel-cadmium stainless steel cases. The ceramic-to-metal seal has an all nickel braze construction to eliminate ceramic shorting through silver migration. Acceptance test results are contained in NAD Crane report QE/C 71-45.

b. Parameters and Capacity Checks:

Orbit Period (Hr)	1.5	1.5	1.5	1.5
Temperature	-20°	0°	20°	40°
Depth of Discharge	25%	25%	25%	25%
Pack Number	81B	92B	95B	106B
88 Days	2.46	6.90	6.99	2.25
264 Days	2.61	4.71	6.78	2.34
440 Days	3.40	7.75	6.78	3.30 F
555 Days	NA	NA	NA	
724 Days	3.00	7.00	6.02	
906 Days	2.85 D	7.89	4.49	
1140 Days		7.75	2.63	
1320 Days		5.72	3.10	
1500 Days		6.74	2.83	
1672 Days		5.40	2.43	
1848 Days			3.13	

	cell number												
Orbit Period (Hrs)		24			24			24			24		
Temp.		-20°**			0°			20°			40°		
Depth of Disch.		60%			60%			60%			60%		
Pack#		75E			123B			109B			91B		
Cutoff Voltage		1.0	0.5	0.0	1.0	0.5	0.0	1.0	0.5	0.0	1.0	0.5	0.0
Cap.Ck. 1 yr.	1	7.44	8.16	8.22	5.70	7.02	7.44	6.36	7.32	7.80	3.18	4.44	4.98
	2	6.06	6.54	6.66	6.30	7.44	7.86	5.88	7.08	7.43	3.30	4.50	5.04
1 yr. 6 mo.	4	5.82	6.72	6.84	5.04	6.96	7.38	4.86	5.82	6.12	3.18	4.20	4 56
	5	7.02	7.68	7.74	4.74	5.64	5.88	4.20	5.04	5.22	3.72	4.98	5.52

Cap.Ck. 2yrs.	1	--	--	7.99	--	--	7.92	--	--	6.63	NA		
	2	--	--	6.68	--	--	7.92	--	--	6.36	--	--	4.49
2yr*, 6 mo.	1	4.79	--	8.51	5.76	--	8.96	--	--	8.19		F	
	2	--	--	7.46	--	--	8.76	4.75	--	8.00			
3yrs.	4	5.41	--	7.57	--	--	5.78	--	--	8.68			
	5	--	--	8.10	4.28	--	5.58	5.10	--	6.53			
3yrs. 6 mo.	1	--	--	1.8	4.31	8.37	8.58	--	6.22	6.56			
	2	4.65	7.14	7.16	--	8.89	8.98	3.65	6.25	6.66			
4yrs.	1	--	--	1.3	4.98	8.84	9.09	--	6.57	6.91			
	2	4.92	7.11	7.34	--	8.90	9.11	3.80	6.31	6.69			
4yrs. 6 mo.	1	--	--	.81	--	6.56	6.75	4.08	8.31	8.63			
	2	4.03	6.42	6.66	3.66	6.10	6.37	--	8.51	8.68			
5yrs.	1	--	--	2.91	--	6.77	6.97	3.88	9.03	9.33			
	2	4.37	7.25	7.44	3.93	6.19	6.41	--	9.20	9.33			

*Run at cycle rate to first cell 1.0V then at 0.6 amp to 0.0V each cell. Number in 0.0 column total ampere-hours.
**Temperature change to 10°C after 270 cycles.

c. Test Results:

(1) Performance on Cycling: (Figures 20 through 24) Cycling was started in March 1971. Packs 92B and 95B (1.5-hour orbits) have completed 29,194 and 30,073 cycles respectively, with two cell failures in pack 92B. Pack 81B had one cell failure, pack was discontinued after 17,190 cycles. Pack 106B failed on cycle 7538. Also, one cell was removed from packs 95B and 106B and shipped to Goddard Space Flight Center, as instructed by that activity. Packs 123B and 109B (24-hour orbits) have completed 1,897 and 1,914 cycles respectively, with no cell failures. Pack 75E has completed 1,928 cycles and one cell failed on cycle 1210. This cell (cell 1) is being allowed to cycle even though it reverses during discharge. Following the 3-year capacity test, cell 5 was removed from each 24-hour orbit pack. Pack 91B (24-hour obit) was discontinued after three cell failures on cycle 792. These packs had two cell capacity checks, after one year of cycling, to the 1.0, 0.5 and 0.0 cut-off levels. Six months later two different cells were capacity checked to the same cut-off levels. Following the 3-year capacity check, only the first 2 cells now receive a capacity check. This method of capacity checking was used to measure the effect of the capacity check itself since two different cells were capacity checked at six-month intervals--thus the need for the two different formats of the previous tabulation.

(2) Failure Analysis: Cell from pack 81B failed because gauge assembly was accidentally broke at bottom of fill tube allowing it to fall into pack stack causing a short. All 3 cells of pack 106B were shorted due to separator deterioration. Cells of pack 91B showed extreme migration and separator deterioration. All cells of these packs had one side of their positive plates that were uncoined and small blisters were seen at the top of the plates.

(3) Results of chemical analysis of extracted electrolyte are as shown:

Pack Number	75E	109B	123B
Cycles	1097	1087	1085
Serial Number	042	048	031
Total meq* KOH/ extract (avg)	79.623	85.489	85.318
Total meq K_2CO_3/ extract (avg)	62.880	45.352	60.221
meq KOH/ separator patch**	.250	.260	.240
Total volume (cc)/ patch	.7150	.9513	1.0020
Wet weight (g)***	.2997	.2881	.3229
Dry weight (g)***	.1956	.1736	.1883

*meq is the abbreviation of milliequivalents.

**The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the center, and one from the last third.

***Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.

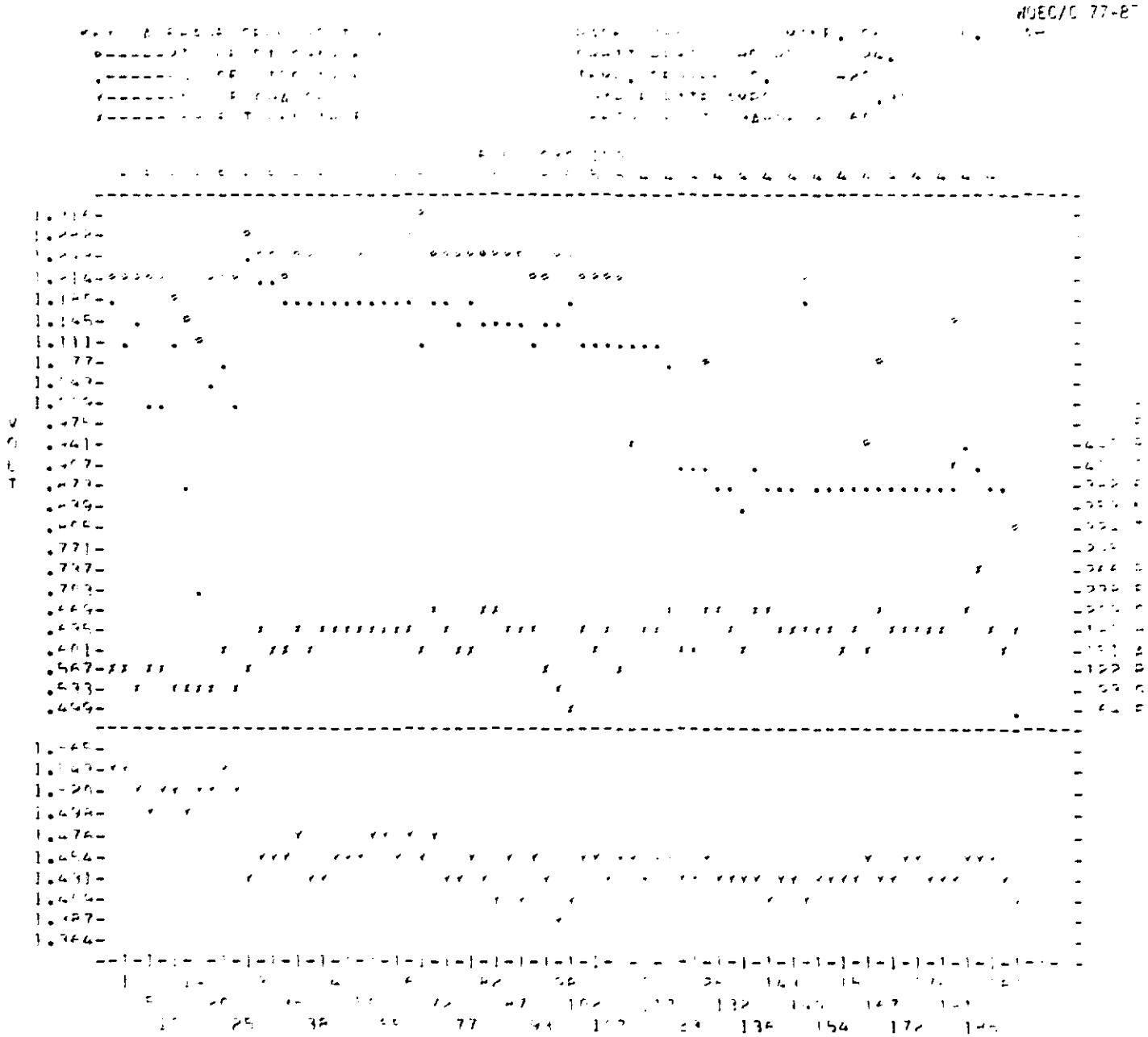

FIGURE 18

NOTE: Temperature 10°C after 270 cycles.

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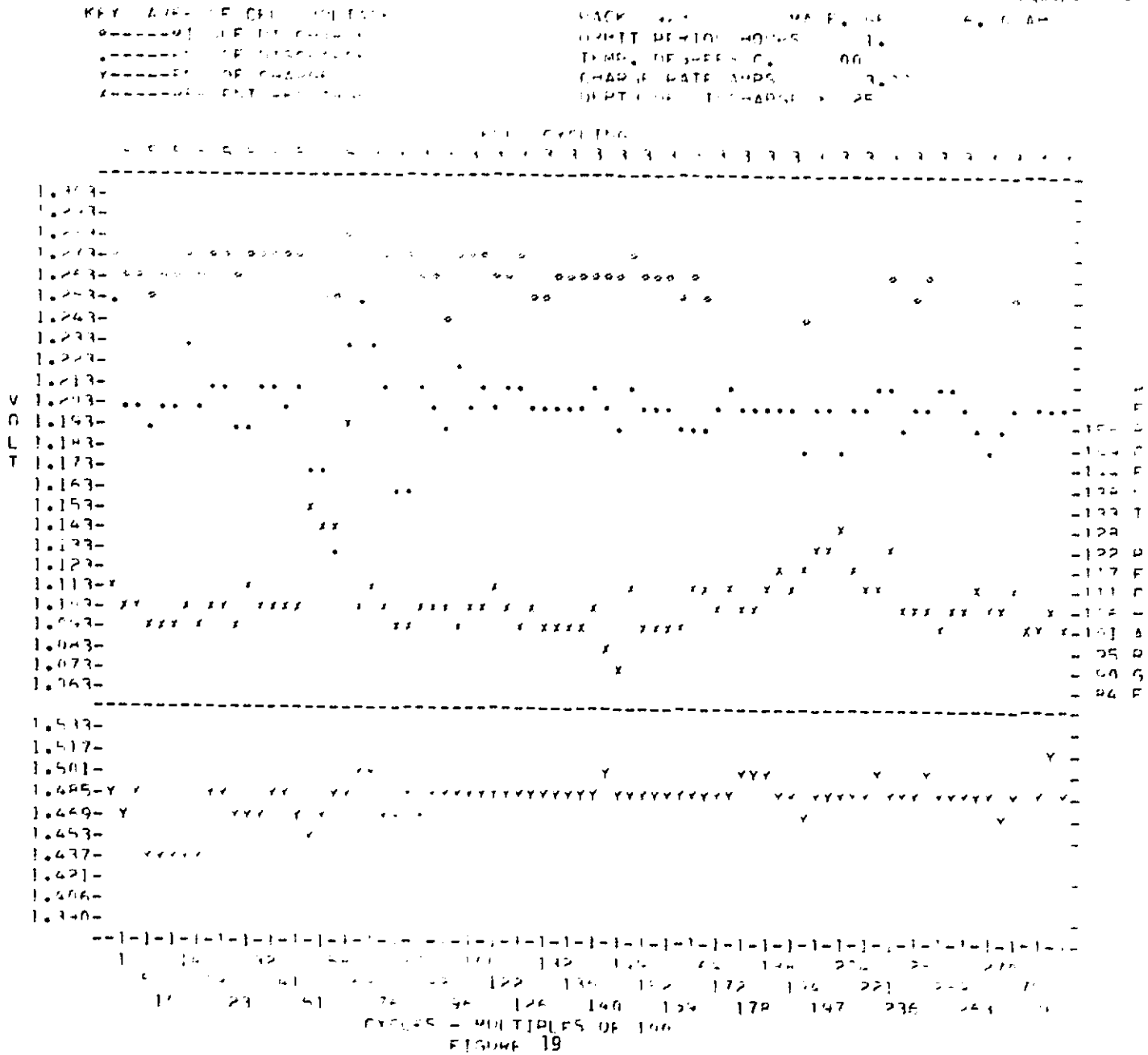

FIGURE 19

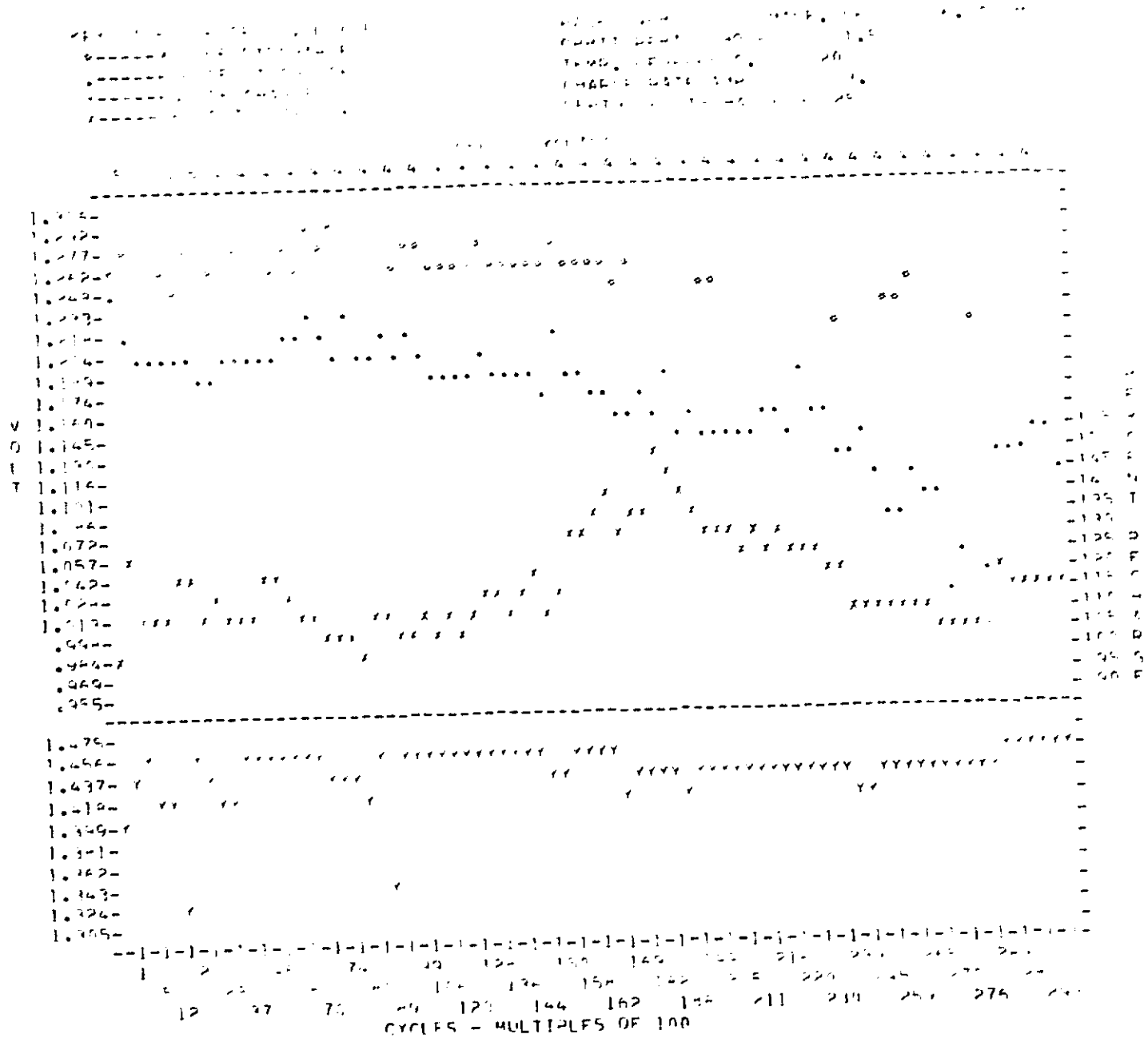

FIGURE 20

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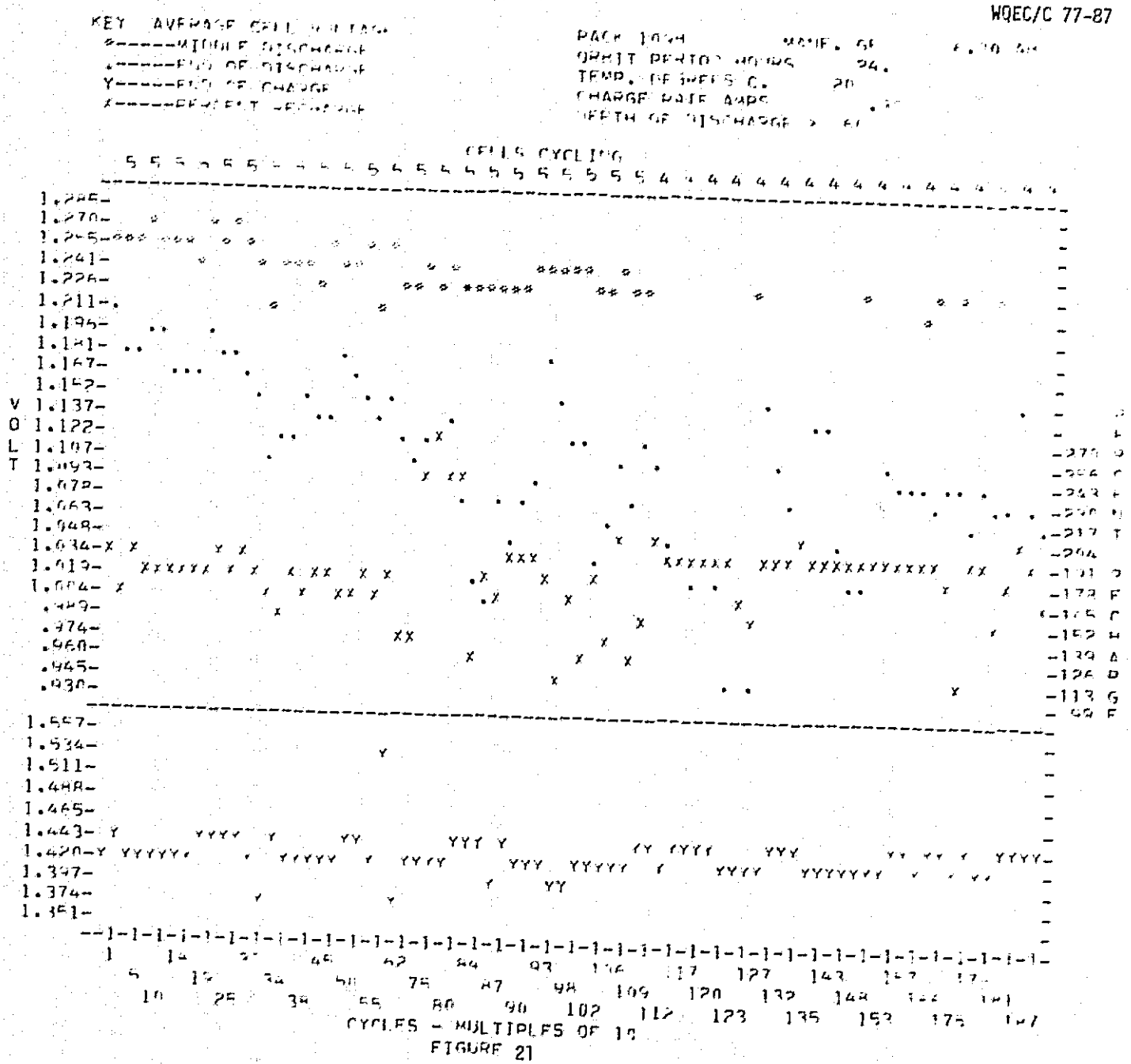
KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE
PACK 1094
ORBIT PERIOD HOURS 24.
TEMP. DEGREES C. 20
CHARGE RATE AMPS
DEPTH OF DISCHARGE
CELLS CYCLING
VOLT
CYCLES - MULTIPLES OF 10

FIGURE 21

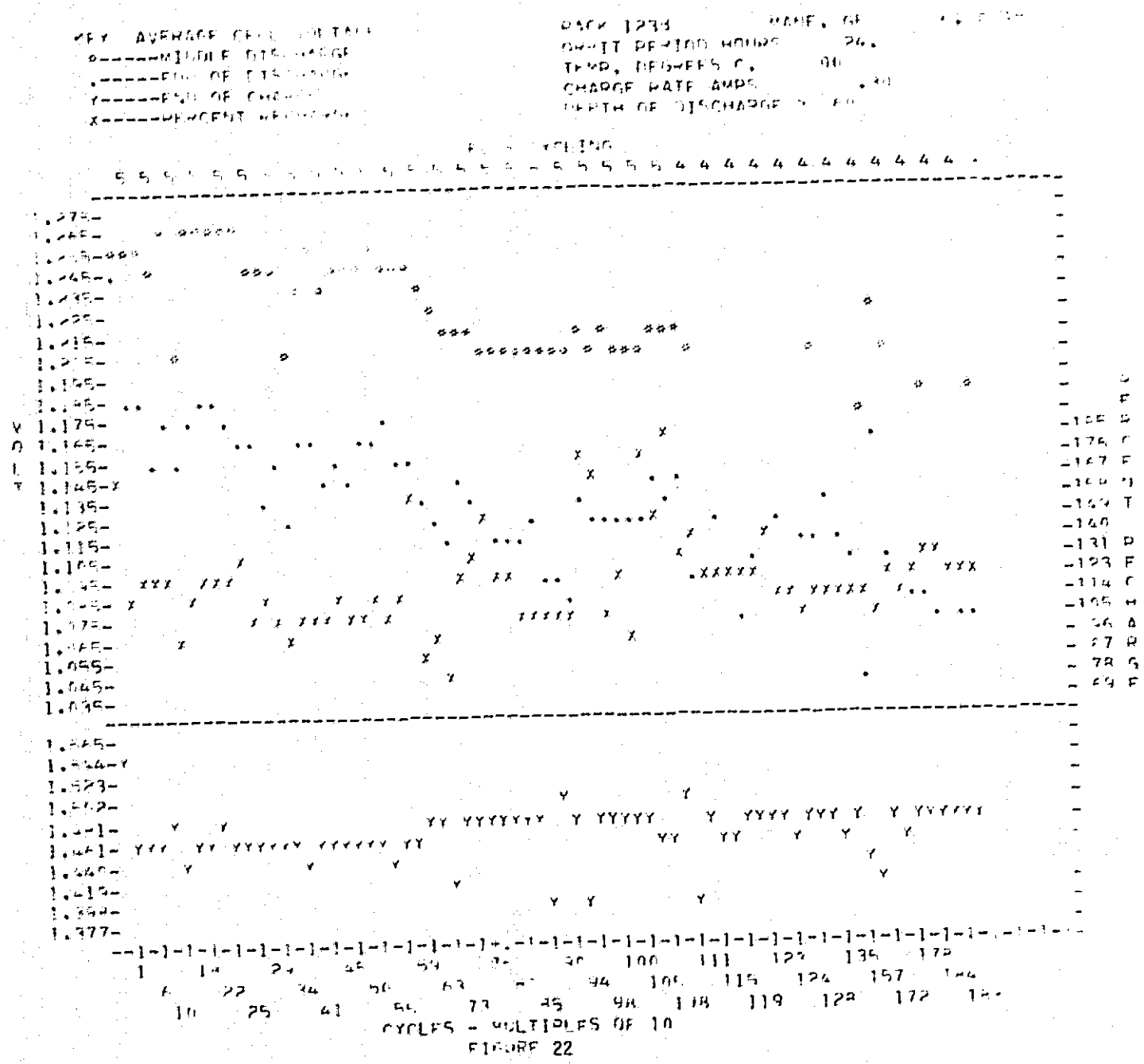

FIGURE 22

NOTE: Charge current reduced to .2A after 15 cycles.

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6. General Electric 6.0 ah (ITOS), one 5-cell Pack:

a. Cell Description: See paragraph I.A., page 12. The cells were manufactured according to RCA's specification 2272642, drawing number 2278372 and were from the same lot of cells as those procured by RCA under NASA contract NAS 5-10306. The cells were identified by General Electric's catalog number 42B006AB49. Initial evaluation test results and detailed cell descriptions are contained in NAVWPNSUPPCEN Crane Report WQEC/C 75-164.

b. Parameters and Capacity Checks:

Orbit Period	1.92-hours
Temperature (°C)	20°
Depth of Discharge (%)	29.6
Pack Number	7D
Precycling Capacity	8.0
7.6 Months	8.04
13.6 Months	7.84

(1) Performance on Cycling: (Figure 23)
Cycling began in May 1975. Various changes in the test parameters began on cycle 1687 and are still continuing as requested by the GSFC's Technical Officer. One cell was analyzed following acceptance test (7 cycles). This pack has completed 6099 cycles without a cell failure.

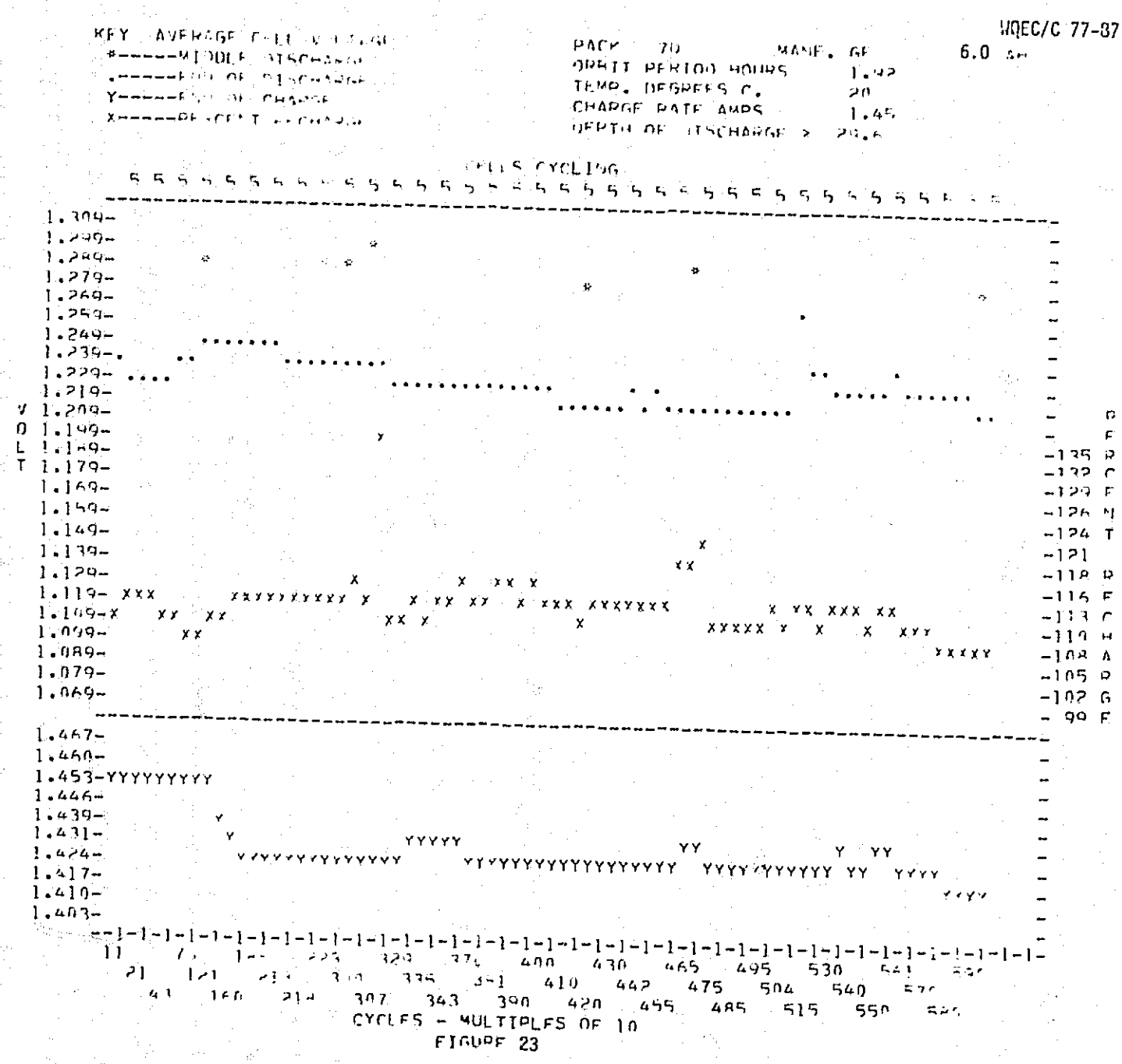
(2) Results of chemical analysis of extracted electrolyte are as shown:

Pack Number	7D
Cycles	7
Serial Number	130-L01
Total meq** KOH/ extract (avg)	*
Total meq K_2CO_3/ extract (avg)	8
meq KOH/ separator patch***	1.3146
meq K_2CO_3/ separator patch	.3967
Total volume (cc) per patch	*
Wet weight (g)****	.4864
Dry weight (g)****	.1921

*Extract of cell core was not performed.
**Meq is the abbreviation of milliequivalents.
***The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the center, and one from the last third.
****Wet weight is determined immediately following removal from the cell core and prior to leaching in water overnight, dry weight is determined following titration and air drying overnight.

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT DISCHARGE

PACK 70 MANF. GE 6.0 AH
ORBIT PERIOD HOURS 1.92
TEMP. DEGREES C. 20
CHARGE RATE AMPS 1.45
DEPTH OF DISCHARGE > 20.6



CYCLES - MULTIPLES OF 10

FIGURE 23

NOTE: Voltage limit 1.425 V/C with 21.6% DOD after 1761 cycles.

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7. Gulton 6.0 ah (Nickel-Cadmium), Two 5-cell Packs:

a. Cell Description: See paragraph I.A., page 12.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms)
58D	*	25	170	6.8
36D	*	15	170	6.8

* These cells were in an ambient temperature which varied sinusoidally from 0° to 40° C within a period of 48 hours until 3-1-71; at which time the test temperature was changed to 20° C and the packs placed under a voltage limit control.

c. Capacity Checks:

Pack Number	36D	58D
Pre-Cycling	7.56	6.05
2 years	6.80	5.64
3 years	5.55	3.40
4 years	4.00	3.26
5 years	2.91	2.19
6 years	3.10	1.90
7 years	1.75	1.12 (Following last cell failure)

d. Test Results:

(1) Performance on Cycling: (Figures 24 and 25) Cycling was started in January 1969. Pack 36D has completed 41,471 cycles with one cell failure on cycle 35,050. Pack 58D has completed 41,756 cycles and all the cells have failed. When these cells failed, they were allowed to remain in the circuit until they shorted. Only one cell, last one that failed, is still cycling and it now reverses to -.070 volts at the beginning of each discharge. Pack 58D had cell failures occur on cycles 21,569, 37,726, 38,241 and 40,393. One cell, also was removed from each pack after approximately 2 years of cycling and sent to Goddard Space Flight Center. These packs are being cycled without interruption for capacity check. The cycle life results will later be compared to packs that receive capacity checks every 88 days. Capacity checks are run at the cycle rate to 0.5 volt, first cell.

(2) Failure Analysis: Analysis of the two failed cells showed that extreme separator deterioration took place and small blisters were located at the top and bottom of the positive plates.

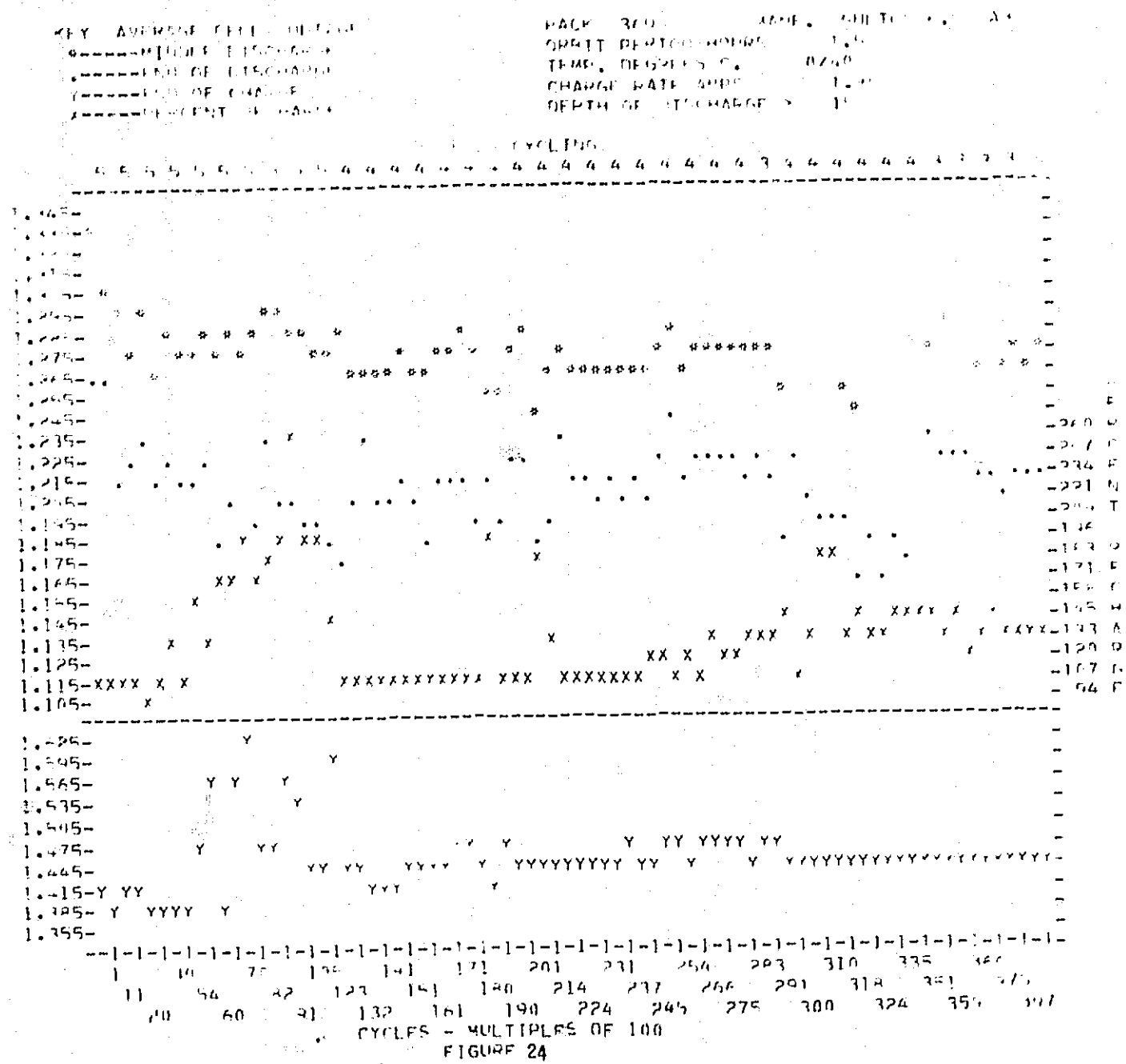

FIGURE 24

NOTE: Voltage limit control at 20°C after 11,777 cycles.

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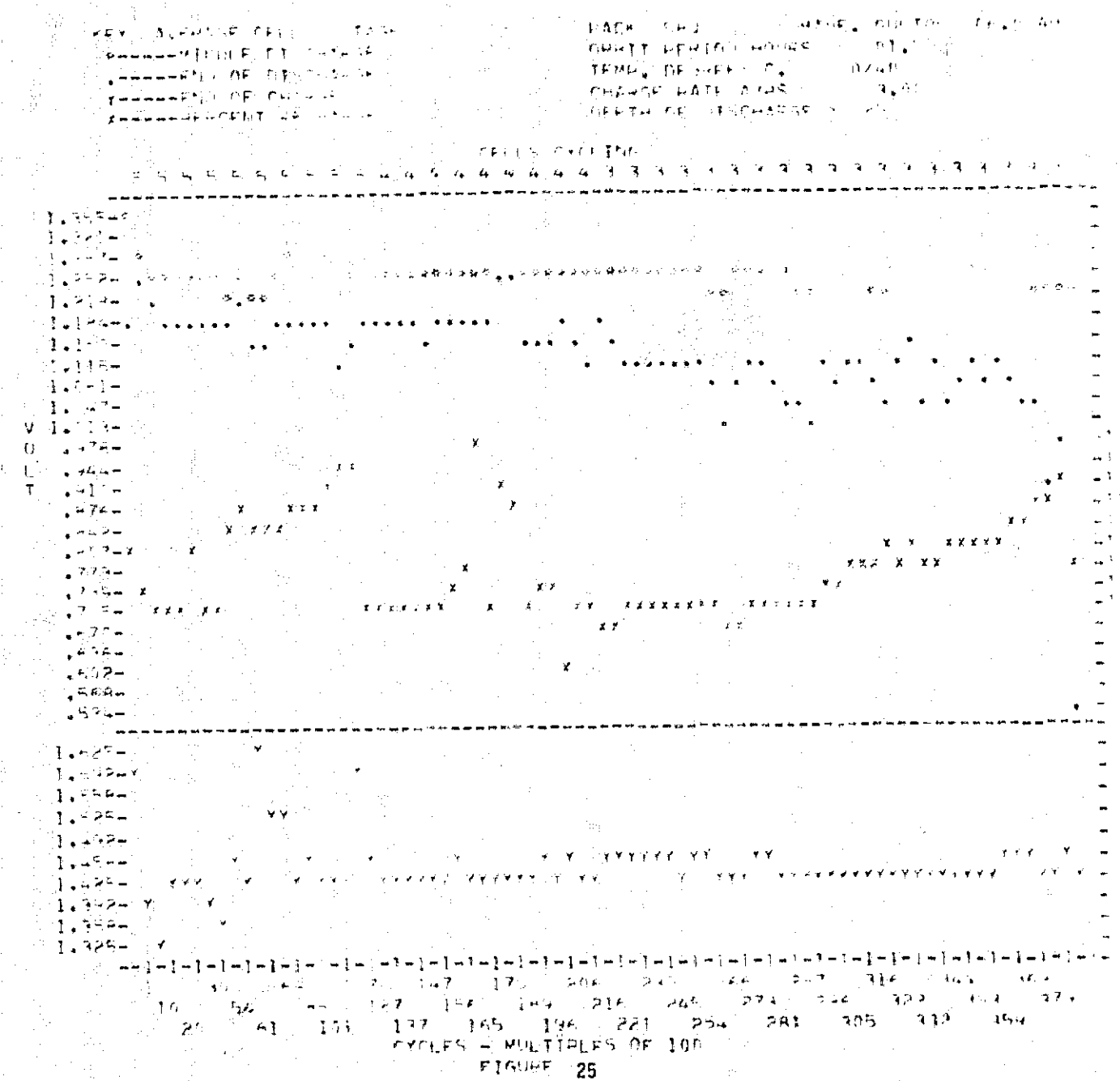

FIGURE 25

NOTE: Voltage limit control at 20°C after 11,766 cycles.

8. GE 8.0 ah (SAS-C), Two 10-cell Packs:

a. Cell Description: See Paragraph I.A., page 12. The cells were procured by the Applied Physics Laboratory (APL) to APL specification 7217-9014-A. Pack 18E contains eight cells, with standard plates and no auxiliary electrodes, which were identified by the manufacturer's part number 42B008AB09-G3; and two cells with standard plates, auxiliary electrodes, and pressure gauges had the part number 42B008AB06-G4. Pack 18F contains 10 cells which have teflon-covered negative plates in which two cells (part number 42B008AB08-G4) have auxiliary electrodes and pressure gauges and the remaining cells (part number 42B008AB07-G3) do not. The auxiliary electrode is a teflon-coated, sintered, nickel plaque located along one side of the narrow edge of the cell. Initial evaluation test results and detailed cell descriptions are contained in NAD, Crane Report QEEL/C 74-252.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hours	
Temperature (°C)	20°	
Depth of Discharge (%)	25	
Auxiliary Electrode Resistor (ohms)	300	
Pack Number	18E	18F
Precycling Capacity	9.6 (cell 1)	10.1 (cell 1)
6 months (cells 9 & 10)	8.6 (cells 9 &10)	10.5 (cell 9)
12 months (cells 7 & 8)	8.7 (cell 7)	10.0 (cell 7)
18 months (cells 5 & 6)	8.7 (cell 5)	9.7 (cell 6)
24 months (cells 3 & 4)	9.2 (cell 4)	9.9 (cell 4)

c. Test Results:

(1) Performance on Cycling: (Figures 26 and 27) Cycling began in March 1974. Packs 18E and 18F have completed 13,912 and 13,948 cycles respectively without a cell failure.

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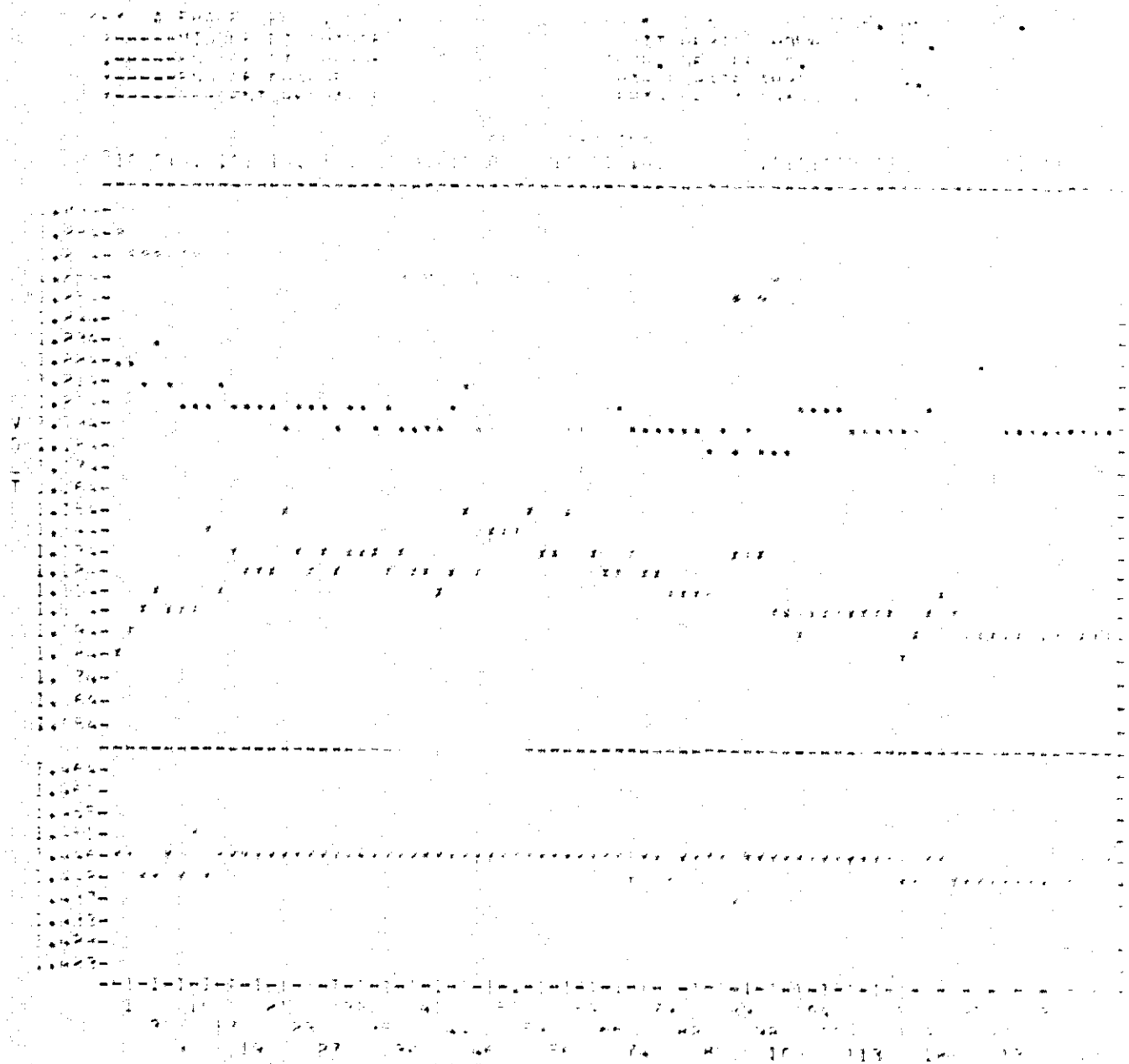

FIGURE 26

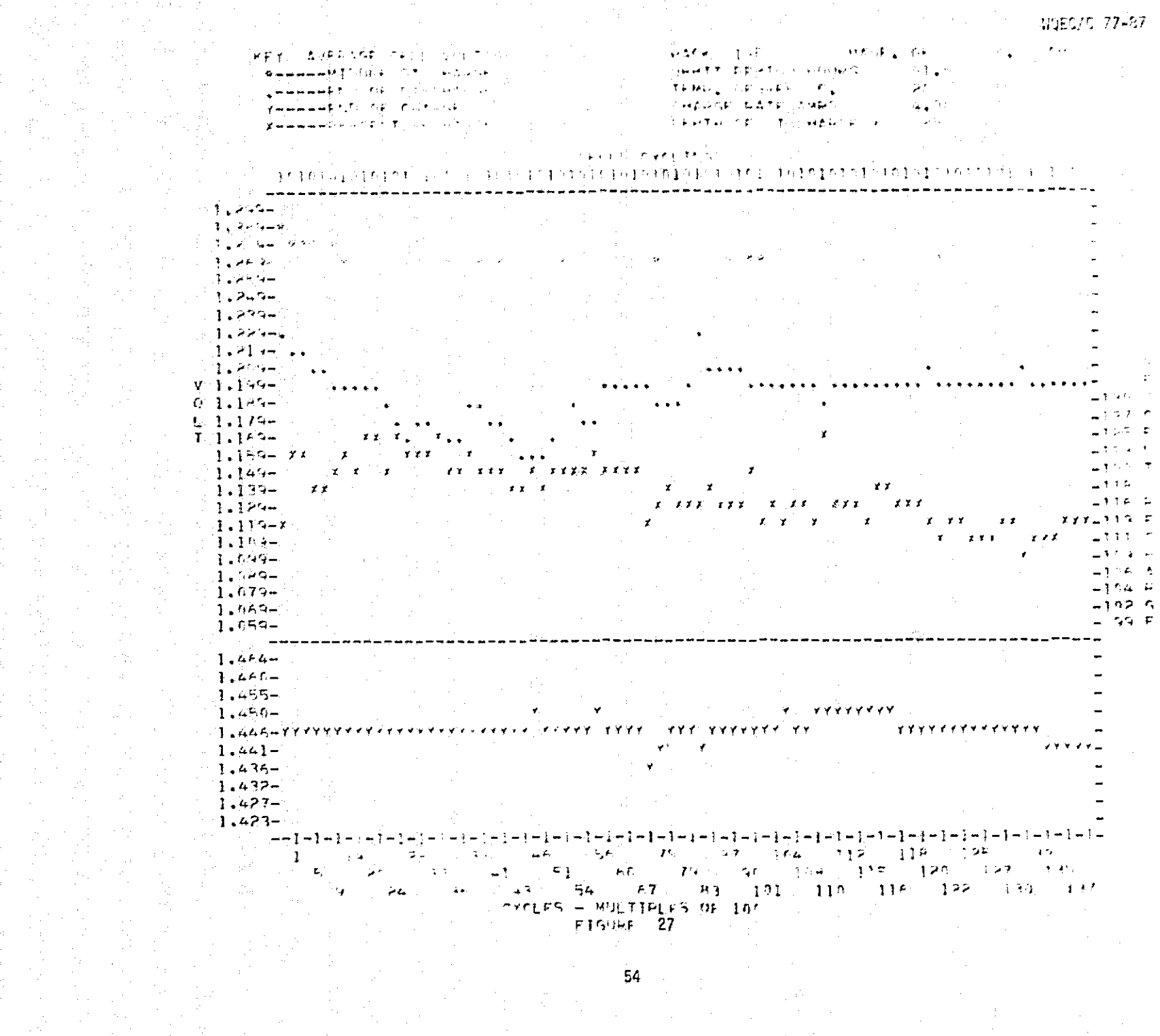

FIGURE 27

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9. Gulton 9.0 ah (SAS-C), one 10-cell Pack:

a. Cell Description: See Paragraph I.A., page 12. The cells were procured by the Applied Physics Laboratory (APL) to APL specification 7217-9014-A. Pack 18G contains eight cells, with no auxiliary electrodes, which were identified by the manufacturer's part number 805051; and two cells with auxiliary electrodes, had the part number 805052. These cells are from the same lot of cells that are being flown in the satellite which was launched in May 1975. The auxiliary electrode is Gulton's standard adhydrode (U-Fold). Initial evaluation test results and detailed cell descriptions are contained in NAVWPNSUPPCEN, Crane Report WQEC/C 75-165.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hours
Temperature (°C)	20°
Depth of Discharge (%)	25
Auxiliary Electrode Resistor (ohm)	47
Pack Number	18G
Precycling Capacity	11.4 (Cell 5)
132 Days (cells 1, 2 & 3)	11.1(Cell 2)
150 Days (cells 3, 4 & 5 @ 27°C)	11.1(Cell 3) 10.1(Cell 5)
1 year (cells 7 & 8)	8.2(Cell 8)

(1) Performance on Cycling: (Figure 23)
Cycling began in April 1975. The pack's voltage limit was lowered and the pack was placed in a test temperature of 27°C for 114 cycles as requested by the GSFC's Technical Officer. This pack has completed 8139 cycles without a cell failure.

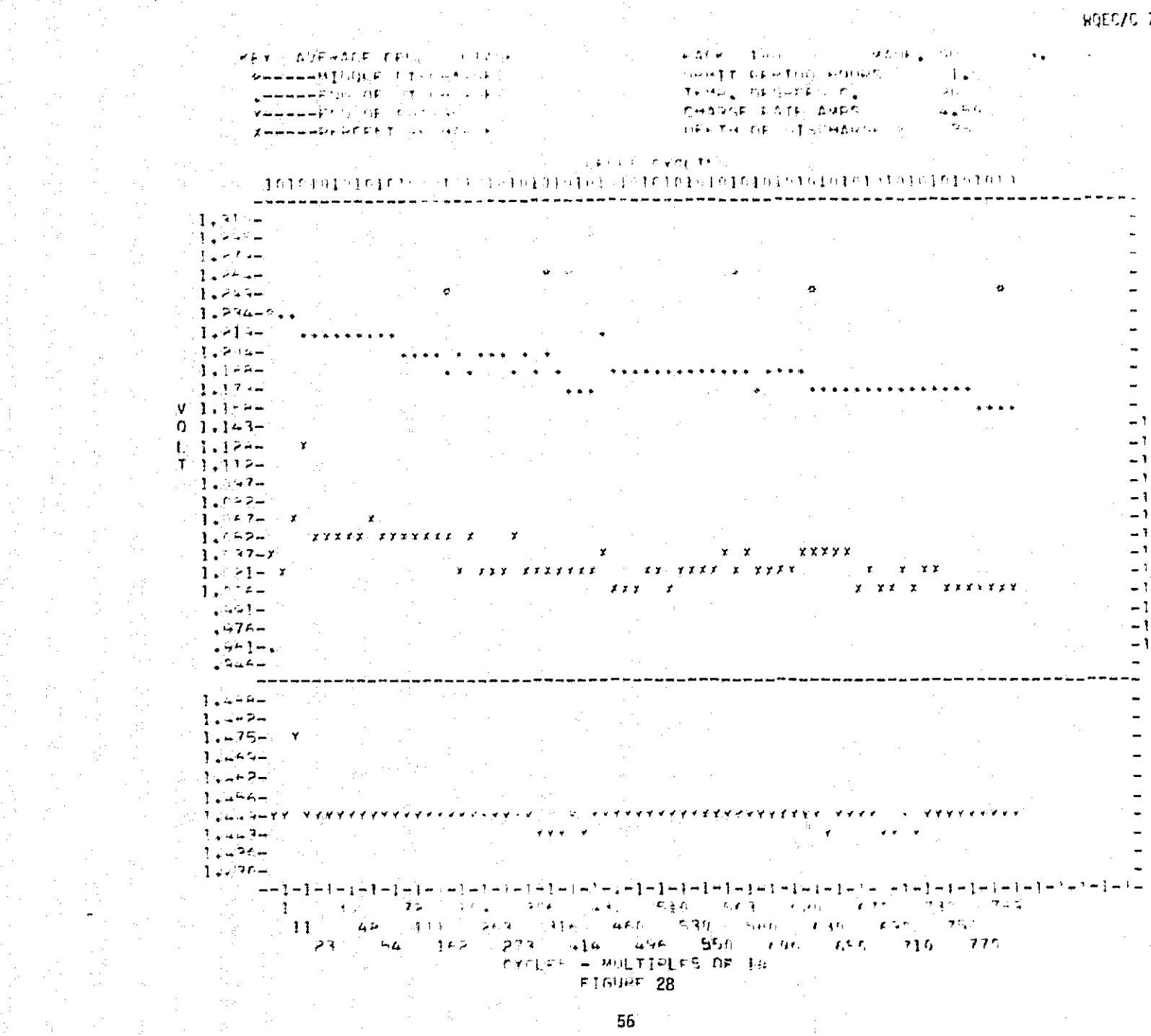

FIGURE 28

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10. GE-12.0 ah (IUE), Two 5-cell and One 4-cell Pack:

a. Cell Description: See Paragraph I.A., page 12. The cells were manufactured for NASA, GSFC, under NASA contract number NAS-5-23153 according to the Manufacturing Control Document (MCD) 232A2222AA-54, Revision 4, and the GSFC's specification number S-761-P-6. Each cell has teflonated, negative electrodes (TFE-II) and a 10 percent reduction in their positive plate loading. The electrodes were teflonated prior to the electrochemical cleaning test (ECT). Cells without auxiliary electrodes have catalog number 42B012AB20-G3 and those with auxiliary electrodes have the catalog number 42B012AB21-G3 or 42B012AB21-G3-A, indicating two different designs. Each pack contains cells of each catalog number. The ceramic-to-metal seal has an all nickel braze construction. Initial evaluation test results and detailed cell descriptions are contained in NAD, Crane Report WQEC/C 74-511.

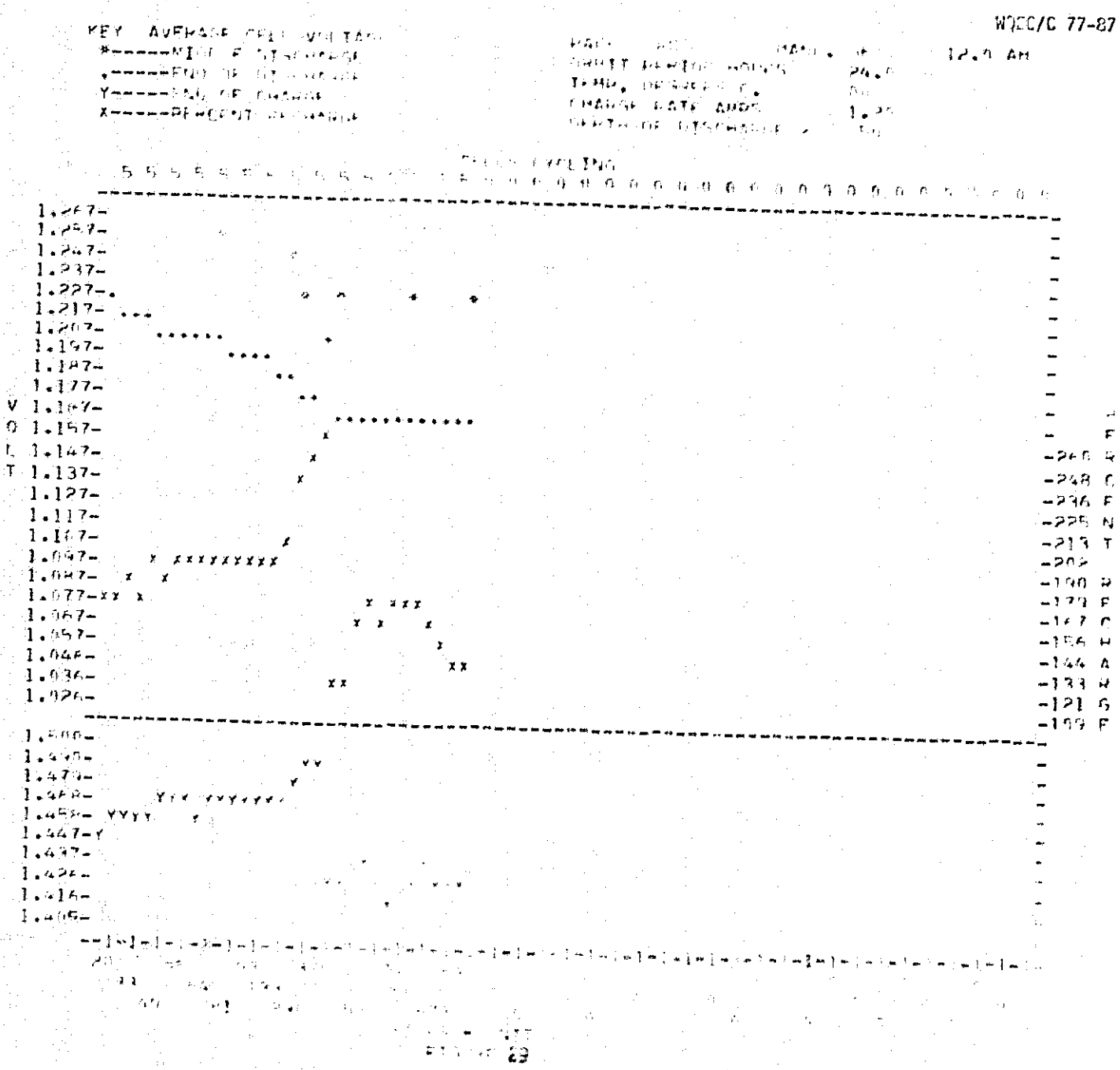
b. Parameters and Capacity Checks:

Orbit	24-hours		
Temperature (°C)	0°	10°	20°
Depth of Discharge (%)	50	50	50
Auxiliary Electrode Resistor (ohms)	300	300	300
Pack Number	8C	8D	8E*
Precycling Capacity *	14.1 (1,4)	14.4 (1)	14.7 (4)
18 Months (cells 4 & 5)	14.2 (4)	13.1 (4,5)	11.4 (3,4)
30 Months (cells 4 & 5)			

*Only four cells, cell 4 is noted as cell 5 in capacity schedule only.
**Number in parenthesis indicates limiting cell on discharge.

c. Test Results:

(1) Performance on Cycling: (Figures 29 through 31) Cycling began in October 1974. Packs 8C, 8D and 8E have completed 705, 722 and 687 cycles without a cell failure. The auxiliary control trip voltage was changed from .30 to .15 volts after 14 months of cycling in order to reduce the percent of recharge.



NOTE: Auxiliary electrode trip voltage reduced after 420 cycles.

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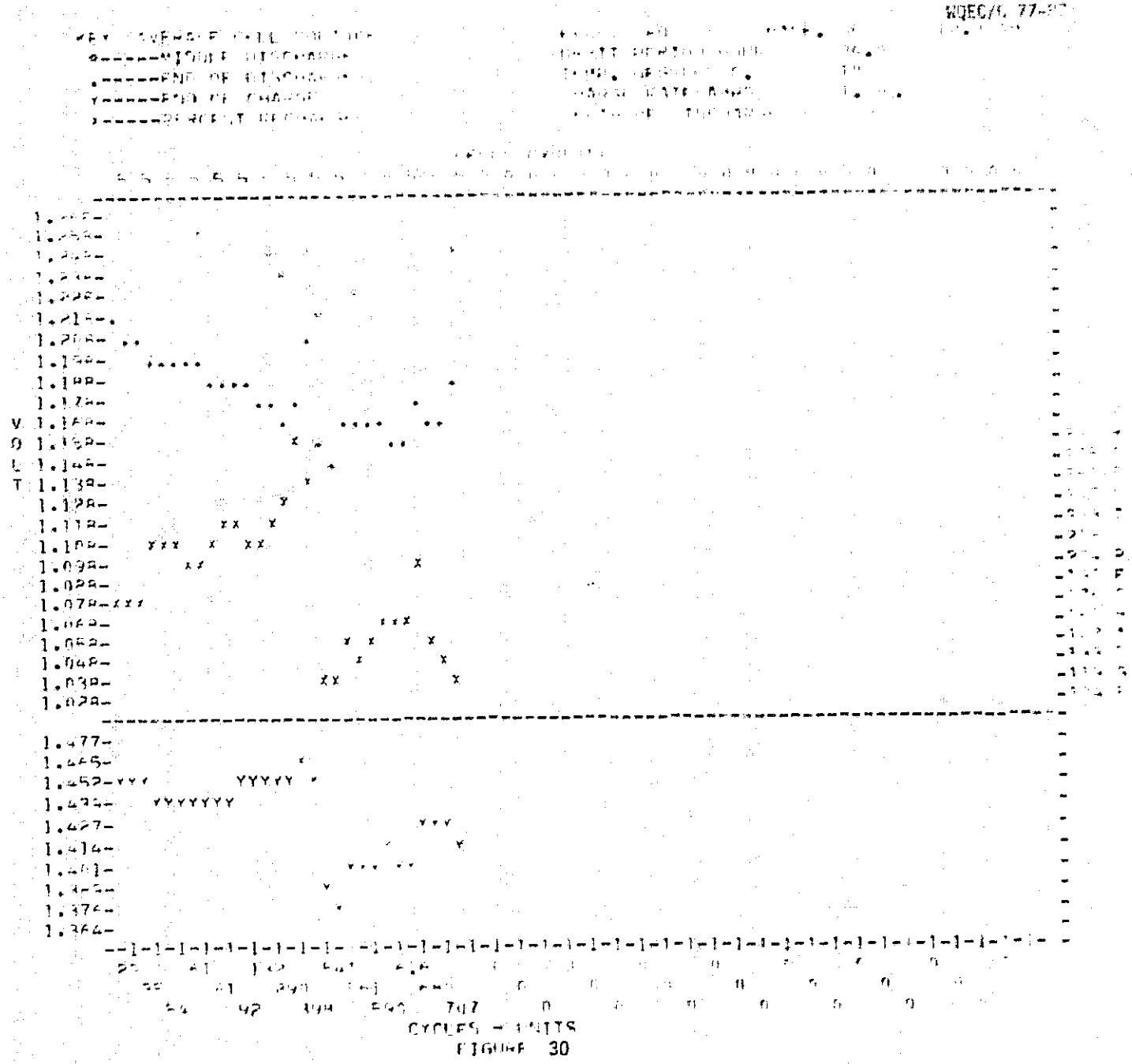

FIGURE 30

NOTE: Auxiliary electrode trip voltage reduced after 420 cycles.

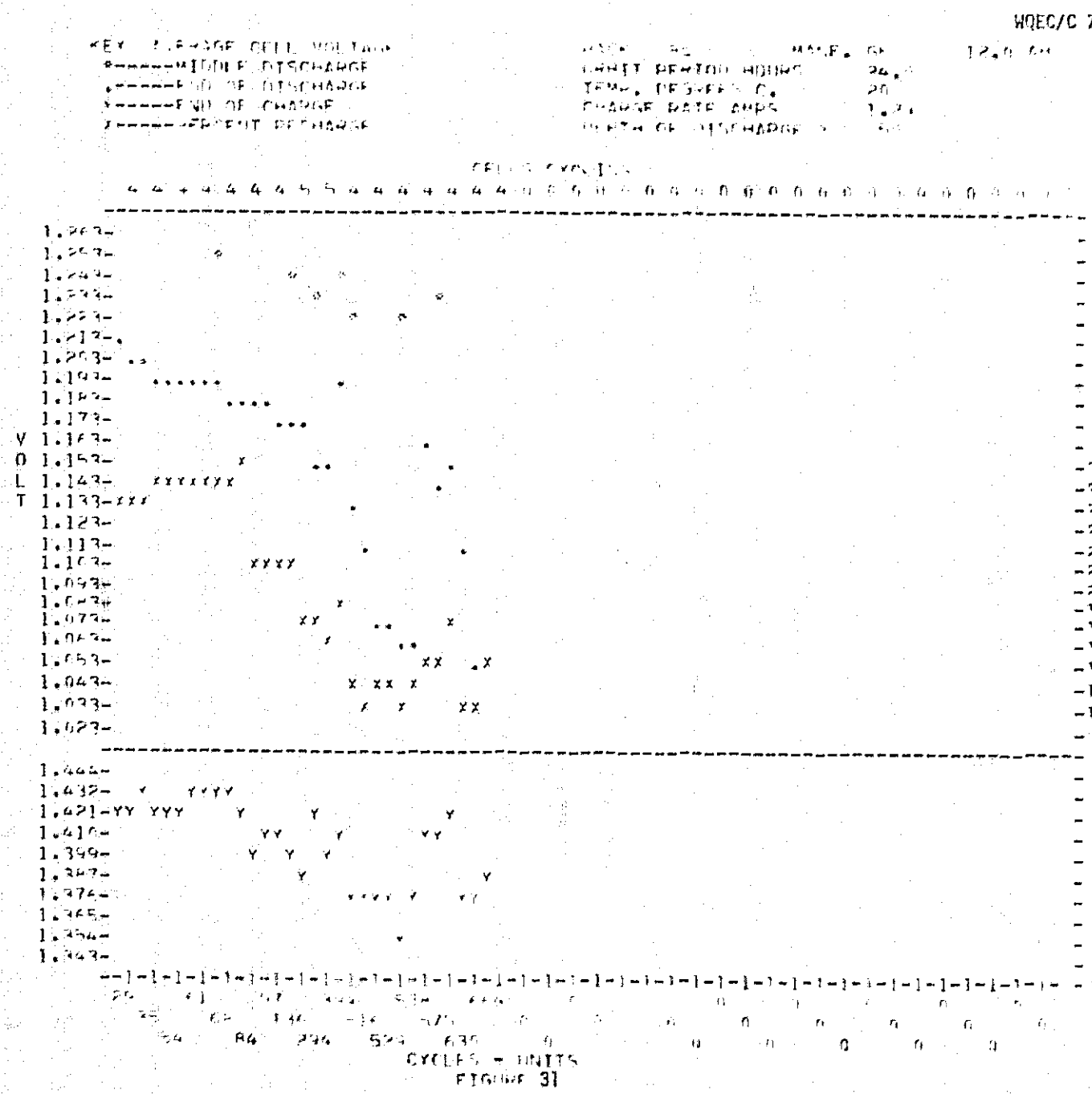

FIGURE 31

NOTE: Auxiliary electrode trip voltage reduced after 420 cycles.

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11. GE 12.0 ah (IUE), Three 5-cell Packs:

a. Cell Description: See paragraph I.A., page 12. The cells were manufactured for NASA, GSFC, under NASA contract number NAS-5-19584 according to the Manufacturing Control Document (MCD) 232A2222AA-54 and the GSFC's specification number S-761-P-6. The production of the cells for the I.U.E. Program represents the second generation of cells manufactured with the specific objective of reducing the active material loading. As a result, several key cell design parameters were incorporated into the production. Details of cell design, construction, manufacturing and performance during acceptance testing by the manufacturer are summarized and reported in GSFC Report X-711-16-18 of January 1976. The cells were identified by the manufacturer's catalog number 42B012AB21-G2. Each pack contains two cells (3 & 5) with auxiliary electrodes although only one pack (8H) is using the electrodes as a charge control. The ceramic-to-metal seal has an all nickel braze construction. Initial evaluation test results are contained in NAVWPNSUPPCEN Crane Report WQEC/C 7689 of 15 March 1976.

b. Parameters and Capacity Checks:

Orbit ((Hrs.)	1.5	1.5	24.0
Temperature (°C)	20	0	20
Depth of Discharge (%)	25	40	50
Auxiliary Electrode Resistor (ohms)	300	300	300
Pack Number	8F	8G	8H
Precycling Capacity*	14.0(5)	12.6(1,3,4)	13.2(4)
6 Months (Cell 5)	15.7	13.0	15.8
12 Months (Cells 4 & 5)			

*Number in parenthesis indicates limiting cell on discharge.

c. Test Results:

(1) Performance on Cycling: (Figures 32 through 34) Cycling began in March 1976. Packs 8F, 8G and 8H have completed 3,643, 3,792 and 232 cycles respectively without a cell failure.

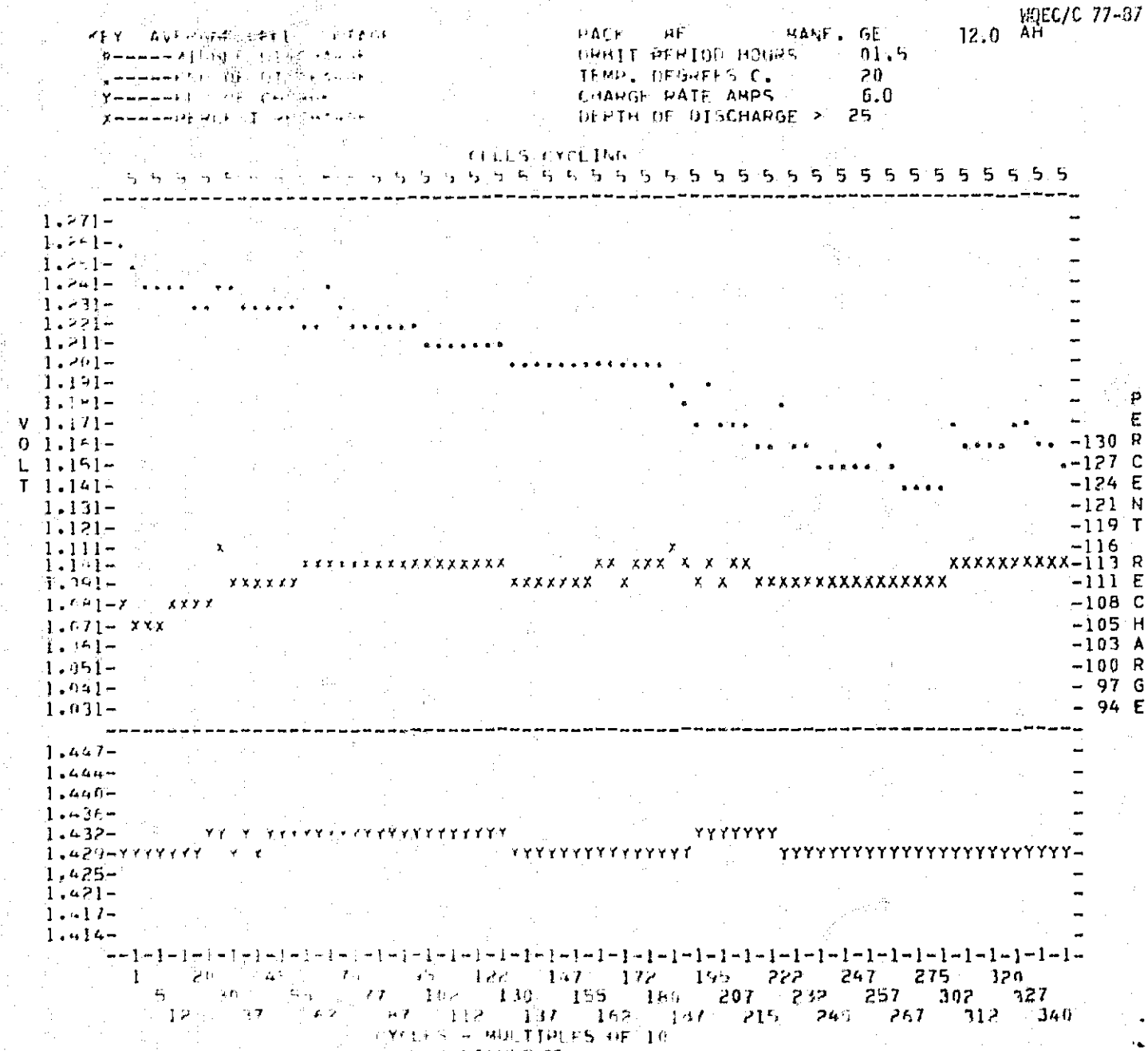

FIGURE 32

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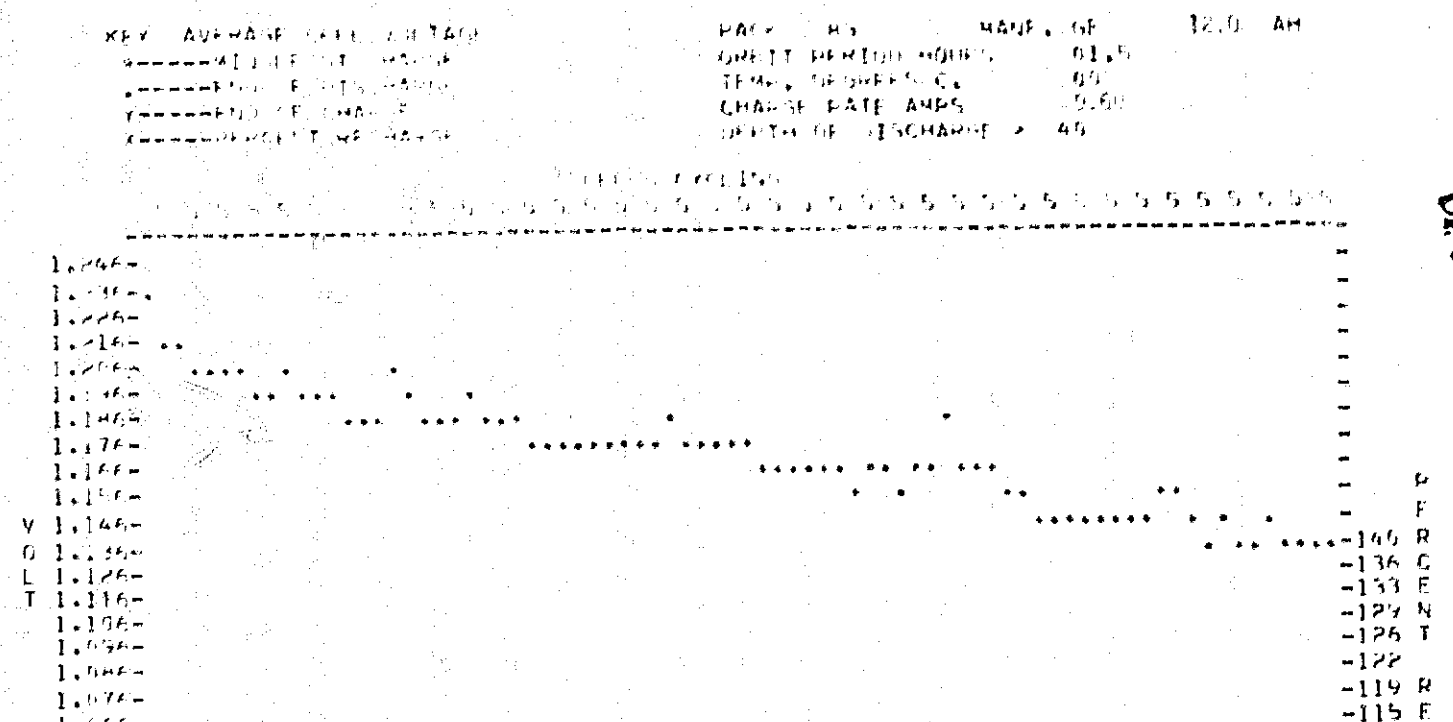

FIGURE 33

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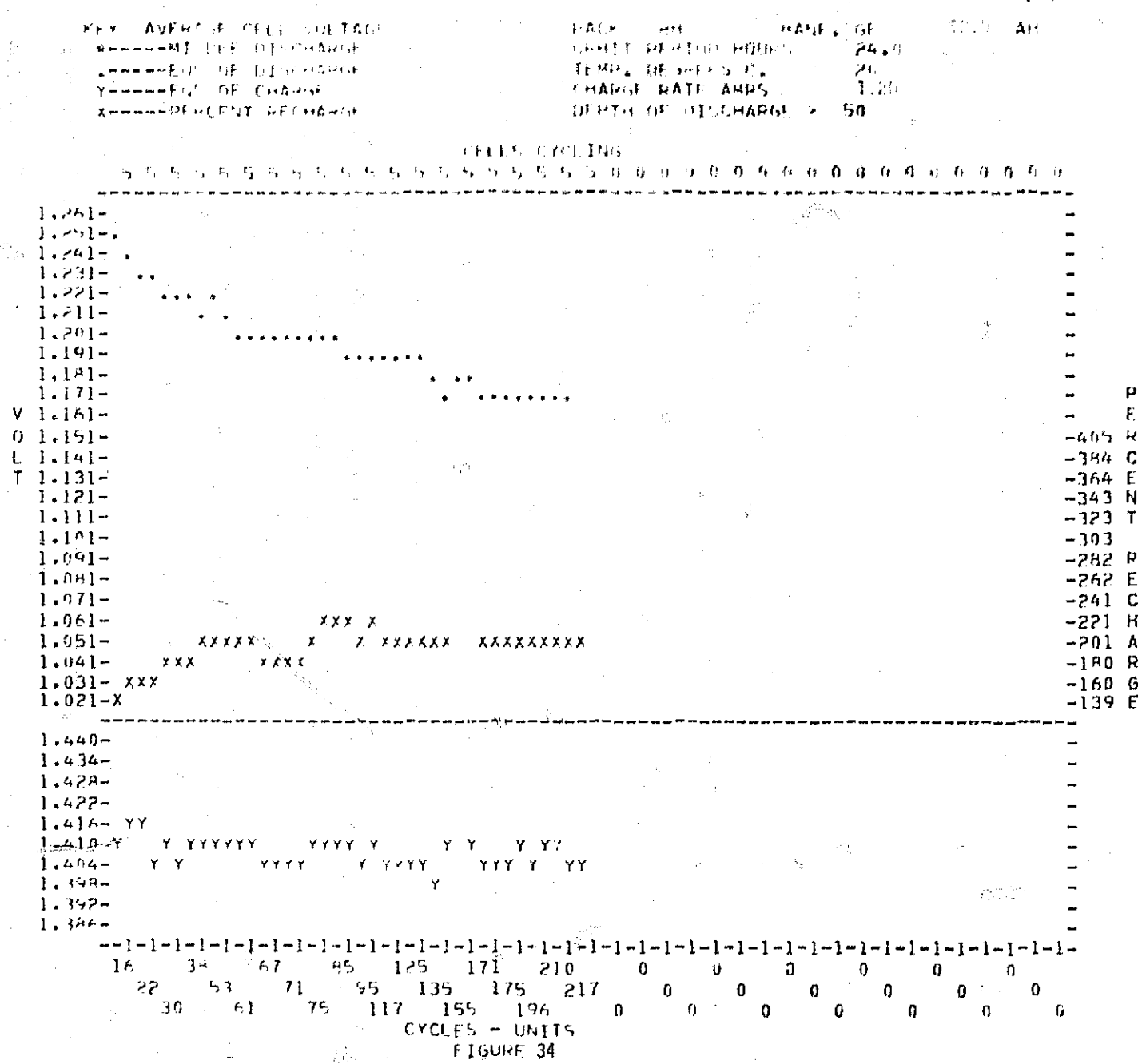

FIGURE 34

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12. GE 12.0 ah (OSO-I), One, 5-cell Pack:

a. Cell Description: See paragraph I.A., page 12. The cells' negative plates were given a proprietary silver treatment by the manufacturer.

b. Parameters and Capacity Checks:

Orbit Period	1.6-hour				
Test Temperature	10°C				
Depth of Discharge	16%				
Voltage Limit	1.440 V/C				
Pack Number	7C				
Capacity Check Precycling	16.8				
6 months (Cell 1)	14.0				
12 months (Cells 1 & 2)	13.2	13.4			
18 months (Cells 1, 2 & 3)	14.3	14.3	14.7		
24 months (Cells 1, 2, 3 & 4)	13.1	13.2	13.4	13.7	
30 months (Cells 1, 2, 3, 4 & 5)	11.6	11.6	11.8	11.6	13.4

c. Test Results:

(1) Performance on Cycling: (Figure 35) Cycling was started in December 1973. This pack has completed 13,894 cycles with no failures.

C-2

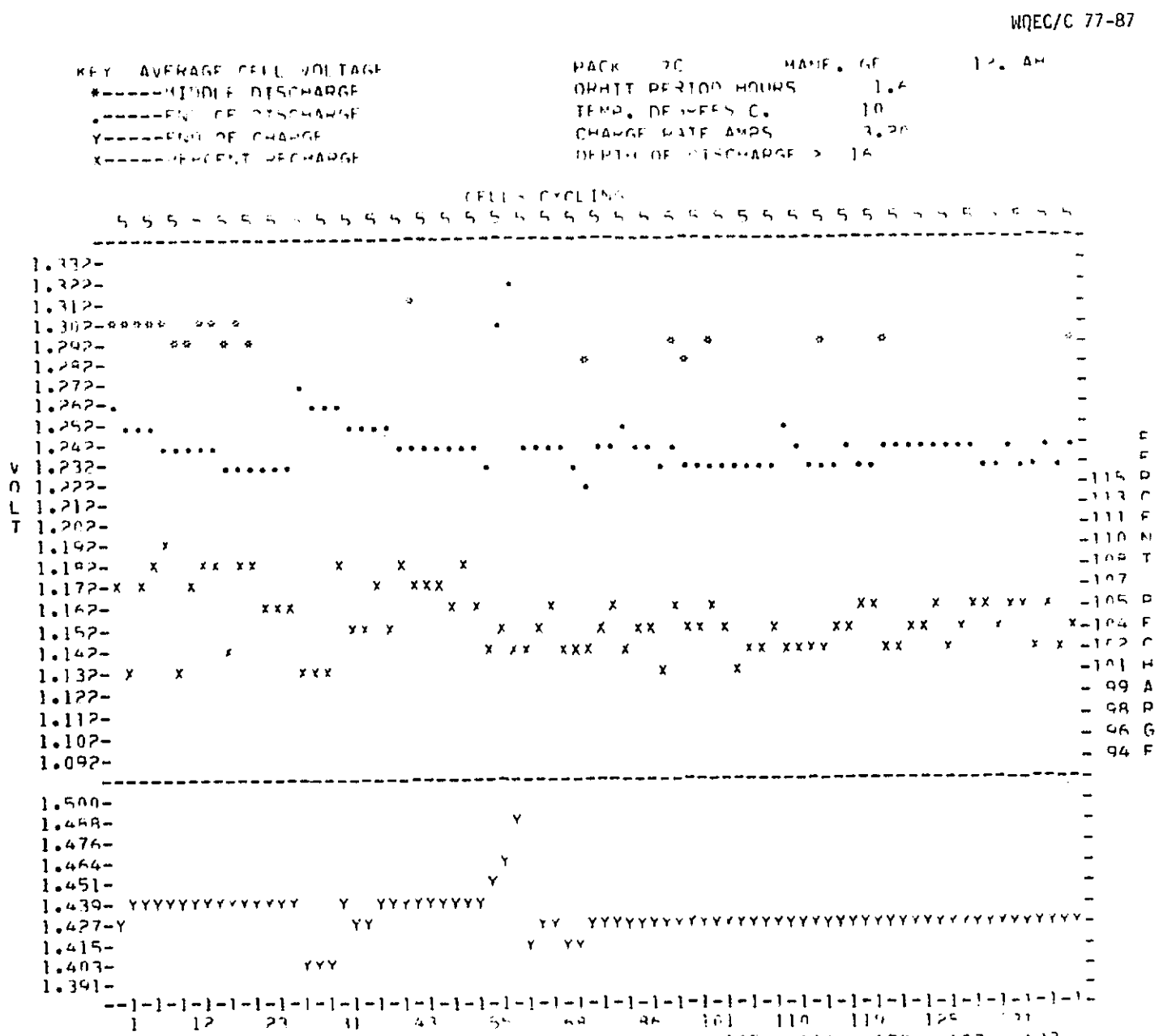

FIGURE 35

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13. GE 12.0 ah (Cycling Since Original Program):

a. Program Description: At the start of the original cycling program there was a total of 84 packs and as of January 1968, 25 of these packs were still cycling. At the request of Goddard Space Flight Center, tests on 20 of these packs were discontinued to make room for newly developed space cells being procured for evaluation. Five of the test performing packs of the original group were maintained on cycling for life capability determination purposes. Of these five packs, two have failed. Thus only three of the original 84 packs continue to cycle. The results of the remaining packs are contained in Figures 36 through 39.

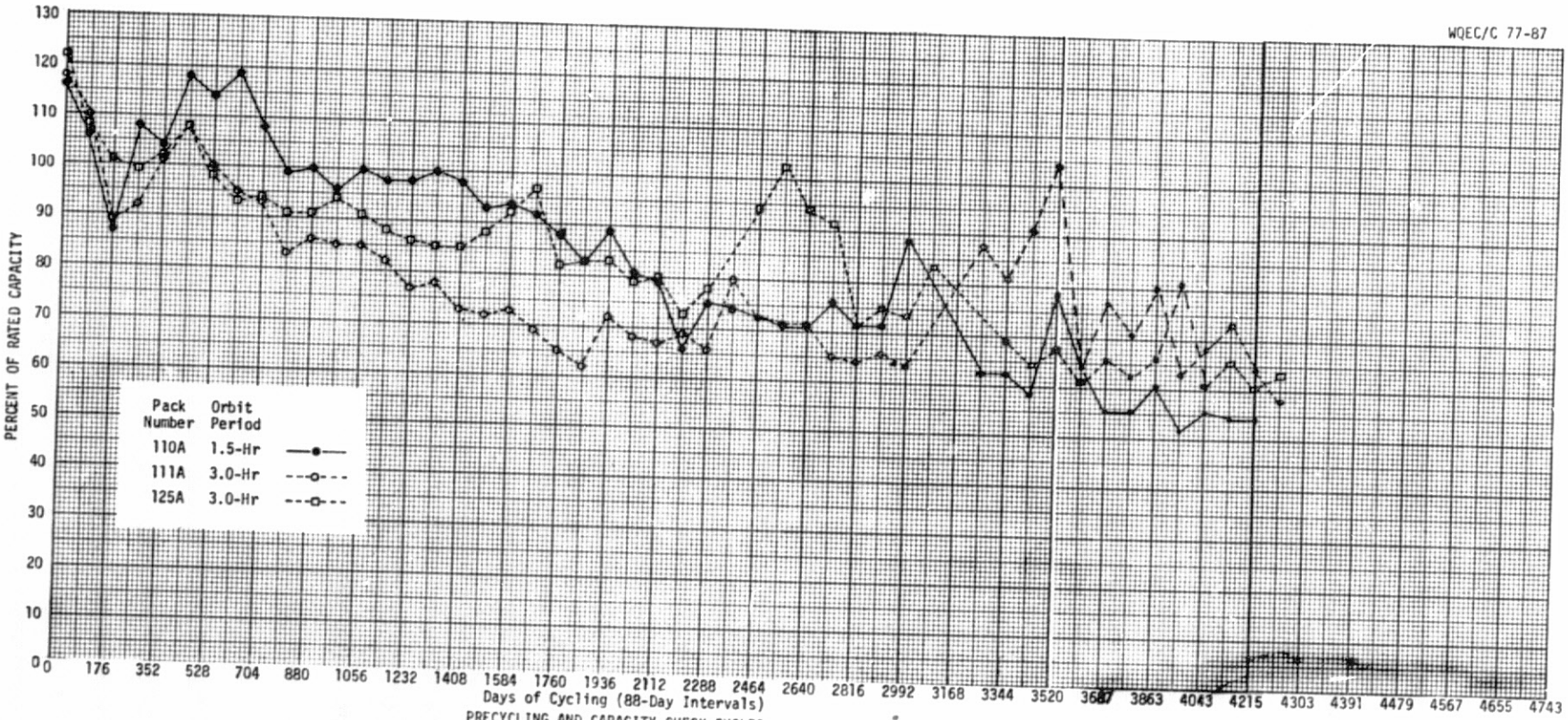
b. Cell Description: The three packs maintained on cycling contain five GE 12 ampere-hour, nickel-cadmium, cells per pack. These cells are rectangular. The cell containers and covers are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude as 1/4-20 threaded posts. Acceptance test results are contained in NAD Crane Report 63-319.

c. Parameters: These packs are being tested under the following parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
110A*	0°C	15
111A	0°C	15
125A	0°C	25

*This pack is cycled at the 1.5-hour orbit period, the others are at the 3.0-hour orbit period.

d. Test Results: Cycling was started in January 1964. Packs 111A and 125A have completed 34,553 and 34,920 cycles respectively, with one cell failure in each pack at 28,312 and 19,654 cycles, respectively. Pack 110A has completed 68,319 cycles with 2 cell failures, 54,972 and 62,680 cycles. Failed cells have not been removed for analysis because this would disturb the packs.



PRECYCLING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

Figure 36

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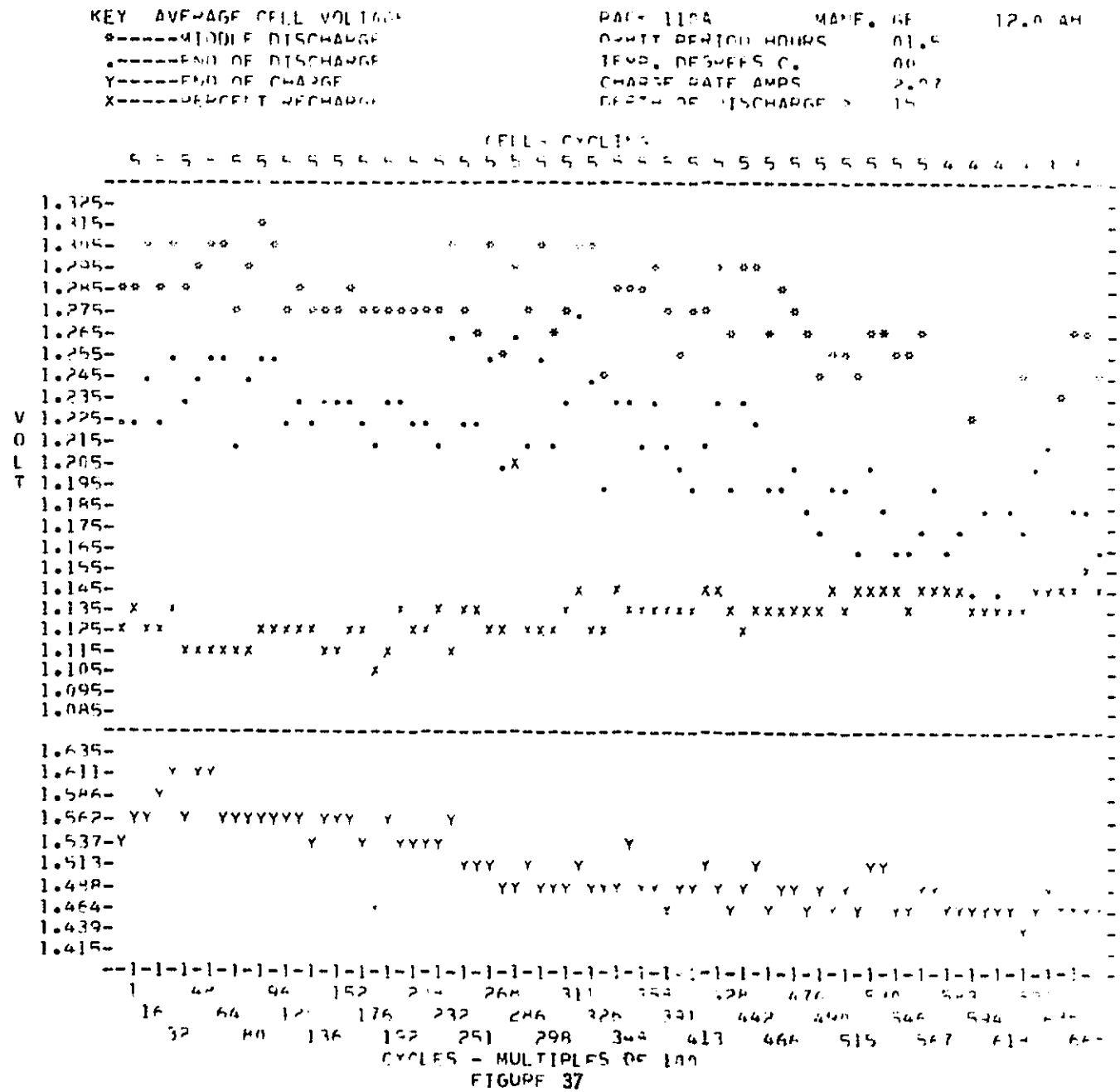

FIGURE 37

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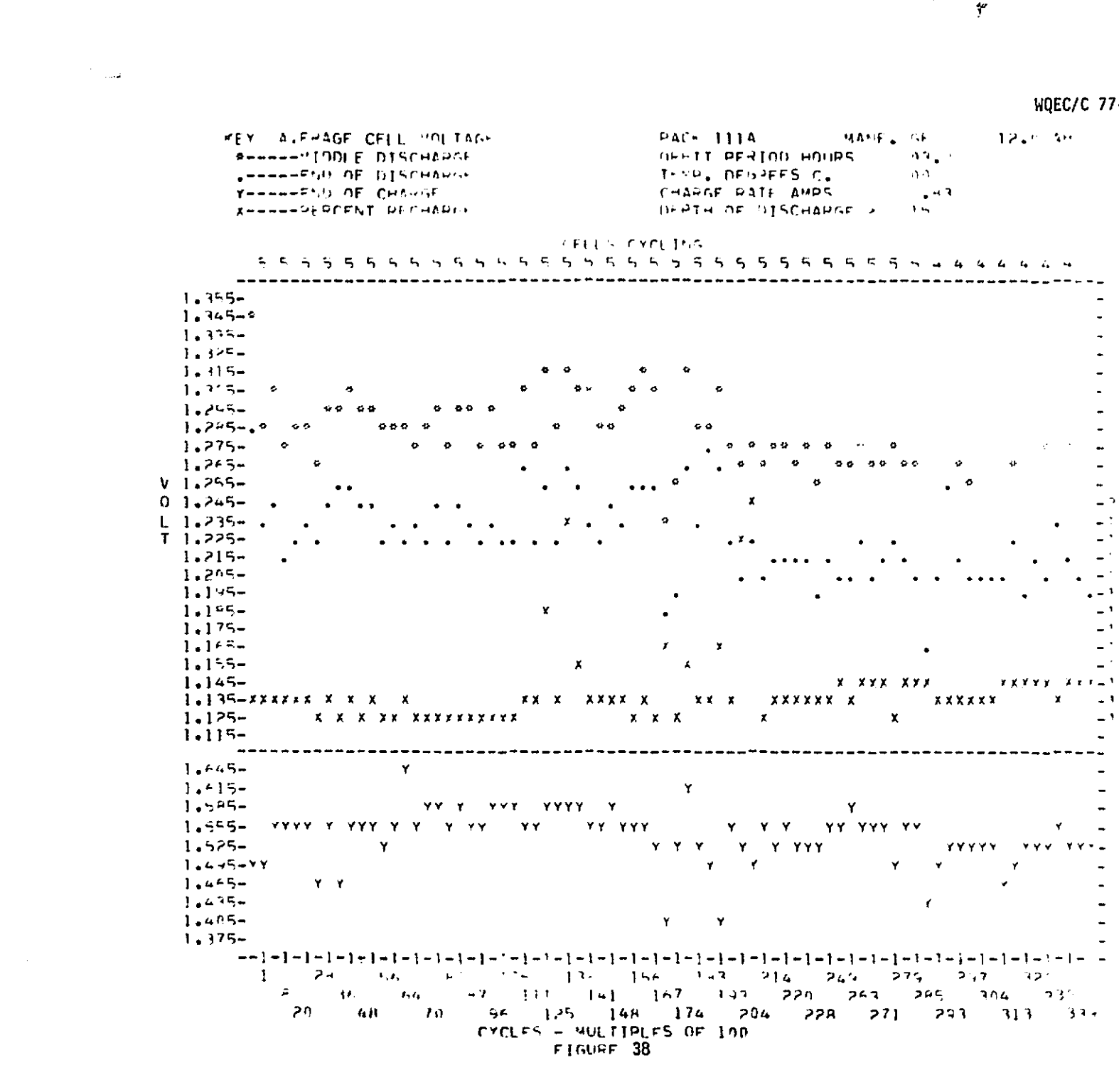

FIGURE 38

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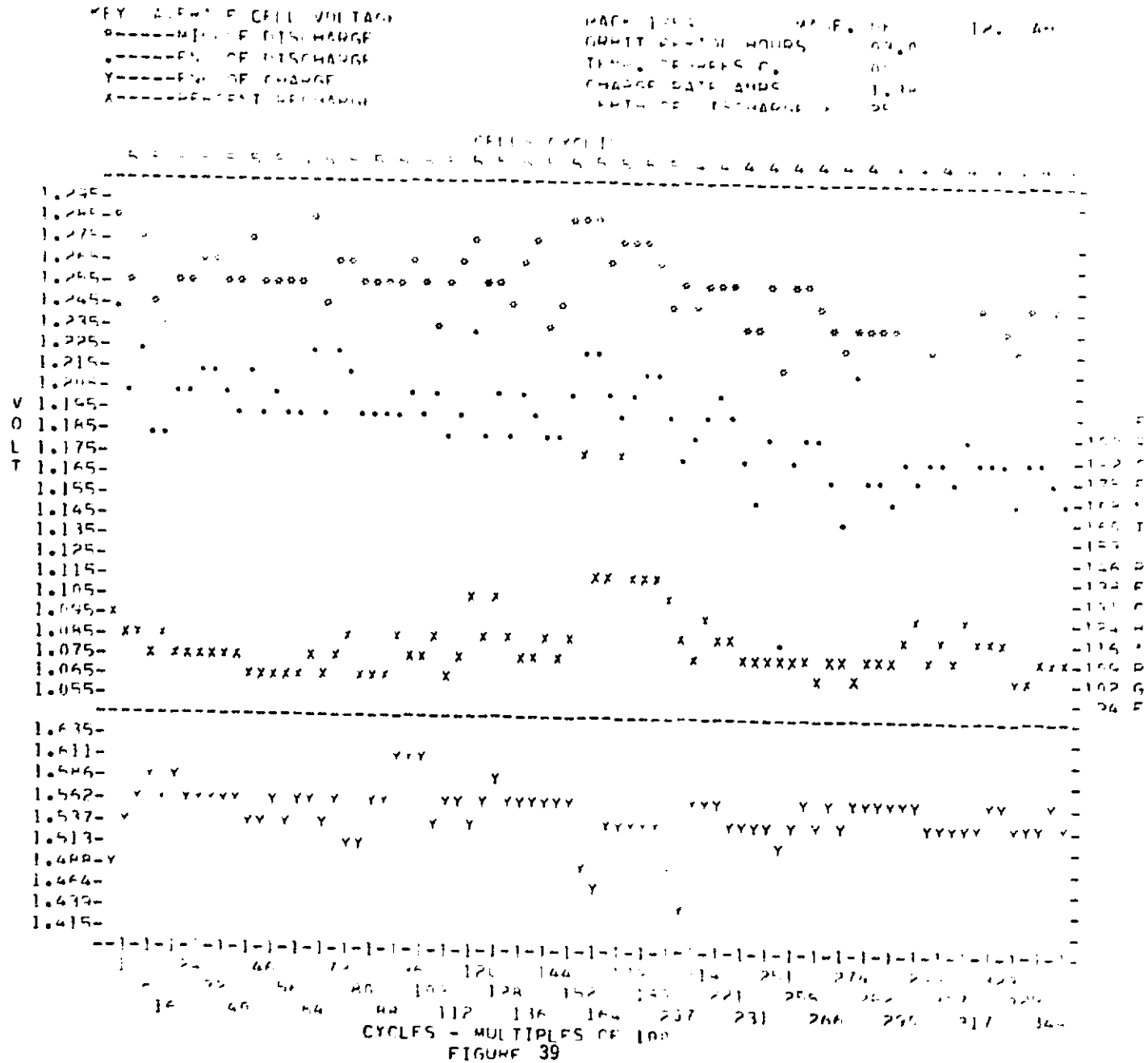

FIGURE 39

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14. Gulton 12.0 ah (Nickel-Cadmium), Four 5-cell Packs:

a. Cell Description: See Paragraph I.A., page 12. Acceptance test results are contained in NAD Crane Report QE/C 67-1.

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b. Parameters and Capacity Checks:

Orbit Period		1.5-hour		
Temperature	0°	0°	25°	40°
Depth of Discharge	25%	40%	40%	25%
Trip Voltage (MV)	70	70	150	230
Auxiliary Electrode Resistor (Ohms)	6.2	6.2	6.2	6.2
Pack Number	70A	71B	11B	47B
Precycling Capacity	15.0	15.4	15.9	14.3
88 Days Disch #2	14.9	15.2	14.0	3.7
264 Days Disch #2	14.7	14.4	6.5	3.2
440 Days Disch #2	11.6	11.5	9.0	3.4 F
616 Days Disch #2	9.5	9.1	7.4 F	
792 Days Disch #2	9.1	10.4		
968 Days Disch #2	8.1	7.8 D		
1144 Days Disch #2	*			
1320 Days Disch #2	6.4			
1496 Days Disch #2	5.7			
1672 Days Disch #2	6.0			
1848 Days Disch #2	4.5			
2000 Days Disch #2	3.9			
2162 Days Disch #2	NA			
2342 Days Disch #2	4.93			
2427 Days Disch #2	4.70			
2619 Days Disch #2	4.49			
2798 Days Disch #2	5.09			
2980 Days Disch #2	5.59			
3156 Days Disch #2	5.57			

*Capacity check not performed.
D - Discontinued.
F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 40) Cycling was started on Pack 11B in October 1966, on packs 47B and 71B in January 1967 and on pack 70A in February 1967. Pack 70A has completed 52,709 cycles to date with no failures. Packs 71B, 11B and 47B failed on cycles 15,275, 11,933 and 6536, respectively. The following table indicates the cycle number that the cells either failed or were discontinued on.

	CELLS				
Pack	1	2	3	4	5
71B	15275 D	9991 F	15275 D	15275 D	15275 F
11B	11933 F	11930 F	11930 F	11933 F	11933 F
47B	6537 F	5463 F	5801 F	6536 D	6537 D

F - Failed
D - Discontinued

(2) Failure Analysis: Analysis of the nine failed cells showed that the failure was due to separator deterioration and migration of the negative plate material. Other conditions found in these cells were high internal pressure and electrolyte leakage.

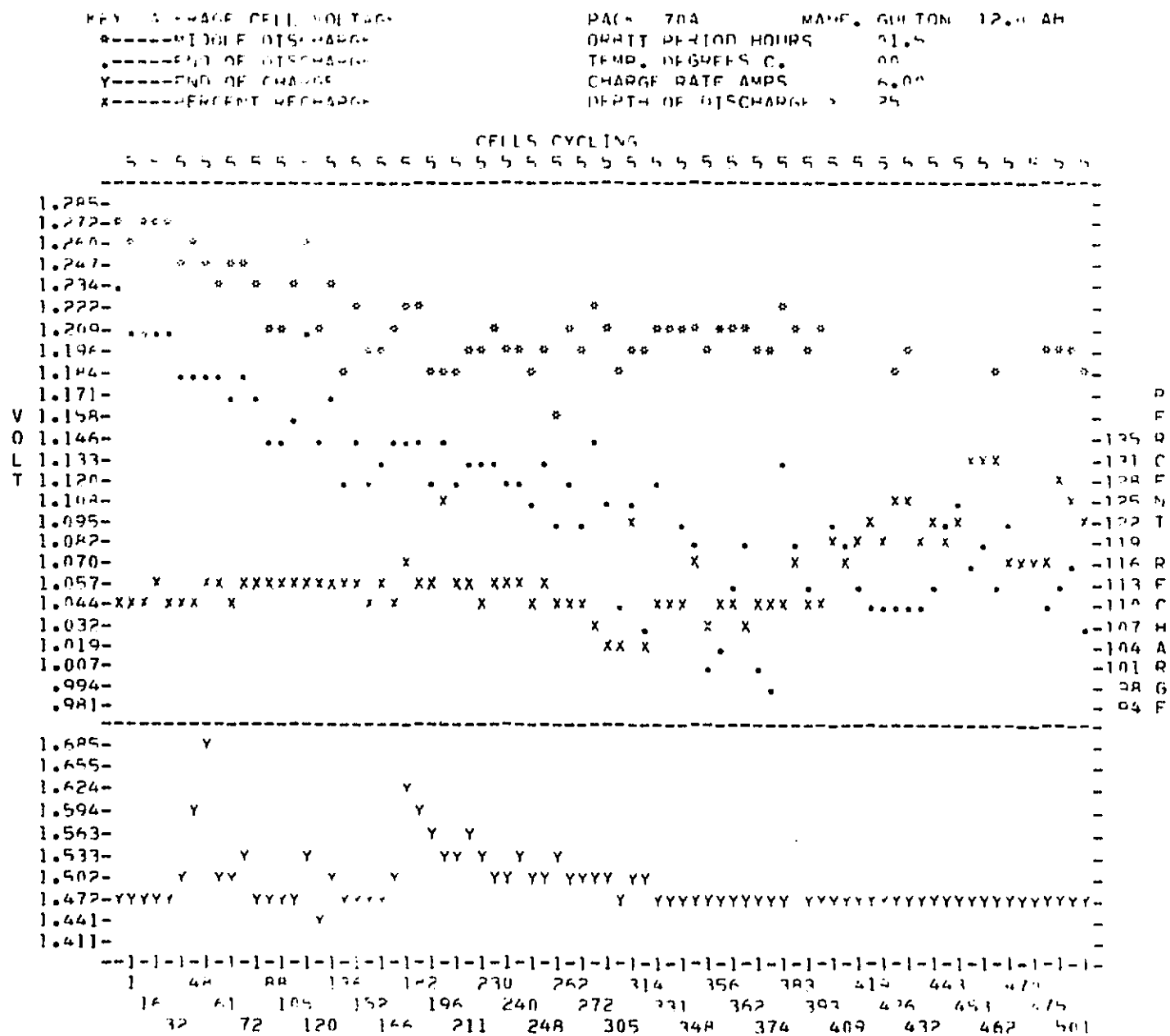

FIGURE 40

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15. GE 20.0 ah (Standard versus Teflonated Negative Electrodes), Four 5-cell Packs:

a. Cell Description: See Paragraph I.A., page 12. The cells were manufactured for NASA, GSFC, under NASA contract number NAS-5-17876, and manufactured to GSFC's specification number S-761-P-6. Packs 1G and 1H contain teflonated, negative electrodes (TFE-II). The electrodes of these cells were teflonated prior to the Electrochemical Cleaning Test (ECT) and had catalog number 42B020AB29-G4. Cells of packs 1I and 1J had standard electrodes and catalog number 42B020AB30-G4. All cells contain a teflon-coated (one side only), sintered, nickel plaque auxiliary electrode, located along the narrow edge of the cell. Initial evaluation test results and detailed cell descriptions are contained in NAD, Crane Report WQEC/C 74-337.

b. Parameters and Capacity Checks:

Orbit	1.5-hours			
Temperature (°C)	20°	0°	20°	0°
Depth of Discharge (%)	25	40	25	40
Auxiliary Electrode Resistor (ohms)	300	300	300	300
Pack Number	1G	1H	1I	1J
Precycling Capacity	26.6	26.3	28.9	27.2
6 months (Cells 4 & 5)	29.0	25.5	30.0	27.0
12 months (Cells 4 & 5)	27.6	26.5	29.1	26.2
18 months (Cells 4 & 5)	25.4	25.7	27.2	24.9

c. Test Results:

(1) Performance on Cycling: (Figures 41 through 44) Cycling began in September 1974 and Packs 1G, 1H, 1I, and 1J have completed 11,025, 11,085, 10,966 and 11,000 cycles, respectively, with no cell failures.

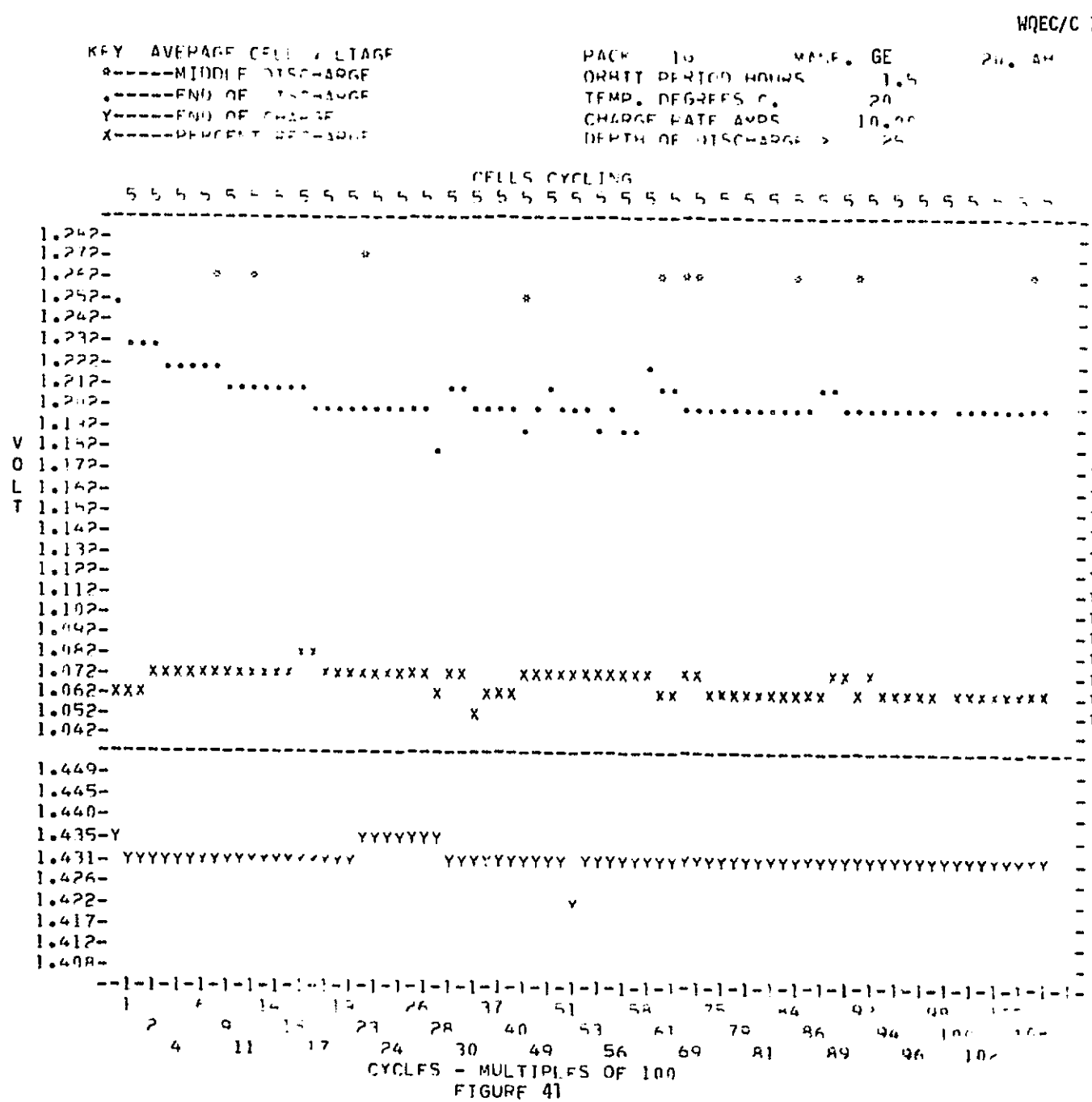

FIGURE 41

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KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE

PACK 1H MANF. GE 21. AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 16.00
DEPTH OF DISCHARGE % 40

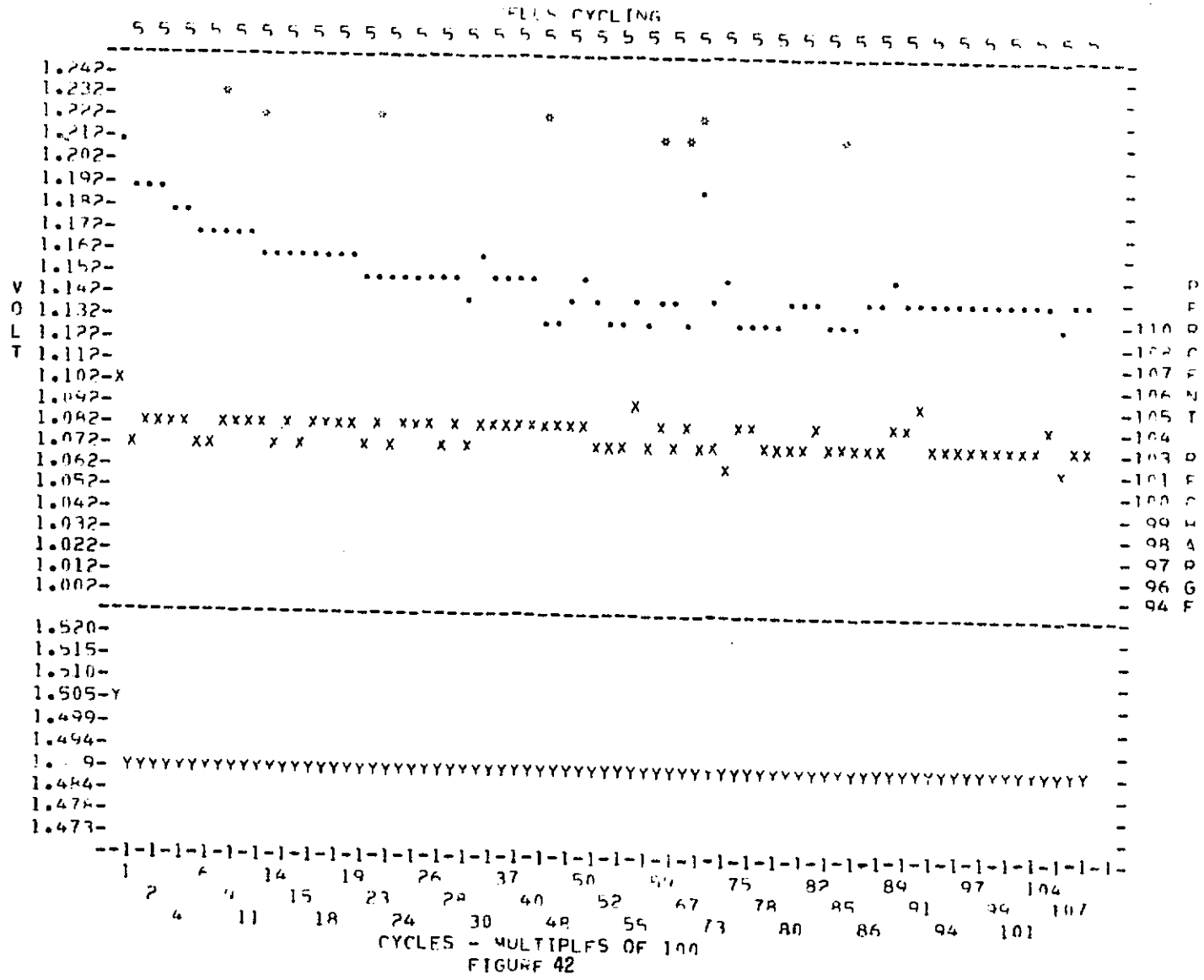

FIGURE 42

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE

PACK 11 MANF. GE 2 . AH
DRATT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 10.00
DEPTH OF DISCHARGE % 25

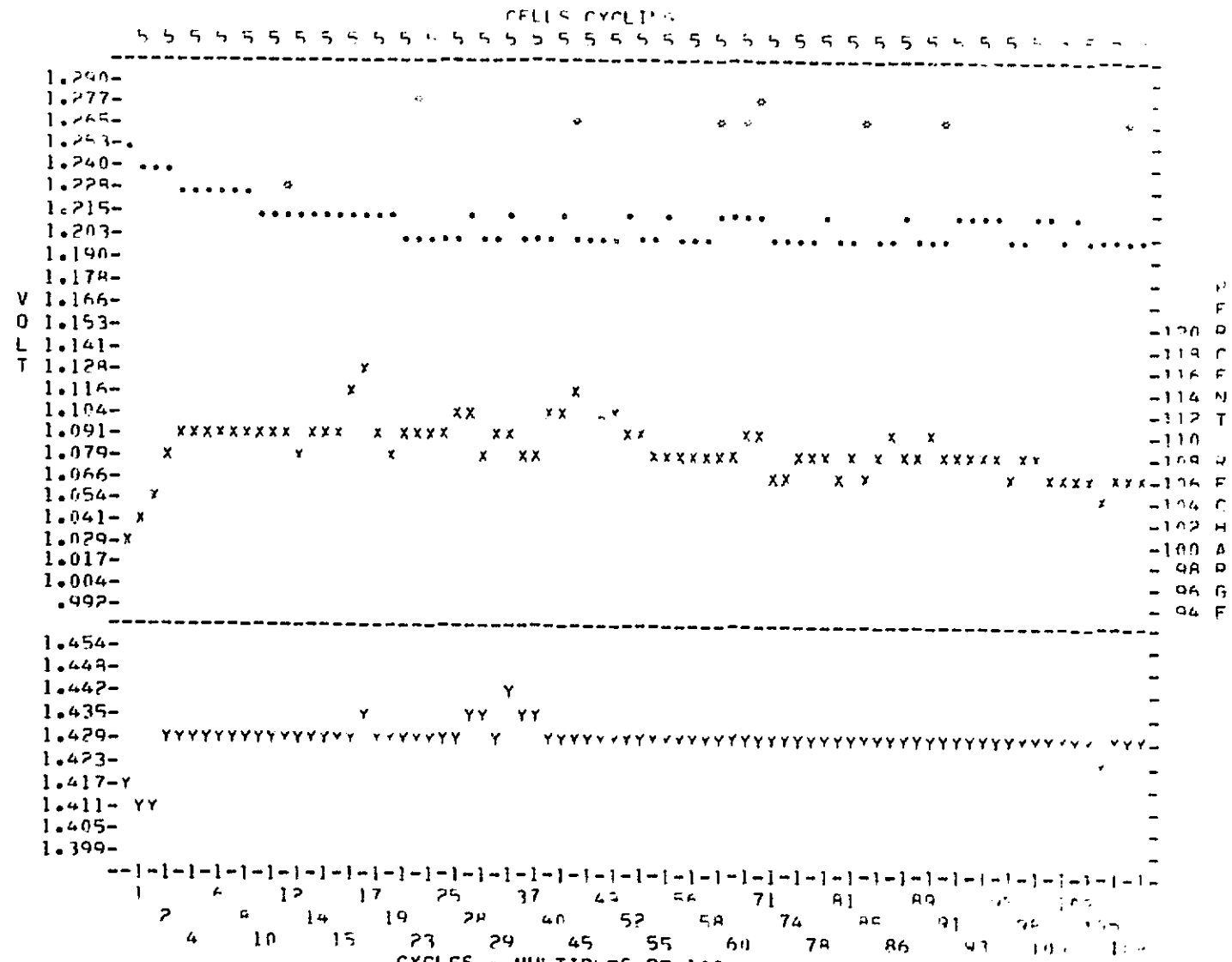

FIGURE 43

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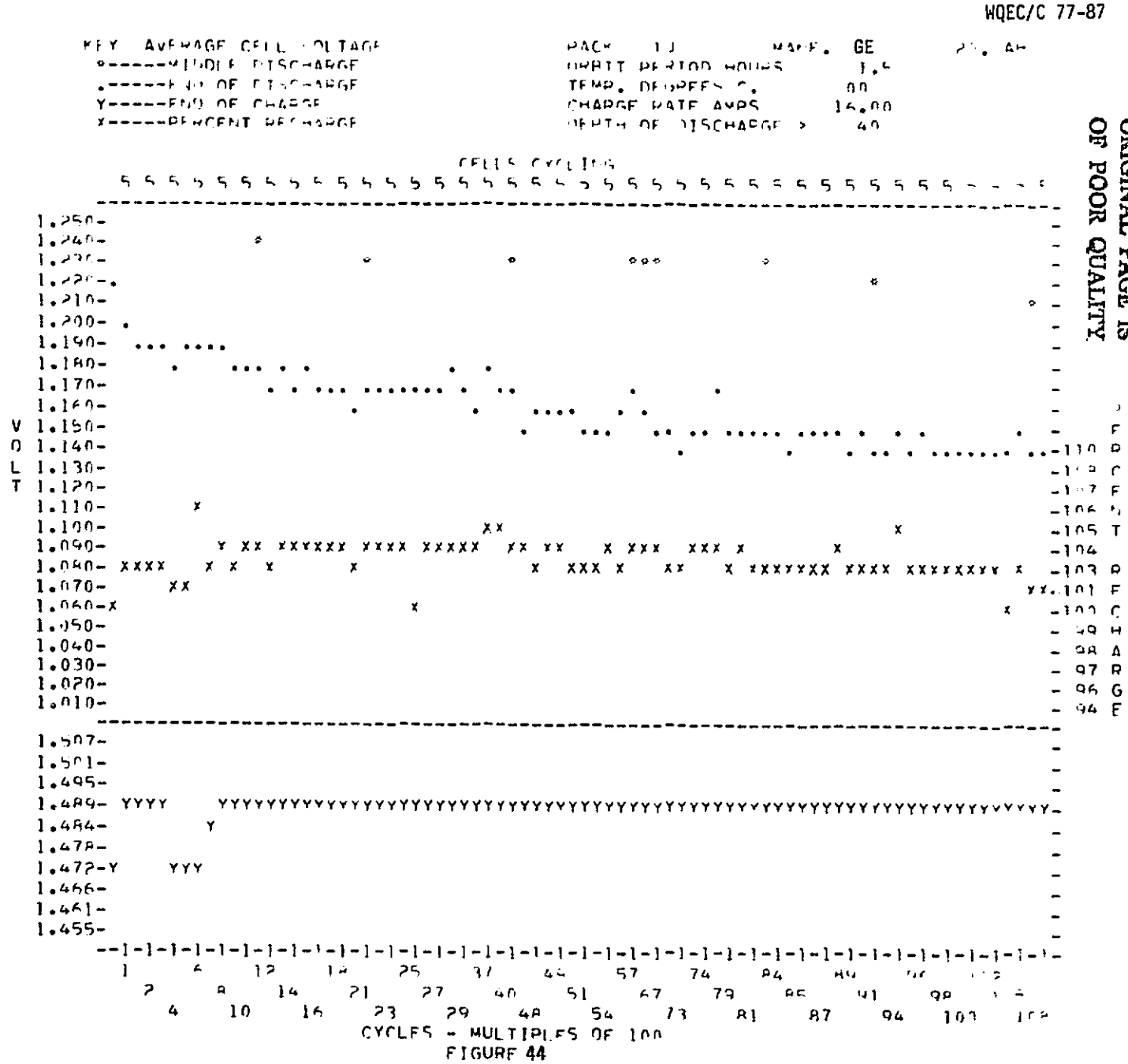

FIGURE 44

16. Gulton 20 ah (Variable Electrolyte), Three 5-cell Packs:

a. Cell Description: See paragraph I.A., page 12. Cells in Pack 1D are designated as control cells with 69 cc electrolyte; Pack 1E has a 20 percent increase, 82 cc electrolyte; and Pack 1F has a 40 percent decrease, 106 cc electrolyte. Evaluation of the cells is to determine effects of life-cycling with variable electrolyte. These cells were manufactured under contract number NAS 5-17365 for GSFC. Initial evaluation test results and detailed cell descriptions are contained in NAD, Crane Report QEEL/C 74-2.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hours	
Temperature (°C)	20°	20°	20°
Depth of Discharge (%)	24	24	24
Auxiliary Electrode Resistor (ohms)	47	47	47
Pack Number	1D	1E	1F
Precycling Capacity	24.0	24.3	24.5
6 months (Cell #)	26.0 (5)	26.5 (1)	26.2 (2)
12 months (Cell #)	25.8 (4)	26.7 (2)	19.7 (5)
24 months (Cell #)	19.5 (3)	16.5 (5)	14.5 (4)
36 months			

c. Test Results:

(1) Performance on Cycling: (Figures 45 through 47) Cycling was started in October 1973 and Packs 1D and 1E have completed 15,403 and 15,329 cycles respectively without a cell failure. There was equipment failure on Pack 1F which resulted in cell reversal and high pressure on cycle 138. As a result, two cells were discontinued from test; but were replaced with two other cells of the same type. One of the replacement cells was discontinued on cycle 1116 due to high pressure. Pack 1F has completed 13,977 cycles. Pack 1D's typical pressure range at EOC is 14 to 40 psia, 1E's is 38 to 55 psia, and 1F's is 20 to 50 psia (although prior to cycle 138 its range was 71 to 78 psia). The packs are voltage limit controlled on charge, and the voltage limit is adjusted to maintain 108 to 110 percent recharge. Cells of each group were analyzed following acceptance test (7 cycles), and one cell from Packs 1D and 1E were analyzed following 6 months of cycling along with the discontinued cell of Pack 1F. Also, one cell of each group was analyzed following 12 and 24 months of cycling.

(2) Analysis has shown that migration has increased with cycle life; but the last cells which were removed from all three packs showed severe migration, with the separator adhering to the negative plates. The separator material was damp. The results of the chemical analysis are as follows:

Pack Number	1D				1E				1F			
Serial Number	553	551	550	549	529	530	531	537	548	541	542	540
Cycles Completed	7	3069	6093	11759	7	3029	5925	11613	7	985	5965	11705
Total meq* KOH per extract	424.698	187.968	408.144	391.548	514.754	227.832	503.514	492.649	606.973	563.468	675.938	543.900
Total meq K_2CO_3 per extract	138.062	70.026	156.750	173.696	136.620	68.772	151.536	177.592	129.410	140.492	161.634	188.533
Meq KOH per separator patch**	4.0389	3.1040	2.260	1.2608	8.0911	7.3480	2.9888	6.0500	13.1842	12.1614	6.4807	8.6693
meq K_2CO_3 per separator patch	2.0665	1.647	3.5815	4.106	2.5912	3.216	3.4597	3.2376	3.0808	3.2818	4.8216	3.0413
Total volume (cc) per patch	3.876	4.293	4.2808	4.5959	3.965	4.921	4.6363	5.0681	3.980	3.894	4.8382	5.5970
Wet Weight per patch, avg (g)***	1.5420	1.7526	1.7983	1.9967	2.3530	2.8355	2.8407	3.2308	3.3110	3.0344	3.7344	2.9535
Dry Weight per patch, avg (g)***	0.5607	0.7447	0.7539	.7885	0.5294	0.7159	0.9675	1.184	0.5998	0.6532	1.0411	0.8013

*meq is the abbreviation of milliequivalents.
**The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the center, and one from the last third.
***Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.

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KEY AVERAGE CELL VOLTAGE
#-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT DEGRADE

PACK 10 NAME. GU 20. AH
DWELL PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 10.00
DEPTH OF DISCHARGE % 25

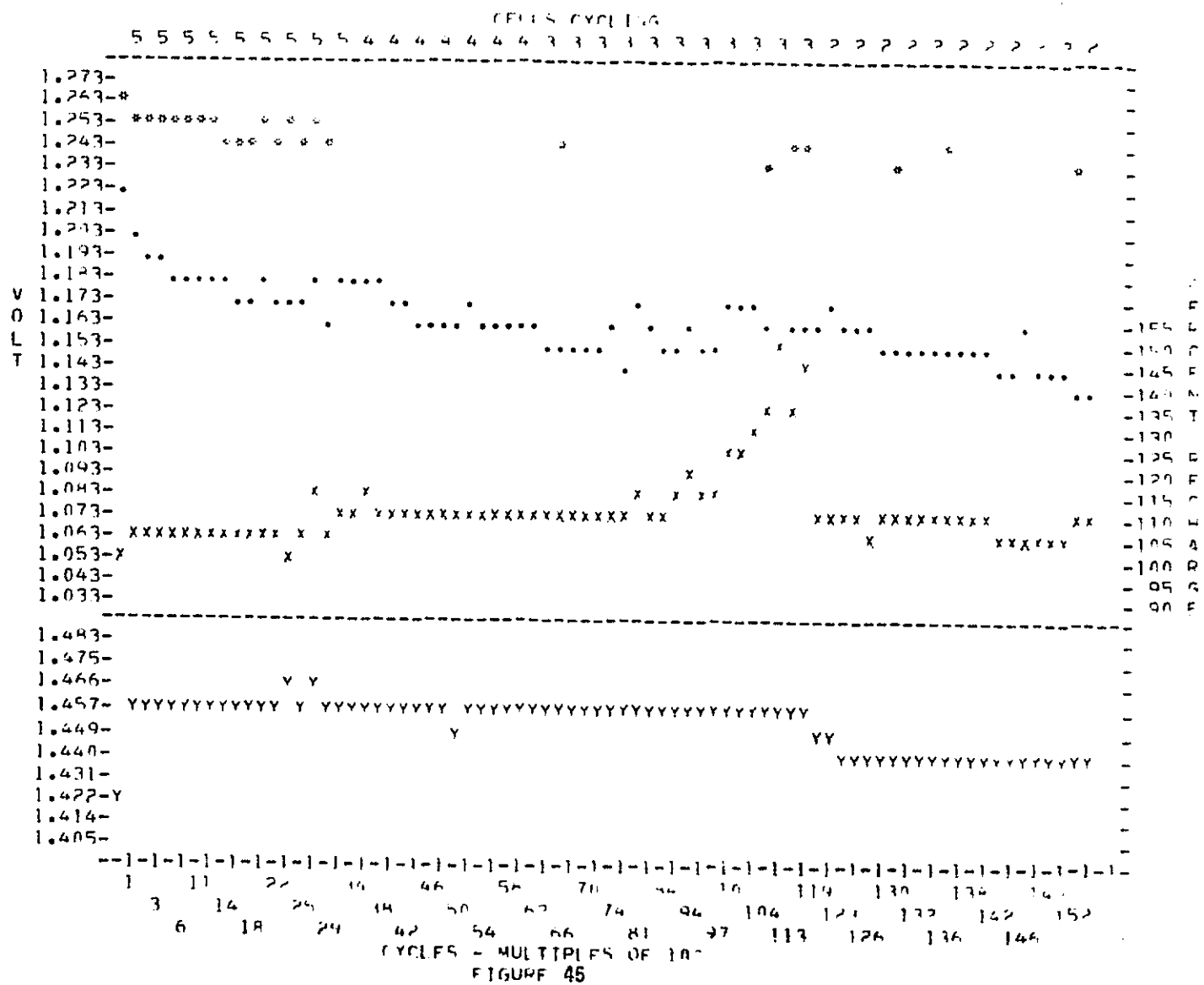

FIGURE 45

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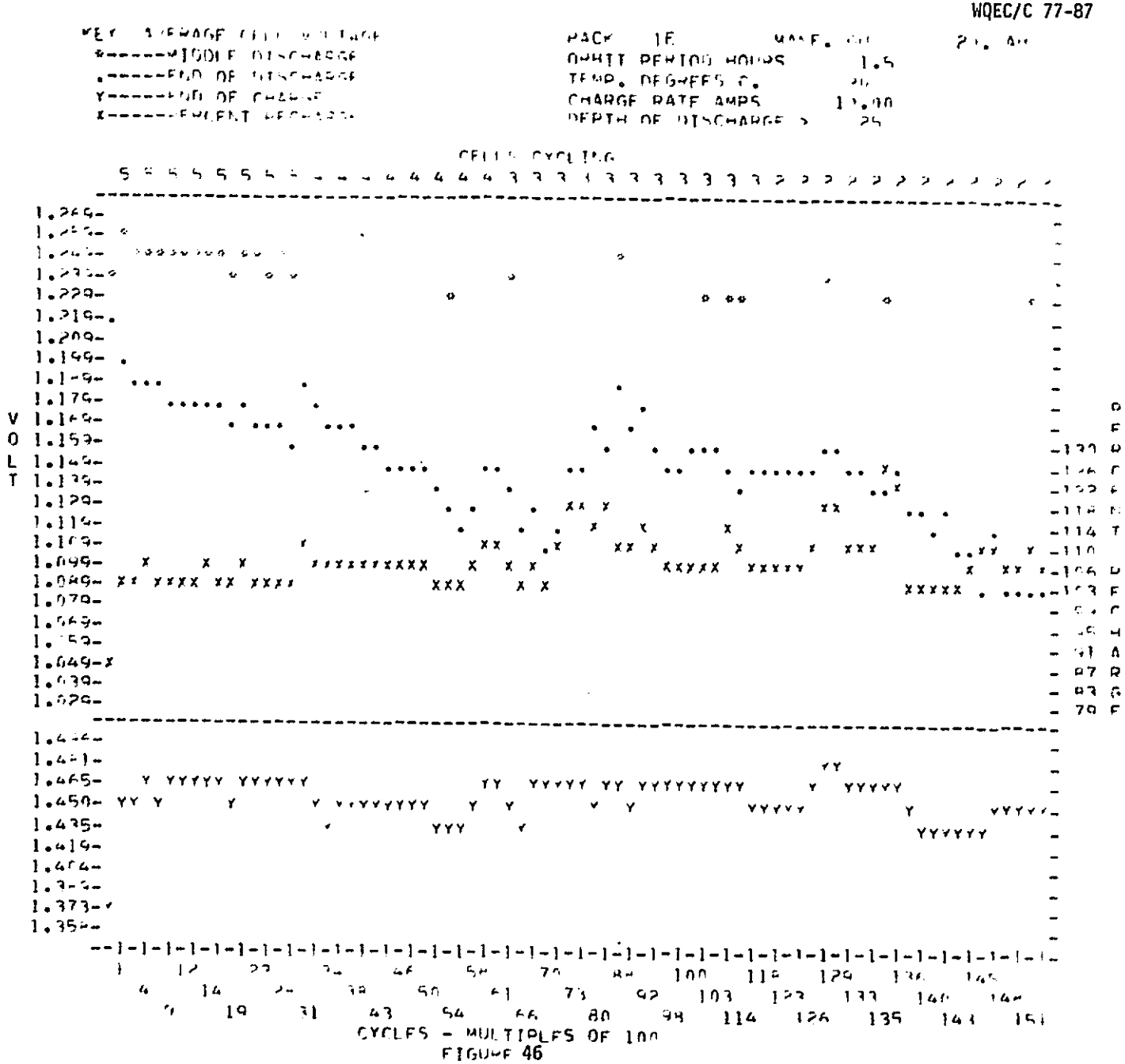

FIGURE 46

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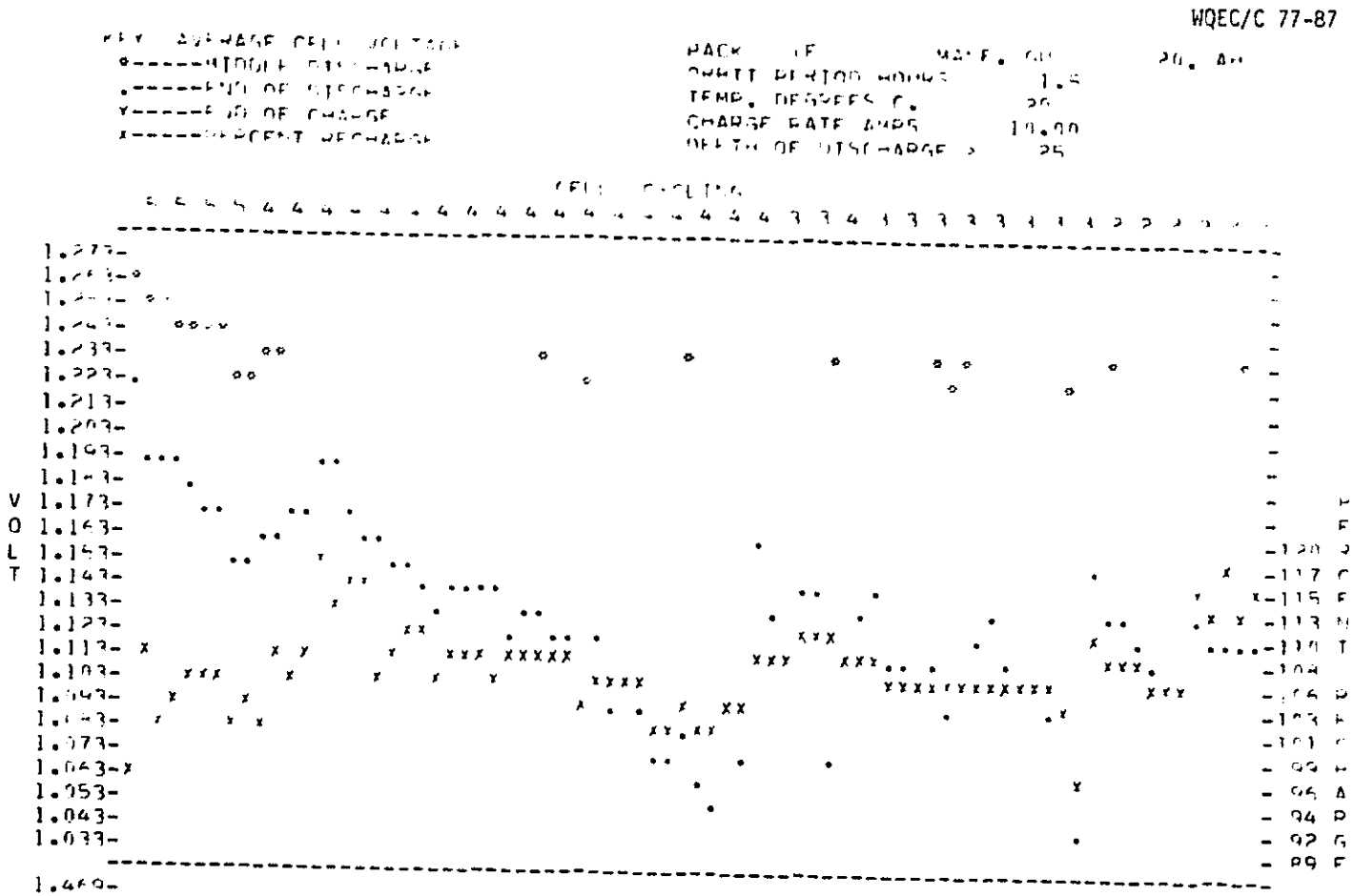

FIGURE 47

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17. Gulton 20 ah (OAO), One 9cell Pack:

a. Cell Description: See paragraph I.A., page 12. Also, the cells contain precharged cadmium material as follows:

Cell	AH	Cell	AH	Cell	AH
1	5.92	4	4.5	7	4.5
2	5.0	5	5.0	8	4.74
3	5.0	6	4.5	9	6.45

b. Parameters and Capacity Checks:

(1) Orbit Period: 1.5hour.

(2) Test Temperature: 10°C.

(3) Depth of Discharge: 15%.

(4) Pack Number: 4C.

(5) Capacity Checks: As requested by Technical Officer at Goddard Space Flight Center.

42 Days (Cells 1 and 2)	26.8
55 Days (Cells 8 and 9)	26.1
93 Days (Cells 6 and 7)	26.3
514 Days (Cells 1, 2 and 3)	28.3

c. Test Results:

(1) Performance on Cycling: (Figure 48) Cycling was started in May 1972. The pack's voltage limit is 1.457 v/c and cell 9, with the greatest amount of precharge, is exhibiting the highest end of charge voltage (1.504 volts). This pack has completed 23,164 cycles with no cell failures.

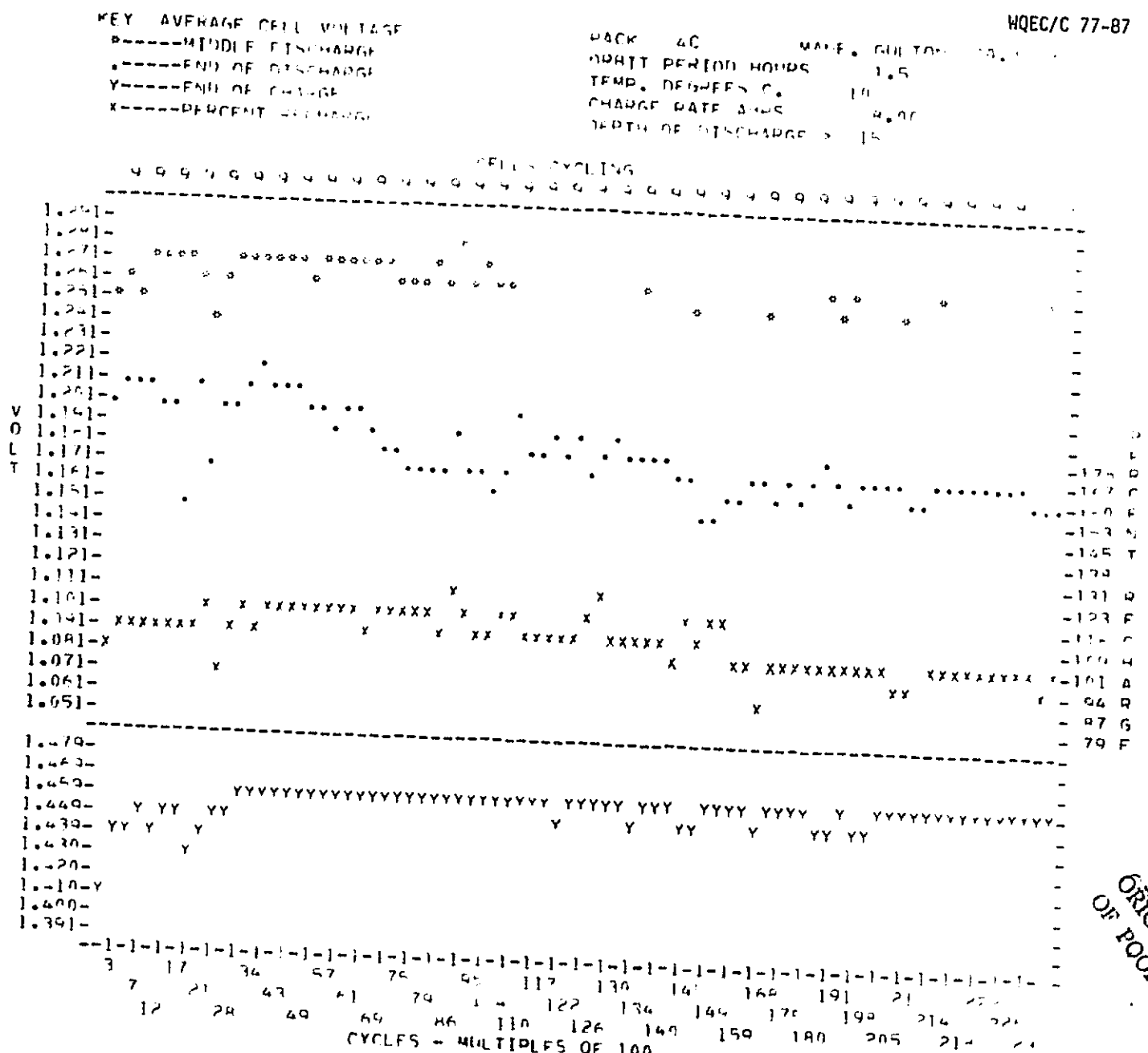

FIGURE 48

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18. Gulton 20 ah (OAO), One 5-cell Pack:

a. Cell Description: See paragraph IA., page 12.

b. Parameters and Capacity Checks:

Orbit Period	1.68-hours
Temperature (°C)	10°
Depth of Discharge (%)	15
Auxiliary Electrode Resistor (Ohms)	47
Pack Number	4D
Precycling Capacity	24.7
Capacity Check	None Scheduled

c. Test Results:

(1) Performance on Cycling: (Figure 49) This pack received 5394 life-cycles at Goddard Space Flight Center before beginning cycling at NAVWPNSUPPCEN, Crane. Since then, it has completed 14,410 cycles with no cell failures.

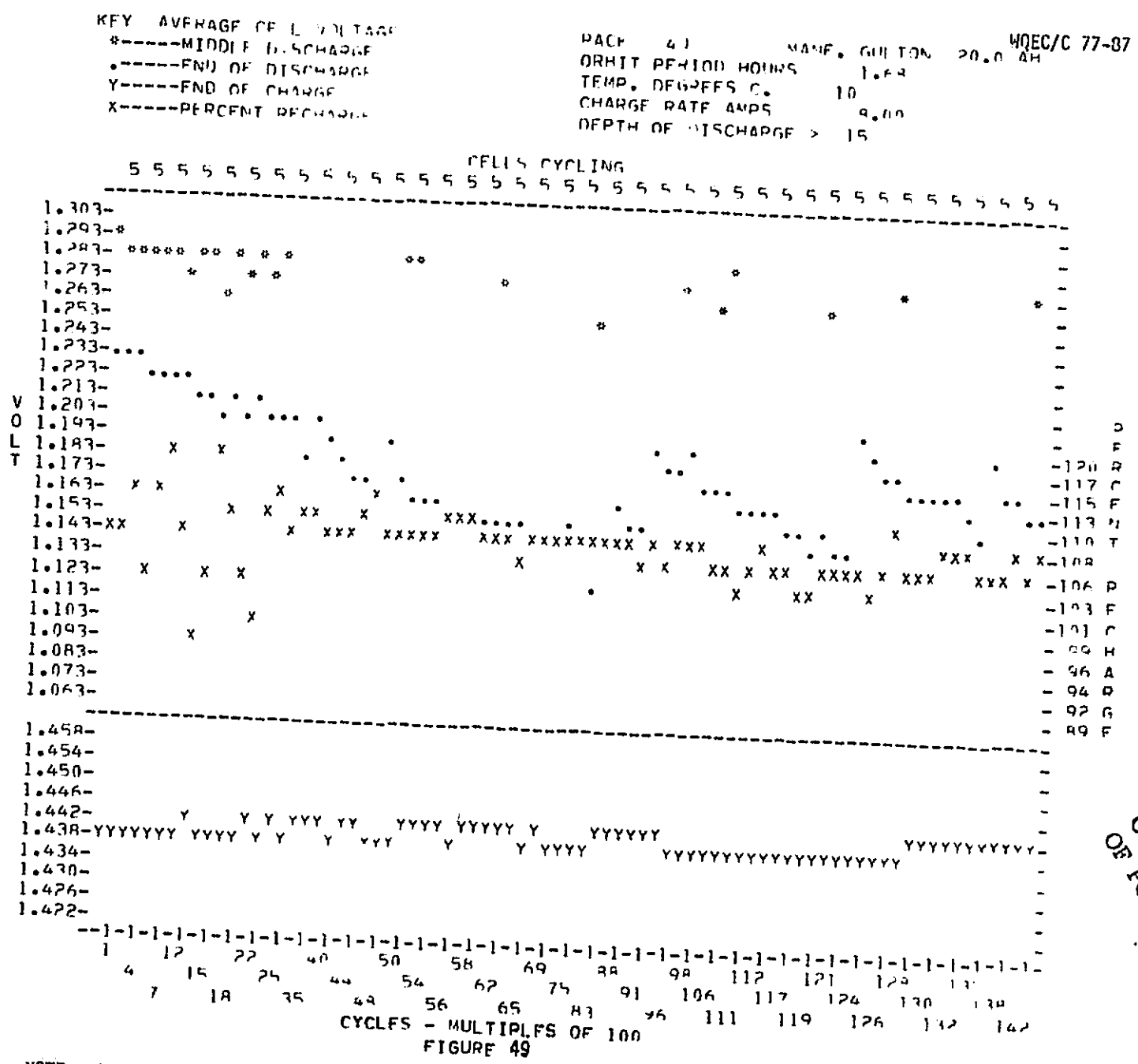

FIGURE 49

NOTE: Completed 5394 additional cycles at GSFC.

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19. Gulton 20 ah (OAO), Three 5-cell Packs:

a. Cell Description: See paragraph I.A., page 12. These cells were manufactured in the same time frame and from the same plate lot as cells for OAO batteries, assemblies 36 and 37. They were manufacted to the "Nickel-Cadmium Storage Cells Power Supply Subsystem Orbiting Astronomical Observatory, Specification for", Grumman specification AV-252CS-25F. (They are V020HS-type cells and the manufacturer's model number is 804325.) Initial evaluation test results are contained in NAD, Crane Report QEEL/C 73-459.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hours		
Temperature (°C)	10°	10°	10°
Depth of Discharge (%)	14.4	14.4	14.4
Auxiliary Electrode Resistor (Ohms)	47	47	47
Pack Number	4E	4F	4G
Precycling Capacity*	25.2(2)	25.1(2,3,5)	24.2(3)
6 months (Cells 1 & 2)	25.7(1)	22.8(2)	26.8(1,2)
12 months (Cells 2 & 3)	26.1(2)	22.3(2)	25.6(3)
18 months (Cells 3 & 4)	26.5(3)	23.3(4)	24.5(3)
24 months (Cells 4 & 5)	24.3(5)	22.5(4)	25.5(5)
30 months (Cells 1,2,3,4 & 5)	25.8(5)	23.4(2)	26.1(1,3)

*Number in parenthesis indicates limiting cell on discharge.

c. Test Results:

(1) Performance on Cycling: (Figures 50 through 52) Cycling began in October 1973 and Packs 4E, 4F and 4G have completed 15,363, 15,410, and 15,154 cycles, respectively with no cell failures. The voltage limit on Pack 4F was reduced to 1.433 v/c, cycle 15405, following its last capacity check; due to the pack temperature reaching 20°C because of cell imbalance during charge. The auxiliary trip voltage of pack 4G was reduced from 300 to 100 millivolts, cycle 14955, following its last capacity check; because of a high percent of recharge caused by cell imbalance.

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE

PACK 4F MAN. GE 20. AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 10
CHARGE RATE AMPS 0.0
DEPTH OF DISCHARGE > 15

CELLS CYCLING

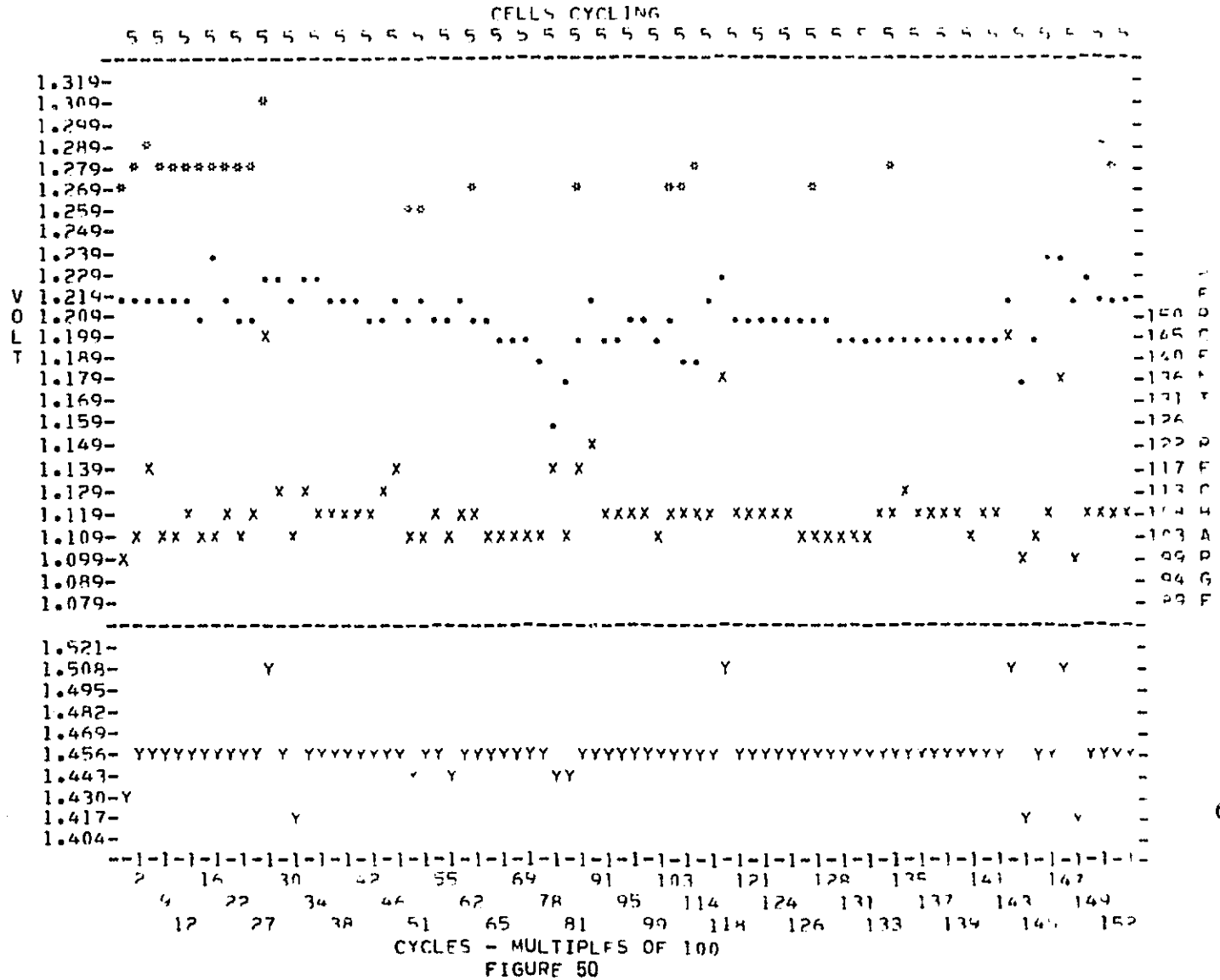

FIGURE 50

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KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE

PACK 4F MANF. GU 2[illegible] AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 10
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE > 15

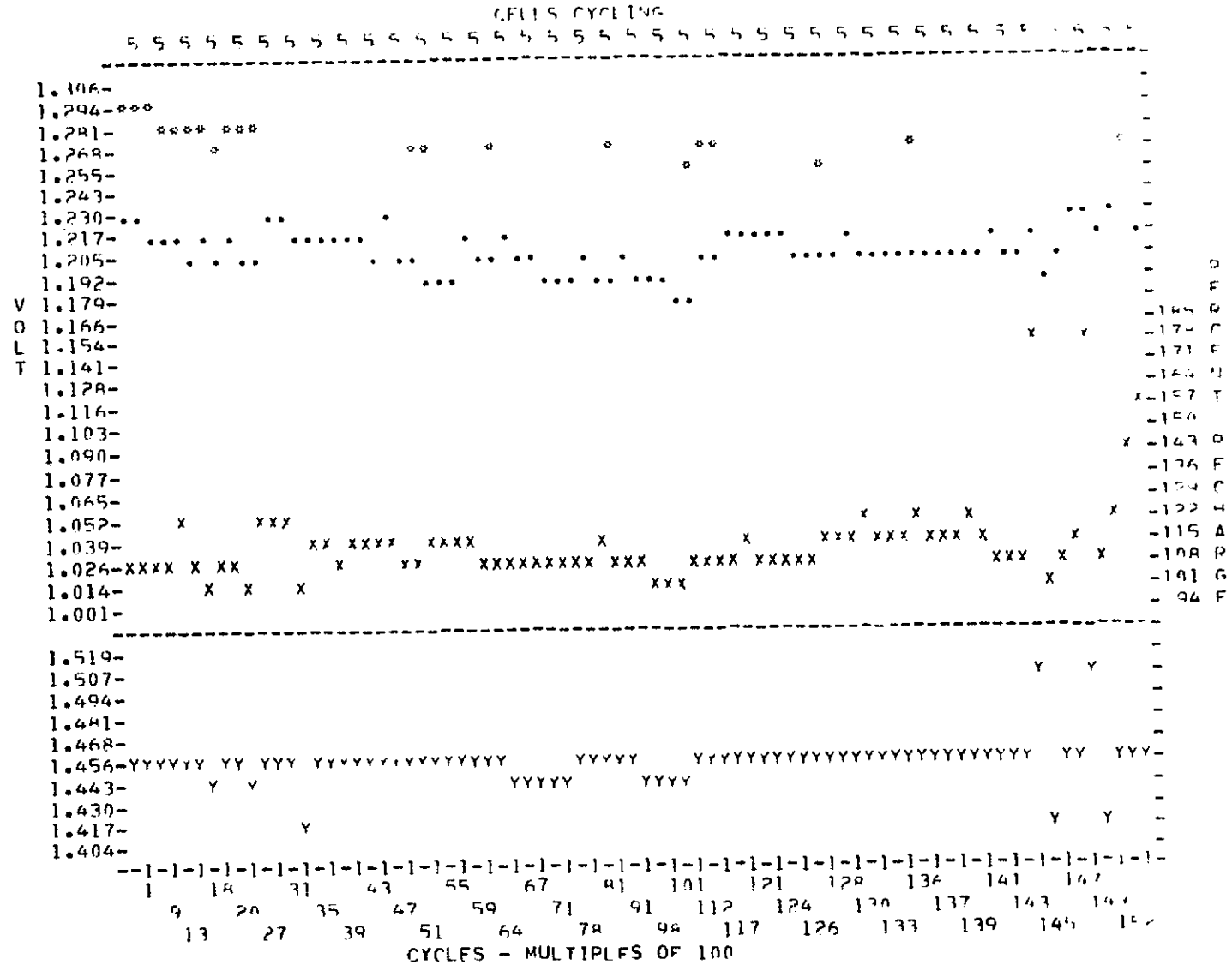

FIGURE 51

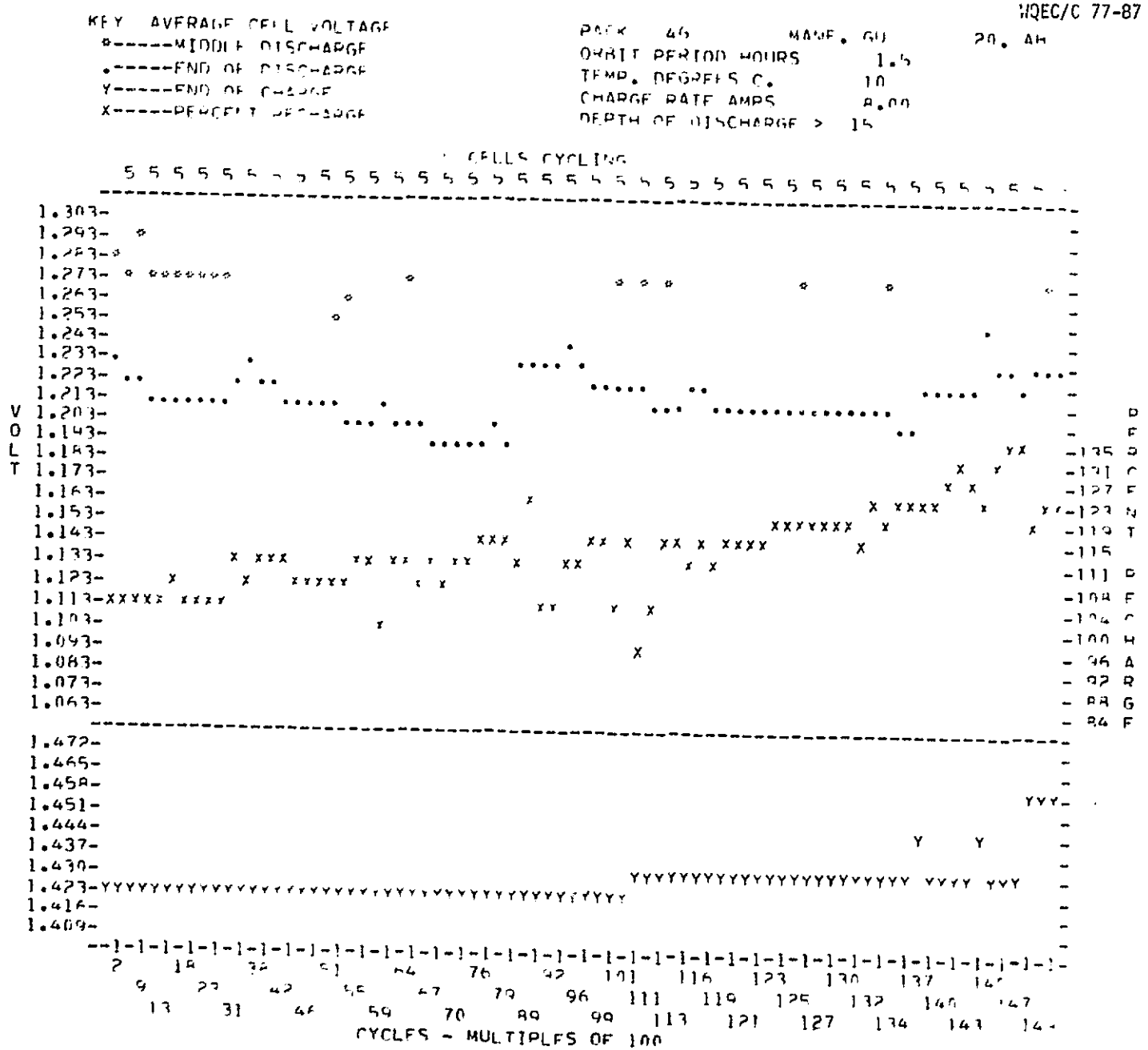

FIGURE 52

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20. Gulton 20 ah (OAO), (Nickel-Cadmium), One 5-cell Pack:

a. Cell Description: The first, third and fifth cells were fitted with pressure transducers. The first cell has the only auxiliary electrode of the pack. They physical description may be found in paragraph I.A., page 12.

b. Parameters and Capacity Checks:

(1) Pack Number: 12E.

(2) Orbit Period: 1.5-hour.

(3) Test Temperature: 20°C.

(4) Depth of Discharge: 15%.

(5) Auxiliary Electrode Resistor: 47 Ohms.

(6) Capacity Checks: The ampere-hour capacities during precycling were determined by discharging each cell at 6.0 amperes to 0.5 volt per cell. The capacity checks during cycling are determined by that time required for the first cell in the pack to reach 0.5 volt. Further, the capacity checks during cycling are not run on a regular 88-day cycle, but only when instructed by Goddard Space Flight Center; and when run, the capacities are determined by the time for the first cell in the pack to reach 0.5 volt.

	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5
Precycling Capacity	25.26	25.38	25.38	24.96	25.56
58 Days*	29.80	29.50	27.60	27.50	28.60
97 Days				25.80	
158 Days				29.22	
174 Days				26.83	
650 Days				28.40	

* This capacity check was run at the c/2 discharge rate as opposed to precycling data and that at 97 days which was run at the cycle rate of 6.0 amperes. When only one column is used (97 days), the capacity is determined by the low cell reaching 0.5 volt.

c. Test Results:

(1) Performance on Cycling: (Figure 53) Cycling started in May 1970. Pack 12E has completed 34,461 cycles with two cells removed. The voltage limit was lowered from 1.420 V/C to 1.380 V/C after 19,488 cycles due to increasing percent recharge.

(2) Analysis: After 2522 cycles, the cells showed a large amount of imbalance at the end of charge. The cell showing the highest end-of-charge voltage (position one) was removed at the request of Goddard Space Flight Center. Analysis showed excessive migration and moderate separator deterioration. Samples of positive and negative (adjacent) plates were removed, and individual plate capacities were measured. The positive capacity exceeded the negative capacity in each case by as much as 13 percent. This leads to high voltage (unusually high pressure also, though not noted in this case) during charge. A second cell (position 4) was removed after 2729 cycles and discharged through reversal to -1.0 volt while flooded with 31% KOH; then recharged for 48 hours and the peak voltage was noted after 35 hours and 12 minutes at 1.516 volts. The cell was then removed from its case and immersed in 31% KOH whereupon it was discharged through reversal to -1.50 volts. The cell remains were then sent to Goddard Space Flight Center.

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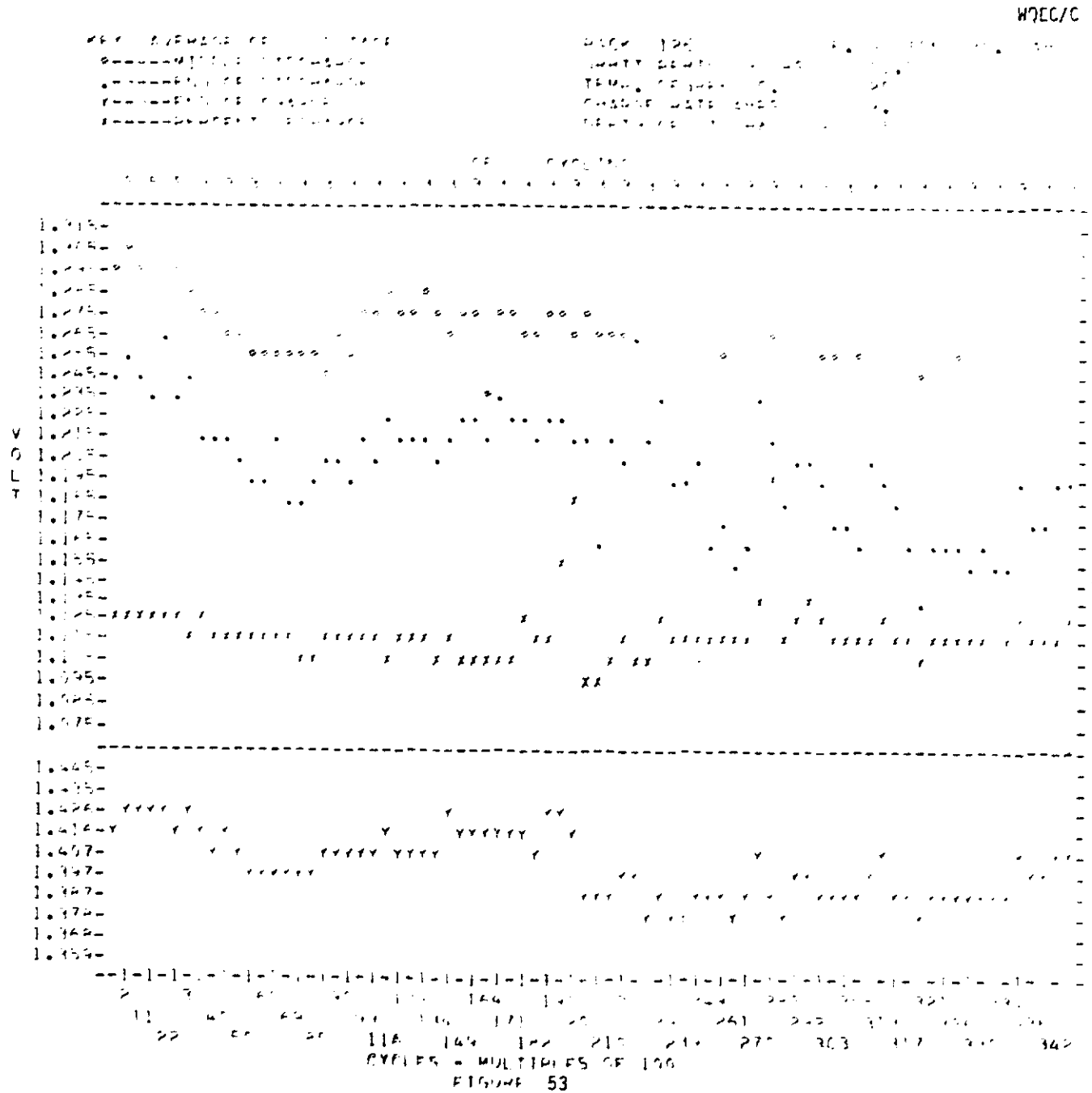

FIGURE 53

21. Gulton 20 ah (OAO), (Nickel-Cadmium), Three 5-cell Packs:

a. Cell Description: See paragraph I.A., page 12.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hours	
Temperature	0°	25°	40°
Depth of Discharge	15%	15%	15%
Trip Voltage (MV)	250	250*	300
Auxiliary Electrode Resistor (Ohms)	47	47	47
Pack Number	54B	19B	38E
Precycling Capacity	22.7	23.3	17.3
88 Days	25.1	19.8	5.6
264 Days	24.7	14.9	2.9 F
440 Days	24.8	8.7	
616 Days	22.1	9.4	
792 Days	6.7	8.2	
968 Days	17.1	8.4	
1144 Days	16.9	11.9	
1320 Days	14.9	5.9	
1496 Days	15.7	4.0 D	
1672 Days	18.8		
1865 Days	14.2		
2027 Days	20.2		
2206 Days	10.5		
2381 Days	6.7		
2559 Days	14.4		
2735 Days	10.2		
2911 Days	5.9		

*Placed on voltage limit control (3-4-71) due to both auxiliary electrode cells in the pack failing.
F - Failed. D - Discontinued.

c. Test Results:

(1) Performance on Cycling: (Figure 54)
Cycling was started in March 1968. Pack 54B has completed 46,915 cycles with no cell failures; pack 19B was discontinued after 24,625 cycles in March 1970 in which it had two cell failures (internal shorts), cycles 17130 and 16028; pack 38E failed after 4943 cycles due to loss of capacity at high temperature. Pack 54B's charge current was reduced to 3.5 amperes after 25,069 cycles due to high percent recharge.

(2) Failure Analysis: Analysis of five failed/discon-continued cells showed that failure was due largely to separator deterioration. Migration was not as extensive as that seen in most failed cells. Other conditions included blistering and high pressure as evidenced by gas escaping from the punctured cell.

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE

PACK 549 MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

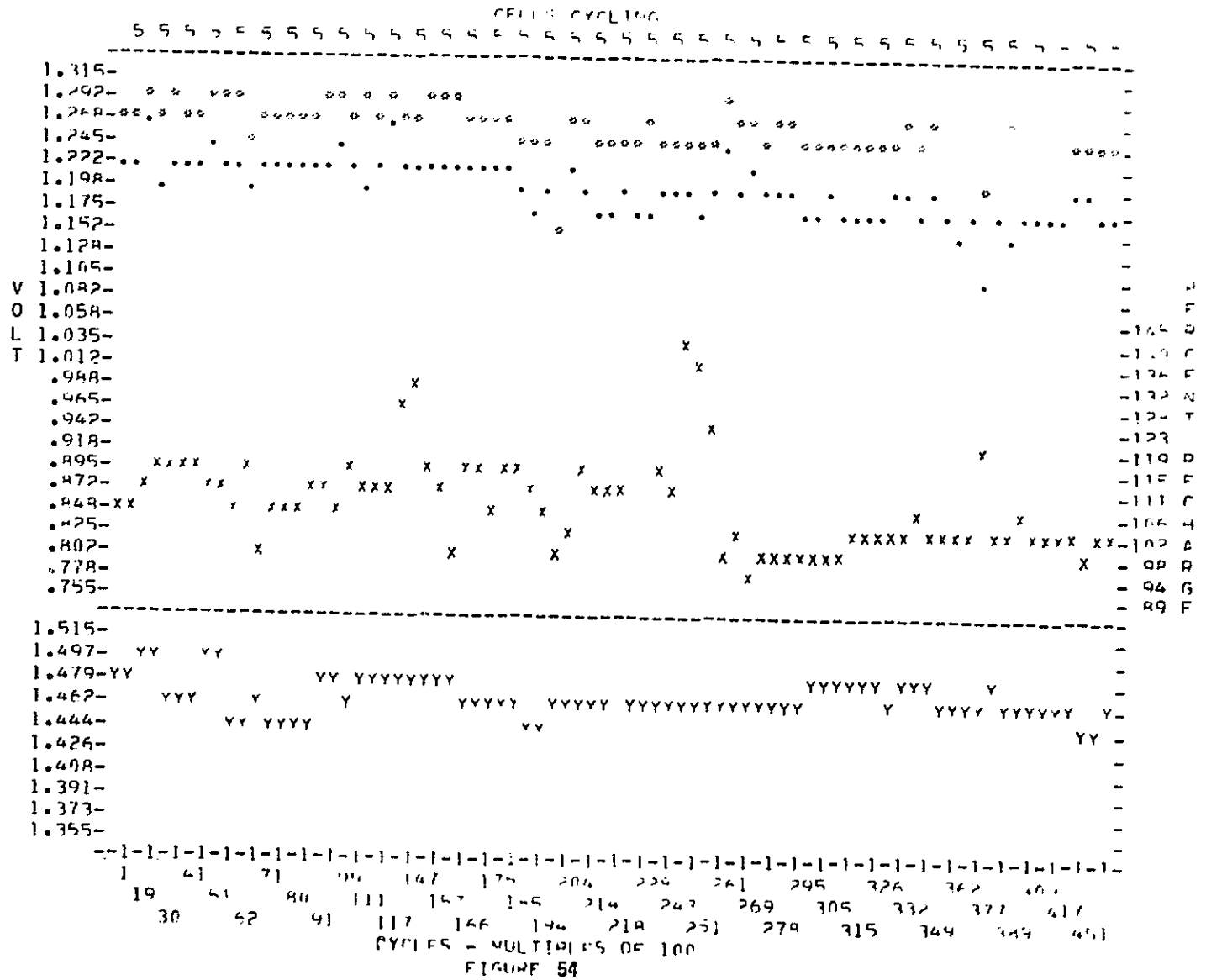

FIGURE 54

NOTE: Charge current reduced to 3.5A after 25,069 cycles due to high percent recharge.

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22. Gulton 20 ah (OAO), (Nickel-Cadmium), One 5-cell Pack:

a. Cell Description: See paragraph I.A., page 12.

b. Parameters and Capacity Checks:

(1) Orbit Period: 1.5-hour.

(2) Test Temperature: 0°C.

(3) Depth of Discharge: 15%.

(4) Auxiliary Electrode Resistor: 47 Ohms.

(5) Pack Number: 68B.

(6) Capacity Checks: The ampere-hour capacities during precycling was determined by discharging each cell at 6.0 amperes to 0.5 volt per cell. The capacity checks are not run on a regular 88-day schedule; they are scheduled by Goddard Space Flight Center. When only one column is used (88 days), the capacity is determined by the low cell reaching 0.5 volts:

	Cell #1	Cell #2	Cell #3	Cell #4	Cell #5
Precycling Capacity	27.00	26.82	27.30	27.12	27.12
88 Days	27.00				

c. Test Results:

(1) Performance on Cycling: (Figure 55) Cycling was started in October 1970. The voltage limit was lowered from 1.495 V/C to 1.457 V/C on cycle 3274 due to cell voltage imbalance at end-of-charge and a percent recharge above 110. Pack has completed 32,102 cycles without a cell failure.

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
Y-----END OF CHARGE
X-----PERCENT RECHARGE

PACK 68H MANF. GULTON 20.0 AH
DRAIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 4.00
DEPTH OF DISCHARGE > 15

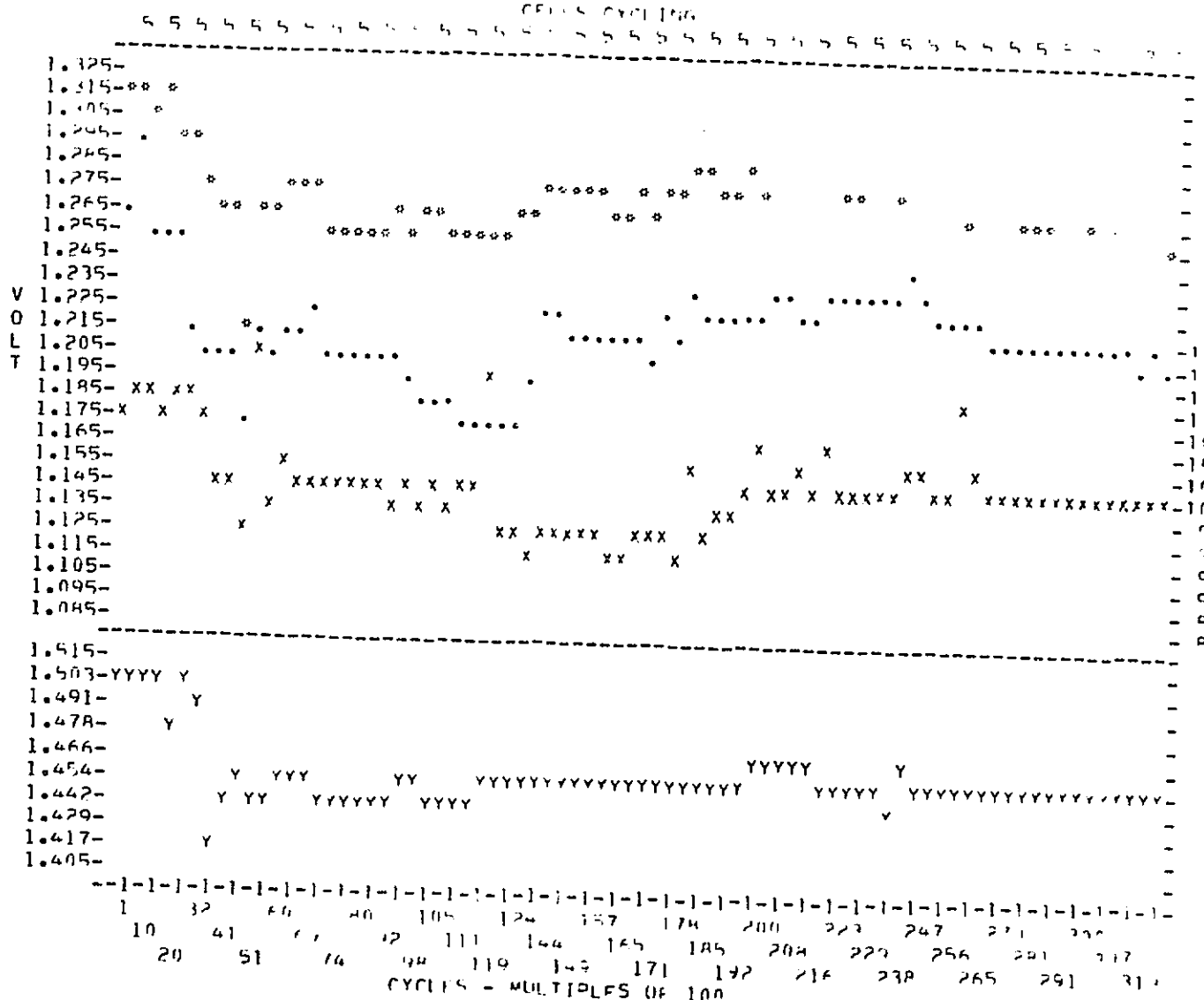

FIGURE 55

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SECTION II

CELLS WHICH HAVE COMPLETED TEST WITHIN LAST YEAR

I. CELLS WHICH HAVE COMPLETED TEST WITHIN THE LAST YEAR

A. General Description:

1. The majority of the nickel-cadmium cells tested for use in space, or related programs, are of one basic type. They are rectangular with stainless steel containers and covers, both terminals are insulated from the cover by a ceramic seal and protrude through the cover as solder-type terminals. Where auxiliary electrodes are present, the terminal is a stainless steel tab welded to the cell cover. Any cells differing from this decription are separately described as they are encountered in the following paragraphs.

B. Nickel-Cadmium Types:

1. Gulton, 5.0 ah (Nickel-Cobalt):

a. Cell description and test results of this pack are located on page 16 since cells of this type make up a group of packs, in which one is currently on test.

2. EP, 6.0 ah (Separator Evaluation), Packs 9J-M and 9P-R:

a. Cell description and test results of this pack are located on page 21 since cells of this type make up a group of packs, in which some are currently on test.

SECTION III

CELLS ON TEST PROGRAM WHICH HAVE COMPLETED TEST

I. CELLS ON TEST PROGRAM WHICH HAVE COMPLETED TEST

In order to gather sufficient data to indicate the performance of nickel-cadmium cells cycled at various test conditions; 660 cells were placed on test during December 1963 and January 1964. These cells were from four manufacturers and consisted of seven different types as shown in Table I. The cells were grouped in packs of 5 or 10 cells depending upon the ampere-hour capacity. All cells rated above 6.0 ampere-hours were grouped into 5-cell packs; the remainder were placed in 10-cell packs.

A. Description of Cycle Test:

The cells were operated at three temperatures and three depths of discharge, which are summarized in Table II. Each pack was cycled under its respective conditions until 60 percent or more of the cells failed. A cell was considered failed when its terminal voltage dropped below 0.5 volt at any time during cycling.

B. Life Test Results:

1. The cycling results show that discharge voltages tend to drop slightly or remain the same during the life test. The drop is usually not more than 0.04 volt per active cell. The exceptions to this are immediately after a capacity check when there is an increase in the discharge voltage and when a cell is about to fail, the average voltage drops more rapidly. The least overall change is seen at 0°C. For a given temperature and cell type, the discharge voltage is generally from 0.02 to 0.08 volt per cell lower at the greater depths of discharge, that is, at the higher rate, as expected. The discharge voltage tends to decrease no more than 0.1 volt per cell with increases in test temperature from 0°C to 40°C for each depth of discharge. The amount of decrease depends on the cell type. The orbit period seems to have little effect on the discharge characteristics of normally functioning cells (the 1.5-hour and 3-hour orbit periods both have 30-minute discharge periods).

2. When pronounced long term changes in percent of recharge and end-of-charge voltage occurred, they were almost always in the direction of lower percent of recharge and higher voltage although some of the packs did have an increase in the percent of recharge. On the average, packs operating at 0°C had an early percent of recharge of 107 percent and after 5 years it was 105 percent. While at 25°C, the early percent of recharge was 120 percent and after 4 years it was 118 percent. At 40°C, the early percent of recharge was 153 percent and after 4 years it was 146 percent. At all temperatures the percent of recharge is, on the average,

below the specified percent of recharge indicating that the amount of recharge need not be as high as was originally set for the testing program--approximately 10 percent less.

3. Capacity Check Results:

a. The ampere-hour capacity was checked approximately every 88 days. These capacity checks showed that temperature had a very definite effect on the loss of capacity. The packs cycled at 40°C showed a very rapid drop in capacity until failure occurred. The loss of capacity was not as severe for the packs at 25°C while those operated at 0°C showed very little capacity loss. Orbit periods and depths of discharge also have a small effect but these do not show any definite trends.

b. The ampere-hour capacity checks also show how the cells degrade during life cycling.

4. Cell Failures:

a. The analysis of the failed cells is a very important phase of the testing program. From these analyses manufacturing defects, poor design, and material weakness can be detected and an effort made to correct or improve them. This in turn will lead to a bettery product with better performance characteristics.

b. Special Considerations:

(1) The charge rates specified in the cycling program usually exceeded the maximum rates recommended by the manufacturers. For example, packs which are cycling in a 1.5-hour orbit at 25°C, 40 percent depth of discharge are being charged at the c/2 rate, although the maximum charge rate recommended by the manufacturers is c/10. The only charge rates below c/10 are those for the 3-hour orbit, 15 percent depth of discharge combinations, the rates for which are calculated to be c/14.5 at 0°C and c/10.4 at 40°C.

(2) These cells were manufactured prior to January 1963. Because of subsequent changes in construction, newer cells of the same capacity and manufacturer may not show the characteristics discussed here. Also, the manufacturers have reported that corrective action has been taken to eliminate the sources of premature mechanical failure.

c. Discussion of Failures:

(1) General Observations:

(a) Most of the cell failures occurred at the higher ambient temperatures. The cell failures were earlier and more frequent at the greater depths of discharge and shorter orbit periods. A detailed summary of the failure analysis for each cell may be obtained by request to the NASA Technical Officer (See Introduction).

(b) Many of the cell failures may be considered premature because they resulted from a defect in manufacture or design. This is in contrast to an end-of-life failure, in which a basic component, such as a separator, has reached the end of its normal life span at the particular cycling conditions. Some examples of premature failures are those due to leakage, pierced separators, burned tab, ceramic short, or extraneous active material.

(c) It is frequently difficult to isolate the exact cause of failure for a particular cell. In some cases several factors may have been responsible. In others, it is not obvious why the conditions found should have resulted in failure. For this reason, unless otherwise stated, this report will not attempt to isolate the direct cause of failure; the conditions noted in the discussions are included because they are abnormalities and because they may have contributed to the cell failure.

(2) Discussion of Failures by Cell Type:

(a) GE:

1. 3.0 ah Cells: There were 48 cell failures, of which four were at 0°C, 19 were at 25°C, and 25 were at the 50°-40°C ambient temperature.

a. Migration was present at all test conditions except 25 percent depth of discharge, 40°C and 1.5-hour orbit period. This was probably because of the burned tabs, along with short separators, which occurred early in life, only 157 days of cycling. Separator deterioration began to appear in failures that occurred after 287 days of cycling. Blistering on the positive plates was very common at 25°C after 436 days of cycling.

2. 12.0 ah Cells: There were 27 failures, of which three were at 0°C, 12 were at 25°C and 12 were at 50°-40°C.

a. Migration was present in most of the cell failures that occurred after 239 days of cycling. Cell failures began to show signs of separator deterioration after 240 days of cycling. High internal pressures occurred in a few cell failures at all ambient temperatures.

(b) Gould:

1. 3.5 ah Cells: There were 63 cell failures, of which eight were at 0°C, 26 were at 25°C and 29 were at 50°-40°C ambient temperature.

a. Weight loss was one of the main conditions found in these failures. Losses ranged from 1.0 gram to 7.1 grams. Deposits were always present with the weight loss which occurred earlier at 25°C and 40°C but did not appear in the cell failures at 0°C until after 687 days of cycling. Migration and separator deterioration were present at all conditions. The number of weak welds inside of the cells analyzed varied with temperature as indicated by 14 weak welds out of 29 failed cells at 40°C; 11 weak welds out of 26 failed cells at 25°C; and 1 weak weld out of 8 failed cells at 0°C.

2. 20.0 ah Cells: There were 29 cell failures, of which five were at 0°C, 12 were at 35°C and 12 were at 50°-40°C ambient temperature.

a. High internal pressure was present in almost all failures. Pierced separator was more predominate at the 1.5-hour orbit period at all ambient temperatures. Blisters were present on the positive plates at 25°C for the 3-hour orbit period and the 1.5-hour and 3-hour orbit periods at 40°C.

(c) Gulton:

1. 6.0 ah Cells: There were 68 cell failures, of which 20 were at 0°C, 24 were at 25°C and 24 were at 50°-40°C ambient temperature.

a. Ceramic shorts were the most common mode of failure. Weight losses were also very common and ranged from 1.0 gram to 12.0 grams. Most of the cells that lost weight did not show signs of leakage in the form of deposits around the seals. Most of the failures due to ceramic short did not show signs of migration or separator deterioration because the failures occurred early in life.

2. 20.0 ah Cells: There were 36 cell failures, of which eight were at 0°C, 15 were at 25°C and 13 were at 50°-40°C ambient temperature.

a. Weight losses were very common at 0°C and 25°C and ranged from 6.8 grams to 26.9 grams. Most of the cells that lost weight did not show signs of leakage in the form of deposits around the seals. Several cell failures were caused by the sides of the case being pushed against the fuses at the top of the plates. Migration and separator deterioration were found at 40°C but not very common at 0°C or 25°C.

(d) Sonotone:

1. 5.0 ah Cells: There were 51 cell failures, of which six were at 0°C, 21 were at 25°C and 24 were at 50°-40°C ambient temperature.

a. Excess scoring, along with migration, was present in most of the cell failures at all ambient temperatures. Separator deterioration was more frequent at 25°C and 40°C. High internal pressure and leakage as shown by deposits around the seal were present at 25°C and 40°C.

TABLE I

PHYSICAL CHARACTERISTICS OF CELLS

Manufacturer and Manufacturer's Rated Capacity	Shape	Average Dimensions (Inches) Height Base to Top of Terminal	Width or Diameter	Length or Depth	Average Weight (Grams)	Case Polarity
GE 3.0 ah	Cylindrical	3.10	1.25 D	--	155.0	Negative
Gould 3.5 ah	Cylindrical	2.22	1.28 D	--	135.2	Positive
Sonotone 5.0 ah	Cylindrical	3.67	1.31 D	--	237.4	Negative
Gulton 6.0 ah	Rectangular	3.58	2.09 W	0.81	267.0	Negative
GE 12.0 ah	Rectangular	4.59	3.02 W	1.11	562.0	--
Gould 20.0 ah	Rectangular	*7.95	3.05 W	0.97	1045.0	--
		**8.10	3.56 W	1.49	1423.0	--
Gulton 20.0 ah	Rectangular	7.10	2.98 W	0.90	871.6	--

* Before Epoxy Cover

** After Epoxy Cover

TABLE II

SUMMARY OF TEST PARAMETERS

For each orbit period, one pack of each of the seven cell types is cycling at each of the six temperature-depth of discharge combinations.

ORBIT PERIODS: 1.5 Hours and 3.0 Hours			
Discharge Time	Charge Time	Temperature °C	Percent Depth of Discharge
30 Minutes	60 Minutes and 2.5 Hours	(50*)	(15) (25)
		40	15 25
		25	25 40
		0	15 25

* All packs changed to 40° C ambient.

II. COMPLETED TESTS OF CELLS WHICH FOLLOWED JANUARY 1964

These packs were added to the cycling program to obtain information either on new cell types or new test parameters. Each pack was cycled until 60 percent or more of the cells failed. A cell is considered a failure when its terminal voltage drops below 0.5 volt during cycling. Testing has been terminated on all packs covered in this section of the report.

III. CELLS USING CONSTANT CURRENT CHARGE WITH VOLTAGE LIMIT CONTROL

A. Nickel-Cadmium Types:

1. NIFE 3.9 ah, Two 5-cell Packs:

a. Cell Description: The cell container and the cell cover of these cylindrical cells are made of stainless steel. The cell container serves as the negative terminal. The positive terminal is a button extension of the positive plate tab through the center of the cover. The positive terminal is isolated from the negative container by means of a membrane seal. Connections are made by soldering directly to the container and the positive terminal.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour	
Temperature	0°	25°
Depth of Discharge	25%	25%
Pack Number	97C	85C
Precycling Capacity	4.10	3.90
88 Days Disch #2	3.93	3.57
264 Days Disch #2	3.33	3.33
440 Days Disch #2	3.27	2.90
616 Days Disch #2	3.60	2.20
792 Days Disch #2	3.50	
968 Days Disch #2	3.23	
1144 Days Disch #2	3.03	

c. Test Results:

(1) Performance on Cycling: Cycling was started in September 1967. Pack 85C and 97C failed on cycles 9356 and 20,000, respectively.

(2) Failure Analysis: The six failed cells showed separator deterioration, migration, shorting across the membrane seal, several weak welds, and leakage of electrolyte as indicated by deposits around the positive terminal.

2. Gulton 3.5 ah (Polymerized Neoprene Seal), Seven 5-cell Packs:

a. An additional 5-cell pack was put on continuous charge at the c/10 rate in an ambient temperature of 25°C in order to evaluate the new seal. This pack was not assigned a pack number as were those appearing in the table.

b. Cell Description: These cells are cylindrical with cell containers and covers made of stainless steel. The positive terminal is insulated from the cell cover by a polymerized neoprene bushing and protrudes through the bushing as a 8-32 threaded post. The negative lead is soldered to the cell container.

c. Parameters and Capacity Checks:

Orbit Period				1.5-hour				
Temperature		-20°	-20°	0°	0°	25°	25°	40°
Depth of Discharge		25%	40%	25%	40%	25%	40%	25%
Pack Number		89C	75D	122C	99C	87C	73C	112C
Precycling Capacity		3.12	3.79	3.70	4.38	4.14	4.26	4.32
88 Days	Disch #2	2.39	3.50	3.33	4.23	3.62	3.50	1.20
264 Days	Disch #2	2.25	2.80	3.00	4.03	2.95	2.33	1.23
440 Days	Disch #2	2.33	3.30	2.65	3.65	2.01	1.87	1.05
616 Days	Disch #2	1.72	2.77	2.45	3.12	1.17	1.60	1.08
792 Days	Disch #2	1.60	2.80	2.33	2.97	1.11		
968 Days	Disch #2	1.25		2.27	2.97	0.93		
1144 Days	Disch #2	1.55		2.19	2.51	0.93		
1320 Days	Disch #2	1.17		2.07	2.54			
1496 Days	Disch #2			1.98	2.30			
1672 Days	Disch #2			2.19	2.01			
1848 Days	Disch #2			1.75	1.93			

d. Test Results:

(1) Performance on Cycling: Cycling was started in December 1966. Packs 122C (discontinued) and 99C (failed) completed 37,578 and 31,769 cycles respectively. Packs 75D, 73C, 112C, 87C and 89C failed on cycles 14, 197, 9978, 11,155, 20,866 and 23,832 respectively.

(2) Failure Analysis:

(a) Analysis of the 19 failed cells showed the major cause to be migration of the negative plate material and separator deterioration. Other conditions found were high internal pressure and electrolyte leakage.

(b) The pack that was put on continuous charge had one cell that developed high internal resistance and was removed from test on 5 November 1969 after 1066 days. The high internal resistance was caused by corrosion of the positive tab. The cell also had electrolyte leakage and high internal pressure. The second cell failed on 26 August 1970 after 1335 days of testing. The positive tab-to-terminal connection had corroded in two. The positive active material was very loose and brittle. Phenolphthalein indicated electrolyte leakage around the positive terminal. The pack remains on test with no more failures to date.

3. Gulton 4.0 ah (Commercial), Six 5-Cell Packs:

a. Cell Description: These are rectangular sealed cells of commercial grade, but were not hermetically sealed as supplied. They were epoxy potted into 5-cell packs at the Goddard Space Flight Center in order to hermetically seal the cells before test.

b. Parameters and Capacity Checks:

Orbit Period			1.5-hour				
Temperature		0°	0°	25°	25°	40°	40°
Depth of Discharge		15%	25%	25%	40%	15%	25%
Pack Number		115B	126B	4B	14B	28B	40B
Precycling Capacity		5.04	4.87	4.63	5.00	4.20	3.37
88 Days	Disch #2	3.57	4.00	2.47	2.00	1.70	1.17
264 Days	Disch #2	4.00	3.73	1.80	1.87	1.43	1.30
440 Days	Disch #2	4.07	3.60	1.67	1.93	1.53	1.17
616 Days	Disch #2	4.60	--	1.60		1.67	0.76
792 Days	Disch #2	4.33	3.63	1.67		1.77	
968 Days	Disch #2	4.03	3.50	1.67		2.07	
1144 Days	Disch #2	3.67	3.30	1.30		0.47	
1320 Days	Disch #2	3.63	3.37	1.47		1.73	
1496 Days	Disch #2	3.40	3.33	1.33			
1672 Days	Disch #2	3.17	3.03	1.70			
1848 Days	Disch #2	3.07	3.63	1.40			
2024 Days	Disch #2	3.17	3.87	0.97			
2200 Days	Disch #2	2.80	3.04				
2376 Days	Disch #2	2.64					
2552 Days	Disch #2	2.66					

c. Test Results:

(1) Performance on Cycling:
Cycling was started in August 1964. Packs 115B (discontinued) and 126B (failed) completed 41,641 and 42,234 cycles respectively. Pack 14B failed on cycle 8476, pack 28B on cycle 20,227, pack 40B on cycle 10,360 and pack 4B on cycle 35,111.

(2) Failure Analysis: The analysis of 14 failed cells showed the major cause to be due to separator deterioration and migration. Other conditions found were weak tab-to-terminal welds, high internal pressure and electrolyte leakage.

4. Gulton 5.0 ah (NIMBUS), Six 5-cell Packs:

a. Cell Description: These cells are cylindrical with a convex base. A threaded stud is fastened to the base to facilitate heat sink mounting. The cell container and the cell cover are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as the contacts for the negative terminal. The positive terminal is insulated from the cell cover by a ceramic seal and protrudes through the cover as a solder type terminal. Two solder tabs are welded to the terminal. Three cells have pressure transducers which are used to read internal pressure in pounds per square inch absolute. These cells were manufactured to the NIMBUS specifications.

b. Parameters and Capacity Checks:

Orbit Period			1.5-hour			
Temperature	0°	0°	25°	25°	40°	40°
Depth of Discharge	15%	25%	15%	25%	15%	25%
Pack Number	117A	121A*	120A	118B*	127A	128A*
Precycling Capacity	5.00	5.38	5.25	5.46	3.29	3.04
88 Days Disch #2	5.17	5.38	5.40	2.55	1.67	1.42
264 Days Disch #2	5.17	5.00	2.79	1.50	1.38	1.71
440 Days Disch #2	4.75	4.29	2.08	2.00	1.71	
616 Days Disch #2	4.70	3.96	**		2.04	
792 Days Disch #2	4.08	4.08	3.21			
968 Days Disch #2	4.17	3.79	2.58			
1144 Days Disch #2	3.83	3.67	2.37			
1320 Days Disch #2	4.46		2.12			
1496 Days Disch #2	4.50		1.79			

* One cell in each pack is equipped with a pressure transducer.
** Capacity check not performed.

Orbit Period			1.5-hour			
Temperature	0°	0°	25°	25°	40°	40°
Depth of Discharge	15%	25%	15%	25%	15%	25%
Pack Number	117A	121A*	120A	118B*	127A	128A*
1672 Days Disch #2	4.33					
1848 Days Disch #2	4.12					
2024 Days Disch #2	4.11					
2200 Days Disch #2	4.45					

* One cell in each pack is equipped with a pressure transducer.

c. Test Results:

(1) Performance on Cycling: Cycling was started in May 1965. Pack 117A was discontinued in March 1972 after completing 38,767 cycles with one cell failure and two discontinuations. Packs 121A, 120A, 118B, 127A and 128A failed on cycles 20,861, 29753, 8108, 10,638 and 6345, respectively.

(2) Failure Analysis: Analysis of the 18 failed or discontinued cells showed the major causes to be separator deterioration and migration of the negative plate material. Other conditions found were electrolyte leakage, ceramic shorts, weak tab-to-plate welds, burned positive tabs, extraneous active materal, pierced separator material by the positive tab, short (vertical height) separators, high internal pressure, corrosive deposits internally at the positive tab and dry separator material.

5. Gulton 5.6 ah (Neoprene Seal), Eight 5-cell Packs:

a. Cell Description: These cells are cylindrical in shape. The cell container and the cell cover are made of cold rolled steel. The positive terminal is insulated from the cell cover by a vulcanized neoprene bushing and protrudes through the bushing as a 1/8 inch projection. The vulcanized neoprene bushings used in the folded cover to terminal seals are longer than those used in the nonfolded cover to terminal seals to protrude through the sleeve formed by the inward fold at the center of the cover (see Figure 51). This design results in a greater length of seal and affords greater protection to the seal from heat during welding of the cover to the can. The possible damage to the neoprene seal of either type cover to terminal seal, by attempting to solder electrical connections to the 1/8 inch positive terminal made it necessary to spot weld metal tabs to these terminals. Metal tabs were also spot welded to the bottom of the cans to serve as the negative terminals.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour							
Temperature	-20°	-20°	0°	0°	25°	25°	40°	40°
Depth of Discharge	25%	25%	25%	25%	25%	25%	25%	25%
Pack Number	44B (FD)	32B (NF)	100B (FD)	90C (NF)	76B (FD)	96C (NF)	42B (FD)	30B (NF)
Precycling Capacity	4.01	4.53	6.25	6.58	5.60	6.30	4.39	4.90
88 Days Disch #2	*	4.57	5.32	5.88	1.63	2.33	1.49	
264 Days Disch #2	4.34	3.64	4.85	5.27	1.59	1.87		
440 Days Disch #2	*	3.64	4.25	4.48	2.10	2.33		
616 Days Disch #2	3.64	3.17	3.64	3.64	1.17			
792 Days Disch #2	3.41	2.85	2.75	3.08				
968 Days Disch #2	3.87	2.10	2.61	2.57				

* Capacity Check Not Performed.
FD - Folded.
NF - Nonfolded.

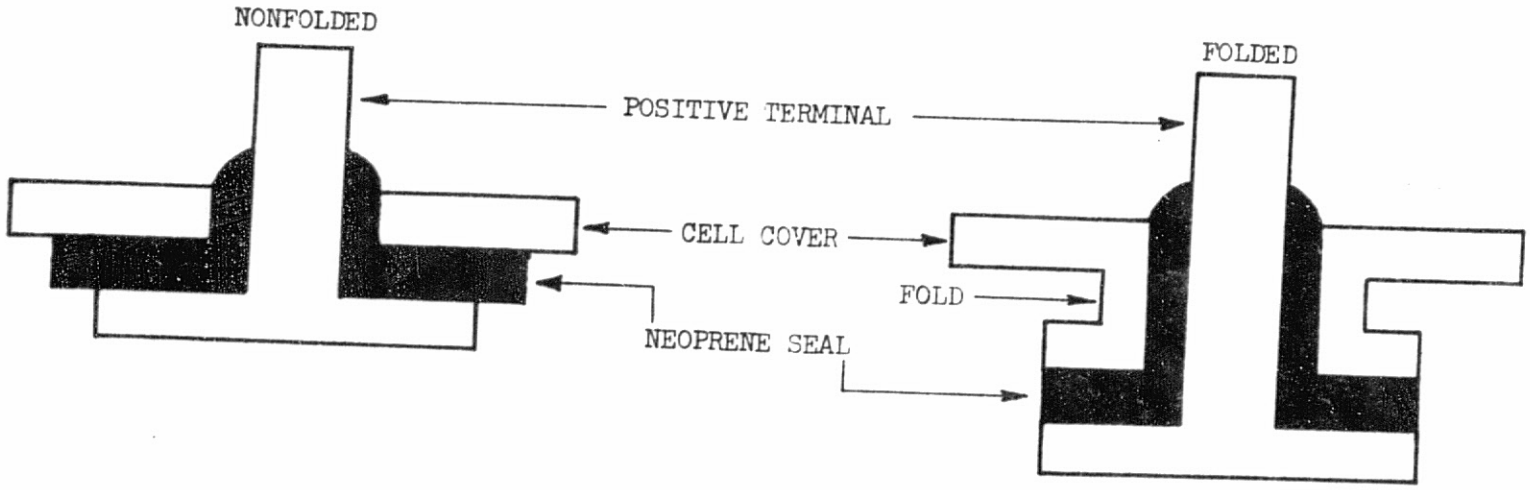
Orbit Period				1.5-hour					
Temperature		-20°	-20°	0°	0°	25°	25°	40°	40°
Depth of Discharge		25%	25%	25%	25%	25%	25%	25%	25%
Pack Number		44B (FD)	32B (NF)	100B (FD)	90C (NF)	76B (FD)	96C (NF)	42B (FD)	30B (NF)
1144 Days	Disch #2	2.66	2.33	2.05	3.17				
1320 Days	Disch #2	2.72		2.01	2.43				
1496 Days	Disch #2	2.66		2.10	2.74				
1672 Days	Disch #2	3.59		2.46	1.90				
1848 Days	Disch #2	2.72			2.01				

FD - Folded.
NF - Nonfolded.

c. Test Results:

(1) Performance on Cycling: Cycling was started in December 1965. Pack 44B failed on cycle 31,907, pack 100B on cycle 28,758, pack 90C on cycle 31,623, pack 32B on cycle 23,303, pack 76B on cycle 11,158, pack 96C on cycle 9791, pack 42B on cycle 3798 and pack 30B on cycle 1275.

(2) Failure Analysis: Failure analysis of the 24 failed cells showed the major cause to be separator deterioration, migration of the negative plate material, electrolyte leakage, and burned positive tabs. Other conditions found were weak positive tab-to-plate welds, burned positive tabs, high internal pressure, corrosive deposits internally at the positive terminal, carbonate deposits externally at positive terminal, and dry separator material.



CROSS SECTION OF NEOPRENE SEAL

6. Gulton 6.0 ah (Improved), Three 5-cell Packs:

a. Cell Description: The cells are rectangular in shape. The cell container and the cell cover are made of stainless steel. The positive terminal is insulated from the cell cover by a ceramic seal, while the negative terminal is welded to the cover. Both are solder type terminals. The silver braze of the ceramic seal is nickel plated to prevent internal cell shorting by silver migration to the cover.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hour	
Temperature	0°	25°	40°
Depth of Discharge	25%	40%	25%
Pack Number	13B	18B	38B
Precycling Capacity	7.30	6.90	5.00
88 Days Disch #2	6.95	3.00	1.75
264 Days Disch #2	7.20	3.80	1.50
440 Days Disch #2	6.75		
616 Days Disch #2	*		
792 Days Disch #2	6.25		
968 Days Disch #2	5.15		
1144 Days Disch #2	4.80		
1320 Days Disch #2	4.15		
1496 Days Disch #2	*		
1672 Days Disch #2	4.00		
1848 Days Disch #2	3.90		
2024 Days Disch #2	3.55		
2200 Days Disch #2	3.74		

* Capacity Check Not Performed.

c. Test Results:

(1) Performance on Cycling: Cycling started in February 1965. Packs 18B, 38B, and 13B failed on cycles 7577, 5766, and 37,650, respectively.

(2) Failure Analysis: Failure analysis of nine cells showed the major causes of failure to be separator deterioration and migration of the negative plate material. Other conditions found were blistering on the positive plates, ceramic shorts, burned positive tabs, electrolyte leakage, high internal pressure, and corrosive deposits internally underneath the positive terminal.

7. Gulton 6.0 ah, One 5-cell Pack, 24-hour Orbit Period (Pack 79A):

a. Cell Description: The cells are rectangular in shape. The cell container and cell cover are made of stainless steel. The positive terminal is insulated from the cell cover by a ceramic seal; while the negative terminal is welded to the cover. Both are solder type terminals.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 50%.

c. Test Results:

(1) Performance on Cycling: Cycling was started in March 1964. The pack failed on cycle 545 with four cell failures.

(a) All cell voltages dropped below 1.0 volt at the end of discharge with the original 150 percent of recharge. Increase of the recharge to 200 percent after cycle 57, caused the end-of-discharge voltages of all five cells to remain fairly constant at about 0.9 volt. Two cells failed at 149 and 168 cycles; then the end-of-discharge voltages of the remaining three cells climbed to an average of 1.08 volts per cell. The end-of-charge voltages remained fairly constant, between 1.39 and 1.40 volts per cell, average, throughout life cycling.

(b) Cell Failures: Analyses of the four cell failures showed that all had separator deterioration and blistering on the positive plates. The first two failures had high internal pressure as indicated by outgassing when opened. The last two failures had pinpoint migration which caused shorts through the separator.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Precycling		6.60
88 Days	Disch #2	3.55
176 Days	Disch #2	4.40
264 Days	Disch #2	4.25
352 Days	Disch #2	4.05
440 Days	Disch #2	3.50

8. Gulton 6.0 ah, One 10-cell Pack (Pack 61B):

a. Cell Description: These cells are rectangular in shape. The cell container and the cell cover are made of stainless steel. The positive terminal is insulated from the cell cover by a ceramic seal, while the negative terminal is welded to the cover. Both are solder type terminals.

b. Test Parameters:

(1) Initial Test Parameters (at another test facility):

(a) Test Temperature: -10° C.

(b) Depth of Discharge: 10%.

(c) Orbit Period: 1.5 hour.

(2) Change in Test Parameters: The test temperature was raised to 0° C after 22,900 cycles at -10° C at another test facility.

c. Parameters and Capacity Checks:

Orbit Period	1.5-hour
Temperature	0°
Depth of Discharge	10%
Pack Number	61B
Precycling Capacity	5.30
88 Days Disch #2	5.40
264 Days Disch #2	5.45
440 Days Disch #2	4.70
616 Days Disch #2	3.75
792 Days Disch #2	3.40
968 Days Disch #2	2.46
1144 Days Disch #2	3.45

Orbit Period	1.5-hour
Temperature	0°
Depth of Discharge	10%
Pack Number	61B
Precycling Capacity	5.30
1320 Days Disch #2	2.45
1496 Days Disch #2	2.76
1672 Days Disch #2	2.94

d. Test Results:

(1) Performance on Cycling: Cycling started at NAD Crane in June 1967. Prior to discontinuation, this pack completed 27,536 additional cycles at 0°C with one cell failure. The pack was discontinued in June 1972 at the request of Goddard Space Flight Center.

(a) The end of discharge voltage is 1.27 volts per cell and the percent of recharge is approximately 105 percent.

(2) Failure Analysis: Analysis of the one failure and four discontinuations revealed heavy carbonate deposits around the terminals, high internal pressure, and dryness of the failed cell. All but one of the discontinued cells showed adequate to very moist separator material. Migration was moderate to extreme.

9. Gulton 6.0 ah, One 10-cell Pack, 1.5-hour Orbit Period (Pack 51B):

a. Cell Description: Four of the 10 cells are from the same lot of cells used for the Test and Training (TETR) satellite. These four cells are of the TETR-B type which has only a single ceramic seal; the other six cells are of the RAE type which has double ceramic seals. In all other respects the 10 cells fit the general description of Paragraph I.A.

b. Test Parameters:

(1) Cycling Test Parameters:

(a) Test Temperature: 20° C.

(b) Discharge Current: 0.10 amperes.

(c) Charge Current: 0.30 amperes.

(2) Special Test: At random times the cycling had a 1.5-ampere discharge superimposed upon the regular cycle. This was done to simulate the type of operation encountered by the TETR Satellite.

c. Test Results:

(1) Performance on Cycling: Cycling started in February 1969. This pack has been discontinued after completing 21,193 cycles. The 1.5-ampere discharge was superimposed on the regular cycling condition at random times and for various lengths of time to simulate the conditions encountered in space. Limiting conditions were encountered on the four cells from the TETR satellite, indicating a deficiency in these cells; thus permitting the TETR project office to predict the performance that could be expected from the satellite. Because of the simulation of the satellite performance, no capacity checks were run on these cells.

(2) Five of the RAE type cells were replaced with TETR-C type cells in February 1970.

(3) Failure Analysis: Analysis of cell 2 and cell 7 showed that cell 2 had extreme migration and cell was moist as compared to cell 7. Cell 7's separator was deteriorated more than cell 2's and cell 7 had silver migration on the positive port of its header. Cell 7 had a single seal whereas cell 2 had a double seal.

10. Gulton 6.0 ah (San Marco), One 10-cell Pack:

a. Cell Description: See Paragraph I.A., page 12. The cells were purchased by NASA, GSFC, under LTV Purchase Order Number 833219 and were manufactured to GSFC's specification number S-761-P-6 with waivers given to the ratio and particle size requirement. Plates had heavier loading of active material and five cells have a higher amount of electrolyte than the other five cells. Initial evaluation test results and detailed cell descriptions are contained in NAD, Crane Report WQEC/C 75-1. Complete test results are contained in project report WQEC/C 76-10.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour
Temperature (°C)	20°
Depth of Discharge (%)	25
Pack Number	6M
Discontinuance (Cell)	4.2 (2)

c. Test Results:

(1) Performance on Cycling: Cycling began in September 1974 and the pack completed 5054 cycles before it was discontinued without a cell failure. The cells with the higher amount of electrolyte, exhibited higher end of charge voltages and pressures and had higher capacities. Three cells were chosen for analysis.

(2) Analysis: Migration was more severe in the cell with the higher amount of electrolyte. Small blisters and flaking of the active material, from the positive plate, was also observed on two cells, one each with the lower and higher amount of electrolyte.

(3) The following table compares chemical analysis of extracted (soxhlet) from the individual cell stacks, and from sample patches of the separator material.

Serial Number	1090	1096	1100
Amount Electrolyte (cc)	13.8	13.6	18.0
Total meq* KOH per extract (avg)	109.150	85.650	126.070
Total meq* K_2CO3 per extract (avg)	46.750	44.090	44.540
meq KOH per separator patch**	0.2380	0.2032	0.6854
meq K_2CO_3per separator patch	0.4928	0.3655	0.6032
Total volume (cc) per patch	1.3289	1.1773	1.1889
Wet Weight (g)***	0.2869	0.2582	0.3594
Dry Weight (g)***	0.1869	0.1668	0.1770

*meq is the abbreviation of milliequivalents.
**The separator patch data is an average of four patches sampled; one from the first third of the plate stack, two from the center, and one from the last third.
***Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.

11. Gulton 12.0 ah (OGO), Six 5-cell Packs:

a. Cell Description: See paragraph I.A., page 12.

b. Parameters and Capacity Checks:

Orbit Period			1.5-hour				
Temperature		0°	0°	25°	25°	40°	40°
Depth of Discharge		15%	25%	25%	40%	15%	25%
Pack Number		16B	101B	27B	96B	78A	90B
Precycling Capacity		14.86	14.20	14.10	13.30	6.80	11.40
88 Days	Disch #2	13.50	14.50	5.90	3.20	4.30	5.40
264 Days	Disch #2	14.20	12.90	4.10	5.00	3.30	3.70
440 Days	Disch #2	13.70	11.90	4.80		3.40	
616 Days	Disch #2	13.10	10.60	4.00		5.30	
792 Days	Disch #2	12.70	9.00	3.90			
968 Days	Disch #2	11.80	9.00				
1144 Days	Disch #2	11.50	8.80				
1320 Days	Disch #2	10.50	8.10				
1496 Days	Disch #2	10.30	7.80				
1672 Days	Disch #2	9.00	8.00				
1848 Days	Disch #2	10.20	7.68				
2024 Days	Disch #2	9.50	6.78				
2200 Days	Disch #2	9.20	6.20				
2376 Days	Disch #2	8.50					
2552 Days	Disch #2	9.00					
2729 Days	Disch #2	NA					
2905 Days	Disch #2	8.54					
3159 Days	Disch #2	8.12					

c. Test Results:

(1) Performance on Cycling: Cycling was started in January 1966. Pack 16B failed on cycle 50,727 following the shorting of three cells. No failures had occurred prior to environmental chamber overheating on cycle 50,431. Packs 27B, 96B, 78A, 90B, and 101B failed on cycles 14,250, 5152, 11,081, 5124, and 38,110 respectively.

(2) Failure Analysis: Analysis of the 19 failed cells showed the major cause of failure to be separator deterioration and migration of the negative plate material. Other conditions found were high internal pressure, blistering on the positive plates, electrolyte leakage, extraneous active material and external carbonate deposits on the negative terminal.

(3) The following table shows results of the chemical analysis of extracted electrolyte (soxhlet) from individual cell stacks, and from sample patches of the separator material from the last failed cell, serial number 1476, of Pack 16B.

Total meq* KOH per extract (avg.)	145.045
Total meq K_2CO_3 per extract (avg.)	104.280
meq KOH per separator patch **	.307
Total volume (cc) per patch	1.994
Wet Weight (g)***	.5961
Dry Weight (g)***	.4190

*meq is the abbreviation of milliequivalents.
**The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the center, and one from the last third.
***Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.

12. Gulton 20 ah (OAO, Orbiting Astronomical Observatory), One 10-cell Pack:

a. Cell Description: See paragraph I.A.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour
Temperature	10°
Depth of Discharge	15%
Pack Number	23B
88 Days (all Cells)	22.1
237 Days (Cells 1 & 2)	18.3
377 Days (Cells 5 & 6)	18.7

c. Test Results:

(1) Performance on Cycling: Cycling was started in February 1971. A cell failure occurred after 8248 cycles and the pack was discontinued after 12,803 cycles because of equipment failure which caused high cell pressure due to cell reversals.

13. Gulton 20 ah (OAO), One 5-cell Pack:

a. Cell Description: See paragraph II.A.

b. Parameters and Capacity Checks:

(1) Orbit Period: 1.5-hour.

(2) Test Temperature: 10° C.

(3) Depth of Discharge: 15%.

(4) Pack Number: 35B.

Pre Cycling	24.1
527 Days (Cell)	35.0 (5)
646 Days	31.8 (Pack Discontinued)

c. Test Results:

(1) Performance on Cycling: Cycling was started in February 1971. This pack completed 10,349 cycles with no cell failures prior to its discontinuation in November 1972, as requested by Goddard Space Flight Center.

14. Gulton 50 ah, Two 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These are rectangular, hermetically sealed, nickel-cadmium cells.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
95A	0° C	25
123A	40° C	25

c. Test Results:

(1) Performance on Cycling: Cycling was started in June 1964.

(a) Pack 95A failed on cycle 3227. The end-of-charge voltage increased and the end-of-charge current decreased steadily until the first cell failed on cycle 2643. The end-of-charge voltage then decreased and the end-of-charge current increased. The second cell failure occurred on cycle 2938 but this did not affect the operation of the pack. The separator in each of the first two failed cells was very dry and short circuits had occurred between the plates. Large blisters were present on the positive plates of the first failed cell and slight migration of material from the negative plates was evident in the second failed cell. The positive plates of the third failed cell showed large blisters, and separators impregnated with negative plate material.

(b) Pack 123A completed 1873 cycles when the first cell failure occurred. It had low voltage during the discharge and the recharge. Two additional cells shorted out while the pack was off cycling to remove the first failed cell. The separators of all three cells had deteriorated, resulting in shorts between the plates in two of these cells. The outside negative plates of two cells were stuck to the case. The three failed cells had bulged cases from high internal pressure; two of which were still under pressure, and the third had a carbonate deposit at the positive terminal.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

(a) Pack 95A:

Precycling		54.6
88 Days	Disch #2	59.6
176 Days	Disch #2	45.4

(b) The precycling capacity of pack 123A at 40° C was 27.9 ampere-hours. An equipment failure interrupted the first capacity check. The pack was then allowed to complete an additional month of cycling in order to let the cells stabilize again before receiving a capacity check, but the pack failed shortly before the capacity check was to have begun.

15. GE, 4.5 ah, (ERTS, Earth Resources Technology Satellite), One 10-cell Pack: 26E

a. Cell Description: The cells are cylindrical and the covers are stainless steel. The positive terminal is insulated from the cover by a ceramic seal and protrudes through the cover as a solder-type terminal. The negative terminal is a stainless steel tab to which the negative lead is soldered. There are three such tabs, any one of which may serve as the negative terminal. In addition, the bottom of the stainless steel container is slightly rounded (come shaped) in a convex manner. At the center of the dome is a threaded stud designed to affix the cell to a heat sinking fixture when installed in the satellite.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour
Temperature	20°
Depth of Discharge	13%
Pre-cycling Capacity	5.65
	5.90
131 Days (Cells 1 & 2)	7.10
137 Days (Cells 1 & 2)	7.00

c. Test Results:

(1) Performance on Cycling: Cycling started in February 1972 and was discontinued in September 1973 after completing 9423 cycles. This pack received excessive overcharge during cycles 4331 to 4631, due to environmental chamber malfunction in which the ambient temperature reached 28°C. This resulted in extreme cell imbalance for the remainder of its life test.

(2) Capacity Tests: Pack was scheduled for capacity test of 2 cells every 365 days. Special capacity tests were performed after 131 and 137 days as requested by the Project Technical Officer (GSFC).

(3) Failure Analysis (Cells 4 and 9): No pressure and severe migration.

16. GE 12.0 ah, One 5-cell Pack, 24-hour Orbit Period (Pack 93A):

a. Cell Description: The cells are rectangular in shape. The cell container and the cell cover are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude as 1/4-20 threaded posts.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 50%.

c. Test Results:

(1) Performance on Cycling: Cycling was started in March 1964. This pack failed on cycle 349.

(a) Average end-of-discharge voltage fell to less than 1.0 volt per cell under the original test parameters, but satisfactory operation was obtained when the percent of recharge was changed to 200 percent after cycle 57.

(b) In order to gain additional information the environmental temperature was raised from 25° C to 40° C after 173 cycles, with the charge voltage limit lowered to 1.45 volts per cell, average. At 40° C the pack did not operate as well. End-of-discharge voltages of the pack were low and quite variable. Two cells appeared to have failed on cycle 266. Since the first cell showed no defects upon failure analysis, the second cell was discharged completely and shorted overnight. It was then charged for 16 hours at the c/10 rate, and discharged again at the c/2 rate, all at 25° C. Its capacity was thus found to be 12.9 ampere-hours. It was returned to the pack and continued to cycle until the pack failed on cycle 349. The cycling behavoir of these two cells was attributed to insufficient charge acceptance. At no time was the on-charge voltage limit reached. The end-of-charge voltage remained close to 1.39 volts per cell at both temperatures.

(c) The four remaining cells (including the one returned cell) failed on cycle 349. All of the cells showed

separator deterioration and migration of the negative plate material. All cells showed signs of leakage around the terminals but no weight loss was detected.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Precycling		25° C	13.0
100 Days	Disch #2	25° C	7.60
231 Days	Disch #2	40° C	6.50
339 Days	Disch #2	40° C	5.00

17. Sonotone 3.0 ah (Triple Seal), Six 5-cell Packs:

a. Cell Description: The cell container and the cell cover of these cylindrical cells are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as the contacts for the negative terminal. The positive terminal is a solder type extension of the positive plate tab extending through the "negative" cover and insulated by a ceramic seal between two glass to metal seals to form a triple seal. Two ring indentations, about 1/32 inch deep, located about 1/2 inch from each end of the cell, were crimped after cell assembly to hold the element snugly in the cylindrical can to withstand vibration.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour					
Temperature	0°	0°	25°	25°	40°	40°
Depth of Discharge	15%	25%	25%	40%	15%	25%
Pack Number	43B	31B	3B	2B	26B	37B
Precycling Capacity	3.23	2.88	3.35	3.60	3.53	3.48
88 Days Disch #2	3.55	3.05	1.40	1.32	1.10	1.05
264 Days Disch #2	2.63	2.67	1.50	1.62	0.90	1.05
440 Days Disch #2	3.27	2.12	1.28			
616 Days Disch #2	3.00	2.67	1.30			
792 Days Disch #2	2.50	2.37				
968 Days Disch #2	2.32	2.27				
1144 Days Disch #2	2.10	2.10				
1320 Days Disch #2	2.35	1.85				
1496 Days Disch #2	2.70	1.95				
1672 Days Disch #2	2.37	1.37				

Orbit Period			1.5-hour			
Temperature	0°	0°	25°	25°	40°	40°
Depth of Discharge	15%	25%	25%	40%	15%	25%
Pack Number	43B	31B	3B	2B	26B	37B
1848 Days Disch #2	2.30					
2024 Days Disch #2	2.40					
2200 Days Disch #2	2.10					
2376 Days Disch #2	1.62					

c. Test Results:

(1) Performance on Cycling: Cycling was started in July 1965. Pack 43B has completed 37,969 cycles with one cell failure, and was discontinued in April 1972. Packs 31B, 3B, 2B, 26B and 37B failed on cycles 28,074, 11,726, 5399, 6289 and 5625, respectively.

(2) Failure Analysis: Analysis of the 18 failed or discontinued cells showed that the major causes of failure were due to separator deterioration, migration of negative plate material and excessive scoring. Other conditions found were weak positive tab-to-plate welds, electrolyte leakage, pierced separator by grid wires and plate tabs, high internal pressure and loosened positive active material.

18. Sonotone 3.5 ah, One 10-cell Pack:

a. Cell Description: These are cylindrical cells made of stainless steel. One stainless steel tab is welded to the cover for the negative connection. The positive terminal is an extension of the positive tab and is insulated from the negative cover by a ceramic seal. Two ring indentations, about 1/32 inch deep, located approximately 1/2 inch from either end of the cell can, were crimped after cell assembly to hold the element snugly in the cylindrical can.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hour
Temperature*		0°
Depth of Discharge		10%
Pack Number		15B
Precycling Capacity		3.18
88 Days	Disch #2	3.09
264 Days	Disch #2	2.95
440 Days	Disch #2	2.60
616 Days	Disch #2	2.77
792 Days	Disch #2	3.06
968 Days	Disch #2	2.73
1144 Days	Disch #2	2.68
1320 Days	Disch #2	2.60
1496 Days	Disch #2	2.77
1672 Days	Disch #2	2.25

* The test temperature was raised to 0° C after 22,900 cycles at -10° C at another test facility.

c. Test Results:

(1) Performance on Cycling: This pack completed 26,353 cycles prior to its discontinuation in June 1972 with no cell failures.

(a) The end-of-discharge voltage is 1.25 volts per cell but the percent of recharge shows some variations between 100 and 105 percent with a corresponding variation in the end-of-charge voltage.

d. Analysis: The 5 cells analyzed revealed green deposits around the positive terminals, high internal pressure, migration of cadmium through separator and separator deterioration. The cells had adequate moisture from electrolyte.

B. Silver-Zinc Types:

1. Astropower Division of McDonnell-Douglas 5.0 ah, Four 10-cell Packs:

a. These cells are sealed, but are provided with vent caps designed to vent the cell at a pressure of 40 psig. The cells are rectangular, with cell jars and cell covers molded of plastic. The zinc electrodes are encapsulated in an inorganic separator. The silver electrodes are separated from the inorganic separator by pellon. A small volume of epoxy potting material is poured into the cell jars just prior to the insertion of the electrodes and prevents movement of the electrodes. The cell top is then sealed to the cell jar by means of epoxy potting. The fill port is sealed by means of a screw and rubber O-ring.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Orbit Period
25B	20° C	25	1.5
25C	20° C	25	12.0
37D	40° C	25	12.0
47D	40° C	25	1.5

c. Test Results:

(1) Performance on Cycling: Cycling was started in December 1969 for Packs 25B and 47D; and in February 1970 for packs 25C and 37D. Packs 25B, 47D, 25C, and 37D failed on cycles 681, 2013, 567 and 391 cycles, respectively. As requested by NASA, Lewis Research Center, each pack was cycled until all cells failed.

(2) Failure Analysis: Analysis of the 40 failed cells showed that 22 cells had cracked inorganic separators due to a shape change of the zinc plate. Cells that were life-cycled at 40° C were dry compared to cells that were cycled at 20° C. The zinc plates of all the cells were found in a discharged condition. Only 10 cells had charged silver plates of which eight had been life-cycled at the 90-minute orbit period. Twenty-seven cells had carbonate deposits either around the negative or postive terminals, fill hole, or pressure relief valve.

(3) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Orbit Period	1.5-hour	
Temperature	20°	40°
Depth of Discharge	25%	25%
Pack Number	25B	47D
30 Days	1.18	3.50
60 Days		1.25
90 Days		1.25
120 Days		1.21

Orbit Period	12-hour	
Temperature	20°	40°
Depth of Discharge	25%	25%
Pack Number	25C	37D
50 Days	4.29	4.50
100 Days	0.12	1.75
150 Days	1.25	2.50
200 Days	4.07	1.25
250 Days	2.50	

2. Delco-Remy 25.0 ah, Two 5-cell Packs, 24-hour Orbit Period:

a. Cell Description:

(1) Pack 89A: Manufacturer's Standard Model. These cells are rectangular in shape with the cell containers and cell covers of nylon. The cells were epoxy potted into 5-cell packs by the manufacturer.

(2) Pack 75A: Same as standard model, Pack 89A, except for the addition of one percent of palladium to the positive plate material.

b. Test Parameters: Both packs were cycled at the test parameters listed below:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Orbit Period: 24 hours.

c. Test Results: Cycling was started in September 1964.

(1) Pack 89A (Standard Model) failed on cycle 80.

(2) Pack 75A (Palladium in Positive Plates) failed on cycle 32.

(3) Both packs were returned to the manufacturer for failure analysis.

3. Delco-Remy 25.0 ah, Two 5-cell Packs, 3-hour Orbit Period:

a. Cell Description:

(1) Pack 88B: Standard model as Pack 89A, except for the addition of one percent palladium in the positive plate material and the use of 2.2xH Radiation Application Company's separators.

(2) Pack 88C: Standard model as Pack 89A, except for the addition of one percent palladium in the positive plate material, and the use of a 45 percent NaOH solution as the electrolyte.

b. Test Parameters: Both packs were cycled at the test parameters listed below:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Orbit Period: 3 hours.

c. Test Results: Cycling was started in March 1965.

(1) Pack 88B: One cell failed on cycle 100. The remaining cells still functioned on cycle 120; at which time the pack was removed from test.

(2) Pack 88C: Pack 88C was discontinued on cycle 325.

(3) Both packs were returned to the manufacturer for analysis.

4. Delco-Remy 40.0 ah, One 5-cell Pack, 24-hour Orbit Period (Pack 75B):

a. Cell Description: Manufacturer's Standard Model. These cells are rectangular in shape with the cell containers and cell covers of nylon. These cells were epoxy potted into one 5-cell pack by the manufacturer.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Orbit Period: 24 hours.

c. Test Results: Cycling was started in October 1964. One cell failed while the pack was being prepared for test; a second cell failed on cycle 34. The remaining three cells still functioned on cycle 139; at which time the pack was removed from test.

5. Yardney 12.0 ah, One 10-cell Pack, 24-hour Orbit Period (Pack 9A):

a. Cell Description: These are vented cells, rectangular in shape, with the containers and covers of plastic material. They contained a limited amount of electrolyte. The cells were individually epoxy potted to hermetically seal them.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 42%.

(3) Orbit Period: 24 hours.

c. Test Results: Cycling was started in May 1965. One cell failed on cycle 53. Three additional cells failed on cycle 58. Following removal of the failed cells, the remaining cells did not respond to cycling; thus failing the pack.

C. Silver-Cadmium Types:

1. Electromite 7.0 ah (IMP), One 4-cell Pack:

a. Cell Description: The cells are rectangular in shape. The cells' containers are made of polystyrene and have a metal/plastic type of seal around their terminals. The cells were epoxy potted into a 4-cell pack.

b. Parameters and Capacity Checks:

Orbit Period	8-hour
Temperature	20°
Depth of Discharge	30%
Pack Number	104C
88 Days	4.10
264 Days	7.47
352 Days	8.13
528 Days	7.70

c. Test Results:

(1) Cell number 3 was found to have a high internal resistance and did not start life cycling.

(2) Performance on Cycling: This pack completed 1380 cycles with no cell failures prior to discontinuation in March 1972.

d. Analysis: Analysis of 4 discontinued cells revealed discharged positive plates, silver migration throughout separators and absorbers, excess electrolyte, and mushy material at the top of some cadmium plates.

2. ESB, Inc. 8.0 ah (Silver-Cadmium), One 5-cell Pack, 8-hour Orbit Period (Pack 1B):

a. Cell Description: These cells are rectangular in shape. The cell jars and cell covers are molded of a plastic material. Each cell is equipped with a pressure gage, auxiliary electrode, and cellophane bellows. The auxiliary electrode is used for gas recombination only. The plastic bellows, located in the bottom of the cell, is used to control the electrolyte level inside the cell.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 25%.

(3) Charge Voltage Limit: 1.51 ± 0.03 volts per cell, average.

(4) Orbit Period: 8 hours.

c. Test Results:

(1) Performance on Cycling: Cycling was started in September 1966. This pack failed in June 1970 after completing 3875 cycles.

(2) Failure Analysis: Analysis of the three cells showed one to develop high pressure resulting in the rupture of the plastic case. All cells showed excessive migration, loose active (mushy) material, separator deterioration, carbonate deposits around the outside negative terminal, and extreme brittleness of the positive plates.

(3) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

PRECYCLING AND CAPACITY CHECKS

Precycling 8.20 ah

Days	ah	Days	ah	Days	ah
80	12.67	106	10.17	175	12.27
211	11.63	238	12.43	290	12.23
304	11.50	332	9.07	365	4.77
392	3.73	425	2.87	453	4.83
475	5.90	506	7.53	533	7.77
568	2.40	601	6.73	629	6.77
661	6.40	694	5.17	722	4.80
754	3.57	787	3.40	815	4.03
841	3.90	868	3.33	902	4.43
935	4.20	999	3.63	1027	3.77
1094	2.67	1125	0.67	1158	6.63
1186	2.63	1213	4.00	1239	2.27
1277	2.47				

3. Yardney 3.0 ah (FR-1), One 9-cell Pack, 1.5-hour Orbit Period (Pack 2C):

a. Cell Description: These are vented cells, rectangular in shape, with the cell jars and cell covers molded of a plastic material. The cells were epoxy potted, by the manufacturer, into a metal container like that used in the French satellite FR-1.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 16.67%.

c. Test Results:

(1) Performance on Cycling: Cycling was started in September 1966. This pack completed 7039 cycles before several cells blew up destroying the pack. The end-of-discharge voltage had been very consistent at 1.08 volts per cell, average. The percent of recharge was very close to 100 percent.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Precycling Capacity	2.52
88 Day Discharge	*
176 Day Discharge	0.85
264 Day Discharge	0.87
352 Day Discharge	0.67

* First 88 day capacity check not performed because of equipment malfunction.

4. Yardney 5.0 ah, Four 5-cell Packs:

a. Cell Description: These are vented cells, rectangular in shape, with cell jars and cell covers molded of a plastic material. The separator material is pellon and cellophane. The cells were individually epoxy potted at the Goddard Space Flight Center to hermetically seal them.

b. Parameters and Capacity Checks:

Orbit Period	24-hour			
Temperature	0°	25°	25°	40°
Depth of Discharge	20%	20%	20%	20%
Pack Number	113B	77B	105B	128B
Precycling Capacity	4.08	5.02	4.95	6.47
100 Days	5.27	4.92		5.53
300 Days	4.67	4.67		
500 Days	4.03	1.25		
700 Days	4.03			
900 Days	5.42			
1100 Days	4.75			
1300 Days	6.10			

c. Test Results:

(1) Performance on Cycling: Cycling was started in January 1967. Packs 113B, 77B, 105B, and 128B failed on cycles 661, 77, 269, and 2542, respectively. (Prior to start of this test, Packs 77B and 105B were cycled at Goddard Space Flight Center for about 1 year. Most of that "cycling" was continuous float.)

(2) Failure Analysis: Analysis of the 12 failed cells showed that the failures were due to silver migration and separator deterioration which resulted in internally shorted cells.

5. Yardney 5.0 ah (C-3 Separator), Three 5-cell Packs, 24-hour Orbit Period:

a. Cell Description: These are vented cells, rectangular in shape, with the cell containers and cell covers of plastic material. The plates were insulated with C-3 separators. The cells were epoxy potted into 5-cell packs, at the Goddard Space Flight Center, in order to hermetically seal them.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
57B	0° C	20
21A	25° C	20
45A	40° C	20

c. Test Results:

(1) During cycle life, the end-of-discharge voltage of the packs, remained around 1.09 volts per cell, average; whereas the approximate percentage of recharge increased from 105 to 115 percent.

(2) Performance on Cycling: Cycling was started in September 1965. Packs 57B, 21A and 45A failed on cycles 267, 98 and 61 respectively.

(a) Pack 57B: One cell failed on cycle 138, and two on cycle 267.

(b) Pack 21A: One cell failed on cycle 90, and two on cycle 98.

(c) Pack 45A: The pack failed on cycle 61 because of severe leakage.

(d) The three packs were returned to Goddard Space Flight Center for analysis.

(3) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

PRECYCLING AND CAPACITY CHECKS

Orbit Period		24-hour	
Temperature	0°	25°	40°
Depth of Discharge	20%	20%	20%
Pack Number	57B	21A	45A
Precycling Capacity	3.67	5.80	6.00
100 Days	1.83	0.76	
200 Days	1.33		

6. Yardney 5.0 ah (Cellophane Separator), Two 5-cell Packs, 24-hour Orbit Period:

a. Cell Description: These are vented cells, rectangular in shape, with the cell jars and cell covers molded of a plastic material. The separator material is cellophane (C-19). One of the 5-cell packs (Pack 9C) had been subjected to gama radiation ($2x10^7$ rads). The cells were epoxy potted into 5-cell packs at the Goddard Space Flight Center.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
9C	25° C	20
33B*	25° C	20

* Control Pack

c. Test Results:

(1) Performance on Cycling: Cycling was started in October 1965. Cycling on Pack 9C was discontinued on cycle 34, and Pack 33B failed on cycle 720.

(a) Pack 9C: One cell failed on cycle 34. Since the separator material of the cells in this pack had been subjected to gama radiation, the pack was returned to Goddard Space Flight Center for analysis.

(b) Pack 33B: Two cells failed on cycle 720. While the pack was removed from cycling to disconnect the two failed cells, the three remaining cells failed. The pack was returned to Goddard Space Flight Center for analysis.

(2) Capacity Checks: The ampere-hour capacities of Pack 33B on the capacity check cycles are as follows:

100 Days	5.85	200 Days	6.13
300 Days	6.35	400 Days	5.48
500 Days	2.08	600 Days	1.88
700 Days	1.00		

7. Yardney 5.0 ah (Pellon Control Separator), One 5-cell Pack, 24-hour Orbit Period (Pack 69A):

a. Cell Description: These are vented cells, rectangular in shape, with the cell jars and cell covers molded of a plastic material. The plates of the cells are insulated with Pellon control separator material. Each cell has a pressure gage for monitoring internal cell pressure. The cells are individually epoxy potted to hermetically seal them.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 20%.

c. Test Results:

(1) Performance on Cycling: Cycling was started in October 1965. This pack failed on cycle 595 with its third cell failure, and was returned to Goddard Space Flight Center for analysis. There was very little variation in both the average end-of-discharge and end-of-charge cell voltages until the first cell failure at cycle 494. Also the internal pressure as read on the gages was very low.

(2) Capacity Checks: The ampere-hour capacities on the capacity check cycles are as follows:

100 Days	4.95
200 Days	4.17
300 Days	3.20
400 Days	4.42
500 Days	1.02
600 Days	2.08

8. Yardney 5.0 ah, Two 5-cell Packs, 8-hour Orbit Period:

a. Cell Description: These are vented cells, rectangular in shape, with cell jar and cell cover molded of a plastic material. The separator material is pellon and cellophane. The cells were individually epoxy potted at the Goddard Space Flight Center to hermetically seal them.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
114B	0° C	20
118C	25° C	20

c. Test Results:

(1) Performance on Cycling: Cycling was started in January 1967. Packs 114B and 118C failed on cycles 1496 and 1505 respectively.

(a) Pack 114B: Failure of three cells, all on cycle 1496 was due to silver migration and separator deterioration.

(b) Pack 118C: Failure of three cells, all due to silver migration and separator deterioration, occurred relatively close together--at cycles 1468, 1491 and 1505.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

PRECYCLING AND CAPACITY CHECKS

Orbit Period	8-hour	
Temperature	0°	25°
Depth of Discharge	20%	20%
Pack Number	114B	118C
Precycling Capacity	4.08	5.70
30 Days	4.00	5.37
60 Days	3.10	5.42
90 Days	2.50	5.32
120 Days	2.90	6.48
150 Days	2.98	6.25
180 Days	3.45	5.20
210 Days	2.48	6.55
240 Days	1.55	6.35
270 Days	1.75	5.83
300 Days	1.17	5.07
330 Days	1.65	6.33
360 Days	1.18	5.73
390 Days	2.40	5.68
420 Days	1.00	5.97
450 Days	0.90	3.32

9. Yardney 10 ah, One 5-cell Pack, 8-hour Orbit Period, (Pack 45D):

a. Cell Description: These are vented cells, rectangular in shape, with cell jars and cell covers molded of a plastic material. The cells were individually epoxy potted at the Goddard Space Flight Center in order to hermetically seal them.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 30%.

c. Test Results:

(1) Performance on Cycling: Cycling was started in May 1967. This pack failed on cycle 1759. Failure of the three cells, all due to silver migration and separator deterioration, occurred at cycles 1666, 1756 and 1759.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Precycling Capacity 13.50

30 Days	8.90	60 Days	9.60	90 Days	7.10
120 Days	8.45	150 Days	9.25	180 Days	8.50
210 Days	7.70	240 Days	10.00	270 Days	9.55
300 Days	10.60	330 Days	8.75	360 Days	5.60
390 Days	4.35	420 Days	5.60	450 Days	4.65
480 Days	3.15	510 Days	6.05	540 Days	3.15

10. Yardney 10 ah (ISEE-International Sun Earth Explorer, formerly IME), Silver-Cadmium, One 5-cell Pack:

a. Cell Description: The cell case is rectangular and made of plastic (polystyrene). The terminals are of gold-plated brass and sealed in epoxy potting. The separator wrapped around the negative (cadmium) plate is woven nylon; that about the positive (silver) plate is C-19 cellophane.

b. Parameters and Capacity Checks:

Orbit Period*	8.0-hours
Temperature (°C)	20°
Depth of Discharge (%)	25
Pack Number	57E
Precycling Capacity (average)	9.64
42 Days	8.02
62 Days	7.62
112 Days	8.03
163 Days	7.27
215 Days	6.01
273 Days**	3.72
323 Days	6.00
372 Days	4.90
423 Days***	5.23 D

*Orbit period changed to 12-hour period after 340 cycles.
**Cell 1 discontinued following capacity check.
***Cell 5 discontinued prior to capacity check.

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c. Test Results:

(1) Performance on Cycling: Cycling was started in August 1973 and the pack completed 1124 cycles, with two cells discontinued due to low capacity (cycles 822 and 1038), before it was discontinued.

(2) Failure Analysis: The pack was returned to the GSFC for analysis.

11. Yardney 11.0 ah, Two 10-cell Packs, 24-hour Orbit Period:

a. Cell Description: These are vented cells, rectangular in shape, with the cell jars and cell covers molded of a plastic material. The cells were epoxy potted into 10-cell packs at the Goddard Space Flight Center in order to hermetically seal them.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
45B	0° C	40
21B	25° C	40

c. Test Results:

(1) Performance on Cycling: Cycling was started in November 1966. Packs 45B and 21B were considered as having failed on cycles 121 and 69 respectively since three of the 10 cells in each pack had by then developed internal shorts. At the request of Goddard Space Flight Center, the packs were returned for analysis.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Temperature	0°	25°
Pack Number	45B	21B
Precycling Capacity	9.26	11.46
100 Days	5.91	

12. Yardney 11 ah, Two 5-cell Packs, 8-hour Orbit Period:

a. Cell Description: These are vented cells, rectangular in shape, with the cell jars and cell covers molded of a plastic material. The cells were epoxy potted into 5-cell packs at the Goddard Space Flight Center in order to hermetically seal them. The cells of pack 21C have pellon (2505K) separators, and those of pack 45C have woven nylon separators.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
21C	25° C	27
45C	25° C	27

c. Test Results:

(1) Performance on Cycling: Cycling was started in March 1967. Packs 21C and 45C failed on cycles 37 and 70 respectively. Several cells in each pack developed high internal pressure which resulted in breakage of those cell jars and the epoxy potting.

(2) Capacity Checks: The precycling capacities for Packs 21C and 45C were 8.40 and 9.45 ampere-hours respectively.

13. Yardney 11.0 ah (Silver-Cadmium), three 5-cell Packs:

a. Cell Description: These cells are rectangular in shape. The cell jars and covers are made of a plastic material. An auxiliary electrode (adhydrode type) was installed in each cell by Goddard Space Flight Center before being individually epoxy potted with a wrap of fiberglass material to hermetically seal and strengthen them. The auxiliary electrode is used for gas recombination only.

b. Parameters and Capacity Checks:

Orbit Period		24-hour	
Temperature	0°	25°	40°
Depth of Discharge	18%	18%	18%
Auxiliary Electrode Resistor (Ohms)	1	1	1
Pack Number	57D	69B	33C
100 Days	4.10	7.55	8.70
300 Days	4.10	3.50	5.15
450 Days	8.35	1.85	
600 Days	3.95		
800 Days	2.90		
1000 Days	6.75		
1200 Days	3.00		
1400 Days	4.55		
1600 Days	3.65		

c. Test Results:

(1) Performance on Cycling: Cycling was started in February 1968. Packs 57D, 69B and 33C failed on cycles 1740, 507 and 447 respectively.

(2) Failure Analysis: Analysis of the nine failed cells showed the major cause of failure to be loose negative material, migration of the negative plate material and separator deterioration. Other conditions found were weak tab-to-plate welds and electrolyte leakage.

14. Yardney 12.0 ah, Two 10-cell Packs, 24-hour Orbit Period:

a. Cell Description: These are double sealed rectangular cells. That is, each sealed polystyrene cell is encased in a hermetically sealed stainless steel container.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
57A	0° C	50
33A	40° C	50

c. Test Results:

(1) Performance on Cycling: Cycling was started in February 1964. These packs failed on cycles 168 and 210.

(a) Pack 57A: Low end-of-discharge cell voltages began on cycle 31 and continued erratically until the pack failed on cycle 168. Although cell voltages had frequently fallen below the 0.5 volt failure point, they had not been classed as failures earlier because of their erratic behavoir. After completion of 162 cycles, electrolyte had leaked out and formed a pool over the tops of the cells, thus shorting them out. The 10 cells were cleaned, after which seven were returned to cycling. All seven cells leaked again after six additional cycling.

(b) Pack 33A: The plateau voltage of the non-failing cells on discharge was fairly steady at about 1.06 volts per cell for the first 110 cycles with little or no drop off at the end of discharge. Thereafter, the plateau voltage began to drop steadily and the end-of-discharge voltage became quite erratic. This pack failed on cycle 210. All of the failed cells had dried out because of electrolyte leakage.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Pack Number		57A	33A
Precycling Capacity		13.8	13.5
140 Days	Disch #2	8.6	12.0

15. Yardney 12.0 ah, Three 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Discription: These are vented cells, rectangular in shape, with cell jars and cell covers molded of a plastic material. The cells were individually epoxy potted to hermetically seal them.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
85B	-20° C	25
97B	0° C	25
82B	25° C	25

c. Test Results:

(1) Performance on Cycling: Cycling was stated in January 1966. Pack 85B failed on cycle 2375, pack 97B on cycle 4481, and pack 82B on cycle 4559. Due to poor charge acceptance at -20° C the end-of-discharge voltage dropped below 0.8 volt per cell. On cycle 214, the test temperature of pack 85B was increased to 40° C with a voltage limit of 1.55 volts per cell, average. The pack then cycled satisfactorily with the end-of-discharge voltage being approximately 1.06 volts per cell. The end-of-discharge voltage of pack 97B and 82B was also approximately 1.06 volts per cell.

(2) Failure Analysis: Analysis of the 10 failed cells showed the cause of failure to be silver penetration of the separator resulting in an internally shorted cell.

(3) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

PRECYCLING AND CAPACITY CHECKS

Orbit Period	1.5-hour		
Temperature	-20°*	0°	25°
Depth of Discharge	25%	25%	25%
Pack Number	85B	97B	82B
Precycling Capacity	5.40	9.00	13.30
88 Days	13.80	**	4.50
176 Days	8.70	3.50	2.90
264 Days	13.70	5.70	3.30
352 Days	9.60	3.70	

* Cycle 214 changed to 40° C

** Capacity check not performed due to low voltage on several cells.

IV. CELLS USING SOPHISTICATED CHARGE CONTROL METHODS AND DEVICES

A. Auxiliary Electrode:

1. Eagle-Picher 6.0 ah, (Nickel-Cadmium, Separator Test), Eight 6-cell Packs, One 8-cell Pack and One 6-cell Replacement Pack:

a. Cell Description: See Paragraph I.A., page 12.

b. Purpose of Test: This experiment is designed to test various types of separator material (listed in following table) while on life cycling. All the usual parameters (temperature, depth of discharge, and orbit period) are held constant.

c. Parameters and Capacity Checks:

Orbit Period	1.5-hour									
Temperature	20°	20°	20°	20°	20°	20°	20°	20°	20°	20°
Depth of Discharge	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
Trip Voltage (MV)	No auxiliary electrode control, 1.55 volt limit for protection.									
Auxiliary Electrode Resistors (Ohms)	200	200	200	200	200	200	200	200	200	200
Type of Separator	(1)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Pack Number	2D	2E*	14E	26D	38F	22C	46C	49B	31C	25D
88 Days		6.45			6.54	7.44	7.44	7.35	7.14	7.50**
176 Days		3.39			5.25	6.60	7.41	7.44	6.30	7.26
264 Days		6.54			5.40	6.54	7.50	6.84	6.75	7.41
352 Days		7.26			6.06	5.76	7.26	6.99	5.34	6.99

(1) Kendall, E1451AR, ppl.
(2) Kendall, E1451W, ppl.
(3) Kendall, E1451T, ppl.
(4) GAF, Wex 1242AR, ppl.
(5) GAF, Wex 1242W, ppl.
(6) Pellon, 2505 K4 AR, nylon.
(7) Pellon, 2505 K4 W, nylon.
(8) Pellon, FT 2140 AR, ppl.
(9) Hercules, RT-37-2665-15, ppl.

* Replaced 2D which failed early.
** Low cell #2 Discharge.

d. Test Results:

(1) Performance on Cycling:
Cycling was started in February 1971. Packs 2D, 14E and 26D have failed and have been sent to Goddard Space Flight Center after completing 376,997, and 25 cycles respectively. Packs 2E, 38F, 22C, 46C, 49B, 31C and 25D have completed testing with portions of each respective pack completing 5801, 5903, 5950, 5888, 5965, 5936 and 5940 cycles. Each of these latter packs had one cell removed and the separator samples, of known dimensions and weight, were soaked in water for 48 hours and then tested for carbonates at approximately 1500-cycle intervals. Tabulation of the results of these tests follows. The averages pertain to four samples removed from each cell and each is defined as follows:

Avg. Area: Average area of the four separator samples.

Avg. Wet Wt.: Average weight of the four separator samples upon removal from cell.

Avg. Dry Wt.: Average weight of the four separator samples following titration and air drying.

Avg. KOH meq: Average milliequivalents of KOH soaked from each of separator samples.

Avg K_2CO_3 meq: Average milliequivalents of K_2CO_3 soaked from each of four separator samples.

% K_2CO_3 (meq): $$\% K_2CO_3 = \frac{\text{Avg. } K_2CO_3 \text{ meq}}{\text{Avg. KOH meq} + \text{Avg. } K_2CO_3 \text{ meq}} \times 10^2$$

(2) On the 3000-cycle analysis, one of the four samples taken from packs 31C and 38F, respectively, indicated no carbonate whatsoever. The "zero-carbonate" sample from pack 38F was taken from an area where a negative plate had been connected to the positive bus. Though not so noted, the "zero-carbonate" sample of pack 31C is believed to have resulted from a similar condition.

(3) For further reporting see the "Minutes of the 1972 Goddard Battery Workshop", report by Mr. Hennigan.

		2E	38F	22C	46C	49B	31C	25D
1500 CYCLES	Avg Area cm^2	35.0	34.4	33.9	34.1	35.3	35.1	33.5
	Avg Wet Wt g	0.6613	0.4436	0.5436	0.5658	0.6218	0.3988	0.4244
	Avg Dry Wt g	0.2645	0.2716	0.3382	0.2606	0.2726	0.2934	0.1944
	Avg KOH meq	1.071	0.340	0.354	0.713	0.793	0.268	0.596
	Avg K_2CO_3 meq	1.350	0.711	0.693	1.112	1.283	0.352	0.857
	$\%K_2CO_3$ (meq)	55.76	67.65	66.19	60.93	61.80	56.77	58.98
3000 CYCLES	Avg Area cm^2	35.5	34.8	34.6	34.4	34.8	34.7	30.5
	Avg Wet Wt g	0.6651	0.4880	0.4670	0.6321	0.6652	0.4740	0.4129
	Avg Dry Wt g	0.2586	0.4081	0.3634	0.3116	0.3594	0.3759	0.2011
	Avg KOH meq	1.089	0.220	0.306	0.670	0.719	0.183	0.601
	Avg K_2CO_3 meq	1.338	0.394	0.481	1.023	1.075	0.346	0.909
	$\%K_2CO_3$ (meq)	55.13	64.17	61.12	60.43	59.92	65.41	60.20
4500 CYCLES	Avg Area cm^2	35.2	35.8	33.2	35.8	36.1	35.8	34.6
	Avg Wet Wt g	0.6716	0.5877	0.6476	0.6196	0.7226	0.4410	0.4457
	Avg Dry Wt g	0.2563	0.4704	0.5090	0.3700	0.4251	0.3306	0.2858
	Avg KOH meq	0.809	0.262	0.276	0.652	0.504	0.191	0.746
	Avg K_2CO_3 meq	1.632	0.534	0.766	0.942	1.194	0.438	0.893
	$\%K_2CO_3$ (meq)	66.68	67.09	73.51	59.10	70.32	69.63	54.48

		2E	38F	22C	46C	49B	31C	25D
6000 CYCLES	Avg Area cm^2	35.7	36.3	35.9	35.0	36.1	35.2	31.6
	Avg Wet Wt g	0.5817	0.7094	0.4518	0.6590	0.6089	0.4944	0.2691
	Avg Dry Wt g	0.2432	0.5669	0.3801	0.3852	0.3730	0.3879	0.1869
	Avg KOH meq	0.931	0.323	0.189	0.589	0.563	0.074	0.238
	Avg K_2CO_3 meq	1.117	0.589	0.253	0.936	0.877	0.261	0.441
	$\%K_2CO_3$ (meq)	54.54	64.58	57.24	61.38	60.90	77.91	64.95

2. Eagle-Picher, 6.0 ah, Three 5-cell Packs:

a. Cell Description: See paragraph I.A.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour		
Temperature	0°	20°	40°
Depth of Discharge	40%	40%	40%
Auxiliary Electrode Trip Voltage (MV)	500	500	500
Auxiliary Electrode Resistor (Ohms)	680	680	680
Pack Number	53C*	65C*	42D
Precycling Capacity	8.26	8.40	8.54
152 Days	7.12	3.04 F	F
330 Days	8.48		
500 Days	NA		
592 Days	3.38 F		

* Percent recharge set at 102.5.

F - Failed.

c. Test Results:

(1) Performance on Cycling: Cycling was started in September 1971. Packs 42D and 65C failed after 95 and 4227 cycles, respectively. Pack 53C had one cell failure after 9998 cycles and the pack was discontinued after 10,325.

(a) Pack 42D, cycling at 40°C, could not exceed 105 percent recharge without experiencing high pressures and this amount of recharge would not sustain the cells at this temperature.

(b) Packs 53C and 65C also were put on a set amount of recharge due to high cell voltages and pressures.

(2) Failure Analysis: Analysis of the nine cells showed weak negative tab-to-plate welds, heavy migration, and moderate separator deterioration.

3. Gulton 6.0 ah (Nickel-Cadmium), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude through the cover as solder type terminals. A stainless steel tab is welded to the cell cover for the auxiliary electrode terminal. The auxiliary electrode is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal. Recharge percentage may be adjusted by adjusting the voltage level of the auxiliary electrode detector circuit and/or varying the auxiliary electrode resistance while maintaining a fixed voltage to the detector circuit.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms) 1	2	3	4	5
59A	0° C	25	150	10	10	10	10	10
71A	0° C	40	150	10	10	10	10	10
23A	25° C	25	300	12	12	20	29	24
11A	25° C	40	300	24	24	10	8	24
35A	40° C	15	70	47	47	47	47	47
47A	40° C	25	300	11	11	12	11	11

c. Test Results:

(1) Performance on Cycling: Cycling was started in February 1965. Pack failures occurred on cycle 14,863 for pack 59A, on cycle 5753 for pack 71A, on cycle 15,713 for pack 23A, on cycle 7743 for pack 11A, on cycle 12,511 for pack 35A and on cycle 5502 for pack 47A.

(2) Failure Analysis: Analysis of 19 failed cells showed that the major cause of failure was due to separator deterioration, migration of the negative plate material, and electrolyte leakage which ranged from 1.3 to 8.7 grams. Other conditions found in the cell were high internal pressure, blisters on the positive plates, extraneous positive material, ceramic short, and weak tab-to-plate welds.

(3) Capacity Checks: The ampere-hour capacities on the capacity check cycles are as follows:

Orbit Period			1.5-hour				
Temperature		0°	0°	25°	25°	40°	40°
Depth of Discharge		25%	40%	25%	40%	15%	25%
Pack Number		59A	71A	23A	11A	35A	47A
100 Cycles		7.15	7.25	3.40	4.12	2.95	3.65
88 Days	Disch #2	7.00	7.50	5.95	5.50	2.25	2.10
176 Days	Disch #2	3.50	7.00	3.85	3.15	1.60	1.70
264 Days	Disch #2	6.75	5.65	5.20	6.20	1.85	2.25
352 Days	Disch #2	6.50		4.00	4.35	2.00	
440 Days	Disch #2	6.85		4.45	3.95	2.75	
528 Days	Disch #2	7.00		4.20	2.75	2.80	
616 Days	Disch #2	6.35		3.85		2.20	
704 Days	Disch #2	6.10		4.40		1.50	
792 Days	Disch #2	5.50		2.45		2.55	
880 Days	Disch #2	2.50		1.50			
968 Days	Disch #2			1.00			
1056 Days	Disch #2			0.78			

4. Gulton 6.0 ah (Nickel-Cadmium), Three 5-cell Packs:

a. Cell Description: See Paragraph I.A., page 12.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hour	
Temperature	20°	20°	20°
Depth of Discharge	25%	25%	25%
Trip Voltage (MV)*	150	300	450
Resistors (Ohms)	6.8	6.8	6.8
Pack Number	28D	40D	52D
Precycling Capacity	7.65	7.74	7.65
88 Days	6.96	8.60	7.65
264 Days	4.35	8.95	7.95
440 Days	6.25	8.45	6.15
616 Days	2.20	7.00	4.60

* The trip voltage levels of packs 40D and 52D were changed to 250 and 300 MV, respectively.

Packs were placed on voltage limit control 6-20-71.

c. Test Results:

(1) Performance on Cycling: Cycling was started in April 1970. Packs 28D, 40D and 52D completed 10,804, 10,846, and 10,446 cycles, respectively, with no cell failures, prior to their discontinuation in May 1972 at the request of Goddard Space Flight Center.

d. Analysis: Though not failed, four cells were given post mortem analysis which revealed evidence of high pressure, limited blistering of positive plates, and migration and separator deterioration.

5. Gulton 6.0 ah (Nickel-Cadmium), Three 5-cell Packs:

a. Cell Description: See paragraph I.A.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hour	
Temperature	*	*	*
Depth of Discharge	40%	25%	15%
Trip Voltage	170	170	170
Auxiliary Electrode Resistor (Ohms)	6.8	6.8	6.8
Pack Number	48B	24C	60B**
Precycling Capacity	7.40	7.20	7.45
88 Days	3.68	6.90	7.02
264 Days	3.76	6.30	6.45
440 Days	3.84 F	3.25	6.33
616 Days		3.10	5.61
792 Days		2.55	4.68
968 Days		3.15 F	3.21
1144 Days			2.25
1320 Days			3.02
1496 Days			2.07
1672 Days			1.62
1848 Days			0.75
1936 Days			1.23 F

F - Failed.

* These cells are in an ambient temperature which varies sinusoidally from 0° to 40° C within a period of 24 hours. After 260 days, the temperature cycle period was increased to 48 hours; all other parameters remained the same. The temperature cycle is stopped at 25° C for capacity checks.

** Test temperature was changed to a constant 20° C on 3-18-71 after more than 23,000 cycles.

c. Test Results:

(1) Performance on Cycling: Cycling was started in April 1967. Packs 48B and 24C failed on cycles 6156 and 17,328, respectively. Pack 30B failed after completing 32,645 cycles with three cell failures.

(a) From the test data obtained to date the indications are that the auxiliary electrode, when used for charge control, operates satisfactorily over the range of temperatures under which these packs were operated, without temperature compensation.

(2) Failure Analysis: Analysis of the nine failed cells showed the major causes of failure to be shorting between the positive and auxiliary electrodes due to insufficient separator material between the edge of the positive plates and the auxiliary electrode. Separator deterioration, migration of negative material and blistered positive plates also were major reasons for failure. Other conditions found were high pressure, electrolyte leakage, weak weld between the auxiliary electrode and the bracket on the inside wall of the cell, and shorting between plates within the cell stack. This latter shorting is due to separator deterioration. The weak welds may result from failure to remove active material from the grid of the auxiliary electrode prior to welding to the bracket.

6. Gulton 10.0 ah (Nickel-Cadmium), Three 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and cover are made of plastic. Each cell is fitted with a pressure gage. Both terminals protrude through the cell cover as solder type terminals. Each cell contains an adhydrode as a signal electrode and an American Cyanamid type AB-6X electrode for a scavenger electrode. The adhydrode is located in the center of the plate stack and welded to the base of the pressure gage fitting. The scavenger electrode is located on the side of the plate stack and connected internally to the negative material. Each 5-cell pack was epoxy potted into a metal container by Gulton Industries in order to hermetically seal the cells. The cells were developed under Contract NAS 5-10241.

b. Test Parameters

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts).	Auxiliary Electrode Resistors (Ohms)
20B	0° C	25	250	47
8B	25° C	25	250	47
6B	40° C	25	250	47

c. Test Results:

(1) Performance on Cycling: Cycling was started in November 1967. Pack 20B failed during the precycling capacity, pack 8B on cycle 2414, and pack 6B on cycle 602. All three packs were returned to Goddard Space Flight Center for analysis.

7. Gulton 20 ah (OAO), (Nickel-Cadmium), Three 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cover by ceramic seals and protrude through the cover as solder type terminals. Each ceramic seal is set in an expansion joint to remove the stress placed on the seal by the movement of the plates or cell cover. A stainless steel tab is welded to the cover for the auxiliary electrode terminal. The auxiliary electrode is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and negative terminal. This type cell was used in the OAO satellites.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms)
58B	0° C	15	40	6.8
12C	25° C	15	200	6.8
36B	40° C	15	200	6.8

(1) The following changes in the charge current were made in order to obtain more data on the auxiliary electrode control.

Pack Number	Cycle	Current	Cycle	Current	Cycle	Current
58B	234	9.5 Amps	794	19.5 Amps	1518	10 Amps
12C	85	9.6 Amps	262	19.5 Amps	629	10 Amps
36B	51	9.6 Amps	226	19.6 Amps	698	10 Amps

c. Test Results:

(1) Performance on Cycling: Cycling was started in March 1967. Pack 36B completed cycle 2740 on 5 September 1967 without any cell failures, at which time cycling was discontinued. Packs 58B and 12C completed 4026 and 4934 cycles respectively on

25 January 1968 without any cell failures, at which time cycling was discontinued on both packs. The three packs were returned to Goddard Space Flight Center for evaluation.

(2) Capacity Checks: The ampere-hour capacities on the capacity check cycles are as follows:

Orbit Period	1.5-hour		
Temperature	0°	25°	40°
Depth of Discharge	15%	15%	15%
Pack Number	58B	12C	36B
30 Days	*	14.7	*
88 Days	20.0	20.6	10.7
176 Days	22.0	20.5	
264 Days		22.4	

* Capacity checks were not run due to the changes in charge rate.

8. Gulton 20 ah (OAO), (Nickel-Cadmium), Three 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description:

(1) Each pack consists of three conventional cells, two cells with an auxiliary electrode, and a coulometer. Both types of cells, used in OAO satellites, are rectangular in shape. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cover by ceramic seals and protrude through the cover as solder type terminals. Each ceramic seal is set in an expansion joint to remove the stress placed on the seal by the movement of the plates or cell covers.

(a) The cells with auxiliary electrode have a stainless steel tab welded to the cover for the auxiliary electrode terminal. The auxiliary electrode is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal.

(b) The coulometers are of the cadmium-cadmium type and are rated at 20 ampere-hours. They are of the same case construction as the cells described above.

(2) These packs are cycled with auxiliary electrode control. A coulometer on each pack is monitored to note how well the two charge control devices in the pack function.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms)
58C	*	40	250	47
36C	*	25	250	47
12D	*	15	250	47

* These cells are in an ambient temperature which varies sinusoidally from 0° to 40° C within a cycle period of 48 hours.

c. Test Results:

(1) Performance on Cycling: Cycling was started in February 1968. Packs 58C and 36C failed on cycles 131 and 966, respectively; but Pack 12D was discontinued on cycle 7262. All three packs were returned to Goddard Space Flight Center for failure analysis.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Pack Number	58C	36C	12D
Temperature	*	*	*
Precycling Capacity	22.7	22.9	25.3
88 Days			13.7
176 Days			6.3
264 Days			5.8
352 Days			5.7
440 Days			6.9

* The temperature cycle is stopped at 25° C for each capacity check cycle.

9. Gulton 20 ah (OAO), (Nickel-Cadmium, Precharge), One 6-cell Pack, 1.5-hour Orbit Period (Pack 48C):

a. Cell Description:

(1) These cells are rectangular in shape. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cover by ceramic seals and protrude through the cover as solder type terminals. Each ceramic seal is set in an expansion joint to remove the stress placed on the seal by the movement of the plates or cell cover. A stainless steel tab is welded to the cover for the auxiliary electrode terminal. The auxiliary electrode is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and negative terminal. This type cell was used in OAO satellites.

(2) Each cell was fitted with either a pressure gage or pressure transducer. Before cycle was started, the amount of precharged cadmium material was adjusted so that cells 2 and 3 had 0.0 ah, cells 4 and 5 had 4.0 ah and cells 1 and 6 had 8.0 ah. This was accomplished by a procedure specified by Goddard Space Flight Center.

b. Test Parameters:

(1) Test Temperature: These cells are in an ambient temperature which varies sinusoidally from 0° to 40° C within a period of 48 hours.

(2) Depth of Discharge: 25%.

(3) Trip Voltage Level: 300 Millivolts.

(4) Auxiliary Electrode Resistors: 51 Ohms.

c. Test Results:

(1) Performance on Cycling: Cycling started in May 1969. Pack 48C was terminated after completing 1984 cycles. On cycles 586 and 627 cell number 1 (8.0 ah of precharged cadmium) developed high internal pressure. In both cases the gas pressure was allowed to decrease while the cells were on open circuit. On cycle 627, four ampere-hours of precharged cadmium were removed and the cell returned to cycling. No further difficulties with high pressure were encountered with this cell. Cell number 5 failed after 1733 cycles, and cell 2 failed after 1984 cycles.

(2) Failure Analysis: Failure analysis was performed on three cells. The analysis showed migration of negative material, separator deterioration, high pressure, carbonate deposits at the positive terminal, and blistering of the positive plates. In addition, samples of positive and negative plates were removed from these three cells plus a fourth, nonfailed, cell. Individual plate capacities on these four samples showed the positive plates to equal or exceed the capacity of the adjacent negative plates in 75 percent of the samples. The cadmium to nickel ratio in such samples ranged from 0.74 to 1.00. Such negative limiting leads to high pressure during charge due to hydrogen evolution which cannot be recombined.

(3) Capacity Checks: The ampere-hour capacity, after 461 cycles, was 8.67 ampere-hours.

10. Gulton 20 ah (OAO, Nickel-Cadmium, Precharge), One 6-cell Pack:

a. Cell Description: Each cell was fitted with a pressure gage, and a pressure transducer. Prior to cycling, the cells were subjected to a series of tests including conditioning, capacity calibration, and overcharge. The final step of the series was an adjustment of precharged cadmium material. Two cells had -3.0 ah, two had 0.0 ah and two had + 3.0 ah of precharge. In negative precharging, the desired ampere-hour equivalent of oxygen is added to fully charged cells. In positive precharging, the desired ampere-hour equivalent of oxygen is removed from the cells as they charge. This preliminary procedure was specified by Goddard Space Flight Center. The methods of precharge adjustment were developed by NAD Crane.

b. Parameters and Capacity Checks:

(1) Precycling capacity was determined prior to precharge adjustment. The capacity of each cell is determined by the time to reach 0.5 volt.

(2) Pack Number: 48D.

(3) Orbit Period: 1.5-hour.

(4) Test Temperature: 20°C.

(5) Depth of Discharge: 25%.

(6) Trip Voltage Level: 300 Millivolts. (Placed on voltage limit control 2-4-71 per instructions from Goddard Space Flight Center.)

(7) Auxiliary Electrode Resistor: 47 Ohms.

	Negative Cell #1 S/N 475	Precharge Cell #4 S/N 953	Zero Precharge Cell #2 S/N 481	Zero Precharge Cell #5 S/N 961	Positive Precharge Cell #3 S/N 493	Positive Precharge Cell #6 S/N 959
Precycling Capacity	25.60	25.60	25.60	24.80	25.50	25.10
88 Days (Cycle 1378)	14.17	11.17	12.67	14.33	12.50	15.00
176 Days (Cycle 2811)	9.20	6.80	8.80	9.00	8.30	10.20
352 Days (Cycle 5790)	6.70	5.80	8.50	7.30	7.50	10.07
528 Days (Cycle 8529)	8.16	7.50	9.66	9.50	9.16	11.33
707 Days (Cycle 11526)	16.66	15.00	16.16	17.66	13.83	15.00
802 Days (Cycle 12834)	14.33 F	13.50 F	14.66 F	15.16 F	15.50 F	16.00 F
Failure Cycle	13,784	13,968	13,848	13,238	13,057	13,288

F - Failed.

c. Test Results:

(1) Performance on Cycling: Cycling was started in July 1970. Pack 48D failed after 13,968 cycles. The pack was placed on voltage limit control (1.420 V/C) after 2845 cycles. The limits were increased to 1.440 V/C (cycle 7011) and 1.46 V/C (cycle 8633) in an attempt to increase the capacity. Each cell failed and the cell failure cycle number is listed under the capacity check information.

d. Failure Analysis: All the cells were shorted out. The shorts occurred at the lower corners of the cells and were due to migration and separator deterioration.

11. GE 6.0 ah (Nickel-Cadmium), Two 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and the cell cover are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude through the cover as solder type terminals. A stainless steel tab, welded to the cover, provides the terminal for the auxiliary electrode. The auxiliary electrode (Type C) is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal. The plates of the cells of Pack 9G are separated with a material called "Chemsorb" whereas those of the cells of Pack 27C are separated with "Pellon" used as the standard for this test.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors	Separator
9G	40° C	25	500	510 Ohms	Chemsorb
27C	40° C	25	500	510 Ohms	Pellon

c. Test Results:

(1) Performance on Cycling: Cycling was started in November 1966.

(a) Pack 9G: This pack failed on cycle 143 at which time three cells shorted internally. In one of these cells the auxiliary electrode shorted to the positive terminal.

1. One of the failed cells was returned to Goddard Space Flight Center for detailed analysis of the separator material "Chemsorb".

2. Failure analysis of the other two cells showed that distortion of the cases and covers, caused by high internal pressure, moved the corner of the plates opposite the tabs in one cell into the bus of the plates of opposite polarity; and in the other cell the positive plates came into contact with the cell case, thereby shorting the auxiliary electrode to the positive terminal. Both cells also showed separator deterioration.

(b) Pack 27C: The two cells which failed on cycle 496 showed signs of high internal pressure and migration of negative plate material. Cycling was discontinued on cycle 559.

(2) Capacity Checks:

(a) Precycling consisted of a charge at the cycling rate until the auxiliary electrode voltage of any of the five cells reached 500 millivolts followed by a discharge at the cycling rate to 1.00 volt per cell, average. Each pack delivered 3.15 ampere-hours on precycling.

(b) Capacity check cycles were to be identical to the precycling check cycle but none were made because of failure or discontinuance of cycling before first scheduled capacity check.

12. GE 6.0 ah (Nickel-Cadmium), Eight 5-cell Packs:

a. Cell Description: The cells of four packs contain Type C auxiliary electrode (Code AB13), which is a sintered nickel plaque with a Teflon coating; whereas, those of the other four packs contain Type B auxiliary electrode (Code AB14), which is a platinum loaded sintered nickel plaque with no Teflon coating.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour							
Temperature	0°	0°	25°	25°	40°	40°	*	*
Depth of Discharge	25%	25%	25%	25%	25%	25%	25%	25%
Trip Voltage (MV)	250	250	250	250	250	250	250	250
Auxiliary Electrode Resistor (Ohms)	82	82	82	82	82	82	82	82
Pack Number	52C	50B	5B	17B	6C	42C	62B	65B
Auxiliary Electrode	C	B	C	B	C	B	C	B
Precycling Capacity	7.05	7.20	7.50	7.38	5.55	5.10	7.40	7.70
88 Days	6.50	7.40	3.20	4.70	1.50	1.50	1.15 D**	5.80
264 Days	3.10	7.25	1.50	2.20	2.10	2.20	5.55 ***	2.65
440 Days	3.35	7.05	1.75	1.90	2.50 F	2.10 D**	5.60	2.00
616 Days	1.45 F	6.60	2.00	1.00			6.00	3.35
792 Days		6.35	2.45 D**	1.77			NA	1.71 D
968 Days		6.00		1.65 F			F	
1144 Days		5.65						
1320 Days		4.25						
1496 Days		3.10						
1584 Days		3.35 F						

* These cells are in an ambient temperature which varies sinusoidally from 0° to 40°C within a cycle period of 48 hours. The temperature cycle is stopped at 25°C for each capacity check cycle.

** These cells were removed from automatic cycling for a series of special tests as instructed by Goddard Space Flight Center.

*** Placed on voltage limit control (4-6-71) at 20°C due to auxiliary electrode allowing cell voltage to go too high.

D - Discontinued F - Failed.

c. Test Results:

(1) Performance on Cycling: Cycling started in June 1968. Pack 62B was discontinued after 2367 cycles and then started again using a voltage limit control and completed 14,406 cycles before pack failure. Packs 6C, 50B, 52C and 17B failed after 8072, 29,206, 9954 and 15,938 cycles, respectively. Packs 42C, 5B and 65B were discontinued after 9047, 13,254 and 14,392 cycles, respectively, due to low capacity. Failures and discontinuations have accounted for a total of 18 cells. The two cells that did not fail in pack 50B were subjected to special tests, as requested by JPL, in May 1974. Results of these tests are contained in NAD Crane Report WQEC/C 74-617.

(2) Failure Analysis: Analysis of 13 cells showed that the major causes of ailure were due to separator deterioration, migration of the negative material, and high internal pressure resulting in case distortion. Other problems included ceramic shorting, dryness of separator, ragged edges on positive plates and blistering of positive plates.

13. GE 6.0 ah (Nickel-Cadmium), Three 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular. The cell container and cover are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude through the cover as solder type terminals. There are two auxiliary electrodes in each cell; the signal and the gas recombination electrodes. The recombination electrode is welded to the inside of the container, and its terminal is a stainless steel tab welded to the outside. The signal electrode, which is used for charge control, is welded to a wire that protrudes through a hole in the cell cover. This hole is potted to seal the cell. Different values of resistance are used to connect the signal and gas recombination electrodes to the negative terminal. The cells were developed under contract NAS 5-10261.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Signal Electrode Resistors (Ohms)*
53B	0° C	15	185	300
28C	25° C	15	70	10
47C	40° C	15	58	10

* Gas Recombination Electrode Resistors: 1 Ohm

c. Test Results:

(1) Performance on Cycling: Cycling was started in July 1968. Packs 53B and 28C failed on cycles 9230 and 9987, respectively. Pack 47C was discontinued on cycle 5842. One cell was removed from each pack and returned to the manufacturer for analysis. These cell removals occurred on cycle 4039 for 53B, on cycle 4095 for 28C and on cycle 4063 for 47C. Two additional cells (one failed and one nonfailed) from 47C were returned to the manufacturer for analysis as outlined in the NASA contract.

(2) Failure Analysis: Analysis of the eight failed cells from the three packs showed the major cause of failure to be separator deterioration, migration of negative plate material and high internal pressure. Additional problems included electrolyte

leakage, corrosive internal deposits, blistering of positive p ates, ragged edges of positive plates, and dry separator material. One cell from 47C which did not fail was analyzed for comparison with the failed cell. The conditions found in this cell were similar to the failed cell except that the separator deterioration and migration were not as severe.

(2) Capacity Checks: The ampere-hour capacities on the capacity check cycles are as follows:

Pack Number	53B	28C	47C
Temperature	0°C	25°C	40°C
88 Days	6.96	7.74	5.22
176 Days	6.80	6.50	1.50
264 Days	6.75	6.30	1.75
352 Days	6.05	5.50	
440 Days	1.71	3.00	
528 Days	1.59	0.90	
616 Days		0.96	

14. GE 6.0 ah (Nickel-Cadmium with Signal and Recombination Electrodes), Three 5-cell Packs:

a. Cell Description: These cells are rectangular with stainless steel containers and covers. Both terminals are insulated from the cell cover by ceramic seals and protrude through the cover as solder type terminals. There are two auxiliary electrodes in each cell; the signal and the gas recombination electrodes. The recombination electrode is welded to the inside of the container, and its terminal is a stainless steel tab welded to the outside. The signal electrode, which is used for charge control, is welded to a wire that protrudes through a hole in the cell cover. This hole is potted to seal the cell.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hour	
Temperature	0°	20°	40°
Depth of Discharge	40%	40%	40%
Trip Voltage (MV)	150	200	600
Signal Electrode Resistors (Ohms)	330	330	330
Recombination Electrode Resistors	2.2	2.2	2.2
Pack Number	30C	64B	6D
88 Days	6.96	4.18	3.75
176 Days	6.73		

c. Test Results:

(1) Performance on Cycling: Cycling was started in April 1971. Packs 30C and 64B completed 4129 and 2712 cycles, respectively, prior to discontinuation in June 1972. Pack 6D failed on cycle 2268.

(2) Failure Analysis: Chemical Analysis of cell 1 from pack 6D revealed a high equivalence percentage of potassium carbonate--averaging 47.2 percent. Physical analysis of the same cell showed blistering of positive plates, ragged plate edges and uneven distribution of electrolyte--highest moisture content toward the center of the plates.

$$\text{Equivalence \% } CO_3 = \frac{\text{Meq } CO_3}{\text{Meq } CO_3 + \text{Meq KOH}} \times 100$$

where Meq = milliequivalence.

15. GE 12.0 ah (Nickel-Cadmium), Four 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and the cell cover are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude through the cover as 1/4-20 threaded posts. A stainless steel tab is welded to the cell cover for the auxiliary electrode terminal. The auxiliary electrode is a fuel cell type electrode and is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms)
60A	0° C	25	400	3
12A	25° C	25	400	1
24A	25° C	40	400	1
48A	40° C	25	400	0.5

(1) Pack 48A was changed to 0° C after 528 cycles with the following parameters: Depth of Discharge, 40 percent; Resistors, 3 ohms on each cell.

c. Test Results:

(1) Performance on Cycling: Cycling was started in October 1965. Cycling of Packs 60A, 12A, 24A and 48A was discontinued on cycles 5650, 1698, 665 and 5110 cycles respectively.

(a) Pack 12A, at 25° C: The end-of-discharge voltage fell below 1.0 volt per cell, average, on cycle 486. The pack was reconditioned and returned to cycling. At cycle 872 the voltage again dropped below 1.0 volt per cell, average. The pack was again reconditioned. At cycle 1051 the pack again lost capacity and was reconditioned for the third time. Cycling of this pack was discontinued at cycle 1698 because of loss of capacity.

(b) Pack 24A, at 25° C: The end-of-discharge voltage fell below 1.0 volt per cell, average, on cycle 410. The pack was reconditioned and returned to cycling. At cycle 537, the voltage again dropped below 1.0 volt per cell, average. The control unit was then set to charge at 2.5 amperes for the remaining portion of the 60-minute charge period after the trip point had been reached. This overcharge did not improve the capacity of the pack so the test was discontinued on cycle 665.

(c) Pack 48A completed 528 cycles at 40° C at which time the test temperature was reduced to 0° C and the depth of discharge was increased from 25 to 40 percent. Cycling was discontinued after cycle 5110 because the cells would not operate satisfactorily over the entire temperature range of 0° to 40° C. Additional data at 0° C would be of little value in evaluating the cells for space application.

(d) Pack 60A, at 0° C, completed 5650 cycles before it was discontinued for the same reasons given for Pack 48A.

(e) Failure Analysis: Consultation with Goddard Space Flight Center and the manufacturer resulted in the decision to forego failure analyses of these cells since it was believed their poor performance was the result of questionable processing.

(2) Capacity Checks: The ampere-hour capacities on the capacity check cycles are as follows:

Orbit Period		1.5-hour			
Temperature		0°	0°	25°	25°
Depth of Discharge		25%	40%	25%	40%
Pack Number		60A	48A	12A	24A
100 Cycles		15.00	5.30*	8.90	9.10
88 Days	Disch #2	15.10	15.20	**	**
176 Days	Disch #2	14.60	15.10		
264 Days	Disch #2		11.50		

* Pack 48A capacity test discharges at this point were at ambient temperature of 40° C.

** Capacity check at 88 days (1440 cycles) was not run because of earlier losses of capacity.

16. GE 12.0 ah (Nickel-Cadmium), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude through the cover as 1/4-20 threaded posts. A stainless steel tab is welded to the cell cover for the auxiliary electrode terminal. One auxiliary electrode was welded internally to the negative terminal and the other one was welded to the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms)
58A	0° C	25	500	6.8
72A	0° C	40	500	6.8
12B	25° C	25	500	6.8
24B	25° C	40	500	6.8
36A	40° C	25	500	6.8
34A	40° C	40	500	6.8

c. Test Results:

(1) Performance on Cycling: Cycling was started in January 1967. Packs 58A, 72A, 12B, 24B, 36A and 34A were discontinued on cycles 136, 304, 404, 38, 75 and 65 respectively. These packs showed excessive capacity losses in relatively few cycles as reflected in the capacity check data.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

(a) Pack 58A, at 0° C: Precycling capacities were 17.4 ampere-hours on the first discharge and 16.6 ampere-hours on the second discharge. After 133 cycles the pack was again given a capacity check and delivered 16.0 ampere-hours on the first discharge and 15.7 ampere-hours on the second discharge.

(b) Pack 72A, at 0° C: Precycling capacities were 17.4 ampere-hours on the first discharge and 16.4 ampere-hours on the second discharge. After 177 cycles the pack was again given a capacity check and delivered 15.6 ampere-hours on the first discharge and 15.6 ampere-hours on the second discharge.

(c) Pack 12B, at 25° C: Precycling capacities were 15.9 ampere-hours on the first discharge and 10.5 ampere-hours on the second discharge. After 401 cycles the pack was again given a capacity check and delivered 6.8 ampere-hours on the first discharge and 7.2 ampere-hours on the second discharge.

(d) Pack 24B, at 25° C: Precycling capacities were 17.2 ampere-hours on the first discharge and 15.1 ampere-hours on the second discharge. After 38 cycles the pack was again given a capacity check and delivered 4.6 ampere-hours on the first discharge and 6.8 ampere-hours on the second discharge.

(e) Pack 36A, at 40° C: Precycling capacities were 12.1 ampere-hours on the first discharge and 6.3 ampere-hours on the second discharge. After 56 cycles the pack was again given a capacity check and delivered 3.5 ampere-hours on the first discharge and 2.6 ampere-hours on the second discharge.

(f) Pack 34A, at 40° C: Precycling capacities were 13.0 ampere-hours on the first discharge and 6.7 ampere-hours on the second discharge. After 43 cycles the pack was again given a capacity check and delivered 4.1 ampere-hours on the first discharge and 3.2 ampere-hours on the second discharge.

(g) Failure Analyses: Consultation with Goddard Space Flight Center and the manufacturer resulted in the decision to forego failure analyses of these cells since it was believed their poor performance was the result of questionable processing.

17. GE 20 ah (Nickel-Cadmium), Two 5-cell Packs:

a. Cell Description: See Paragraph I.A., page 12.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour	
Temperature	0°	0°
Depth of Discharge	15%	15%
Trip Voltage (MV)	300	300
Resistors (Ohms)	300	300
Pack Number	7B	67B
Precycling Capacity	22.7	21.8
88 Days	27.3	29.3
176 Days	24.9	28.8
264 Days	27.3	30.0
352 Days	27.0	29.8
440 Days	27.9	30.4
528 Days	28.5	28.1
704 Days	24.4	29.1

c. Test Results:

(1) Performance on Cycling: Cycling was started in February 1970. Packs 7B and 67B have completed 12,652 and 12,634 cycles, respectively, prior to discontinuation in May 1972.

18. Sonotone 5.0 ah (Nickel-Cadmium), One 5-cell Pack, 1.5-hour Orbit Period (Pack 14D):

a. Cell Description: These cells are rectangular in shape. The cell jars and cell covers are made of a plastic material. Each cell is equipped with an auxiliary electrode which is used for gas recombination. The cells were constructed at the Goddard Space Flight Center from parts supplied by Sonotone. The cells were then individually epoxy potted in order to hermetically seal them.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 25%.

(3) Auxiliary Electrode Resistors: All 1 ohm.

(a) Following the low end-of-discharge voltage condition of one cell between cycles 1110 and 1136, the auxiliary electrode resistors on each of the five cells were changed to 50 ohms, at the request of Goddard Space Flight Center, to note any changes in the cell voltage characteristics.

c. Test Results:

(1) Performance on Cycling: Cycling was started in November 1967. This pack failed on cycle 1179 due to failure of three cells at that time as a result of severe migration of negative plate material. The positive plates of one cell were blistered; and imbedded in one was a piece of extraneous plastic material.

(2) Capacity Checks: The ampere-hour capacity on precycling was 3.99 ampere-hours.

19. Yardney 12.0 ah (Silver-Cadmium), Two 5-cell Packs, 24-hour Orbit Period:

a. Cell Description: The cells are rectangular in shape. The cell jars and covers are molded of a plastic material. A fuel cell type auxiliary electrode for gas recombination was installed in each cell by Goddard Space Flight Center before being individually epoxy potted with a wrap of fiberglass material to hermetically seal and strengthen them.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Auxiliary Electrode Resistor (Ohms)
21D	0° C	43	1
9F	40° C	43	1

c. Test Results:

(1) Performance on Cycling: Cycling was started in June 1967.

(a) Pack 21D: This pack failed on cycle 60 due to low capacity of several cells.

(b) Pack 9F: The first of four cell failures occurred on cycle 258, the second on cycle 288, and the remaining two on cycle 310.

(c) The two packs were returned to Goddard Space Flight Center for analysis.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Pack Number	21D	9F
Precycling Capacity	4.33	5.53
100 Days		8.33
200 Days		7.60
273 Days		5.33

B. Stabistor: The stabistor is a semiconductor device that is used to shunt current around a fully charged cell. The stabistor will pass current when the voltage across it has reached the breakdown value. The breakdown voltage depends upon the temperature of the stabistor. At higher temperatues the breakdown voltage is lower than at cold temperatures. Across the terminals of each cell is mounted a 5-ampere stabistor to limit the charge current, and an antireversal diode to prevent cell reversal on discharge.

1. Sonotone 5.0 ah (Nickel-Cadmium), Eight 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These are cyclindrical cells made of stainless steel. Two stainless steel tabs are welded to the cover for the negative connections. The positive terminal is an extension of the positive plate tab and is insulated from the "negative" cover by a ceramic seal. Two ring indentations, about 1/32 inch deep, located approximately 7/8 inch from either end of the cell can, were crimped after cell assembly to hold the element snugly in the cylindrical can. This type cell was used in the TIROS (Television Infrared Observation Satellite) satellite.

b. Test Parameters:

(1) Initial Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
75C	-20° C	25
89B	-20° C	40
92A	0° C	25
122B	0° C	40
73B	25° C	25
87B	25° C	40
99B	40° C	25
112B	40° C	40

(1) Pack 112B did not cycle satisfactorily at 40 percent depth of discharge so at cycle 48 the depth of discharge was reduced to 15 percent, with all other parameters unchanged.

(2) It was necessary to recharge all packs at the c/1 rate (5 amperes) since the 5-ampere stabistor (with heat sink) in parallel with each cell was designed to maintain the proper stabistor temperature for the correct breakdown voltage when shunting the 5 amperes.

c. Test Results:

(1) Performance on Cycling: Cycling was started in August 1965. Pack 75C failed on cycle 2145, pack 89B on cycle 1530, pack 92A on cycle 8774, pack 122B on cycle 5190, pack 73B on cycle 4742, pack 87B on cycle 2392, pack 99B on cycle 4399, and pack 112B on cycle 3294. The breakdown voltage of the stabistors was too high for proper voltage limiting, thereby resulting in excessive gassing and high internal pressure. This in turn caused leakage as evidenced by carbonate deposits around the ceramic seal of the terminal of 26 of the 29 failed cells, of which the containers of 23 cells were bulged. Other conditions found during the failure analysis were excess scoring, migration of the negative plate material, weak tab-to-plate welds, ceramic shorts, separator deterioration, blistering on the positive plates, loosened active material, and extraneous active material.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

PRECYCLING AND CAPACITY CHECKS

Orbit Period	1.5-hour							
Temperature	-20°	-20°	0°	0°	25°	25°	40°	40°
Depth of Discharge	25%	40%	25%	40%	25%	40%	25%	40%
Pack Number	75C	89B	92A	122B	73B	87B	99B	112B
Precycling Capacity	4.92	4.96	3.38	4.13	5.33	5.50	4.21	3.71
88 Days Disch #2	1.21	2.58	2.75	2.33	2.33	3.66	1.88	1.04
176 Days Disch #2			1.71	1.50	1.29		1.50	
264 Days Disch #2			0.75	0.79			1.17	
352 Days Disch #2			*	*				
440 Days Disch #2			1.38					

* Cell failure occurred during capacity check.

C. Coulometer: (See Section I, Paragraph I.7.b., for description of cadmium-cadmium coulometer.)

1. Gulton 3.6 ah (Nickel-Cadmium with Neoprene Seal), One 10-cell Pack, 1.5-hour Orbit Period (Pack 39B):

a. Cell Description: These are cyclindrical cells with a folded neoprene seal.

b. The coulometer used was built by GE with a capacity of 6.0 ampere-hours.

c. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

d. Test Results:

(1) Performance on Cycling: Cycling was started in November 1965. This pack completed 5399 cycles before failure by self destruction. During recharge following the first capacity check after cycle 5399, one or more cells of the seven cells cycling shorted and caught fire. All seven cells were completely destroyed thereby preventing failure analysis. The coulometer failed after 1868 cycles due to loss of capacity. The end-of-discharge voltage improved after a new coulometer was placed in the pack.

(a) The first three cell failures occurred at cycles 2182, 4949 and 4976. The three cells showed migration of negative plate material and separator deterioration. The positive plates of the three cells had loosened active material and were blistered. The welded seam of each of the three cells showed leakage as evidenced by deposits.

(b) The cadmium-cadmium coulometer failed due to internal shorting caused by cadmium migration through the single layer of nonwoven nylon separator. Because of this cadmium migration, the coulometer must have at least twice the amount of plate separation as regular nickel-cadmium cells also requiring the cells to be operated in the flooded state to keep the internal resistance down.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Precycling	3.06
88 Days	2.07
176 Days	2.01
264 Days	2.55
352 Days	1.71

2. Gulton 4.0 ah (Nickel-Cadmium), Seven 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These are rectangular sealed cells of commercial grade. The containers and covers are of a plastic material. They were epoxy potted into 5-cell packs with a coulometer at the Goddard Space Flight Center in order to hermetically seal the cells and the coulometer before test.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
40C	-20° C	25
52B	0° C	25
26C	25° C	15
14C	25° C	25
37C	25° C	40
38D	25° C	60
39C	40° C	25

c. Test Results:

(1) Performance on Cycling: Pack 40C failed during precycling capacity checks at -20° C. Cycling of the remaining six packs started in March 1967. The first cell failure occurred on cycle 5685 for pack 52B, on cycle 11,455 for pack 26C, on cycle 2428 for 14C, on cycle 790 for 37C, on cycle 1927 for 38D and on cycle 1508 for 39C. At the request of Goddard Space Flight Center, cycling of any pack was stopped upon failure of any cell within the pack since there was no way of physically or electrically removing the failed cells from the pack. No failure analyses were performed because failure of these commercial cells was due to high internal pressure because too much electrolyte in the cells prevented gas recombination to occur which caused the cells to rupture.

(2) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

PRECYCLING AND CAPACITY CHECKS

Orbit Period			1.5-hour				
Temperature	-20°	0°	25°	25°	25°	25°	40°
Depth of Discharge	25%	25%	15%	25%	40%	60%	25%
Pack Number	40C	52B	26C	14C	37C	38C	39C
Precycling Capacity	*	4.43	4.67	4.23	5.03	4.57	3.30
88 Days Disch #2		4.10	3.10	3.50		1.87	1.13
176 Days Disch #2		3.37	2.43				
264 Days Disch #2		2.33	3.37				
352 Days Disch #2		3.80	3.37				
440 Days Disch #2			3.40				
528 Days Disch #2			2.33				
616 Days Disch #2			1.33				
704 Days Disch #2			0.93				

* Pack failure occurred during precycling capacity check.

3. Gulton 6.0 ah (Nickel-Cadmium), RAE, Four 5-cell Packs:

a. Cell Description: See paragraph I.A., page 12.

b. Parameters and Capacity Checks:

Orbit Period	3.0-hour			
Temperature	-20°	0°	25°	40°
Depth of Discharge	25%	25%	25%	25%
Pack Number	41B	66B	18C	29B
Precycling Capacity	6.60	7.15	7.00	6.25
88 Days Disch #2	6.45	6.90	2.75	2.35
264 Days Disch #2	4.50	5.70	1.50	1.80
440 Days Disch #2	3.05	4.75	1.35	1.55
616 Days Disch #2	2.40	4.00	1.50	1.50
792 Days Disch #2	1.45	4.25	1.55	1.60
968 Days Disch #2	2.15	6.25	1.60	
1091 Days* Disch #2	3.30	*	*	
1232 Days Disch #2	2.00	6.10		
1408 Days Disch #2	2.25	6.05		
1584 Days Disch #2	1.95	1.15		
1760 Days Disch #2	0.45			

* Number of days does not fit into 88-day sequence due to loss of time with numerous coulometer changes on Pack 41B.

c. Test Results:

(1) Performance on Cycling: Cycling was started in November 1966. Packs 29B, 18C, 66B and 41B failed after 7941, 9633, 13,396 and 15,724 cycles, respectively.

(2) Failure Analysis:

(a) Analysis of eleven failed cells showed the major causes to be separator deterioration, ceramic short, and migration of the negative plate material. Other conditions found were high internal pressure, blistering of the positive plate material, electrolyte leakage and loose active material.

(b) It was necessary to replace the coulometer in pack 41B, operating at -20° C, on nine occasions; and on one occasion in pack 66B operating at 0° C because each coulometer had shorted internally. The number of cycles between failures range from 193 to 3698 cycles for an average of 965 cycles. These failures were due to inadequate plate separation having one layer of nonwoven nylon. The failure mode being combated is cadmium migration. It has been found that coulometers require twice the effectiveness of plate separation as that found in its nickel-cadmium counterpart. These results have lead to the use of two layers of nonwoven nylon in RAE coulometers.

4. Gulton 6.0 ah (Nickel-Cadmium with Gulton Plates), Four 5-cell Packs:

a. Cell Description: These cells are different from previous Gulton cells in that the plates were manufactured by Gulton rather than SAFT of France.

b. Coulometer: The coulometer is a device which measures the amount of electrical charge (coulombs or ampere-hours) passed through it. It accomplishes this by means of an electrochemical reaction which is directly proportional to the product of the magnitude of the current and the time for which it is passed. The coulometer used with nickel-cadmium cells is made from two sets of cadmium hydroxide plates bathed in KOH electrolyte, and constructed in a manner similar to that of a nickel-cadmium cell. Coulometer action is obtained by imbalancing the two sets of plates, so that when one set is reduced to cadmium by the passage of charge, the other set is oxidized to cadmium hydroxide. This reaction continues at a low voltage on the coulometer until the imbalance is complete. Then the coulometer voltage rises very sharply. The coulometer reaction can take place in either direction, charge or discharge, because the coulometer reaction is completely reversible. Thus, it is easy to detect when 100 percent of the discharge has been returned to the cells.

Orbit Period		1.5-hours		
Temperature	-20°	0°	20°	40°
Depth of Discharge*	50%	50%	50%	50%
Pack Number	39D	63B	3C	27D
Precycling Capacity	6.30	5.70	6.09	6.00
88 Days	5.00 F	6.08	4.96	2.96
176 Days		6.08	3.60	3.76
264 Days		5.92	4.08	5.44
352 Days		6.32	3.36	2.64 F
528 Days		6.48	3.28	
704 Days		6.16	3.76	
893 Days		4.32	NA	
1062 Days		4.61	4.93	
1240 Days		3.80	4.24	
1434 Days		2.88	3.23	
1613 Days		F	4.64	

* Depth of Discharge was changed to 40% on 9-29-70 by NASA, Goddard Space Flight Center Technical Monitor. This change occurred within the first 75 cycles for all packs.

F - Failed.

c. Test Results:

(1) Performance on Cycling: Cycling was started in September 1970. Packs 63B and 3C completed 23,121 and 26,829 cycles before failure. One cell was removed from each pack for separator analysis on cycle 16,011 (Pack 63B) and cycle 16,544 for Pack 3C. Packs 27D and 39D failed after 6869 and 1376 cycles respectively.

(2) Failure Analysis: Analysis of the 12 failed cells showed extreme pitting of both the negative and positive plates throughout the plate stack. The cell cases were bulged due to internal pressure. Ultimate failure resulted in low capacity due to pitting and loosened active material. When compared, migration was more pronounced in the cells of 63B and separator deterioration was predominate in the cells of 3C.

Pack Number	3C	3C	63B	63B
Serial Number	920	914 (failed)	912	900 (failed)
Cycles Completed	16,554	26,829	16,011	23,121
Total meq KOH per extract	78.27	72.75	89.08	103.290
Total meq K_2CO_3 per extract	57.66	72.46	45.26	42.900
meq KOH per separator patch	0.5877	0.7016	0.8691	0.5280
meq K_2CO_3 per separator patch	0.7197	1.4961	0.7409	0.9174
Total volume (cc) per patch	1.004	N/A	1.156	1.2623
Wet weight per patch, avg (g)	0.4200	0.5164	0.5327	0.4793
Dry weight per patch, avg (g)	0.1472	0.1571	0.1772	0.1842

N/A - Not Available.

5. Heliotek 20.0 ah, One, 5-cell Pack:

a. Cell Description: See Paragraph I.A., page 12.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour
Test Temperature	20°C
Depth of Discharge	40%
Pack Number	34D
Precycling Capacity	16.0
88 Days	7.73
	Discontinued

c. Test Results:

(1) Performance on Cycling: Cycling was started in March 1972. This pack completed 2903 cycles, with one cell failure, before a malfunction of the control system severely discharged the remaining cells resulting in the pack being discontinued. One cell was returned to Heliotek, three cells to Goddard Space Flight Center, and the remaining cell was stored.

6. Sonotone 5.0 ah, One 5-cell Pack, 1.5-hour Orbit Period:

a. Cell Description:

(1) The cell container and the cell cover are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as contacts for the negative terminal. The positive terminal is a solder type extension of the positive plate tab through the center of the cover. The positive terminal is insulated from the "negative" cover by a glass to metal seal. Two ring indentations, about 1/32 inch deep, located approximately 7/8 inch from either end of the cell can, were crimped after cell assembly to hold the element snugly in the cylindrical can.

b. The coulometer used was built by the Goddard Space Flight Center.

c. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: Started at 80 percent but was lowered by steps of 10 percent until the pack operated satisfactorily at 30 percent depth of discharge.

d. Test Results: Cycling was started in August 1964. Upon completion of a total of 13,540 cycles at the various depths of discharge listed below, cycling was stopped because the coulometer developed a short and could not control the cycling operation any longer.

(1) At 80 percent, the pack completed 59 cycles. The end-of-discharge voltage dropped below 1.0 volt.

(2) At 70 percent, the pack completed 61 cycles. The end-of-discharge voltage again dropped below 1.0 volt.

(3) At 60 percent, the pack completed 55 cycles before the end-of-discharge voltage fell below 1.0 volt.

(4) At 50 percent, the pack completed 90 cycles before the end-of-discharge voltage fell below 1.0 volt.

(5) At 40 percent, the pack completed 250 cycles before the end-of-discharge voltage fell below 1.0 volt.

(6) At 30 percent, the pack completed 13,025 cycles before the coulometer developed a short. The end-of-discharge voltage was about 1.07 volts per cell, average, with an end-of-charge voltage of 1.42 volts per cell, average, over the entire cycle life. The percent of recharge, as controlled by the coulometer, ranged from 104 to 111 percent with an average value of 106 percent.

D. Sherfey Upside-Down Cycling: This type of cycling starts with the cells in a completely discharged condition. Each cycle consists of a charge of 60 percent followed by a discharge of 40 percent of the cell's rated capacity. Upon completion of each fifth cycle, the cells are discharged through resistors for 90 additional minutes to return the cells to the completely discharged condition (bleed portion of cycle) for the start of the next sequence of five cycles. In this manner, the cells operate below the 100 percent charged state much of the time thereby preventing overcharging and buildup of excessive gas pressure.

1. Test Equipment: The charge and discharge currents for the pack are supplied by a power supply. The rates and cycling regimen are controlled by the Sherfey cycling unit which contains the resistors used to completely discharge the cells after each fifth cycle. The cycle timing is done by using a synchronous motor timer.

2. Gulton 3.6 ah (Nickel-Cadmium with Neoprene Seal), One 10-cell Pack, 1.5-hour Orbit Period:

a. Cell Description: These are cyclindrical cells with a folded neoprene seal as described in Section II, Paragraph III.B.2.a.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

c. Test Results: Cycling was started in September 1965. This pack failed on cycle 5505. Each of the cell failures was caused by the loss of electrolyte around the weld between the cell container and cell cover. Because of this leakage, which began at the start of cycling, the cells began to dry out and the charge voltage began to increase. The end-of-charge voltage gradually increased from 1.44 volts initially to 1.60 volts per cell, average, at the end of cycle life reflecting the effects of the drying out of the cells. On each successive discharge following the bleeding of every fifth cycle, the end-of-discharge voltage increased about 0.02 volt per cell.

E. Two-Step Charge Regulator: When silver-cadmium and silver-zinc cells are put on a long charge period with only a voltage limit, the cells begin to unbalance when the pack goes into overcharge. A new method of charging cells of these types was developed at Goddard Space Flight Center. Charging of the battery is by constant current to the upper voltage limit, then is automatically crossed over to constant potential. When the current decreases to a predetermined level, the constant potential charge is reset to the lower voltage limit which is equal to the open circuit voltage of the battery. The unit will not return to the upper voltage limit until the charge current goes above the predetermined value. This method prevents the cells from becoming unbalanced during long charge periods.

1. Test Equipment: The charge and discharge currents are supplied by a unit described in Section VI, Paragraph I.B.1. The two-step regulator, designed by the Goddard Space Flight Center, is used to control the rate of charge and the voltage limits.

2. Delco-Remy 25.0 ah (Silver-Zinc), Two 10-cell Packs, 24-hour Orbit Period:

a. Cell Description: These cells are rectangular in shape with sealed nylon cases. Each cell was individually epoxy potted by the manufacturer. The positive plates have one percent of palladium added to the active material.

b. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Upper Voltage Limit: 1.97 $\pm$ 0.03 volts per cell, average.

(4) Low Current Level: 0.35 amps.

(5) Lower Voltage Limit: 1.87 $\pm$ 0.03 volts per cell, average.

c. Test Results:

(1) Performance on Cycling:

(a) Cycling was started on Pack 9D in December 1965. This pack completed 121 cycles with two cell failures.

The test was discontinued, at the request of Goddard Space Flight Center when the two cells failed, because the voltage limit settings could not be lowered. The failed cells were returned to the manufacturer for analysis. This analysis indicated that the zinc plates were in better condition (very little shape change) than plates of previous samples, but that silver penetration was still a problem.

(b) Cycling of pack 9E was started in October 1966. This pack completed 90 cycles with three cell failures. The test was discontinued at that time. The cells were returned to the manufacturer; no report on the failure analysis has been received.

3. Yardney 16.0 ah (Silver-Zinc), One 10-cell Pack, 24-hour Orbit Period (Pack 57C):

a. Cell Description: These are vented cells, rectangular in shape, with the cell jars and cell covers molded of a plastic material. They contain a limited amount of electrolyte. The cells were individually epoxy potted to hermetically seal them.

b. Test Parameters:

(1) Depth of Discharge: 31%.

(2) Upper Voltage Limit: 1.98 ± 0.03 volts per cell, average.

(3) Low Current Level: 0.10 amperes.

(4) Lower Voltage Limit: 1.86 ± 0.03 volts per cell, average.

(5) Test Temperature: 25° C for 100 cycles, then 0° C for 100 cycles. Repeat until pack failure occurs.

c. Test Results:

(1) Performance on Cycling: Cycling was started in December 1966. This pack completed 281 cycles with one cell failure. The failed cell began leaking electrolyte after 137 cycles. The cells operated very well at both temperatures. Because of the difficulty in changing the voltage limits, as set by the two-step regulator, Goddard Space Flight Center requested that the test be discontinued.

(2) Capacity Checks: Each cell was discharged to the cutoff voltage of 1.30 volts and the ampere-hour capacities determined. After 80 days of cycling the capacities ranged from 6.67 to 20.0 ampere-hours. After 203 days of cycling the capacity range was 0.67 to 18.5 ampere-hours.

F. Internal Mechanical Pressure Devices: In certain instances the capacity output of a cell can be improved by applying pressure to the face of the plate stack. This test is designed to determine what effect, if any, a constant mechanical pressure has on the life of the cell.

1. Sonotone 20.0 ah (Nickel-Cadmium), Five 10-cell Packs, 1.5-hour and 3-hour Orbit Periods:

a. Cell Description: These cells are rectangular. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cell cover by a teflon seal and protrude through the cover as a threaded terminal. Each cell is also fitted with a pressure relief valve. Cells 1 through 5 in each pack are standard cells; cells 6 through 10 contain a stainless steel eliptical spring which supplies the presssure to the face of the plates.

b. Parameters and Capacity Checks:

Orbit Period	1.5	1.5	1.5	1.5	3.0
Temperature	20°	20°	20°	20°	20°
Depth of Discharge	25%	25%	40%	75%	40%
Pack Number	10B	22B	34C	72C	46B
Precycling Capacity	20.80	20.70	20.50	23.10	21.70
88 Days	21.67	20.00	19.70	22.70	20.20
176 Days	22.20	7.00	18.30	22.00	9.00
264 Days	22.17		18.00	16.18	
352 Days	9.33		16.00		
440 Days	8.67		14.16		
616 Days	5.33				
792 Days	5.00				

c. Test Results:

(1) Performance on Cycling: Cycling was started in May 1970. Packs 22B and 46B were discontinued after 3419 and 1686 cycles, respectively, with two cell failures in pack 46B. Pack 10B completed 13,964 cycles with three cell failures prior to failure in October 1972. Packs 34C and 72C failed on cycles 8357 and 4381 respectively.

(2) Failure Analysis: Analysis of four failed cells revealed that separator deterioration and migration of the negative mateial were the major causes of failure. High pressure, weak tab-to-plate welds, extraneous active material, and blistering on the positive plates were also in evidence. Packs 22B and 46B were discontinued when they failed to reach the voltage limit on cycling thereby receiving a recharge in excess of 200 percent which was causing the cell cases to become exceedingly hot. These packs were sent to NASA, Lewis Research Center, for further testing and/or failure analysis.

2. Sonotone 20.0 ah (Nickel-Cadmium), Five 10-cell Packs, 1.5-hour and 3-hour Orbit Periods:

a. Cell Description: These cells are rectangular in shape. The cell container and cell cover are made of stainless steel. Both terminals are insulated from the cell cover by a teflon seal and protrude through the cover as a threaded terminal. Each cell is also fitted with a pressure relief valve. Cells 1 through 5 in each pack are standard cells; cells 6 through 10 contain a stainless steel eliptical spring which supplies the pressure to the face of the plates.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
10A	25° C	25
22A	25° C	25
34B	25° C	40
46A*	25° C	40
72B	25° C	75

* This pack has an orbit period of 3 hours, all others are 1.5 hours.

c. Test Results:

(1) Performance on Cycling: Packs 34B and 72B failed on cycles 5634 and 1143, respectively. In order to use the same equipment for replacement cells pack 10A was discontinued on cycle 7188, pack 22A on cycle 6664, and pack 46A on cycle 3501.

(a) Shortly after the start of cycling in September 1967, high internal pressure developed in all cells as evidenced by bulged case and the rupture of four. Cycling was stopped in November 1967 with 1170 cycles on pack 10A, 599 cycles on pack 22A, 943 cycles on pack 34B, 427 cycles on pack 46A, and 609 cycles on pack 72B.

(b) A representative from NASA, Lewis Research Center, and one from the manufacturer reviewed the results in order to determine what steps should be taken before continuation of the cycling test. Five of the 14 failed cells were analyzed at NAD Crane, the manufacturer's representative took the remaining nine failed cells with him in order to determine the cause for the excessive pressure buildup in both the control and spring loaded cells.

(c) After completion of his testing, the manufacturer recommended that new relief valves be installed, the cells be reconditioned, and the charge current be reduced from 20 to 15 amperes on packs 22A, 34B and 46A. It was necessary that the charge rate on pack 72B remain at 20 amperes because of the deep depth of discharge. The packs were then returned to cycling.

(2) Failure Analysis:

(a) Analysis of five of the first 14 failed cells showed the major cause to be the plates shorting against the cell case because of the high internal pressure.

(b) Analysis of the 24 cells that failed after the test modification showed the major cause of failure to be migration of the negative plate material and separator deterioration in both the control and spring loaded cells.

(3) Capacity Checks: The ampere-hour capacities on the precycling and capacity check cycles are as follows:

Orbit Period (Hr)	1.5	1.5	1.5	3.0	1.5
Temperature	25°	25°	25°	25°	25°
Depth of Discharge	25%	25%	40%	40%	75%
Pack Number	10A	22A	34B	46A	72B
Precycling Capacity	28.7	28.8	29.7	25.7	26.2
88 Days Disch #2	22.5	21.3	20.0	24.3	
176 Days Disch #2	22.2	7.7	13.5	15.2	
264 Days Disch #2	21.3	10.8	11.3	23.5	
352 Days Disch #2	18.2	21.2		4.7	

G. High Overcharge Current Capabilities: These cells were constructed to withstand continuous charge rates as high as c/1 for extended periods of time.

1. Gulton 1.25 ah, (Nickel-Cadmium), Four 5-cell Packs:

a. Cell Description: These cells are rectangular. The cell container and cell cover are made of stainless steel. The positive terminal is insulated from the cell cover by a ceramic seal whereas the negative terminal is common to the can. Both are solder type terminals. Each cell was equipped with a pressure gage.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hour		
Temperature	-20°	-20°	0°	0°
Depth of Discharge	25%	60%*	25%	60%
Pack Number	74B	88D	108B	98B
Precycling Capacity	1.43	1.28	1.78	1.83
88 Days Disch #2	0.39	0.36	1.76	1.60
264 Days Disch #2	0.40	0.35	1.43	0.95
440 Days Disch #2	0.36	0.35	1.32	0.87
616 Days Disch #2	0.41	0.36	0.92	0.99
792 Days Disch #2	0.29	0.28	1.01	
968 Days Disch #2	0.27	0.28	0.66	
1144 Days Disch #2	0.25	0.28	0.42	
1320 Days Disch #2	0.38	0.39	0.47	
1496 Days Disch #2	0.27	0.27	0.54	
1672 Days Disch #2	0.30	0.29	0.41	
1848 Days Disch #2	0.33	0.37	0.39	
2024 Days Disch #2	0.37	0.43	0.30	

* Depth of discharge was reduced to 25% after 46 cycles.

c. Test Results:

(1) Performance on Cycling: Cycling was started in March 1966. Packs 74B (discontinued), 88D (failed) and 108D (discontinued) completed 33,878, 32,144 and 33,063 cycles, respectively. They failed or were discontinued on June, March and April 1972. Pack 98B failed on cycle 12,247. All four packs have experienced high pressure (some in excess of 150 psig).

The cells operating at -20° C required a reduction in charge current from 1.25 to 1.00 ampere in order to cycle and avoid high internal pressure. After this reduction in charge current, packs 74B and 88D averaged 10,500 cycles before high pressure was noticed and released. Pressure again developed in packs 74B and 88D after 13,400 cycles and was released.

(2) Failure Analysis: Analysis of the seven failed and five discontinued cells shows severe migration of negative material, blistering of the positive plates. high internal pressure, external carbonate deposits around the terminals, rust on inside positive tab, loose active material and excessive dryness.

H. Thermistor:

1. GE 6.0 ah (SAS B), One 8-cell Pack:

a. Cell Description: See Paragraph I.A., page 12.

b. Project: Small Astronomy Satellite.

c. Parameters and Capacity Checks:

Pack Number	1C
Orbit Period	1.5
Test Temperature	25°
Depth of Discharge	21%
Precycling Capacity	6.99
88 Days	6.13
176 Days	6.17
264 Days	5.95
352 Days	5.18
440 Days	5.13
616 Days	4.75
894 Days	NA
1054 Days	3.73
1247 Days	3.53
1429 Days	2.17 D

d. Test Results:

(1) Performance on Cycling: Cycling started in July 1970. The pack completed 24,064 cycles with three cell failures (cycles 13,600, 23,617 and 24,064) before it was discontinued. One cell was removed for analysis (cycle 5300) and replaced with a cell of the same type. Analysis showed the equivalence percentage of carbonate to range from 53.2 percent to 64.9 percent, averaging 58.2 percent. Also noted was migration and blistering of positive plates. Three cells also were removed for analysis on cycle 16,385. Pack was placed on voltage limit control only, after 12,256 cycles.

(2) Failure Analysis: Of the three cells that failed: separator was moist, migration heavy in the middle of the plate stack, and its positive plates were uncoined along one side and at the bottom.

(3) The following table compares chemical analysis of extracted electrolyte (soxhlet) from individual cell stacks, and samples of separator patch material for cells experiencing varying cycle life.

	Uncycled	Replacement	Original (recon)	Original	Original (failed)	Original
Serial Number	55	13	54	53	44	43
Cycles Completed	0	11,087	16,385	16,385	24,064	24,064
Total meq* KOH per extract (avg)	83.66	67.60	55.83	58.29	61.611	52.899
Total meq K_2CO_3 per extract (avg)	62.81	80.30	90.64	90.37	113.25	107.97
meq KOH per separator patch**	0.8374	0.4550	0.1890	0.2190	0.0356	0.1567
meq K_2CO_3 per separator patch	0.7955	0.5973	0.9425	0.5998	0.7366	0.9016
Total volume (cc) per patch	1.1691	1.1299	0.7883	0.9652	1.1186	0.9019
Wet Weight (g)***	0.4238	0.3292	0.3696	0.3039	0.3952	0.3059
Dry Weight (g)***	0.1717	0.1660	0.1760	0.1627	0.1615	0.1307

* meq is the abbreviation of milliequivalents.
** The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the center, and one from the last third.
*** Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.

2. Gulton 6.0 ah (SAS A, Small Astronomy Satellite), One 8-cell Pack:

a. Cell Description:

(1) See Paragraph I.A.

(2) Thermistor: This method of charge control utilizes a thermistor to maintain a constant total voltage on a cell pack at a specified temperature. Should the specified temperature be exceeded or lowered, the resistance of the thermistor is correspondingly changed. The charging circuitry then establishes a new voltage limit and the charge current is automatically adjusted to maintain the new limit.

b. Parameters and Capacity Checks:

Pack Number	18D
Orbit Period	1.5
Test Temperature	25°
Depth of Discharge	21%
Precycling Capacity	6.99
88 Days	7.75
176 Days	7.33
264 Days	6.08
352 Days	6.88
440 Days	5.75
616 Days	4.96
894 Days	NA
1065 Days	2.80
1257 Days	2.23
1437 Days	1.96 D

c. Test Results:

(1) Performance on Cycling: Cycling started in July 1970. This pack completed 23,230 cycles with three cell failures (cycles 19,429, 22,577 and 23,230) before it was discontinued. During life cycling, one cell was removed for analysis (cycle 5296) and replaced with a cell of the same type. Analysis showed the equivalence percentage of carbonate to range from 37.4 percent to 40.9 percent, averaging 39.6 percent. Three more cells were removed for analysis after 16,573 cycles. Pack was placed on voltage limit control only, after 12,259 cycles.

(2) The following table compares chemical analysis of extracted electrolyte (soxhlet) from individual cell stacks, and samples of separator patch material for cells experiencing varying cycle life.

	Uncycled	Replacement (Discont.)	Original (Recon.)	----------Original----------			
				Discont.	Failed	Failed	Discont.
Serial Number	1944	1940	1937	1939	1968	1965	1946
Cycles Completed	0	11,279	16,573	16,573	19.429	22,577	23,230
Total meq* KOH per extract (avg)	102.58	80.88	83.24	71.83	63.324	68.845	69.894
Total meq K_2CO_3 per extract (avg)	33.80	57.87	59.96	69.12	77.543	80.493	74.844
meq KOH per separator patch**	1.3278	0.4064	0.2472	0.2674	0.0341	0.1320	0.1584
meq K_2CO_3 per separator patch	0.5040	0.4624	0.2469	0.4142	0.4365	0.3470	0.4277
Total volume (cc) per patch	1.2902	0.9246	0.5907	1.1083	Δ	Δ	Δ
Wet Weight (g)***	0.4593	0.2900	0.1915	0.2969	0.0888	0.2218	0.2333
Dry Weight (g)***	0.1724	0.1165	0.0897	0.1195	0.7620	0.0808	0.0886

*meq is the abbreviation of milliequivalents.
**The separator patch data is an average of four patches sampled. One from the first third of the plate stack, two from the center, and one from the last third.
***Wet weight is determined immediately following removal from the cell case and prior to leaching in water overnight; dry weight is determined following titration and air drying overnight.
ΔSeparator material extremely thin, measurement could not be attained.

(3) Failure Analysis: Analysis of two of the three failed cells (one shorted) indicated the major cause of failure was severe separator deterioration. Migration was heaviest at upper half of pack stack. The third cell that failed was not analyzed as per GSFC instructions.

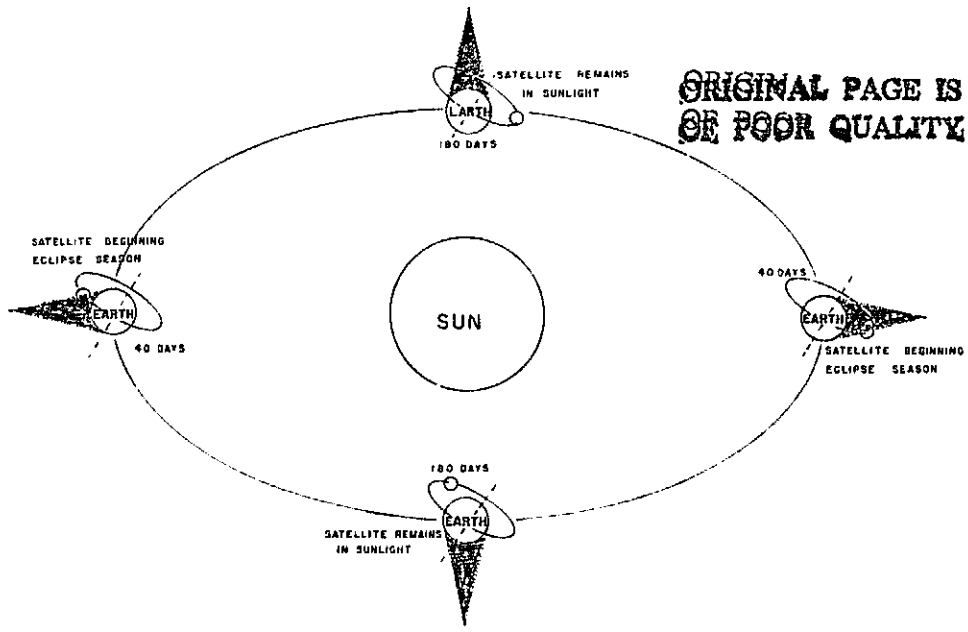
SECTION IV

SUMMARY OF SYNCHRONOUS ORBIT TESTING

I. SUMMARY OF SYNCHRONOUS ORBIT TESTING

A. The synchronous orbit tests were begun on six, 5-cell packs on 18 July 1967. These packs were 6ah GE and became known as packs 201A, 202A, 203A, 204B (replacement to 204A), 205A and 206A. Two reports (QE/C 70-634 and QEEL/C 73-302) have collectively covered the bulk of these packs' progress since 1967. These packs were followed in March 1969 by six, 12ah GE packs, known as 207A, 208A, 209A, 210A, 211A and 212A. One report (QE/C 71-183) has covered the progress of these cells through 1971. The remainder of the synchronous testing has encompassed: packs 213A through 227A, 226B, 227B, 227C, 228A, (excluding 215A, 216A, and 217A) four additional manufacturers, and one additional cell type--silver-zinc. An official report, WQEC/C 77-14, will be released in March 1977 which updates packs previously reported and will include those nickel-cadmium packs which have never been reported. However, no official reports have covered silver-zinc testing. The purpose of this section to summarize the vast amount of synchronous orbit testing by this activity.

B. In a synchronous orbit, the velocity of a satellite and its distance from the earth are adjusted such that one revolution of the satellite matches one rotation of the earth. The earth's shadow cone changes relative to the satellite's plane of orbit. (See diagram.) Thus, every 180 days the satellite enters an eclipse season. This season lasts approximately 40 days after which the remaining 140 days are in continuous sunlight. At the beginning of an eclipse season, the satellite first moves through the outer area of the earth's shadow cone. Each day of the eclipse season it progresses through a different section of the shadow cone until it has completely traversed the cone at the end of the season. The satellite's time within the shadow cone thus varies from day to day within the eclipse season beginning with a minimum, progressing to a maximum, and returning to a minimum.



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II. TEST CONDITIONS

A. To simulate the conditions experienced by the space cells aboard a synchronous orbiting satellite, the following 182-day test regime was adopted for the original 6 ah packs.

1. Period simulating continuous sunlight (140 days):

a. The cells were continuously charged at 200 milliamperes except the cells in pack 204B whose coulometer limited them to 25 milliamperes.

2. Period simulating eclipse season (42 days):

a. All cells were discharged for 12 minutes the first day of the eclipse season. The discharge time increased by 3 to 4 minutes per day for 18 days to a maximum of 1 hour and 12 minutes. This maximum discharge then occurs once a day for 8 days (18th through 25th day of eclipse season) with one exception--a capacity check was always run during the middle of each eclipse season.

b. The capacity check was run on the 21st day of the eclipse season. The capacity check consisted of a constant current discharge (rate depending on the depth of discharge) to an average voltage or low cell cutoff (values dependent on type of cell), whichever came first.

c. Following the capacity check, the cells continued the daily discharge of 1 hour and 12 minutes through the 25th day of the season. From the 26th day to the end of the season, the discharge was shortened 3 to 4 minutes per day. The last day's discharge was 12 minutes, the same as the first day. The cells then returned to continuous charge (sunlight) completing the 180-day cycle.

B. The following table identifies the synchronous packs and gives their present status.

PACK NUMBER	MFR	DEPTH	TEMP	TYPE	AH	SHADOW PERIOD COMPLETED	DAYS RUN	STATUS	PROJECT
201A	GE	40%	40°	NICD	6	#11	1948	Completed 11-19-72	Sync. Orbit
202A	GE	40%	25°	NICD	6	#17	3377	In shadow #18	Sync. Orbit
203A	GE	40%	0°	NICD	6	#17	3377	In shadow #18	Sync. Orbit
204A	GE	40%	-20°	NICD	6	#1 (failed 2nd day of #2)	200	Completed 2-5-68	Sync. Orbit
204B	GE	40%	-20°	NICD	6	#12	2198	Discontinued 8-28-74	Sync. Orbit
205A	GE	60%	0°	NICD	6	#17	3377	In shadow #18	Sync. Orbit
206A	GE	80%	0°	NICD	6	#17	3377	In shadow #18	Sync. Orbit
207A	GE	60%	0°	NICD	12	#14	2786	In shadow #15	ATS F&G
208A	GE	80%	0°	NICD	12	#14	2786	In shadow #15	ATS F&G
209A	GE	60%	20°	NICD	12	#14	2786	In shadow #15	ATS F&G
210A	GE	80%	20°	NICD	12	#14	2786	In shadow #15	ATS F&G
211A	GE	60%	40°	NICD	12	#5	793	Completed 5-26-71	ATS F&G
212A	GE	80%	-20°	NICD	12	#11	1962	Discontinued 8-28-74	ATS F&G
213A	ASTRO	60%	25°	AGZN	5	#2	425	Completed 3-24-71	Sync. Orbit
214A	ASTRO	60%	40°	AGZN	5	#2	425	Completed 3-24-71	Sync. Orbit
218A	ASTRO	60%	0°	AGZN	40	#2	389	Completed 7-4-72	Sync. Orbit
219A	ASTRO	60%	20°	AGZN	40	#2	389	Completed 7-4-72	Sync. Orbit
220A	ASTRO	60%	40°	AGZN	40	#2	228	Completed 1-25-72	Sync. Orbit
221A	EP	60%	20°	NICD	12	#9	1975	In shadow #10	Sync. Orbit
222A	EP	60%	10°	NICD	12	#9	1975	In shadow #10	Sync. Orbit
223A	EP	60%	0°	NICD	12	#9	1975	In shadow #10	Sync. Orbit
224A	YD	60%	20°	AGZN	5		10	Discontinued 5-8-73	PE
224B	YD	60%	20°	AGZN	5	14 days of shadow		Discontinued 10-5-73	PE
224C	YD	60%	20°	AGZN	5	#1	392	Discontinued 10-2-74	PE
225A	YD	60%	20°	AGZN	21	#3	739	Discontinued 3-18-75	PE
226A	GU	50%	20°	NICD	15	#8*	1310	In shadow #9	ATS F
226B	GU	50%	20°	NICD	15	#4	948	In shadow #5	ATS F
227A	EP	60%	20°	NICD	3	#1	59	Discontinued 2-6-74	SMS
227B	EP	60%	20°	NICD	3	#4	920	In shadow #5	SMS
227C	EP	60%	20°	NICD	3	#1	238	In shadow #2	GOES B & C
228A	GE	80%	20°	NICD	12	#1	235	In shadow #2	IUE

*completed 2 at GSFC.

SECTION V

EQUIPMENT AND PROGRAMS TO BE ADDED TO THE CYCLE LIFE TEST PROGRAM

I. EQUIPMENT AND PROGRAMS TO BE ADDED TO THE CYCLE LIFE TEST PROGRAM

A. New Equipment:

1. None--New items will only be used for replacement of existing equipment.

B. New Programs:

1. GE, 6.0 ampere-hour, nickel-cadmium, IVE type cells for evaluation of life-cycle capability.

2. SAFT, 20.0 ampere-hour, nickel-cadmium cells for evalution of standard versus light plate loading.

3. EP, 9.0 ampere-hour, nickel-cadmium cells, AEM program (HCMM satellite), for evaluation of life-cycle capability.

4. 20.0 ampere-hour, nickel-cadmium cells, for evaluation on the standard cell program. Cells from four manufacturers will be evaluated.

SECTION VI

TEST FACILITIES

I. TEST FACILITIES

A. The ambient test temperatures of 0°C, +10°C, +20°C, +30°C, +40°C and +50°C, are maintained by environmental chambers with temperature controls accurate to within ±1.5°C; whereas test items cycling at +25°C are located in an air conditioned room with other temperature critical equipment and the temperature is maintained at 25°C ± 2°C. Several chambers, with a temperature range of -75°C to +175°C, are available for additional tests which require special temperatures.

B. Automatic Data Acquisition and Control System (ADACS):

1. Brief Summary:

a. The system (Photograph 1) is capable of testing 256 battery packs with 3000 channels available for data input from these packs.

(1) Each battery pack has its own power supply and system interface, remotely programmed by the system, to provide its test requirements. During test, the system routinely scans each pack's data every 2.4 minutes and compares each data point, whether voltage, temperature, or pressure, with programmed limits to insure that the test items meet their test specifications. If a parameter is out of limits the system will initiate an alarm and also type out a message identifying which pack's parameter was out of limits.

(2) As data is being scanned, it is recorded on magnetic tape and also on a teletype, in report form, if requested.

(3) The system was designed to provide an accuracy of 1.0 millivolt on directly read data such as auxiliary electrode and cell voltages. The accuracy of temperature (thermistor) and pressure (transducer) measurements are 0.05°C and 0.05 psia respectively.

b. The system is organized in three functional hardware groupings as follows:

(1) Computer and computer peripherals:

(a) Honeywell 316 computer and options,

(b) Two ASR35 heavy duty teletypes,

(c) Honeywell 316-50 high speed paper tape recorder and spooler.

(d) Datum, Inc., Model 5091-H316 magnetic tape I/O system with four tape transports.

(e) Datum, Inc., two Model 6078-H316 mass memory systems with 131,000 work drum memory each.

(f) Tally, Model 2200 line printer.

(2) Auxiliary digital functions include:

(a) The real time clock, the system shut-down time and alarm circuits, and medium speed analog input sub-system.

(b) Two John Fluke, Mode 83000-A digitizers.

(c) 3000-Channel reed relay scanner.

(d) Computer interface.

(3) Control sub-system:

(a) 200 Control channels providing the digital resistance conversion and control-relay outputs to the interface between the system and the test items.

2. Measurements:

a. Cell and auxiliary electrode voltages are presented directly to the system. Throughput measurement is 1.0 millivolt maximum.

b. Currents are measured by means of sampling the voltage drop across a low-resistance shunt of 100 MV full current value. Throughput measurement error of the shunt voltage is 1 millivolt maximum.

c. Temperature; cell and ambient, are measured by means of sampling the output of a thermistor bridge which is driven by an excitation voltage. The temperature range is -30°C to +70°C and is resolved in increments of 0.1°C, with an error of less than 0.05°C resulting from linearity.

d. Cell pressures are measured by means of sampling the output of a pressure transducer which is driven by an excitation voltage. The pressure range is 0 to 200 psia, and is resolved in increments of 0.1 psia with an error of less than 0.05 psia resulting from linearity.

e. Battery pack voltages, which exceed 10 volts, are attenuated by resistors to the extent that the scanner and system measures a maximum of 10 volts.

3. Expandability:

a. The system is expandable on a modular plug-in cabled-together basis up to a maximum of 5000 analog input channels.

b. The computer memory may be expanded from 24K words to 32K words.

4. Calibration:

a. The system was designed for a maximum throughput measurement error of 1.0 millivolt.

b. The digitizers are routinely calibrated off-line, and when on line, measures the temperature and pressure bridge excitation voltages along with a secondary standard reference voltage each scan (2.4 minutes) to insure maximum system accuracy.