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EVALUATION PROGRAM for SECONDARY SPACECRAFT CELLS

NINTH ANNUAL REPORT
OF
CYCLE LIFE TEST

prepared for
GODDARD SPACE FLIGHT CENTER

Contract S-23404-G

QUALITY EVALUATION LABORATORY
NAD CRANE, INDIANA

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QUALITY EVALUATION AND ENGINEERING LABORATORY
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EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

NINTH ANNUAL REPORT OF CYCLE LIFE TEST

QEEL/C 73-4 22 MAY 1973

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Enclosure (1)

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REPORT BRIEF

CYCLE LIFE TEST OF SECONDARY SPACECRAFT CELLS

Ref: (a) NASA Purchase Order Number S-23404-G
(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 25 Aug 1961
(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 ninth annual report covers the cycle life test of the evaluation program of secondary spacecraft cells, through 14 December 1972. 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. and from Director, Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

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 NAD 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 1078 nickel-cadmium, 178 silver-cadmium and 125 silver-zinc cells from several manufacturers have been added to the program. The capacities of the nickel-cadmium cells ranged from 1.25 to 50 ampere-hours; 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, 3.0, 8.0, 12 and 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 face 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, 20° C, 25° C, 40° C, 50° C, and a cycling temperature of 0° to 40° C within a period of 48 hours. A "Summary in Brief of Test Parameters" is listed on 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 have shown several failure modes such as little or no insulation around tabs and busses, 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. Better 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.

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

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, 12.0, 20.0	1.5, 3.0, 24.0	15, 21, 25, 40, 50	0°, 20°, 25°, 40°, 50°-40°, *	AE, AE14, AE14, THER	403
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, 10.0, 12.0, 20.0, 50.0	1.5, 3.0, 24.0	10, 15, 21, 25, 40, 50, 60	-20°, 0°, 20°, 25°, 50°-40°, 40°, *	AE, CLM, MULTI THER	714
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	6.0	1.5	25	0°, 20°	AE	76
			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°, 25°, 40°	AE-GE	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
Mc-Donnell Douglas	5.0, 40.0	1.5, 12.0 4.0	25	20°,40°		60
Yardney	12.0, 16.0	24.0	31, 42	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-GE: General Electric type.

   AE-GU: Gulton type.

   AE13: General Electric type AB13.

   AE14: General Electric type AB14.

   ASTRO: Astropower Laboratory, McDonnell-Douglas.

   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.

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

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

   IPD: Cells containing an internal pressure device.

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

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

NB: NIMBUS cells.

NBPT: NIMBUS cells with pressure transducers.

PLSP: Pellon separator.

PS: Polymerized neoprene terminal to cover seal.

RC-AE: Recombination and auxiliary electrodes.

RCPSP: Radiated cellophane separator.

RS: Vulcanized neoprene terminal to cover seal.

SAS: Small astronomical satellite.

ST: Stabistors used for charge control of cells.

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

ACTIVE AND COMPLETED PACKS

QEEL/C 73-4

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	
NICD	3.00	1.5	15%	0°	GE		63A	0.52	0.90	10	12-6-63	22,923	2-15-68	D
NICD	3.00	3.0	15%	0°	GE		67A	0.21	0.90	10	12-20-63	11,532	2-15-68	D
NICD	3.00	1.5	25%	0°	GE		64A	0.86	1.50	10	12-5-63	23,441	2-14-68	D
NICD	3.00	3.0	25%	0°	GE		68A	0.34	1.50	10	12-20-63	11,740	2-13-68	D
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
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
NICD	3.00	1.5	15%	40°	GE		39A	0.72	0.90	10	12-12-63	8,109	6-19-65	F
NICD	3.00	3.0	15%	40°	GE		43A	0.29	0.90	10	12-20-63	2,656	12-26-64	F
NICD	3.00	1.5	25%	40°	GE		40A	1.20	1.50	10	12-12-63	2,511	7-9-64	F
NICD	3.00	3.0	25%	40°	GE		44A	0.48	1.50	10	12-20-63	4,487	9-14-65	F
NICD	4.50	1.5	13%	20°	GE	NB	26E	1.10	1.20	10	2-23-72	4,541		
NICD	5.00	1.5	15%	0°	GE	NB	103A	0.83	1.50	5	4-24-65	43,340		
NICD	5.00	1.5	25%	0°	GE	NBPT	107A	1.38	2.50	5	6-5-65	39,775	6-14-72	D
NICD	5.00	1.5	15%	25°	GE	NB	106A	0.90	1.50	5	4-24-65	26,013	12-31-69	F
NICD	5.00	1.5	25%	25°	GE	NBPT	104B	1.50	2.50	5	6-10-65	13,149	11-15-67	F
NICD	5.00	1.5	15%	40°	GE	NB	113A	0.98	1.50	5	4-24-65	4,998	3-15-66	F
NICD	5.00	1.5	25%	40°	GE	NBPT	114A	1.63	2.50	5	6-12-65	8,273	12-19-66	F
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
NICD	6.00	1.5	25%	0°	GE	AE-14	50B	3.00	3.00	5	5-20-68	26,356		
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
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
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
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
NICD	6.00	1.5	25%	*	GE	AE-13	62B	3.00	3.00	5	7-3-68	11,807		
NICD	6.00	1.5	25%	*	GE	AE-14	65B	3.00	3.00	5	7-3-68	14,392	1-31-71	D

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
NICD	6.00	1.5	15%	0°	GE	AE	53B	1.80	1.80	5	7-18-68	9,230	2-23-70 F
NICD	6.00	1.5	15%	25°	GE	AE	28C	1.80	1.80	5	7-18-68	9,987	4-8-70 F
NICD	6.00	1.5	15%	40°	GE	AE	47C	1.80	1.80	5	7-18-68	5,842	7-28-69 F
NICD	6.00	1.5	25%	40°	GE	CHSP	9G	4.80	4.80	5	11-7-68	143	11-21-68 F
NICD	6.00	1.5	25%	40°	GE	PLSP	27C	4.80	4.80	5	11-7-68	559	12-16-68 D
NICD	6.00	1.5	21%	25°	GE	SAS B	1C	3.50	2.50	8	7-22-70	13,598	
NICD	6.00	1.5	25%	20°	EP	AE	2D	1.80	3.00	6	2-15-71	376	3-23-71 D
NICD	6.00	1.5	25%	20°	EP	AE	14E	1.80	3.00	6	2-15-71	997	4-18-71 D
NICD	6.00	1.5	25%	20°	EP	AE	26D	1.80	3.00	6	2-15-71	25	3-07-71 D
NICD	6.00	1.5	25%	20°	EP	AE	22C	1.80	3.00	6	2-16-71	5,950	3-22-72 D
NICD	6.00	1.5	25%	20°	EP	AE	25D	1.80	3.00	8	2-17-71	5,950	3-22-72 D
NICD	6.00	1.5	25%	20°	EP	AE	31C	1.80	3.00	6	2-17-71	5,936	3-22-72 D
NICD	6.00	1.5	25%	20°	EP	AE	38F	1.80	3.00	6	2-17-71	5,903	3-22-72 D
NICD	6.00	1.5	25%	20°	EP	AE	46C	1.80	3.00	6	2-17-71	5,888	3-22-72 D
NICD	6.00	1.5	25%	20°	EP	AE	49B	1.80	3.00	6	2-17-71	5,965	3-22-72 D
NICD	6.00	1.5	25%	-20°	GE		81B	3.00	3.00	5	3-14-71	9,084	
NICD	6.00	1.5	25%	20°	GE		95B	3.00	3.00	5	3-14-71	10,025	
NICD	6.00	1.5	25%	0°	GE		92B	3.00	3.00	5	3-14-71	9,699	
NICD	6.00	1.5	25%	40°	GE		106B	3.00	3.00	5	3-14-71	7,538	7-2-72 F
NICD	6.00	24.0	60%	40°	GE		91B	0.30	3.60	5	3-18-71	641	
NICD	6.00	24.0	60%	20°	GE		109B	0.30	3.60	5	3-18-71	630	
NICD	6.00	24.0	60%	0°	GE		123B	0.30	3.60	5	3-18-71	612	
NICD	6.00	24.0	60%	-20°	GE		75E	0.30	3.60	5	3-18-71	628	
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
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
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

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	
NICD	6.00	1.5	25%	20°	EP	AE	2E	1.65	3.00	5	5-2-71	5,801	6-7-72	D
NICD	6.00	1.5	40%	40°	EP	AE	42D	4.80	4.80	5	9-1-71	95	9-13-71	D
NICD	6.00	1.5	40%	20°	EP	AE	65C	4.80	4.80	5	9-1-71	4,227	5-24-72	F
NICD	6.00	1.5	40%	0°	EP	AE	53C	4.80	4.80	5	9-1-71	7,260		
NICD	12.00	1.5	15%	0°	GE		110A	2.07	3.60	5	1-4-64	49,061		
NICD	12.00	3.0	15%	0°	GE		111A	0.83	3.60	5	1-4-64	24,770		
NICD	12.00	1.5	25%	0°	GE		124A	3.45	6.00	5	1-4-64	34,343	11-5-69	F
NICD	12.00	3.0	25%	0°	GE		125A	1.38	6.00	5	1-4-64	25,119		
NICD	12.00	1.5	25%	25°	GE		82A	3.75	6.00	5	1-4-64	10,878	12-30-65	F
NICD	12.00	3.0	25%	25°	GE		83A	1.50	6.00	5	1-4-64	13,897	1-24-69	F
NICD	12.00	1.5	40%	25°	GE		96A	6.00	9.60	5	1-4-64	4,020	10-2-64	F
NICD	12.00	3.0	40%	25°	GE		97A	2.40	9.60	5	1-4-64	5,002	11-8-65	F
NICD	12.00	1.5	15%	40°	GE		85A	2.88	3.60	5	1-9-64	9,710	11-8-65	F
NICD	12.00	3.0	15%	40°	GE		86A	1.15	3.60	5	1-4-64	10,661	1-2-68	F
NICD	12.00	1.5	25%	40°	GE		99A	4.80	6.00	5	1-9-64	4,853	1-5-65	F
NICD	12.00	3.0	25%	40°	GE		100A	1.92	6.00	5	1-4-64	4,424	9-24-65	F
NICD	12.00	24.0	50%	25°	GE		93A	0.52	6.00	5	3-28-64	349	4-28-65	D
NICD	12.00	1.5	25%	0°	GE	AE	60A	6.00	6.00	5	10-6-65	5,650	10-20-66	D
NICD	12.00	1.5	25%	25°	GE	AE	12A	6.00	6.00	5	7-20-65	1,698	12-1-65	D
NICD	12.00	1.5	40%	25°	GE	AE	24A	9.60	9.60	5	10-2-65	665	11-19-65	D
NICD	12.00	1.5	40%	0°	GE	AE	48A	9.60	9.60	5	10-12-65	5,110	2-10-67	D
NICD	12.00	1.5	25%	0°	GE	AE	58A	6.00	6.00	5	1-20-67	136	2-10-67	D
NICD	12.00	1.5	40%	0°	GE	AE	72A	6.00	9.60	5	1-20-67	304	2-2-67	D
NICD	12.00	1.5	25%	25°	GE	AE	12B	6.00	6.00	5	1-6-67	404	2-10-67	D
NICD	12.00	1.5	40%	25°	GE	AE	24B	6.00	9.60	5	1-5-67	38	2-10-67	D
NICD	12.00	1.5	25%	40°	GE	AE	36A	6.00	6.00	5	1-27-67	75	2-3-67	D

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	
NICD	12.00	1.5	40%	40°	GE	AE	34A	6.00	9.60	5	1-27-67	65	2-3-67	D
NICD	20.00	1.5	15%	0°	GE	AE	7B	8.00	6.00	5	2-27-70	12,652	5-6-72	D
NICD	20.00	1.5	15%	0°	GE	AE	67B	8.00	6.00	5	2-27-70	12,634	5-6-72	D
NICD	3.50	1.5	15%	0°	GOULD		51A	0.60	1.05	10	12-5-63	22,364	2-15-68	D
NICD	3.50	3.0	15%	0°	GOULD		55A	0.24	1.05	10	12-20-63	11,546	2-15-68	D
NICD	3.50	1.5	25%	0°	GOULD		52A	1.00	1.75	10	12-5-63	13,730	6-11-66	F
NICD	3.50	3.0	25%	0°	GOULD		56A	0.40	1.75	10	12-20-63	11,897	2-15-68	D
NICD	3.50	1.5	25%	25°	GOULD		3A	1.09	1.75	10	12-6-63	4,751	10-31-64	F
NICD	3.50	3.0	25%	25°	GOULD		7A	0.44	1.75	10	12-20-63	4,173	7-26-65	F
NICD	3.50	1.5	40%	25°	GOULD		4A	1.75	2.80	10	12-5-63	3,164	7-9-64	F
NICD	3.50	3.0	40%	25°	GOULD		8A	0.70	2.80	10	12-20-63	2,494	11-29-64	F
NICD	3.50	1.5	15%	40°	GOULD		27A	0.84	1.05	10	12-12-63	4,485	11-6-64	F
NICD	3.50	3.0	15%	40°	GOULD		31A	0.34	1.05	10	12-20-63	2,517	1-3-65	F
NICD	3.50	1.5	25%	40°	GOULD		28A	1.40	1.75	10	12-12-63	1,811	5-29-64	F
NICD	3.50	3.0	25%	40°	GOULD		32A	0.56	1.75	10	12-20-63	975	6-10-64	F
NICD	20.00	1.5	15%	0°	GOULD		84A	3.45	6.00	5	1-16-64	22,448	2-13-68	D
NICD	20.00	3.0	15%	0°	GOULD		80A	1.38	6.00	5	1-21-64	11,378	2-13-68	D
NICD	20.00	1.5	25%	0°	GOULD		98A	5.75	10.00	5	1-21-64	10,641	1-14-66	F
NICD	20.00	3.0	25%	0°	GOULD		94A	2.30	10.00	5	1-24-64	11,162	2-13-68	D
NICD	20.00	1.5	25%	25°	GOULD		104A	6.25	10.00	5	1-16-64	2,980	8-20-64	F
NICD	20.00	3.0	25%	25°	GOULD		105A	2.50	10.00	5	1-21-64	5,690	3-17-66	F
NICD	20.00	1.5	40%	25°	GOULD		118A	10.00	16.00	5	2-1-64	2,937	9-7-64	F
NICD	20.00	3.0	40%	25°	GOULD		119A	4.00	16.00	5	2-1-64	1,793	9-27-64	F
NICD	20.00	1.5	15%	40°	GOULD		112A	4.80	6.00	5	1-16-64	5,213	2-15-65	F
NICD	20.00	3.0	15%	40°	GOULD		108A	1.92	6.00	5	1-24-64	4,237	8-31-65	F

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	
NICD	20.00	1.5	25%	40°	GOULD		126A	8.00	10.00	5	1-16-64	1,574	5-23-64	F
NICD	20.00	3.0	25%	40°	GOULD		122A	3.20	10.00	5	1-24-64	983	7-2-64	F
NICD	1.25	1.5	25%	-20°	GULTON		74B	1.00	0.63	5	3-3-66	33,878	6-2-72	D
NICD	1.25	1.5	60%	-20°	GULTON		88D	1.00	0.63	5	3-3-66	32,144	3-30-72	F
NICD	1.25	1.5	25%	0°	GULTON		108B	1.25	0.63	5	3-4-66	33,063	4-5-72	D
NICD	1.25	1.5	60%	0°	GULTON		98B	1.25	1.50	5	3-4-66	12,247	5-28-68	F
NICD	3.50	1.5	25%	-20°	GULTON	PS	89C	0.96	1.75	5	12-24-66	23,832	3-13-71	F
NICD	3.50	1.5	40%	-20°	GULTON	PS	75D	1.54	2.80	5	12-24-66	14,197	9-28-69	F
NICD	3.50	1.5	25%	0°	GULTON	PS	122C	1.01	1.75	5	12-24-66	37,578	5-12-72	D
NICD	3.50	1.5	40%	0°	GULTON	PS	99C	1.61	2.80	5	12-24-66	31,769	7-30-72	F
NICD	3.50	1.5	25%	25°	GULTON	PS	87C	1.09	1.75	5	12-23-66	20,866	9-2-70	F
NICD	3.50	1.5	25%	40°	GULTON	PS	112C	1.40	1.75	5	1-2-67	11,155	1-3-69	F
NICD	3.50	1.5	40%	25°	GULTON	PS	73C	1.75	2.80	5	12-23-66	9,978	10-28-68	F
NICD	3.60	1.5	40%	25°	GULTON	CLM	39B	3.60	2.88	10	11-11-65	5,399	12-6-66	F
NICD	4.00	1.5	15%	0°	GULTON	CC	115B	0.69	1.20	5	7-25-64	41,641	4-5-72	D
NICD	4.00	1.5	25%	0°	GULTON	CC	126B	1.15	2.00	5	7-25-64	42,234	1-10-72	F
NICD	4.00	1.5	25%	25°	GULTON	CC	4B	1.25	2.00	5	8-4-64	35,111	10-13-70	F
NICD	4.00	1.5	40%	25°	GULTON	CC	14B	2.00	3.20	5	8-4-64	8,474	3-19-66	F
NICD	4.00	1.5	15%	40°	GULTON	CC	28B	0.96	1.20	5	8-4-64	20,227	7-6-68	F
NICD	4.00	1.5	25%	40°	GULTON	CC	40B	1.60	2.00	5	8-4-64	10,360	6-22-66	F
NICD	4.00	1.5	25%	-20°	GULTON	CLM	40C	2.00	2.00	5	3-4-67	2	3-4-67	F
NICD	4.00	1.5	25%	0°	GULTON	CLM	52B	2.00	2.00	5	3-3-67	5,685	3-5-68	F
NICD	4.00	1.5	15%	25°	GULTON	CLM	26C	1.20	1.20	5	2-18-67	11,455	2-28-69	F
NICD	4.00	1.5	25%	25°	GULTON	CLM	14C	2.00	2.00	5	3-3-67	2,428	8-8-67	F
NICD	4.00	1.5	40%	25°	GULTON	CLM	37C	4.80	4.80	5	3-4-67	790	5-5-67	F
NICD	4.00	1.5	60%	25°	GULTON	CLM	38D	3.20	3.20	5	2-18-67	1,927	6-25-67	F

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	
NICD	*4.00*	*1.5*	*25%*	*40°*	*GULTON*	*CLM*	*39C*	*2.00*	*2.00*	*5*	*3-3-67*	*1,508*	*6-20-67*	*F*
NICD	5.00	1.5	15%	0°	GULTON	NB	117A	0.83	1.50	5	5-8-65	38,767	3-29-72	D
NICD	5.00	1.5	25%	0°	GULTON	NBPT	121A	1.38	2.50	5	6-5-65	20,861	3-5-69	F
NICD	5.00	1.5	15%	25°	GULTON	NB	120A	0.90	1.50	5	5-2-65	29,753	11-03-70	F
NICD	5.00	1.5	25%	25°	GULTON	NBPT	118B	1.50	2.50	5	6-10-65	8,108	11-22-66	F
NICD	5.00	1.5	15%	40°	GULTON	NB	127A	0.98	1.50	5	4-29-65	10,638	5-24-67	F
NICD	5.00	1.5	25%	40°	GULTON	NBPT	128A	1.63	2.50	5	6-21-65	6,345	8-18-66	F
NICD	5.00	1.5	25%	0°	GULTON	CO-NI	21E	1.40	2.50	10	9-2-70	13,018		
NICD	5.00	1.5	25%	25°	GULTON	CO-NI	45E	1.40	2.50	10	9-2-70	13,086		
NICD	5.00	1.5	40%	25°	GULTON	CO-NI	69C	2.20	4.00	10	9-2-70	12,755		
NICD	5.00	1.5	25%	40°	GULTON	CO-NI	9H	1.40	2.50	10	9-2-70	12,681		
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
NICD	5.60	1.5	25%	-20°	GULTON	FRS	44B	1.61	2.80	5	1-2-66	31,907	8-30-71	F
NICD	5.60	1.5	25%	-20°	GULTON	RS	32B	1.61	2.80	5	1-2-66	23,303	3-4-70	F
NICD	5.60	1.5	25%	0°	GULTON	FRS	100B	1.61	2.80	5	12-17-65	28,758	2-5-71	F
NICD	5.60	1.5	25%	0°	GULTON	RS	90C	1.61	2.80	5	12-17-65	31,623	7-20-71	F
NICD	5.60	1.5	25%	25°	GULTON	FRS	76B	1.75	2.80	5	12-10-65	11,158	1-2-68	F
NICD	5.60	1.5	25%	25°	GULTON	RS	96C	1.75	2.80	5	12-10-65	9,791	9-19-67	F
NICD	5.60	1.5	25%	40°	GULTON	FRS	42B	2.24	2.80	5	12-3-65	3,798	9-10-66	F
NICD	5.60	1.5	25%	40°	GULTON	RS	30B	2.24	2.80	5	12-3-65	1,275	3-8-66	F
NICD	6.00	1.5	15%	0°	GULTON		61A	1.04	1.80	10	12-31-63	10,146	12-17-65	F
NICD	6.00	3.0	15%	0°	GULTON		65A	0.41	1.80	10	12-31-63	11,208	2-15-68	D
NICD	6.00	1.5	25%	0°	GULTON		62A	1.72	3.00	10	12-30-63	22,779	2-15-68	D
NICD	6.00	3.0	25%	0°	GULTON		66A	0.69	3.00	10	12-31-63	4,414	8-31-65	F
NICD	6.00	1.5	25%	25°	GULTON		13A	1.88	3.00	10	12-31-63	4,021	11-11-64	F
NICD	6.00	3.0	25%	25°	GULTON		17A	0.75	3.00	10	12-20-63	2,885	1-31-65	F

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
NICD	6.00	1.5	25%	25°	GULTON		14A	3.00	4.80	10	12-30-63	2,086	6-19-64 F
NICD	6.00	3.0	40%	25°	GULTON		18A	1.20	4.80	10	12-31-63	1,500	8-18-64 F
NICD	6.00	1.5	15%	40°	GULTON		37A	1.44	1.80	10	12-31-63	6,064	4-14-65 F
NICD	6.00	3.0	15%	40°	GULTON		41A	0.58	1.80	10	12-31-63	1,689	9-14-64 F
NICD	6.00	1.5	25%	40°	GULTON		38A	2.40	3.00	10	12-30-63	1,377	5-22-64 F
NICD	6.00	3.0	25%	40°	GULTON		42A	0.96	3.00	10	12-31-63	4,133	8-23-65 F
NICD	6.00	24.0	50%	25°	GULTON		79A	0.20	3.00	5	3-28-64	545	10-13-65 F
NICD	6.00	1.5	25%	0°	GULTON	IM	13B	1.73	3.00	5	2-22-65	37,650	10-27-71 F
NICD	6.00	1.5	40%	25°	GULTON	IM	18B	3.00	4.80	5	2-22-65	7,577	7-21-66 F
NICD	6.00	1.5	25%	40°	GULTON	IM	38B	2.40	3.00	5	2-22-65	5,766	3-31-66 F
NICD	6.00	1.5	10%	0°	GULTON		61B	0.66	1.20	10	6-7-67	27,536	6-2-72 D
NICD	6.00	1.5	25%	0°	GULTON	AE	59A	3.00	3.00	5	4-15-65	14,863	2-28-68 F
NICD	6.00	1.5	40%	0°	GULTON	AE	71A	4.80	4.80	5	4-15-65	5,753	5-18-66 F
NICD	6.00	1.5	25%	25°	GULTON	AE	23A	3.00	3.00	5	2-5-65	15,713	1-24-68 F
NICD	6.00	1.5	40%	25°	GULTON	AE	11A	4.80	4.80	5	2-5-65	7,743	7-9-66 F
NICD	6.00	1.5	15%	40°	GULTON	AE	35A	1.80	1.80	5	6-28-65	12,511	11-30-67 F
NICD	6.00	1.5	25%	40°	GULTON	AE	47A	3.00	3.00	5	5-16-65	5,502	5-11-66 F
NICD	6.00	1.5	15%	*	GULTON	AE	60B	1.80	1.80	5	4-25-67	32,368	
NICD	6.00	1.5	25%	*	GULTON	AE	24C	3.00	3.00	5	4-25-67	17,328	5-24-70 F
NICD	6.00	1.5	40%	*	GULTON	AE	48B	4.80	4.80	5	4-25-67	6,156	6-27-68 F
NICD	6.00	3.0	25%	-20°	GULTON	CLM	41B	3.00	3.00	5	11-18-66	15,132	7-23-72 F
NICD	6.00	3.0	25%	0°	GULTON	CLM	66B	3.00	3.00	5	11-18-66	13,396	8-9-71 F
NICD	6.00	3.0	25%	25°	GULTON	CLM	18C	3.00	3.00	5	11-18-66	9,633	6-3-70 F
NICD	6.00	3.0	25%	40°	GULTON	CLM	29B	3.00	3.00	5	11-18-66	7,941	9-17-69 F
NICD	6.00	1.5	15%	*	GULTON	AE	36D	1.80	1.80	5	1-8-69	21,806	
NICD	6.00	1.5	25%	*	GULTON	AE	58D	3.00	3.00	5	1-8-69	21,920	

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
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
NICD	6.0	1.5	50%	-20°	GULTON	CLM	39D	6.00	6.00	5	9-21-70	1,376	5-10-71 F
NICD	6.0	1.5	50%	0°	GULTON	CLM	63B	6.00	6.00	5	9-21-70	12,107	
NICD	6.0	1.5	50%	20°	GULTON	CLM	3C	6.00	6.00	5	9-21-70	12,590	
NICD	6.0	1.5	50%	40°	GULTON	CLM	27D	6.00	6.00	5	9-21-70	6,808	11-6-71 F
NICD	6.0	1.5	21%	25°	GULTON	SAS A	18D	3.50	2.50	8	7-22-70	13,565	
NICD	6.0	1.5	25%	20°	GULTON	AE	28D	3.00	3.00	5	6-9-70	10,804	5-4-72 D
NICD	6.0	1.5	25%	20°	GULTON	AE	40D	3.00	3.00	5	6-9-70	10,846	5-4-72 D
NICD	6.0	1.5	25%	20°	GULTON	AE	52D	3.00	3.00	5	6-9-70	10,446	5-4-72 D
NICD	10.00	1.5	25%	0°	GULTON	AE	20B	5.00	5.00	5	1-15-69	2	1-15-69 F
NICD	10.00	1.5	25%	25°	GULTON	AE	8B	5.00	5.00	5	11-27-67	2,414	5-6-68 F
NICD	10.00	1.5	25%	40°	GULTON	AE	6B	5.00	5.00	5	11-27-67	602	3-14-68 F
NICD	12.00	1.5	15%	0°	GULTON		16B	2.07	3.60	5	2-20-65	44,139	
NICD	12.00	1.5	25%	0°	GULTON		101B	3.45	6.00	5	12-19-64	38,110	10-5-71 F
NICD	12.00	1.5	25%	25°	GULTON		27B	3.75	6.00	5	1-28-65	14,250	9-5-67 F
NICD	12.00	1.5	40%	25°	GULTON		96B	6.00	9.60	5	12-2-64	5,152	11-9-65 F
NICD	12.00	1.5	15%	40°	GULTON		78A	2.88	3.60	5	12-22-64	11,081	1-4-66 F
NICD	12.00	1.5	25%	40°	GULTON		90B	8.00	10.00	5	12-5-64	5,124	11-10-65 F
NICD	12.00	1.5	25%	0°	GULTON	AE	70A	6.00	6.00	5	2-10-67	33,065	
NICD	12.00	1.5	40%	0°	GULTON	AE	71B	6.00	9.60	5	1-6-67	15,275	10-6-69 F
NICD	12.00	1.5	40%	25°	GULTON	AE	11B	6.00	9.60	5	10-17-66	11,933	12-31-68 F
NICD	12.00	1.5	25%	40°	GULTON	AE	47B	6.00	6.00	5	1-5-67	6,537	6-19-68 F
NICD	20.00	1.5	15%	0°	GULTON		101A	3.45	6.00	5	1-16-64	3,629	9-20-64 F
NICD	20.00	3.0	15%	0°	GULTON		102A	1.38	6.00	5	1-21-64	11,212	2-13-68 D
NICD	20.00	1.5	15%	10°	GULTON		23B	8.00	6.00	10	2-4-71	10,389	
NICD	20.00	1.5	15%	10°	GULTON	AE-PT	35B	8.00	6.00	5	2-4-71	10,341	11-20-72 D
NICD	20.00	1.5	15%	10°	GULTON	AE	4C	8.00	6.00	9	5-14-72	3,192	

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	
NICD	20.00	1.5	25%	0°	GULTON		115A	5.75	10.00	5	1-16-64	2,291	6-24-64	F
NICD	20.00	3.0	25%	0°	GULTON		116A	2.30	10.00	5	2-11-64	10,971	2-13-68	D
NICD	20.00	1.5	25%	25°	GULTON		73A	6.25	10.00	5	1-16-64	7,763	6-30-65	F
NICD	20.00	3.0	25%	25°	GULTON		74A	2.50	10.00	5	1-21-64	1,754	9-27-64	F
NICD	20.00	1.5	40%	25°	GULTON		87A	10.00	16.00	5	2-1-64	627	4-7-64	F
NICD	20.00	3.0	40%	25°	GULTON		88A	4.00	16.00	5	2-1-64	358	3-21-64	F
NICD	20.00	1.5	15%	40°	GULTON		76A	4.80	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	4-20-66	F
NICD	20.00	1.5	25%	40°	GULTON		90A	8.00	10.00	5	1-18-64	4,045	11-12-64	F
NICD	20.00	3.0	25%	40°	GULTON		91A	3.20	10.00	5	1-24-64	4,480	10-14-65	F
NICD	20.00	1.5	15%	0°	GULTON	AE	58B	5.00	6.00	5	4-8-67	4,026	1-25-68	D
NICD	20.00	1.5	15%	25°	GULTON	AE	12C	5.00	6.00	5	3-9-67	4,934	1-25-68	D
NICD	20.00	1.5	15%	40°	GULTON	AE	36B	5.00	6.00	5	3-11-67	2,740	9-5-67	D
NICD	20.00	1.5	15%	*	GULTON	MULTI	12D	10.00	6.00	5	2-8-68	7,262	5-13-69	D
NICD	20.00	1.5	25%	*	GULTON	MULTI	36C	10.00	10.00	5	2-8-68	966	8-14-68	F
NICD	20.00	1.5	40%	*	GULTON	MULTI	58C	10.00	16.00	5	2-8-68	131	3-2-68	F
NICD	20.00	1.5	15%	0°	GULTON	AE	54B	8.00	6.00	5	3-23-68	27,177		
NICD	20.00	1.5	15%	25°	GULTON	AE	19B	8.00	6.00	5	3-23-68	24,625	7-2-72	D
NICD	20.00	1.5	15%	40°	GULTON	AE	38E	8.00	6.00	5	3-23-68	4,943	2-12-69	D
NICD	20.00	1.5	25%	*	GULTON	MULTI	48C	10.00	10.00	6	5-26-69	1,948	3-24-70	F
NICD	20.00	1.5	25%	20°	GULTON	MULTI*	48D	10.00	10.00	6	7-9-70	13,404		
NICD	20.00	1.5	15%	20°	GULTON	MULTI*	12E	8.00	6.00	5	5-13-70	14,786		
NICD	20.00	1.5	15%	0°	GULTON	MULTI*	68B	8.00	6.00	5	10-18-70	12,397		
NICD	50.00	1.5	25%	0°	GULTON		95A	14.38	25.00	5	6-8-64	3,227	2-9-65	F
NICD	50.00	1.5	15%	40°	GULTON		123A	12.00	15.00	5	6-8-64	1,873	11-11-64	F
NICD	20.00	1.5	40%	20°	HELIOTEK		34D	16.00	16.00	5	3-14-72	2,903	10-15-72	F

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	
NICD	3.90	1.5	25%	0°	NIFE		97C	1.07	2.00	5	9-29-67	20,009	4-6-71	F
NICD	3.90	1.5	25%	25°	NIFE		85C	1.07	2.00	5	9-29-67	9,356	6-19-69	F
NICD	3.00	1.5	15%	0°	SONOTONE	3S	43B	0.52	0.90	5	6-24-65	37,969	4-19-72	D
NICD	3.00	1.5	25%	0°	SONOTONE	3S	31B	0.86	1.50	5	6-24-65	28,074	8-10-70	F
NICD	3.00	1.5	25%	25°	SONOTONE	3S	3B	0.94	1.50	5	6-25-65	11,726	8-23-67	F
NICD	3.00	1.5	40%	25°	SONOTONE	3S	2B	1.50	2.40	5	7-10-65	5,399	7-26-66	F
NICD	3.00	1.5	15%	40°	SONOTONE	3S	26B	0.72	0.90	5	7-10-65	6,289	10-4-66	F
NICD	3.00	1.5	25%	40°	SONOTONE	3S	37B	1.20	1.50	5	7-10-65	5,625	8-4-66	F
NICD	3.50	1.5	10%	0°	SONOTONE		15B	0.39	0.70	10	6-7-67	26,353	6-2-72	D
NICD	5.00	1.5	15%	0°	SONOTONE		49A	0.86	1.50	10	12-31-63	23,112	2-15-68	D
NICD	5.00	3.0	15%	0°	SONOTONE		53A	0.35	1.50	10	12-31-63	11,427	2-13-68	D
NICD	5.00	1.5	25%	0°	SONOTONE		50A	1.44	2.50	10	12-17-63	22,525	2-15-68	D
NICD	5.00	3.0	25%	0°	SONOTONE		54A	0.58	2.50	10	12-31-63	11,331	2-7-68	D
NICD	5.00	1.5	25%	25°	SONOTONE		1A	1.56	2.50	10	12-17-63	11,745	2-27-66	F
NICD	5.00	3.0	25%	25°	SONOTONE		5A	0.62	2.50	10	12-31-63	11,092	2-12-68	D
NICD	5.00	1.5	40%	25°	SONOTONE		2A	2.50	4.00	10	12-17-63	6,671	4-24-65	F
NICD	5.00	3.0	40%	25°	SONOTONE		6A	1.00	4.00	10	1-2-64	5,211	12-13-65	F
NICD	5.00	1.5	15%	40°	SONOTONE		25A	1.20	1.50	10	12-17-63	9,328	10-31-65	F
NICD	5.00	3.0	15%	40°	SONOTONE		29A	0.48	1.50	10	12-31-63	5,975	4-17-66	F
NICD	5.00	1.5	25%	40°	SONOTONE		26A	2.00	2.50	10	12-17-63	3,625	10-15-64	F
NICD	5.00	3.0	25%	40°	SONOTONE		30A	0.80	2.50	10	12-31-63	4,141	8-7-65	F
NICD	5.00	1.5	25%	-20°	SONOTONE	ST	75C	5.00	2.50	5	10-24-65	2,145	4-5-66	F
NICD	5.00	1.5	40%	-20°	SONOTONE	ST	89B	5.00	4.00	5	10-24-65	1,530	2-26-66	F
NICD	5.00	1.5	25%	0°	SONOTONE	ST	92A	5.00	2.50	5	9-5-65	8,774	5-10-67	F
NICD	5.00	1.5	40%	0°	SONOTONE	ST	122B	5.00	4.00	5	9-5-65	5,190	9-24-66	F
NICD	5.00	1.5	25%	25°	SONOTONE	ST	73B	5.00	2.50	5	8-12-65	3,742	4-15-66	F

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	
NICD	5.00	1.5	40%	25°	SONOTONE	ST	87B	5.00	4.00	5	8-12-65	2,392	1-27-66	F
NICD	5.00	1.5	25%	40°	SONOTONE	ST	99B	5.00	2.50	5	8-23-65	4,388	7-9-66	F
NICD	5.00	1.5	15%	40°	SONOTONE	ST	112B	5.00	1.50	5	8-23-65	3,294	4-1-66	F
NICD	5.00	1.5	25%	25°	SONOTONE	AE	14D	2.50	1.47	5	11-7-67	1,179	2-7-68	F
NICD	20.00	1.5	25%	25°	SONOTONE	IPD	22A	20.00	10.00	10	9-20-67	6,664	10-7-69	D
NICD	20.00	1.5	25%	25°	SONOTONE	IPD	10A	7.00	10.00	10	9-20-67	7,188	10-7-69	D
NICD	20.00	1.5	40%	25°	SONOTONE	IPD	34B	20.00	16.00	10	9-20-67	5,634	7-3-69	F
NICD	20.00	3.0	40%	25°	SONOTONE	IPD	46A	20.00	16.00	10	9-20-67	3,501	10-7-69	D
NICD	20.00	1.5	75%	25°	SONOTONE	IPD	72B	20.00	30.00	10	9-20-67	1,143	4-5-69	F
NICD	20.00	1.5	25%	20°	SONOTONE	IPD*	10B	7.00	10.00	10	5-13-70	13,964	10-30-72	F
NICD	20.00	1.5	25%	20°	SONOTONE	IPD*	22B	15.00	10.00	10	5-13-70	3,419	11-23-70	D
NICD	20.00	1.5	40%	20°	SONOTONE	IPD*	34C	15.00	16.00	10	5-13-70	8,357	11-2-71	F
NICD	20.00	3.0	40%	20°	SONOTONE	IPD*	46B	15.00	16.00	10	5-13-70	686	11-23-70	D
NICD	20.00	1.5	75%	20°	SONOTONE	IPD*	72C	20.00	30.00	10	5-13-70	4,381	2-22-71	F
AGCD	7.00	8.0	30%	20°	ELECTROMITE		104C	0.40	2.10	3	12-23-70	1,380	3-29-72	D
AGCD	8.00	8.0	25%	25°	ESB	AE	1B	0.50	2.00	5	9-9-66	3,875	6-8-70	F
AGCD	3.00	1.5	16%	25°	YARDNEY		2C	1.30	1.00	9	9-16-66	7,039	12-12-67	F
AGCD	5.00	24.0	20%	0°	YARDNEY	C3SP	57B	0.30	1.00	5	9-17-65	267	6-17-66	F
AGCD	5.00	24.0	20%	25°	YARDNEY	C3SP	21A	0.30	1.00	5	9-17-65	98	12-25-65	F
AGCD	5.00	24.0	20%	40°	YARDNEY	C3SP	45A	0.30	1.00	5	9-27-65	61	11-16-65	F
AGCD	5.00	24.0	20%	25°	YARDNEY	RCPSP	9C	0.30	1.00	10	10-27-65	34	12-1-65	D
AGCD	5.00	24.0	20%	25°	YARDNEY	CPSP	33B	0.30	1.00	5	10-17-65	720	11-4-67	F
AGCD	5.00	24.0	20%	25°	YARDNEY	PLSP	69A	0.30	1.00	5	10-27-65	595	7-17-67	F
AGCD	5.00	24.0	20%	0°	YARDNEY		113B	0.30	1.00	5	1-22-67	2,542	2-19-71	F
AGCD	5.00	24.0	20%	25°	YARDNEY		77B	0.30	1.00	5	1-12-67	661	11-12-68	F
AGCD	5.00	24.0	20%	25°	YARDNEY		105B	0.30	1.00	5	1-12-67	77	4-19-67	F

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	
AGCD	5.00	24.0	20%	40°	YARDNEY		128B	0.30	1.00	5	1-19-67	269	11-4-67	F
AGCD	5.00	8.0	20%	0°	YARDNEY	PLCPSP	114B	0.30	1.00	5	1-22-67	1,496	6-25-68	F
AGCD	5.00	8.0	20%	25°	YARDNEY	PLCPSP	118C	0.30	1.00	5	1-17-67	1,505	7-9-68	F
AGCD	10.00	8.0	30%	25°	YARDNEY		45D	0.50	3.00	5	5-3-67	1,759	11-19-68	F
AGCD	11.00	24.0	40%	0°	YARDNEY		45B	0.30	4.40	10	11-5-66	121	3-13-67	F
AGCD	11.00	24.0	40%	25°	YARDNEY		21B	0.30	4.40	10	11-5-66	69	1-13-67	F
AGCD	11.00	8.0	27%	25°	YARDNEY	PLSP	21C	0.50	3.00	5	3-28-67	37	4-9-67	F
AGCD	11.00	8.0	27%	25°	YARDNEY	WNSP	45C	0.50	3.00	5	3-28-67	70	4-22-67	F
AGCD	11.00	24.0	18%	0°	YARDNEY	AE-GU	57D	0.25	2.00	5	2-14-68	1,711		
AGCD	11.00	24.0	18%	25°	YARDNEY	AE-GU	69B	0.25	2.00	5	2-14-68	507	7-13-69	F
AGCD	11.00	24.0	18%	40°	YARDNEY	AE-GU	33C	0.25	2.00	5	2-14-68	447	5-15-69	F
AGCD	12.00	24.0	50%	0°	YARDNEY		57A	0.60	6.00	10	2-14-64	168	9-3-64	F
AGCD	12.00	24.0	50%	40°	YARDNEY		33A	0.60	6.00	10	2-14-64	210	9-20-64	F
AGCD	12.00	1.5	25%	-20°	YARDNEY		85B	3.90	6.00	5	1-19-66	2,375	3-25-67	F
AGCD	12.00	1.5	25%	0°	YARDNEY		97B	3.90	6.00	5	1-19-66	4,481	3-15-67	F
AGCD	12.00	1.5	25%	25°	YARDNEY		82B	3.90	6.00	5	1-17-66	4,559	11-27-66	F
AGCD	12.00	24.0	43%	0°	YARDNEY	AE-GE	21D	0.50	5.20	5	6-16-67	60	8-13-67	F
AGCD	12.00	24.0	43%	40°	YARDNEY	AE-GE	9F	0.50	5.20	5	6-16-67	310	5-28-68	F
AGZN	5.00	1.5	25%	20°	ASTRO		25B	1.60	2.50	10	12-4-69	681	2-1-70	F
AGZN	5.00	12.0	25%	20°	ASTRO		25C	0.35	2.50	10	2-8-70	567	11-27-70	F
AGZN	5.00	12.0	25%	40°	ASTRO		37D	0.35	2.50	10	2-8-70	391	9-4-70	F
AGZN	5.00	1.5	25%	40°	ASTRO		47D	1.60	2.50	10	12-4-69	2,013	4-19-70	F
AGZN	40.00	4.0	20%	20°	ASTRO		20C	3.00	5.00	10	10-25-71	519	2-7-72	D
AGZN	40.0	4.0	20%	20°	ASTRO		33E	3.00	5.00	10	10-25-71	502	5-8-72	D
AGZN	25.00	24.0	40%	25°	DELCO-REMY		89A	15.00	10.00	5	9-18-64	80	12-8-64	D
AGZN	25.00	24.0	40%	25°	DELCO-REMY		75A	15.00	10.00	5	8-18-64	32	9-18-64	F

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	
AGZN	25.00	3.0	40%	25°	DELCO-REMY		88B	15.00	20.00	5	3-1-65	120	3-16-65	D
AGZN	25.00	3.0	40%	25°	DELCO-REMY		88C	15.00	20.00	5	3-26-65	325	5-6-65	D
AGZN	25.00	24.0	40%	25°	DELCO-REMY		9D	1.00	10.00	10	12-13-65	121	4-18-66	D
AGZN	25.00	24.0	40%	25°	DELCO-REMY	2SR	9E	1.00	10.00	10	10-5-66	90	1-4-67	D
AGZN	40.00	24.0	25%	25°	DELCO-REMY		75B	25.00	10.00	5	10-28-64	139	3-15-65	D
AGZN	12.00	24.0	42%	25°	YARDNEY		9A	0.50	5.00	10	5-7-65	58	7-7-65	D
AGZN	16.00	24.0	31%	25°	YARDNEY	2SR	57C	0.50	5.00	10	12-2-66	281	8-30-67	D

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 NAD 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 ninth annual report covers the cycle life test, the third phase of the evaluation program of secondary spacecraft cells, through 14 December 1972. 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 1078 nickel-cadmium, 178 silver-cadmium and 125 silver-zinc sealed cells from several manufacturers have been added to the program. The capacities of the nickel-cadmium cells ranged from 1.25 to 50 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 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, 3.0, 8.0, 12, and 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 charge current is determined by the theoretical percent of recharge returned to the cells following each constant current discharge.

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°, 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 vii through xviii for further information on parameters.)

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 cells remaining in the pack continue test until 60 percent of the cells have failed constituting a pack failure. By direction of Goddard Space Flight Center cell failure analysis is performed at NAD Crane. 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.

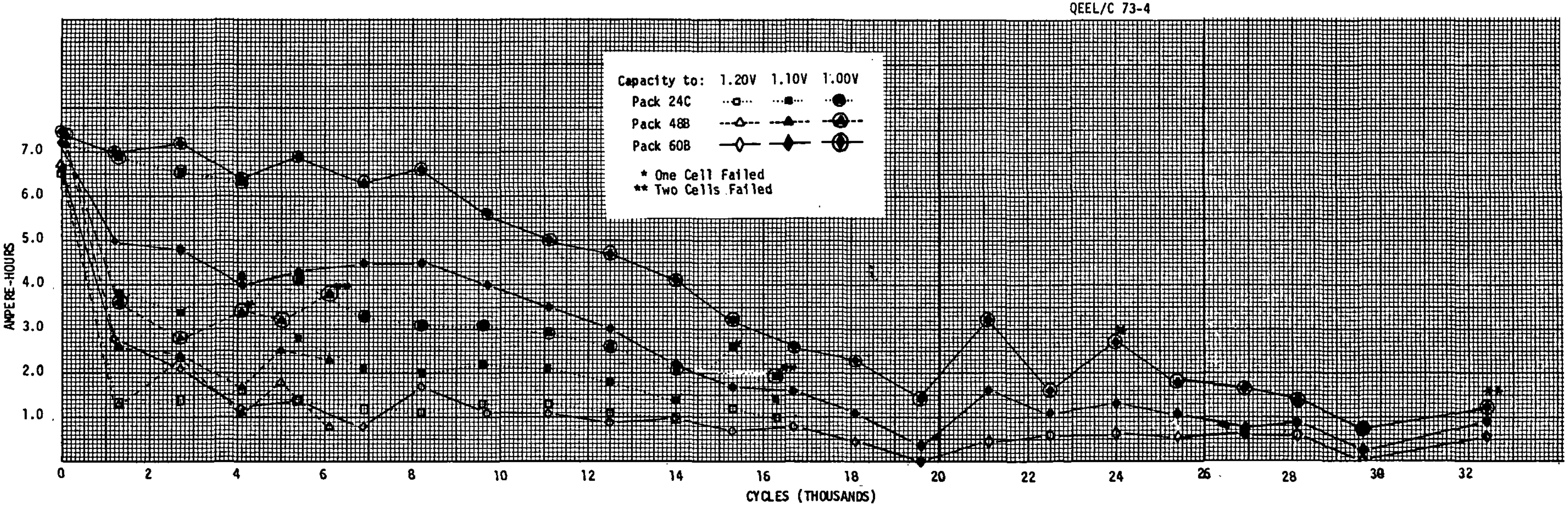
On 31 August 1972, the first battery pack was placed on the new Automatic Data Acquisition and Control System (ADACS) for test. The conversion of the battery packs from the old "Tally" system to ADACS was completed 27 November 1972.

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:

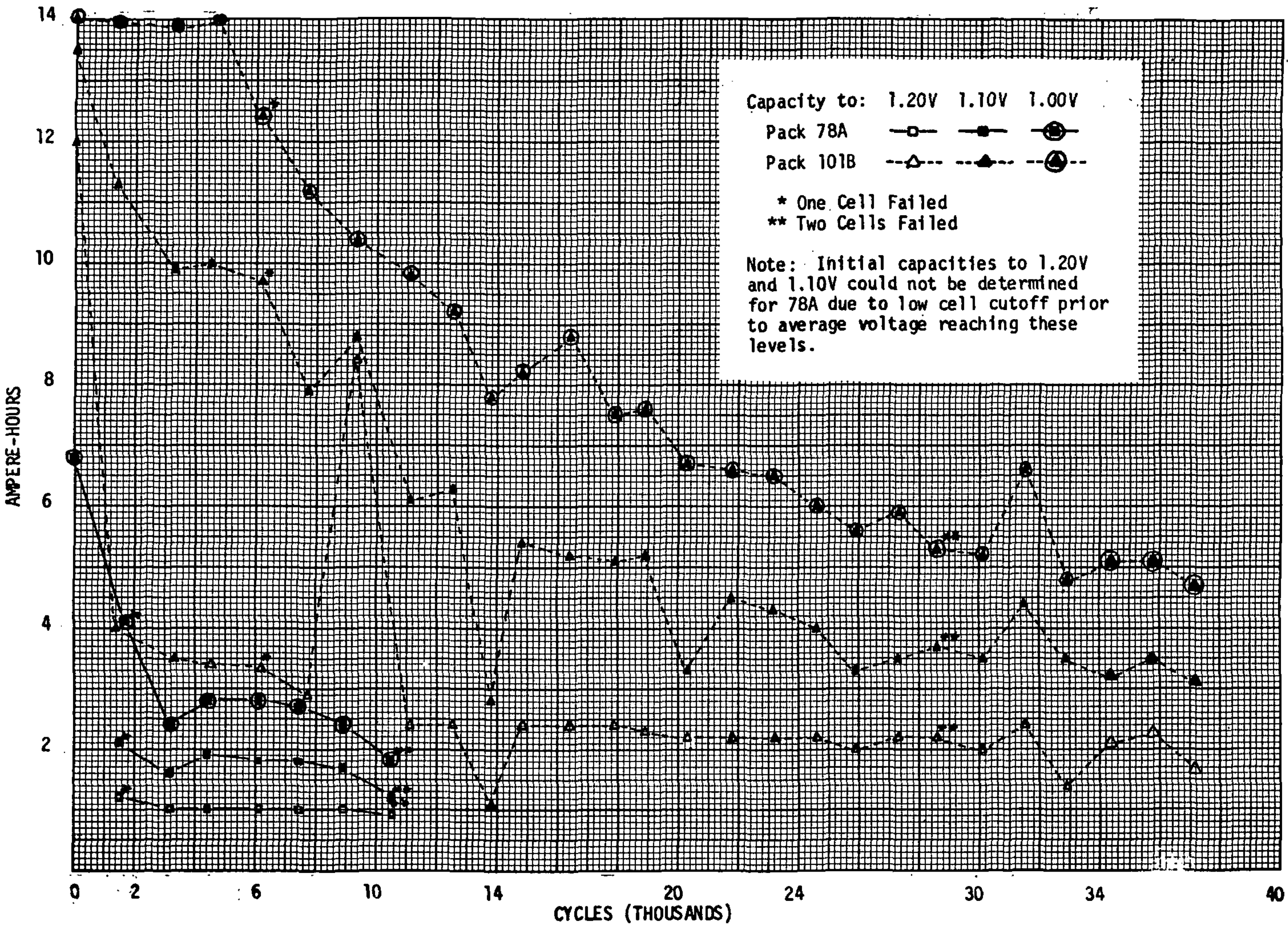
Multiples of 10	Multiples of 100
0-4 Cycles, 0	0-49 Cycles, 0
5-14 Cycles, 1	50-149 Cycles, 1
15-24 Cycles, 2	150-249 Cycles, 2
25-34 Cycles, 3	250-349 Cycles, 3

* 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

SPACE ORIENTED TESTS IN ADDITION TO LIFE CYCLING TESTS

The following tests have been, or are being performed at NAD Crane. The results are reported by Crane unless otherwise specified and copies of data are available on request to the NASA Technical 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) cell short test, (4) overcharge test, and (5) internal resistance test.

B. Separator Testing: Separator tests are conducted on all types of separators including pellon, cellophane, polyprophylene, various materials by RAI, and ceramic material. The tests are performed in three modes: (1) constant current charge, (2) constand 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 6 and 12 ampere-hour nickel-cadmium cells and on 5 and 40 ampere-hour silver-zinc. 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.

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 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 it 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. Shorts between the plates may result. In some of the round cells this condition may be absent at the outermost portion of the separator, but become progressively worse toward the center of the core. Shorts between the plates may result at the center of the core.

SECTION I

CELLS ON ORIGINAL TEST PROGRAM STILL CYCLING

I. CELLS ON ORIGINAL TEST PROGRAM STILL CYCLING

A. 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 best 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 all but these three remaining packs (110A, 111A and 125A) have been summarized in Section III of this report. The results of the remaining packs are contained in Figures 3 through 6 at the end of this section.

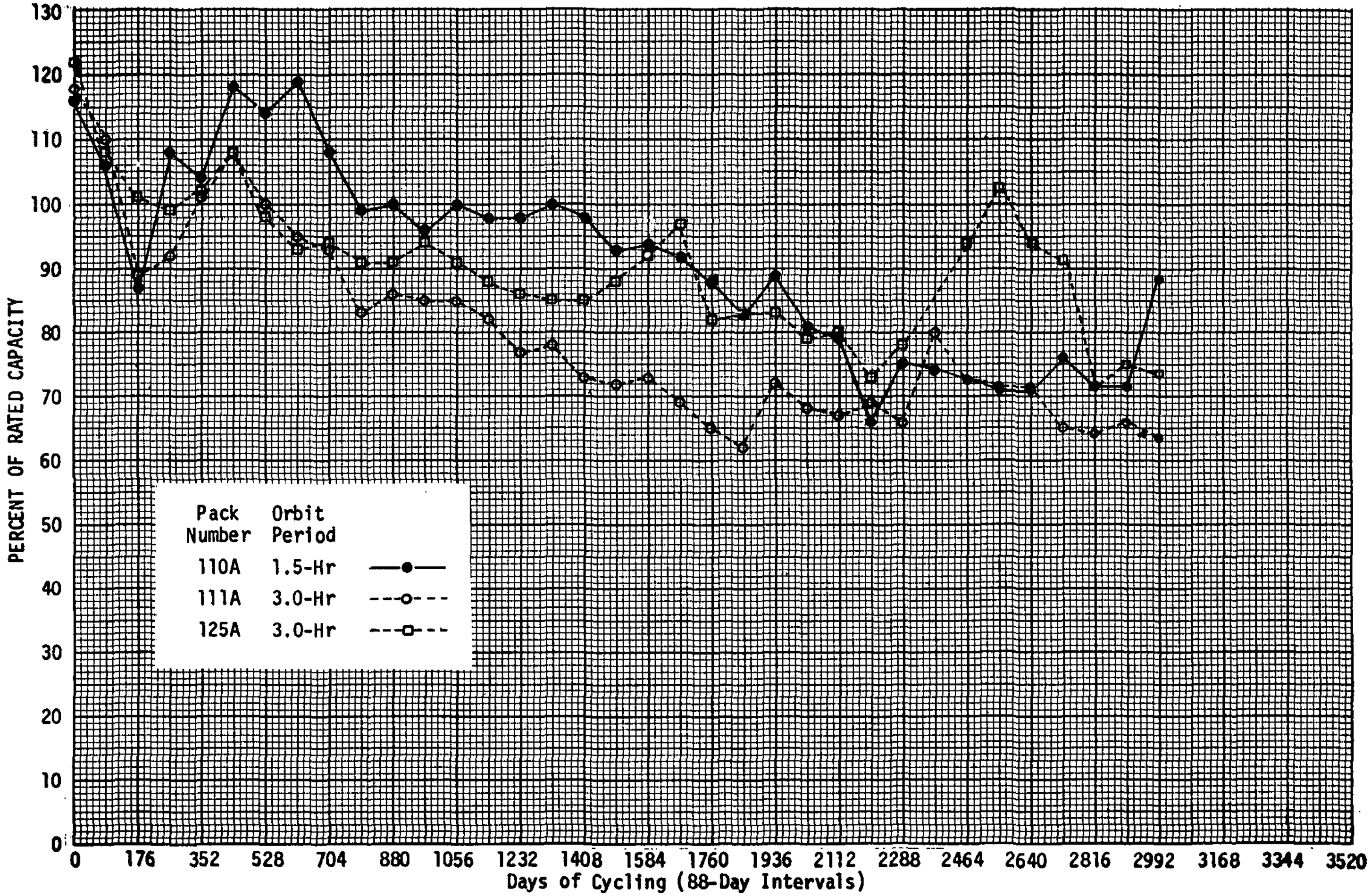
B. The three packs maintained on cycling contain five GE 12 ampere-hour, nickel-cadmium, cells per pack. These cells are rectangular. The cell containers and covers are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude as 1/4-20 threaded posts.

C. 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. Cycling was started in January 1964. Packs 110A, 111A, and 125A have completed 49,061, 24,770, and 25,119 cycles, respectively. Only one cell failure has occurred to date. This was in pack 125A after 19,645 cycles.



PRECYCLING AND CAPACITY CHECK CYCLES

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

FIGURE 3

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

PACK 110A MANF. GE 12.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 2.07
DEPTH OF DISCHARGE % 15

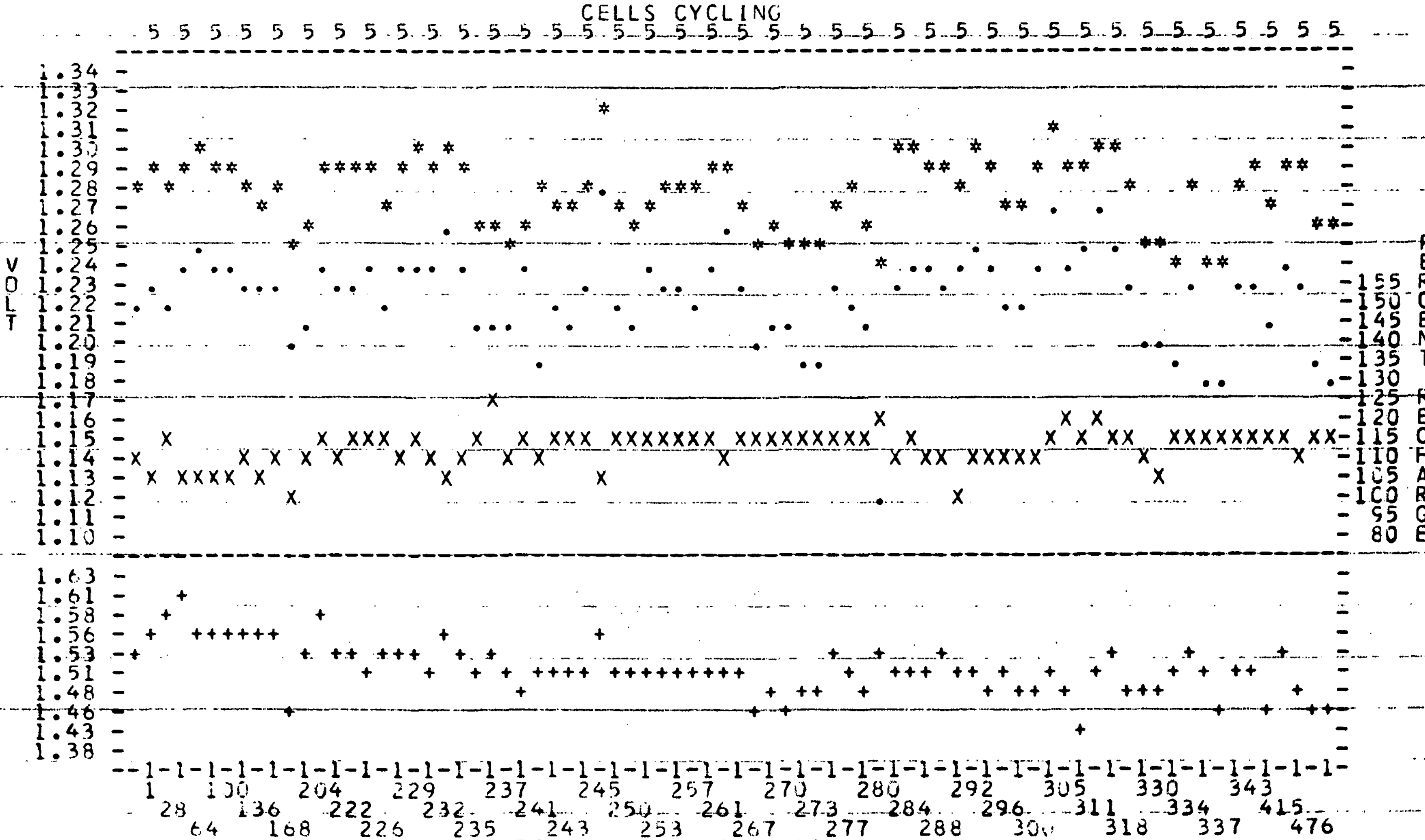


FIGURE 4

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

PACK 111A MANF. GE 12.0 AH
ORBIT PERIOD HOURS 03.0
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.83
DEPTH OF DISCHARGE % 15

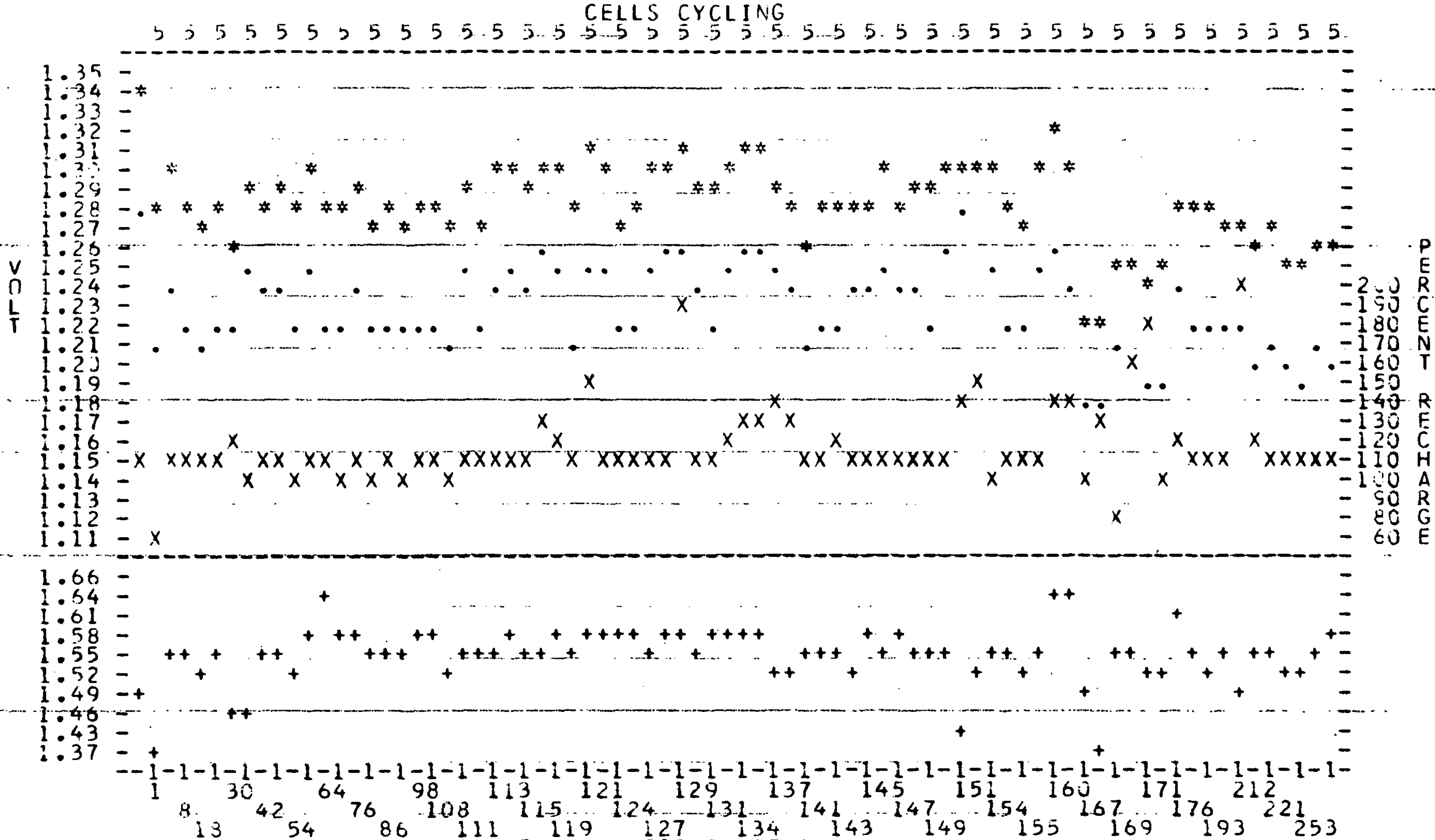


FIGURE 5

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

PACK 125A MANF. GE 12.0 AH
ORBIT PERIOD HOURS 03.0
TEMP. DEGREES C. 00
CHARGE RATE AMPS 1.38
DEPTH OF DISCHARGE % 25

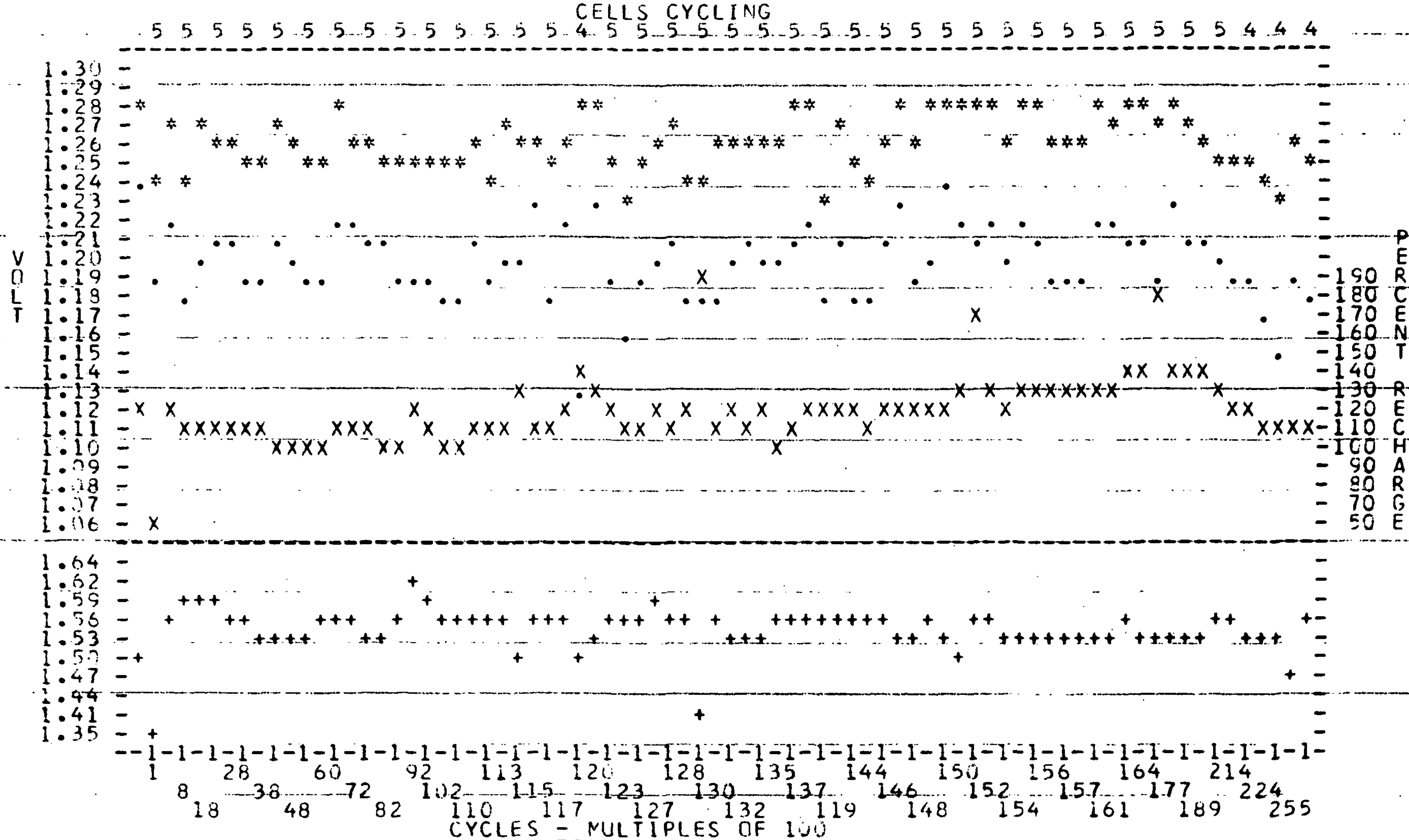


FIGURE 6

SECTION II

CELLS USING CONSTANT CURRENT CHARGE WITH VOLTAGE LIMIT CONTROL (CELLS PRESENTLY CYCLING WHICH FOLLOWED THE ORIGINAL PROGRAM)

I. CELLS USING CONSTANT CURRENT CHARGE WITH VOLTAGE LIMIT CONTROL

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 60 percent of the cells have failed. A cell is considered a failure when its terminal voltage drops below 0.5 volt during cycling.

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 the cells differ from this description, a separate description has been written in the sections to follow.

B. Nickel-Cadmium Types:

1. 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 F	1.08 F
792 Days Disch #2	1.60	2.80 F	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 F		
1320 Days Disch #2	1.17 F		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 D	1.93 F			

F - Failed.
D - Discontinued.

d. Test Results:

(1) Performance on Cycling: (Figures 7 and 8) 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.

GEEL/C 73-4

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

PACK 122C MANF. GULTON 03.5 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 1.01
DEPTH OF DISCHARGE % 25

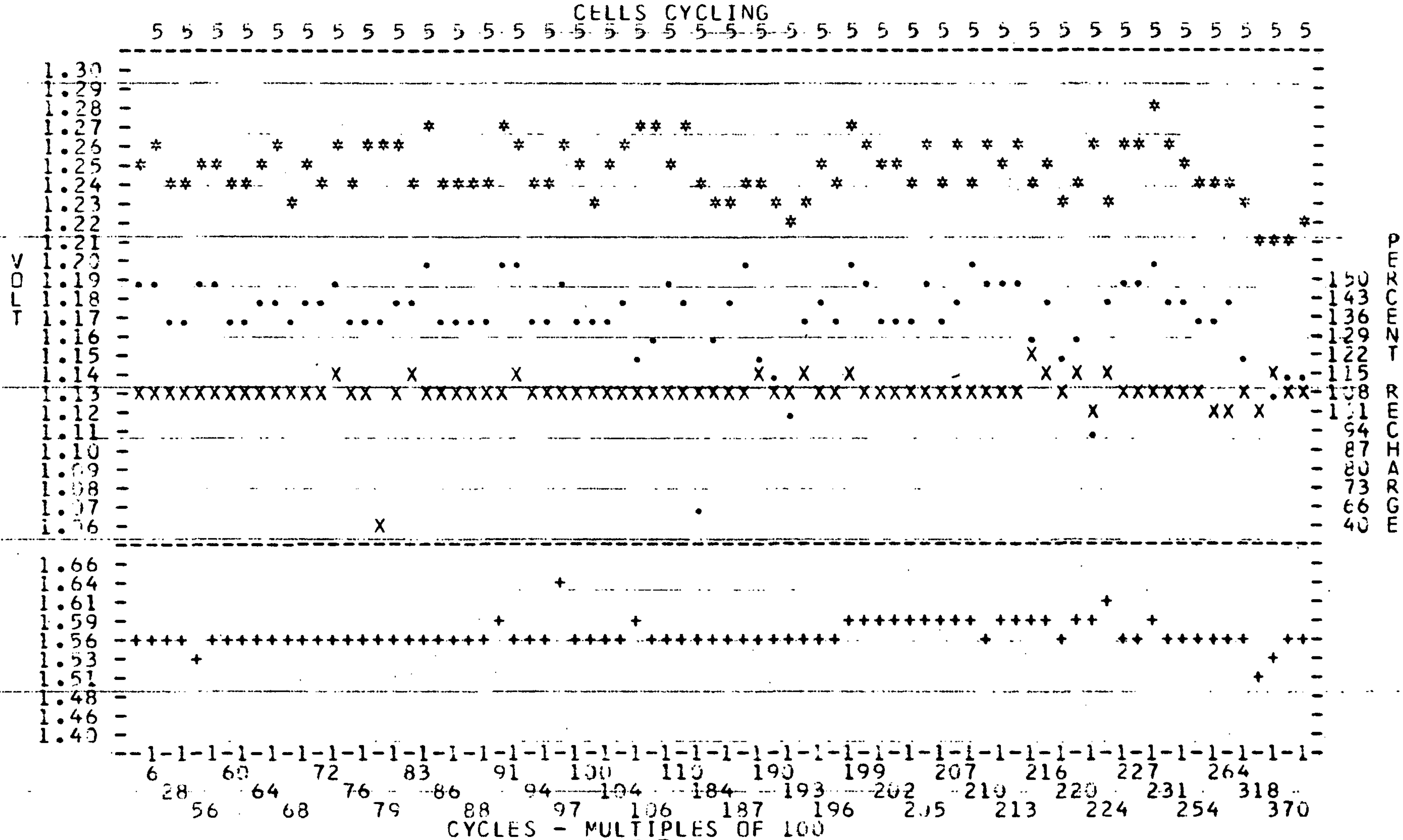


FIGURE 7

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

PACK 99C MANF. GULTON 03.5 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 1.61
DEPTH OF DISCHARGE % 40

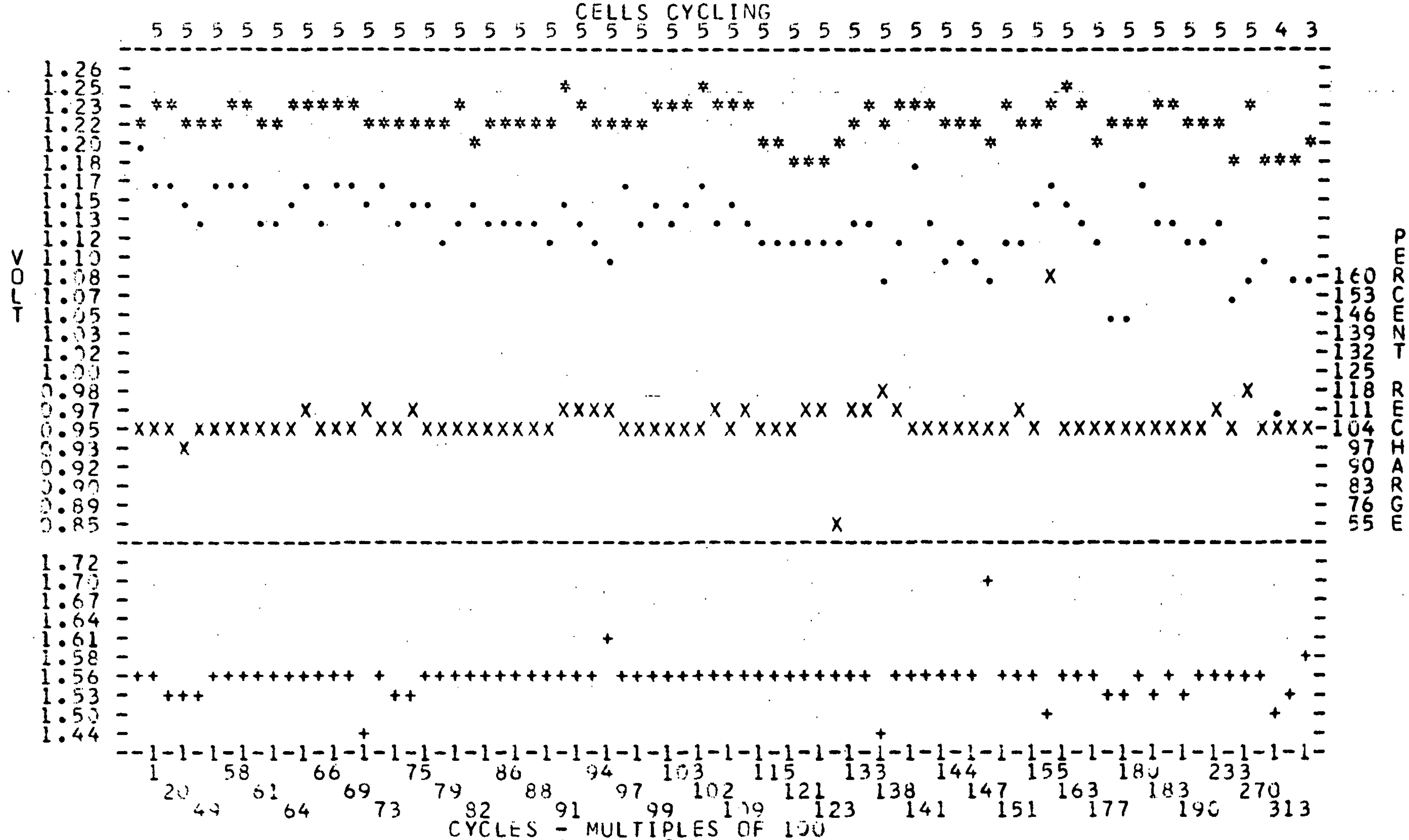


FIGURE 8

2. 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 F	1.53	1.17
616 Days Disch #2	4.60	--	1.60		1.67	0.76 F
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 F	
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 F			
2200 Days Disch #2	2.80	3.04 F				
2376 Days Disch #2	2.64					
2552 Days Disch #2	2.66 D					

F-Failed
D-Discontinued

c. Test Results:

(1) Performance on Cycling: (Figures 9 and 10) 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.

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

PACK 115B MANF. GULTON 04.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.69
DEPTH OF DISCHARGE % 15

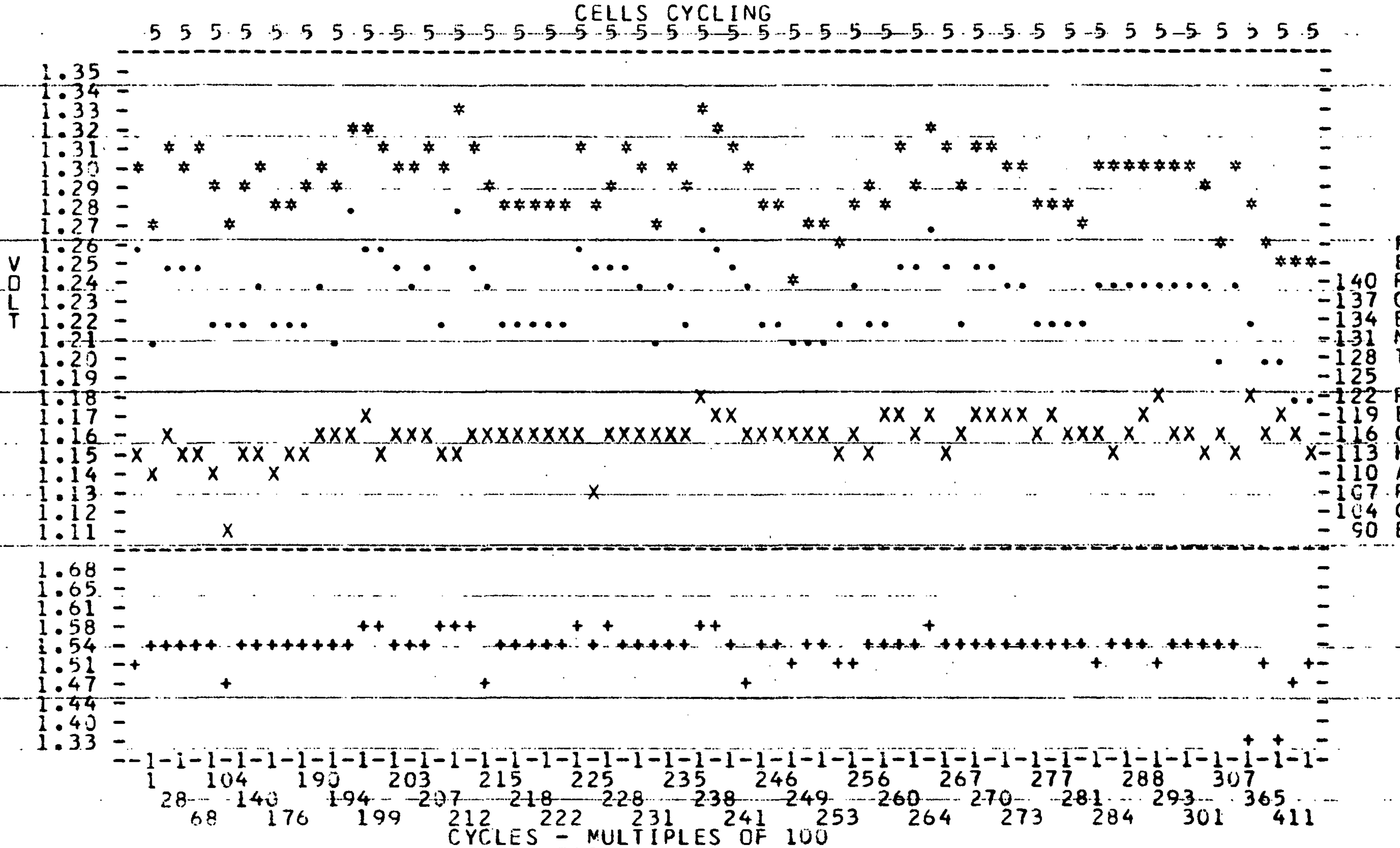


FIGURE 9

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

PACK 126B MANF. GULTON 04.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 1.15
DEPTH OF DISCHARGE % 25

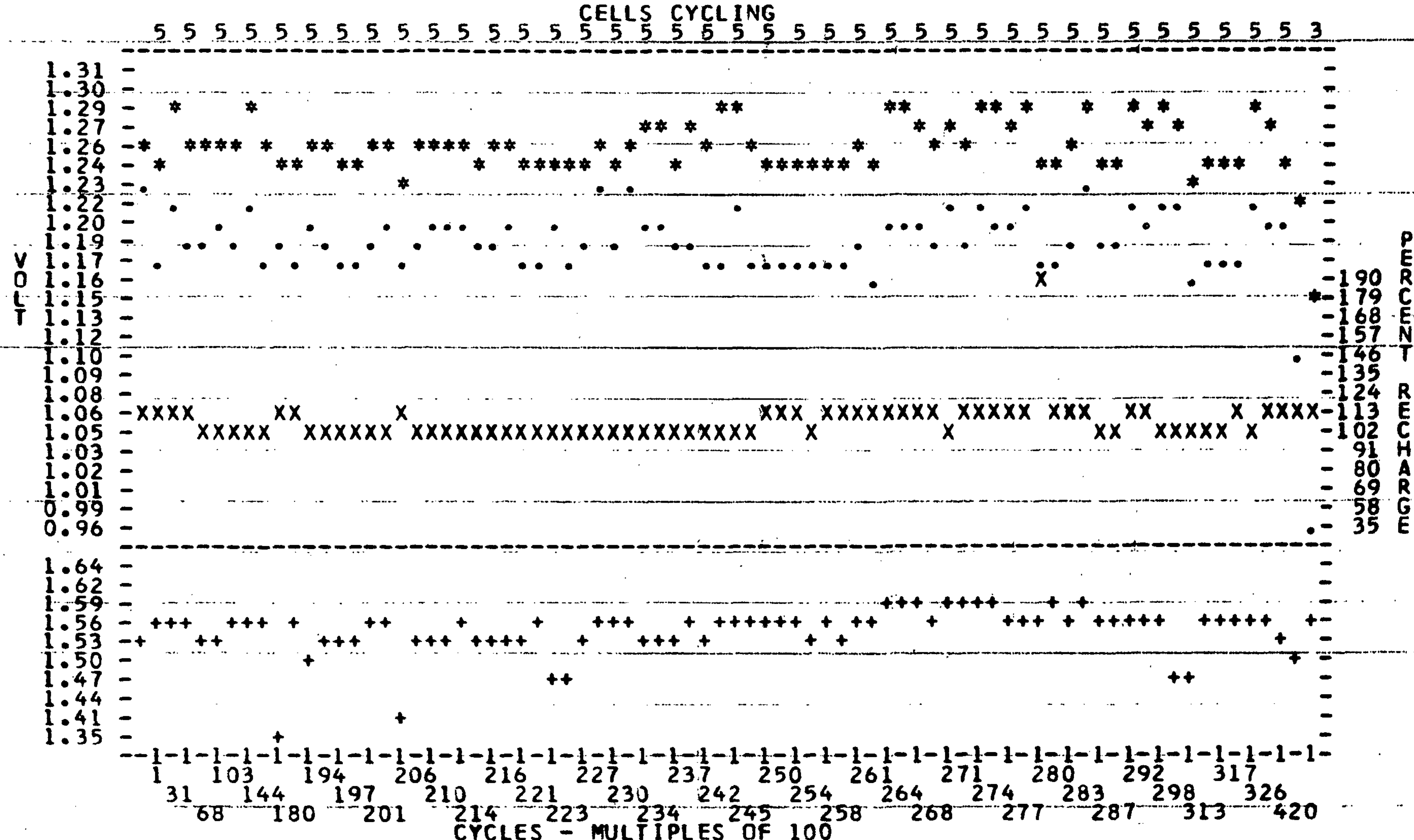


FIGURE 10

3. Gulton 5.0 ah (Cobalt Additive with Pellon 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 pellon separator and 26 cells contain a polypropylene separator (PPL). The cells were divided into packs as indicated in the table below.

Pack	Type and Number of Cells per Pack			
Number	Cobalt-Pellon	Control-Pellon	Cobalt-PPL	Control-PPL
21E	5	5		
45E	2	2	3	3
69C	5	5		
9H			5	5
33D			5	5

b. Parameters and Capacity Checks:

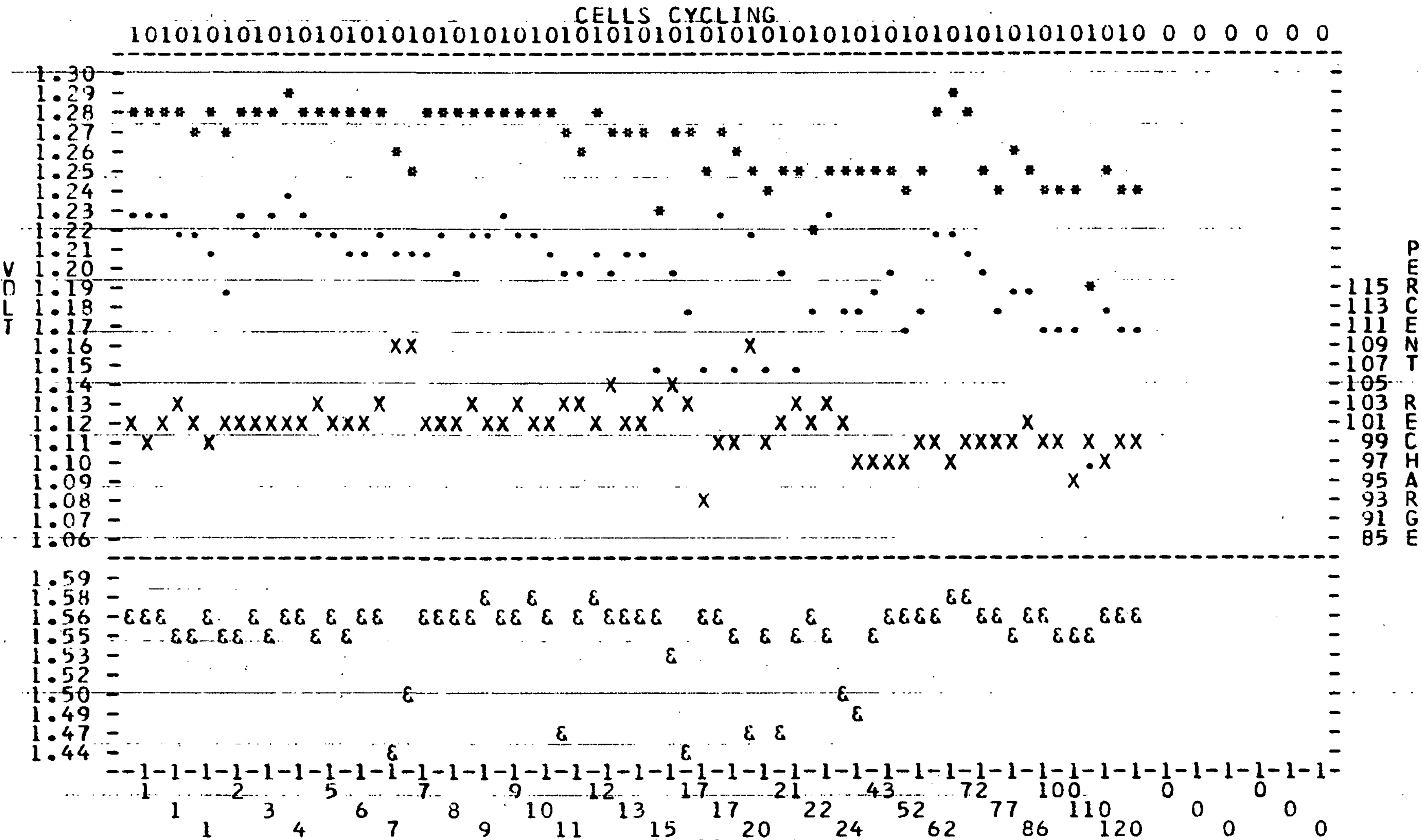
Orbit Period	1.5-hour				
Temperature	0°	25°	25°	40°	40°
Depth of Discharge	25%	25%	40%	25%	40%
Pack Number	21E	45E	69C	9H	33D
Precycling Capacity	4.83	5.70	5.70	3.33	3.30
88 Days	5.08	2.75	3.52	2.38	3.92 F
264 Days	5.08	2.93	3.08	3.50	
440 Days	5.00	2.80	4.72	2.88	
616 Days	5.05	5.50	3.80	2.63	

c. Test Results:

(1) Performance on Cycling: (Figures 11 through 14) Cycling was started in June 1970. Packs 21E, 45E, 69C and 9H have completed 13,018, 13,086, 12,755 and 12,681 cycles, respectively with five failures to date - 3 in pack 69C and 2 in pack 9H. Pack 33D failed on cycle 4523; no failure analysis was performed on this pack or the cells of packs 69C and 9H. All failures will be returned to NASA, Lewis Research Center, as instructed by Goddard Space Flight Center.

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

PACK 21E MANF. GULTON 05.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 1.40
DEPTH OF DISCHARGE % 25



CYCLES - MULTIPLES OF 100
FIGURE 11

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

PACK 45E MANF. GULTON 05.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 1.40
DEPTH OF DISCHARGE % 25

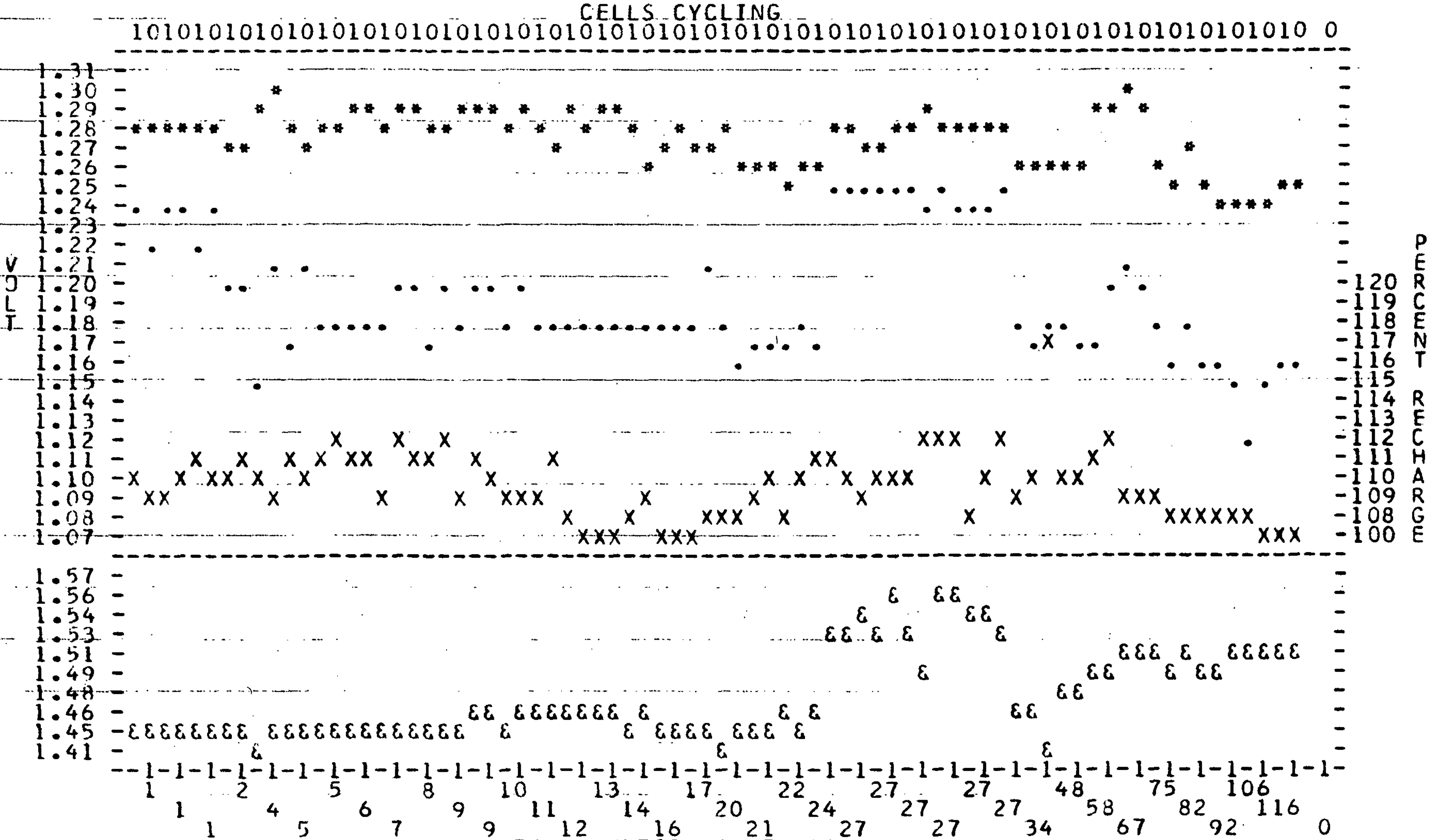


FIGURE 12

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

PACK 69C MANF. GULTON 05.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 2.20
DEPTH OF DISCHARGE % 40

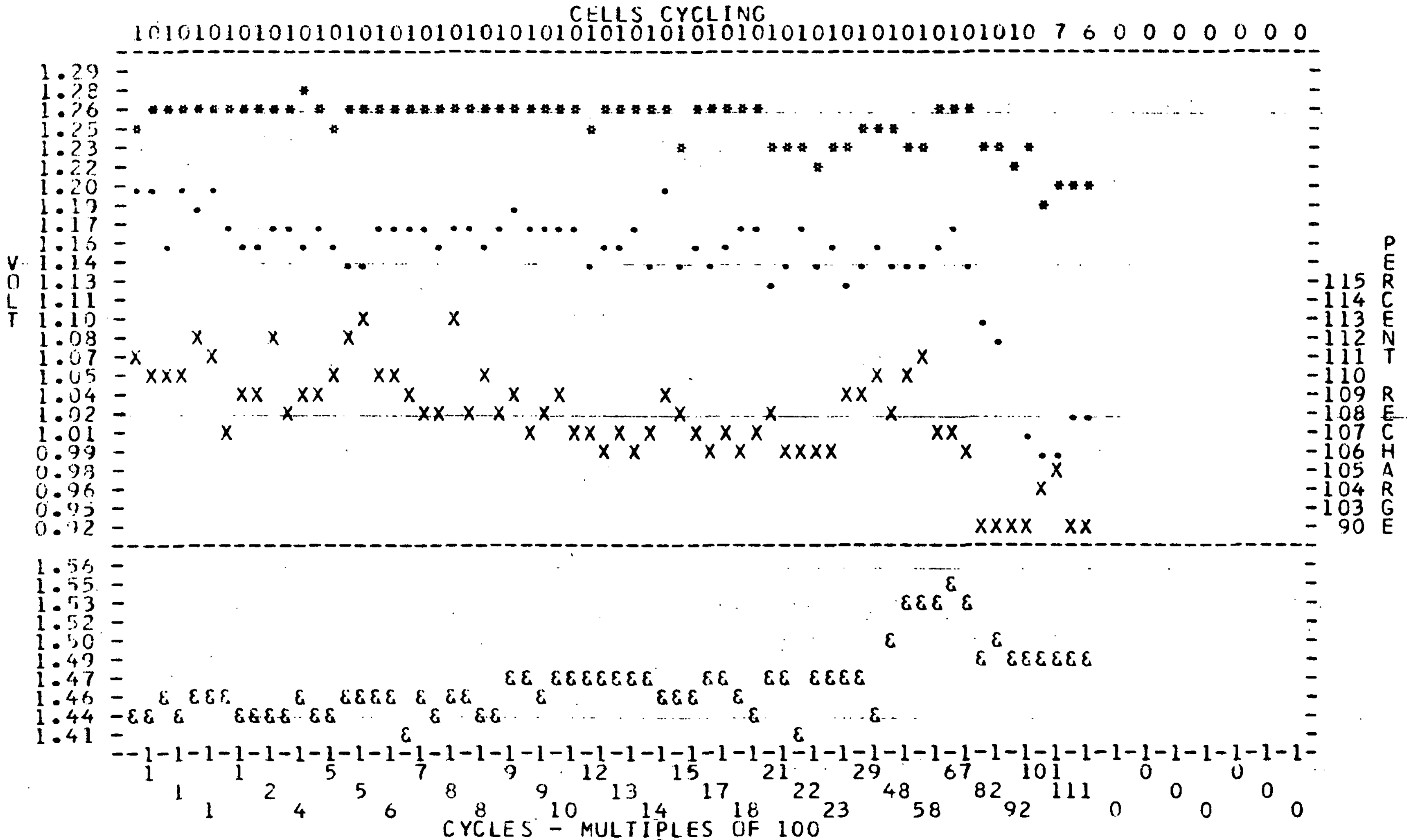


FIGURE 13

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

PACK 9H MANF. GULTON 05.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 40
CHARGE RATE AMPS 1.40
DEPTH OF DISCHARGE % 25

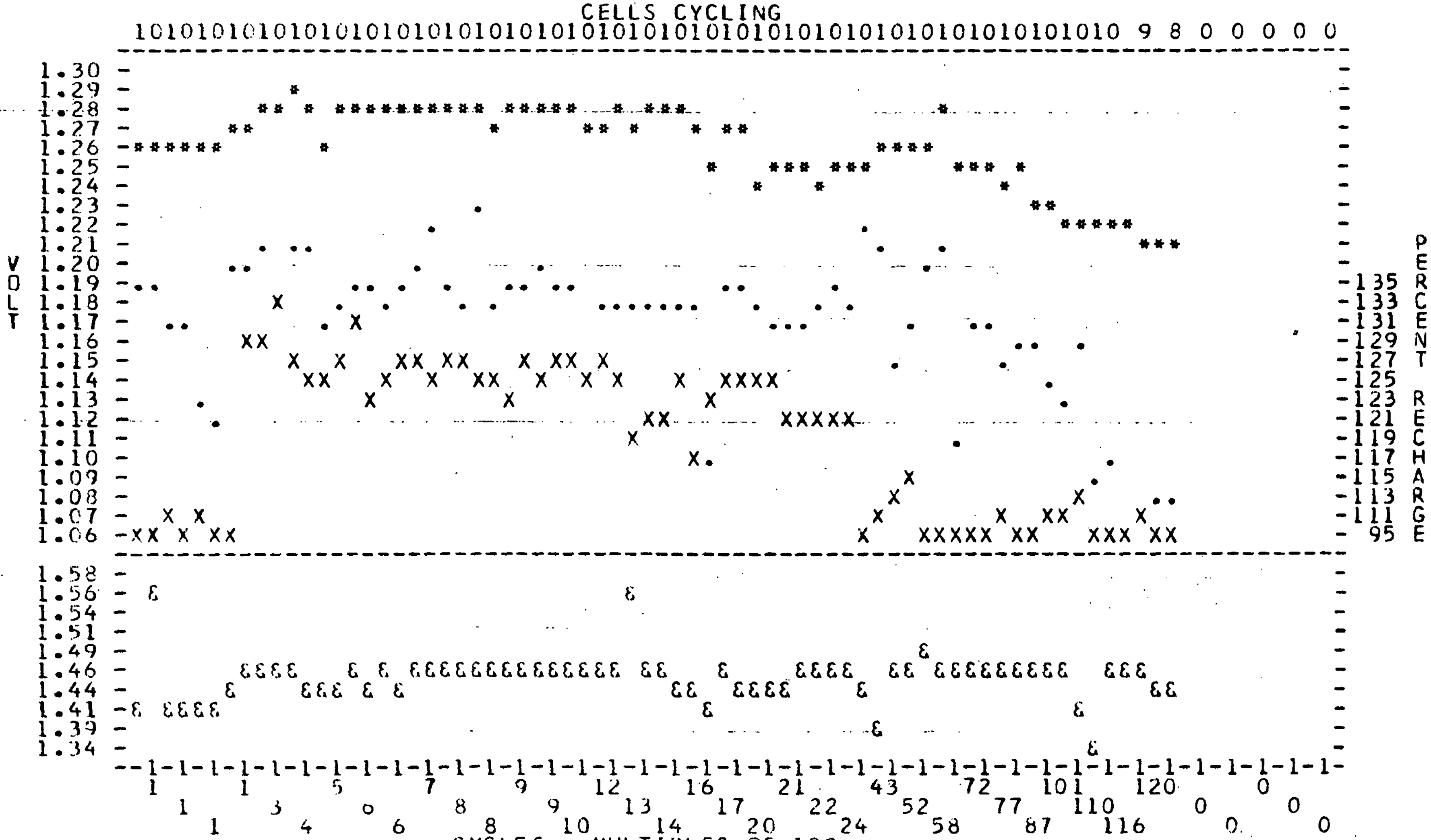


FIGURE 14

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 F
440 Days	Disch #2	4.75	4.29	2.08	2.00 F	1.71	
616 Days	Disch #2	4.70	3.96	**		2.04 F	
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 F	2.37			
1320 Days	Disch #2	4.46		2.12			
1496 Days	Disch #2	4.50		1.79 F			

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

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 D					

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

c. Test Results:

(1) Performance on Cycling: (Figure 15) 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, 29,753, 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.

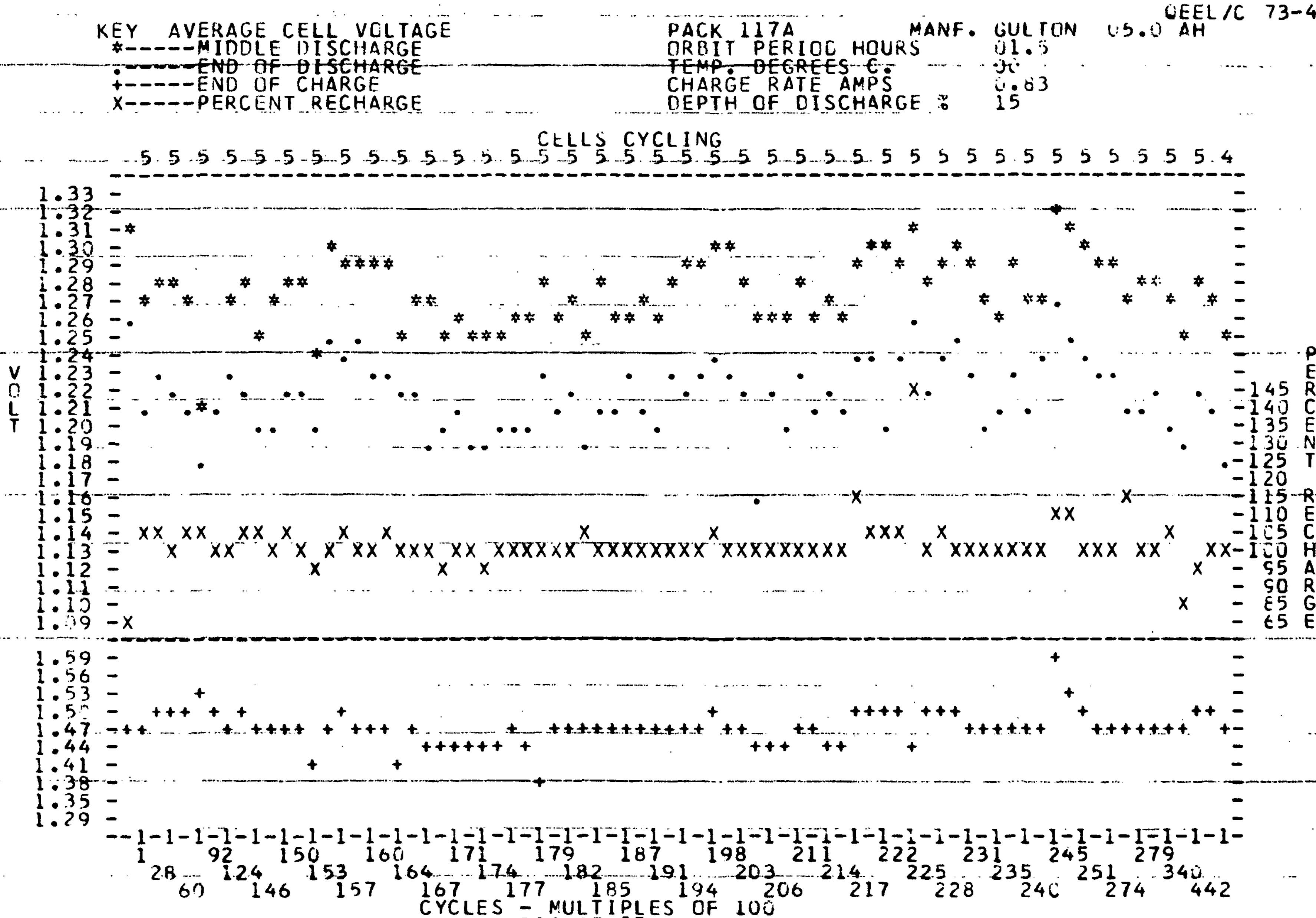

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
+-----END OF CHARGE
X-----PERCENT RECHARGE
PACK 117A
MANF. GULTON 05.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C.
CHARGE RATE AMPS 0.83
DEPTH OF DISCHARGE % 15
CELLS CYCLING
VOLT
PERCENT RECHARGE
CYCLES - MULTIPLES OF 100

FIGURE 15

5. 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

D - Discontinued.

d. Test Results:

(1) Performance on Cycling: (Figure 16) 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.

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

PACK 61B MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.66
DEPTH OF DISCHARGE % 10

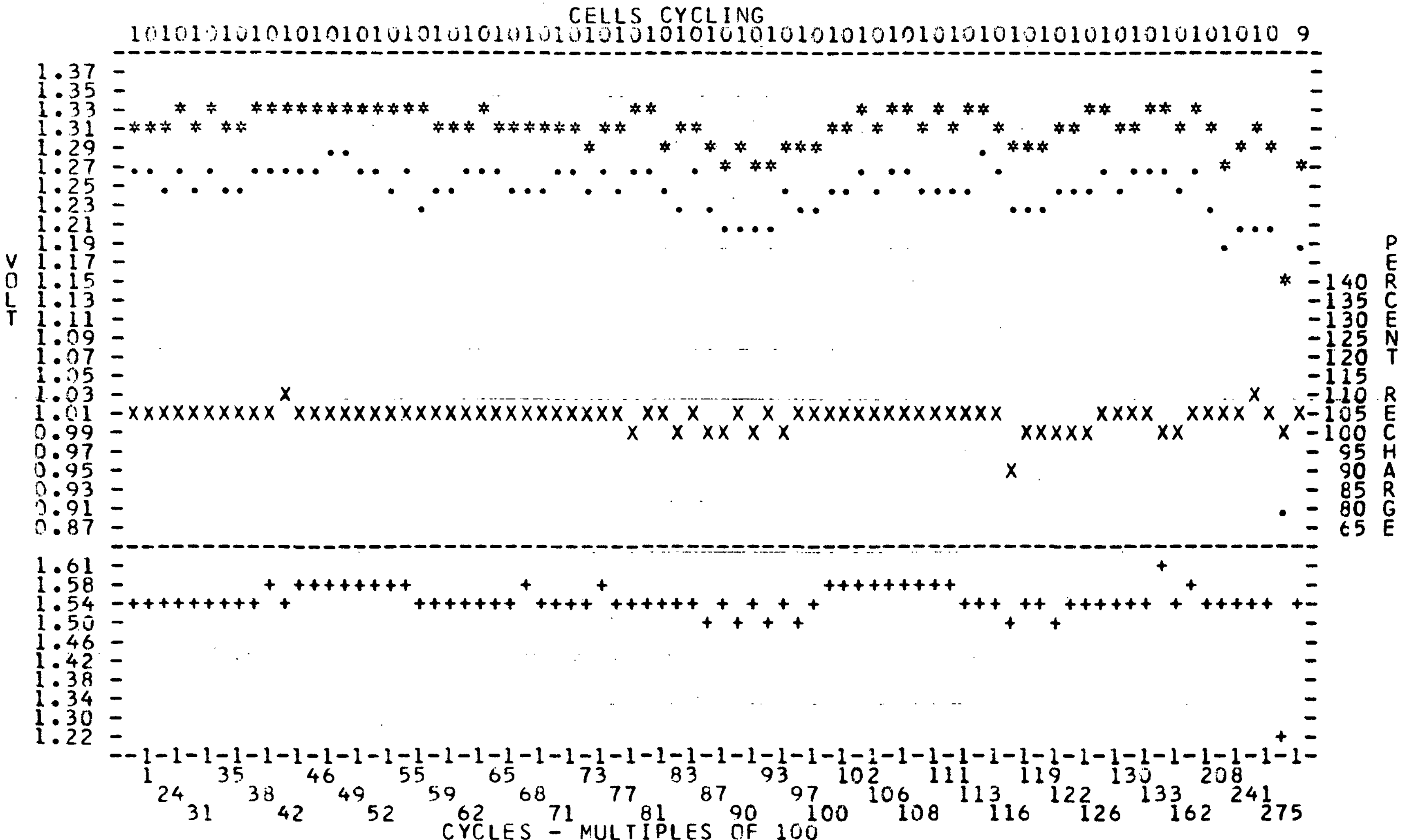


FIGURE 16

6. 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: (Figure 17) 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.

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

PACK 51B MANF. GULTON 6.0 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 0.24
DEPTH OF DISCHARGE % VAR

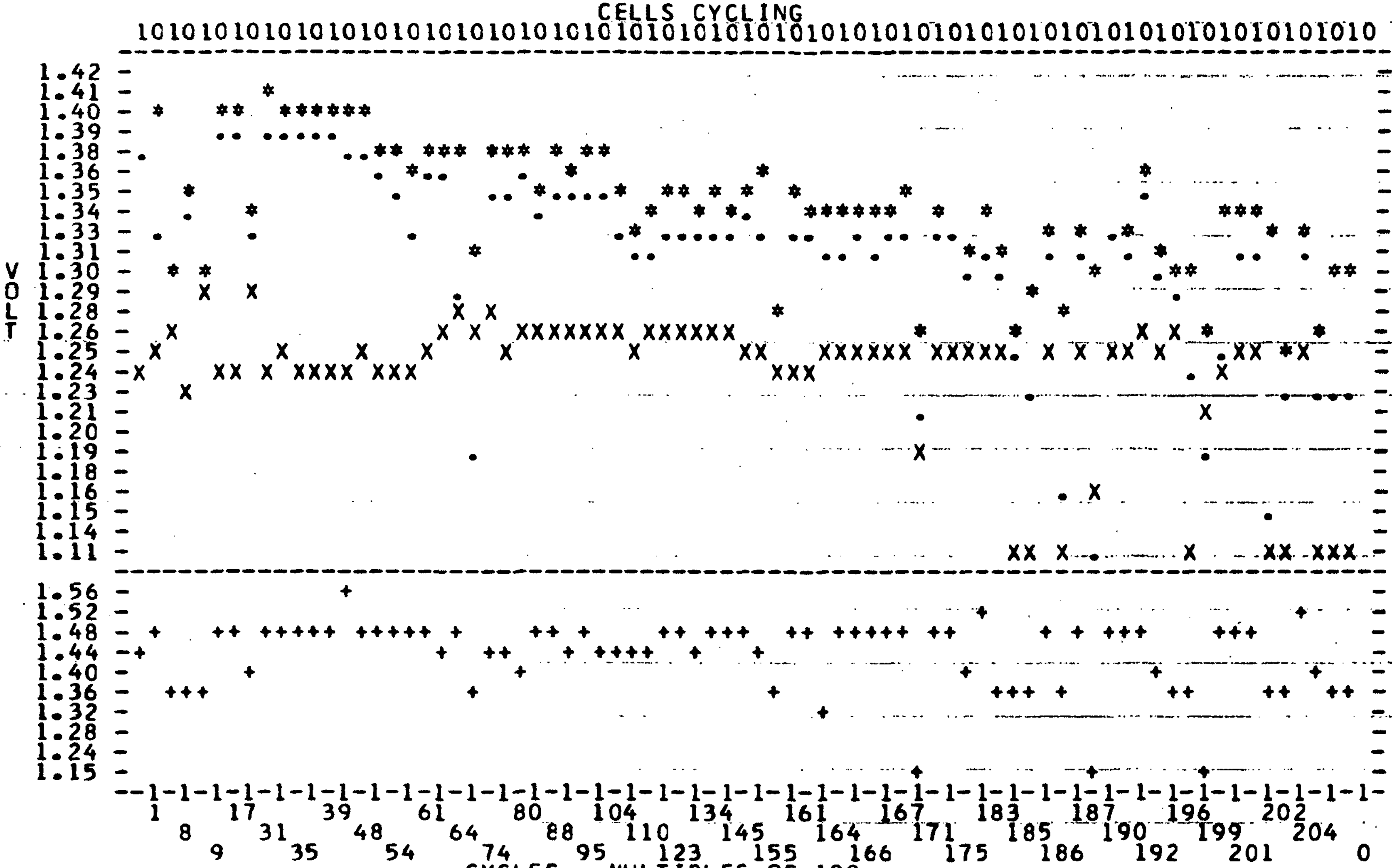


FIGURE 17

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

a. Cell Description: See paragraph I.A.

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 F	3.30	3.70 F
440 Days Disch #2	13.70	11.90	4.80		3.40	
616 Days Disch #2	13.10	10.60	4.00		5.30 F	
792 Days Disch #2	12.70	9.00	3.90 F			
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 F				
2376 Days Disch #2	8.50					
2552 Days Disch #2	9.00					

F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 18)
Cycling was started in January 1966. Pack 16B has completed 44,139 cycles with no cell failures. 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 16 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.

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

PACK 16B MANF. GULTON 12.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 2.07
DEPTH OF DISCHARGE % 15

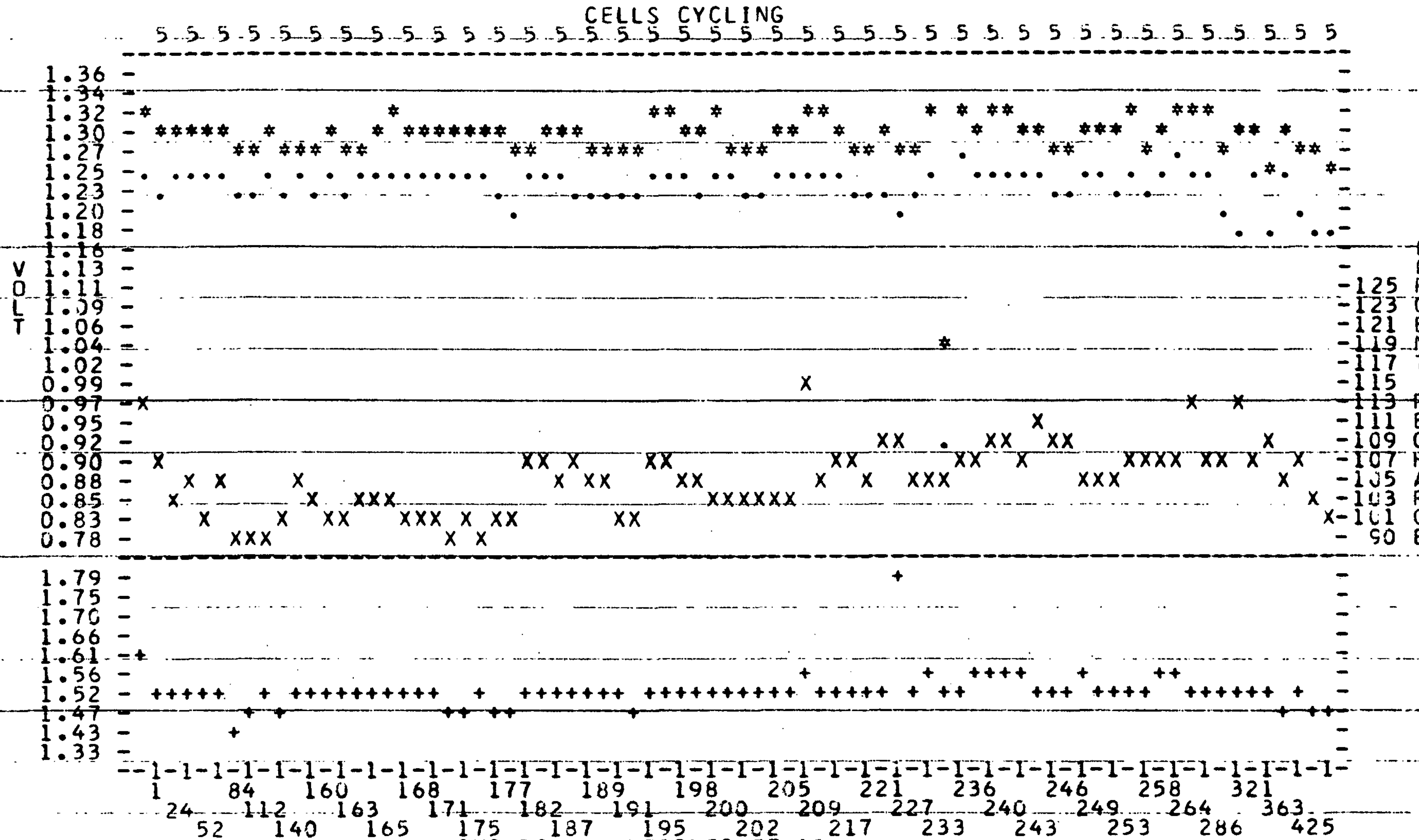


FIGURE 18

8. Gulton 20 ah (OAO), 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	22.1

c. Test Results:

(1) Performance on Cycling: (Figure 19) Cycling was started in February 1971. The pack has completed 10,389 cycles with no failures.

(2) Capacity Checks: After the first capacity check this pack was placed on a special schedule in which approximately every 5 months two different cells will receive a capacity check; and at the end of 2 years, when cells 9 and 10 are scheduled, the whole pack will receive the capacity check.

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

PACK 23B MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 10
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

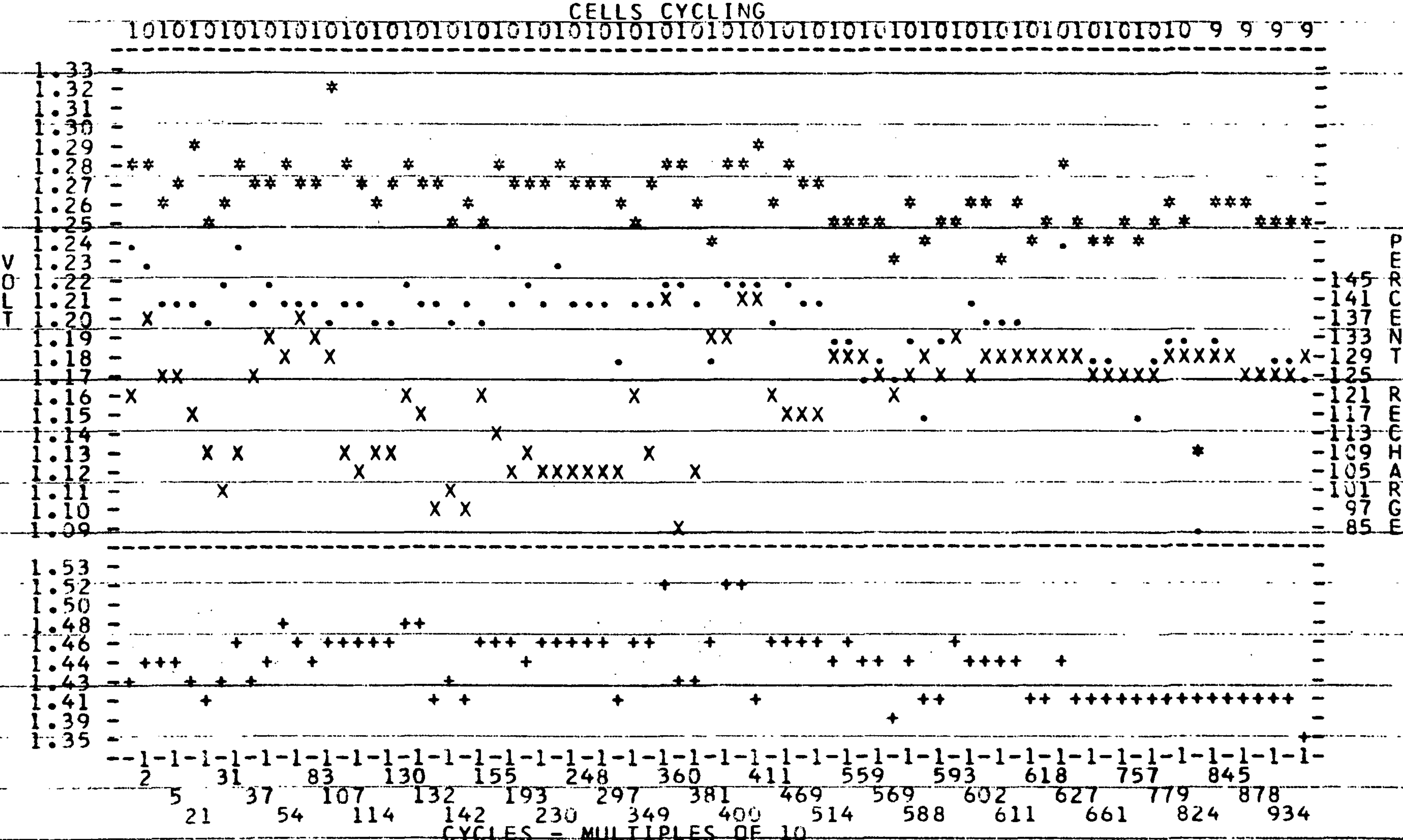


FIGURE 19

9. GE, 4.5 ah, One 10-cell Pack:

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 (dome 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 NIMBUS satellite.

b. Parameters and Capacity Checks:

Orbit Period	1.5-hour
Temperature	20°
Depth of Discharge	13%
Pack Number	26E

c. Test Results:

(1) Performance on Cycling: (Figure 20) Cycling started in February 1972 and the pack has completed 4541 cycles to date with no failures.

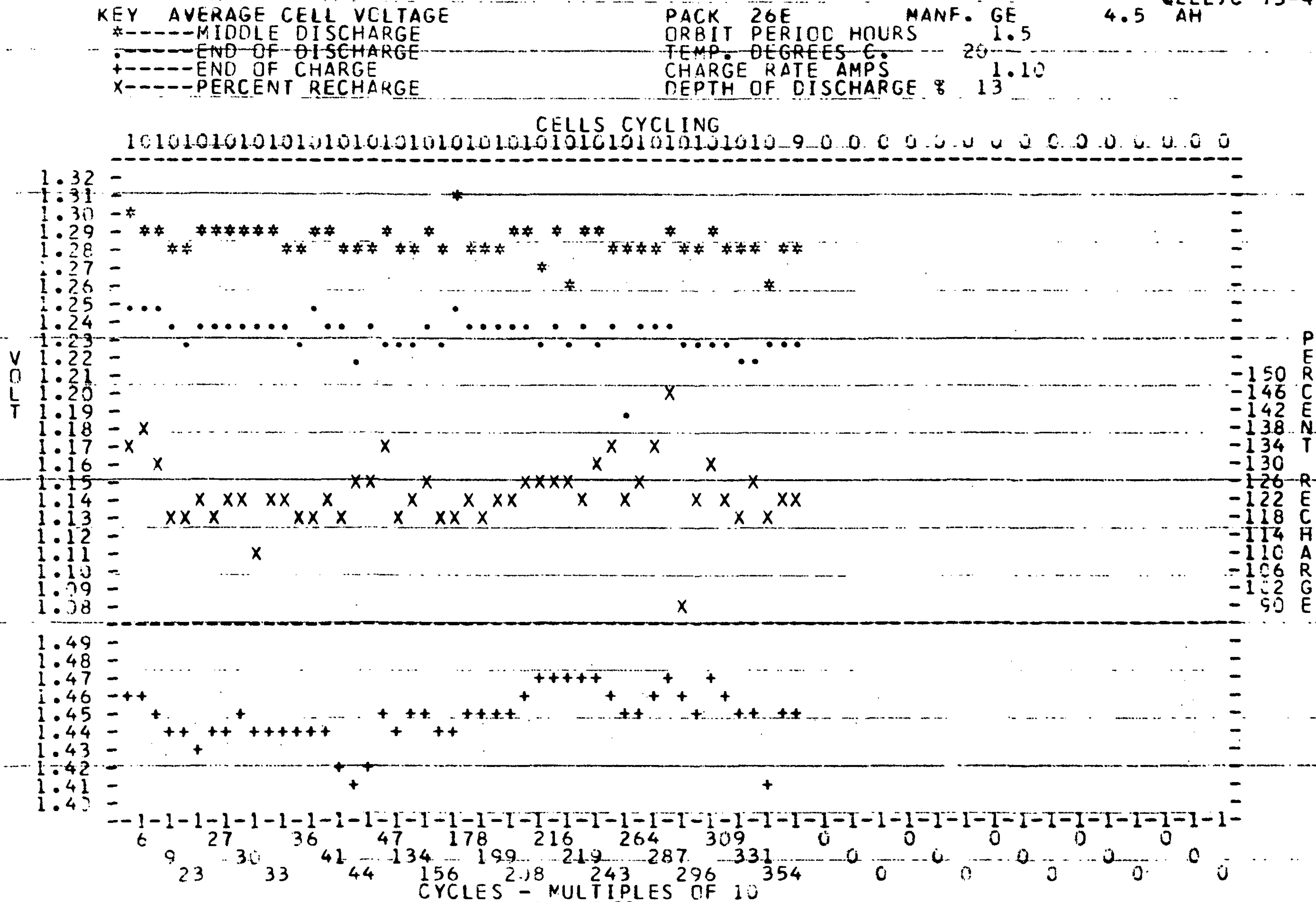

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
+-----END OF CHARGE
X-----PERCENT RECHARGE
PACK 26E MANF. GE 4.5 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 1.10
DEPTH OF DISCHARGE % 13
CELLS CYCLING
VOLT
PERCENT RECHARGE
CYCLES - MULTIPLES OF 10

FIGURE 20

10. 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.

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	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.

Orbit Period	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		2.83 D				

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

c. Test Results:

(1) Performance on Cycling: (Figures 21 and 22) Cycling was started in May 1965. Pack 103A has completed 43,340 cycles with no cell failures to date. 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 showed the major causes 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.

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

PACK 103A MANF. GE 05.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.83
DEPTH OF DISCHARGE % 15

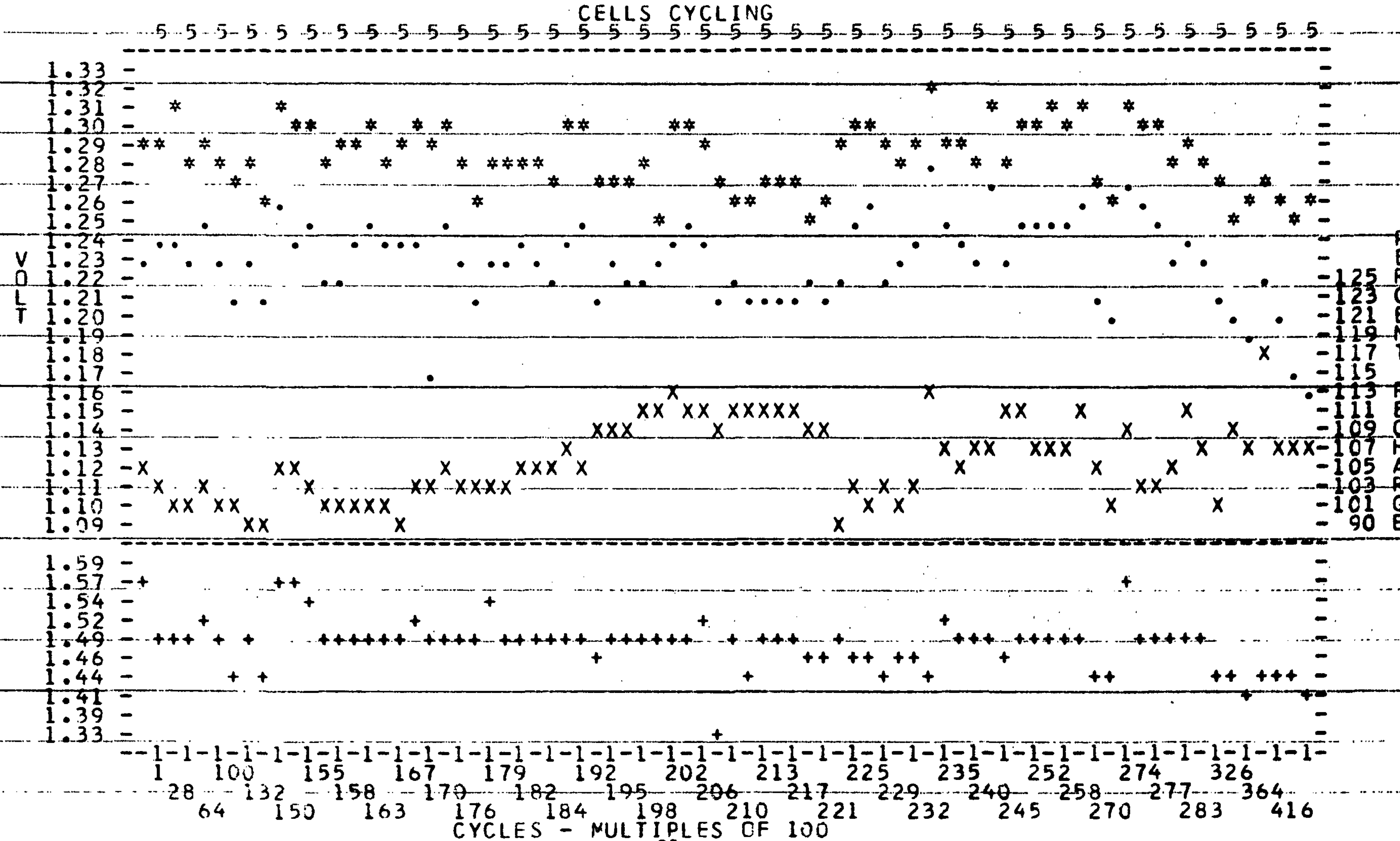


FIGURE 21

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

PACK 107A MANF. GE 05.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 1.38
DEPTH OF DISCHARGE % 25

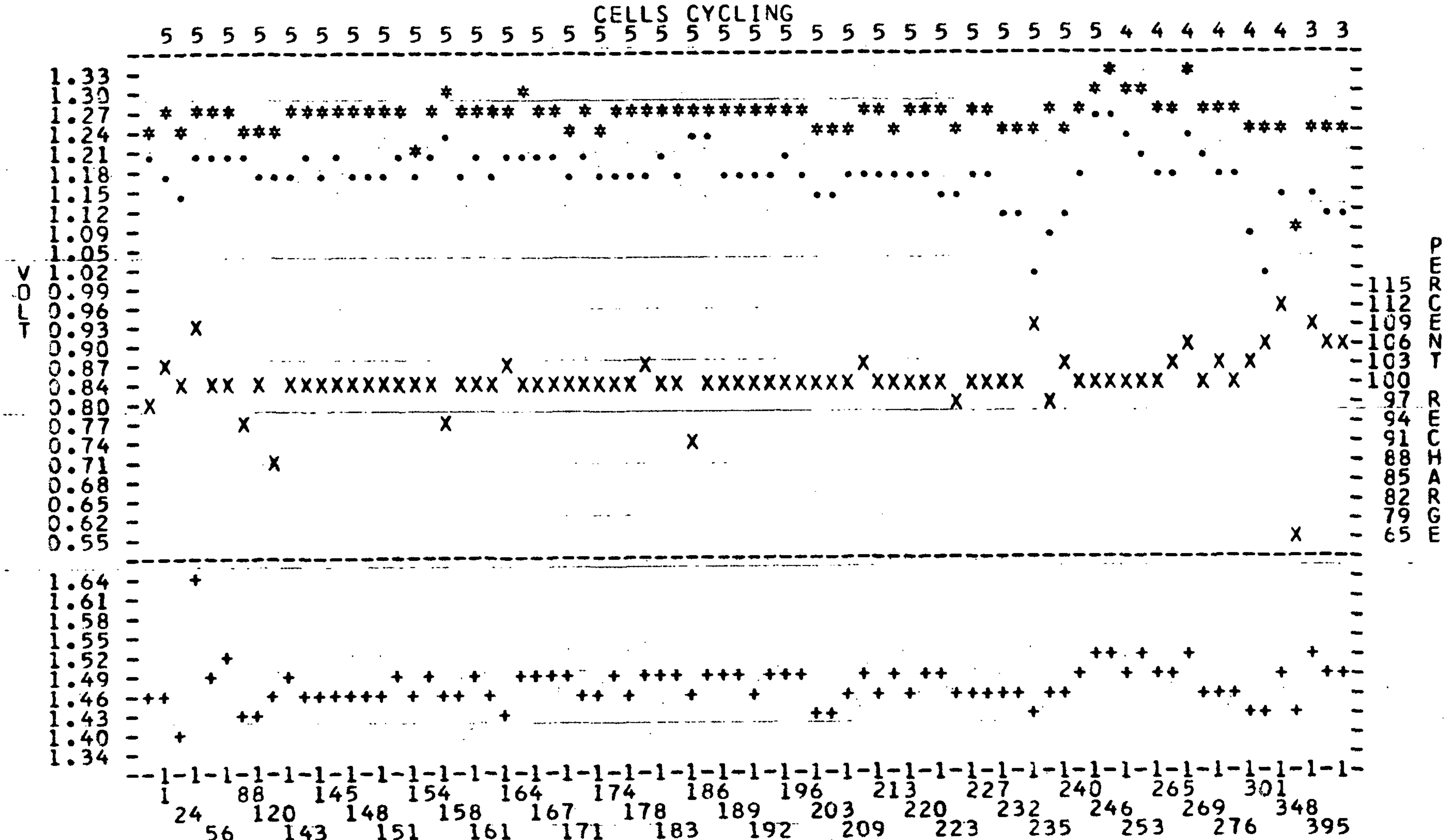


FIGURE 22

11. 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.

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	8.64	2.34
440 Days	3.40	7.75	7.05	3.30
616 Days	2.15			0

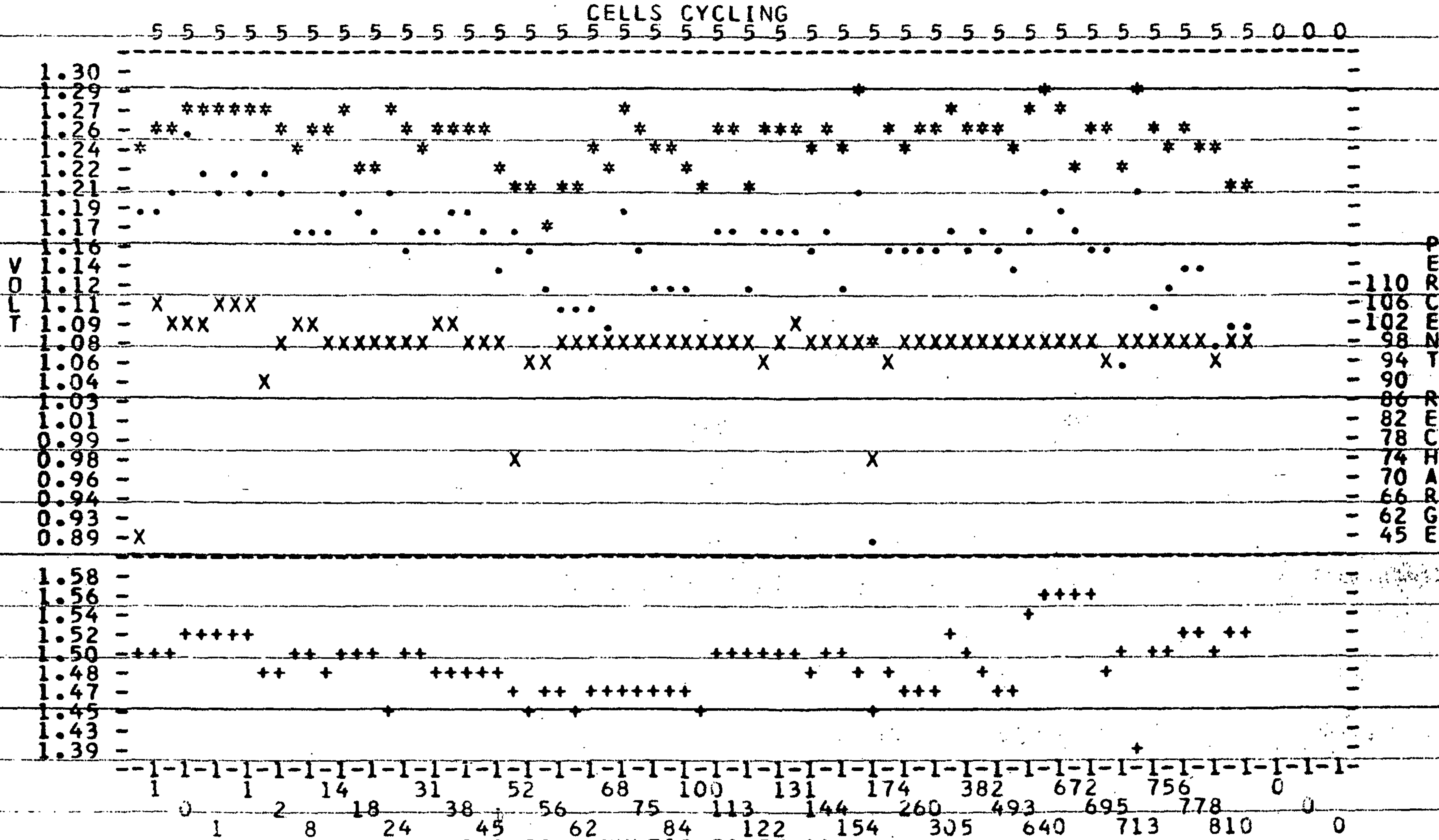
	cell number												
Orbit Period (Hrs)		24			24			24			24		
Temp.		-20°			0°			20°			40°		
Depth of Disch.		60%			60%			60%			60%		
Pack#		75E			123B			109B			91B		
Cutoff Voltage		1.0	0.5	0.0	1.0	0.5	0.0	1.0	0.5	0.0	1.0	0.5	0.0
Cap.Ck. 1 yr.	1	7.44	8.16	8.22	5.70	7.02	7.44	6.36	7.32	7.80	3.18	4.44	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

c. Test Results:

(1) Performance on Cycling: (Figures 23 through 30) Cycling was started in March 1971. Packs 81B, 92B, 95B and 106B (1.5-hour orbits) have completed 9084, 9699, 10,025 and 7538 cycles, respectively, with one cell, each, removed from packs 95B and 106B and shipped to Goddard Space Flight Center as instructed by that activity. Packs 75E, 123B, 109B and 91B (24-hour orbits) have completed 628, 612, 630 and 641 cycles, respectively with no failures or cell removals to date. These packs had two cell capacity checks, after one year of cycling, to the 1.0, 0.5 and 0.0 volt cut-off levels. Six months later two different cells were capacity checked to the same cut-off levels. This method of capacity checking is used to measure the effect of the capacity check itself since two different cells are capacity checked at six-month intervals -- thus the need for the two different formats of the previous tabulation.

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

PACK 818 MANF. GE 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. -20
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25



CYCLES - MULTIPLES OF 10
FIGURE 23

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

PACK 928 MANF. GE 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

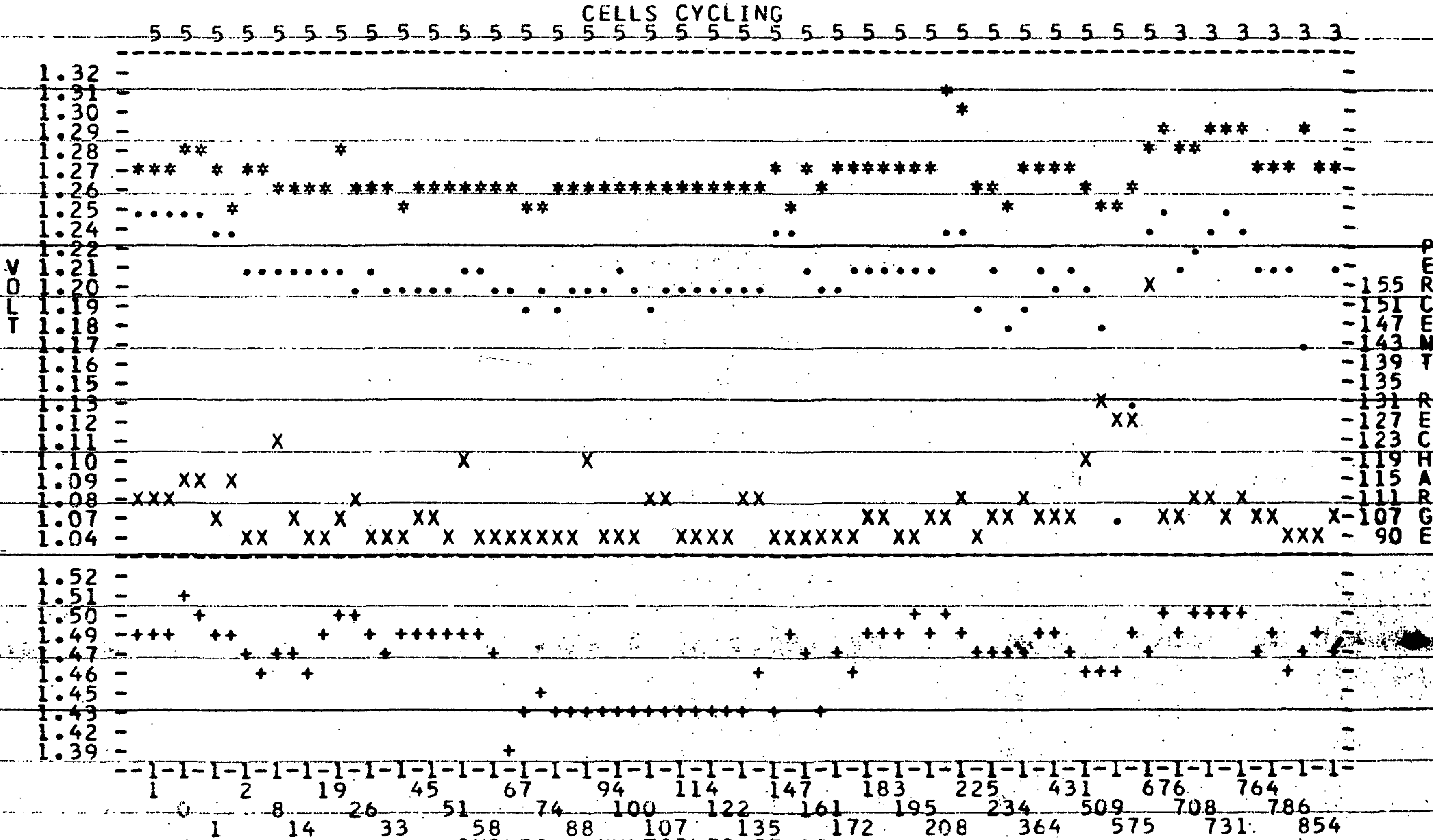


FIGURE 24

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

PACK 95B MANF. GE 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

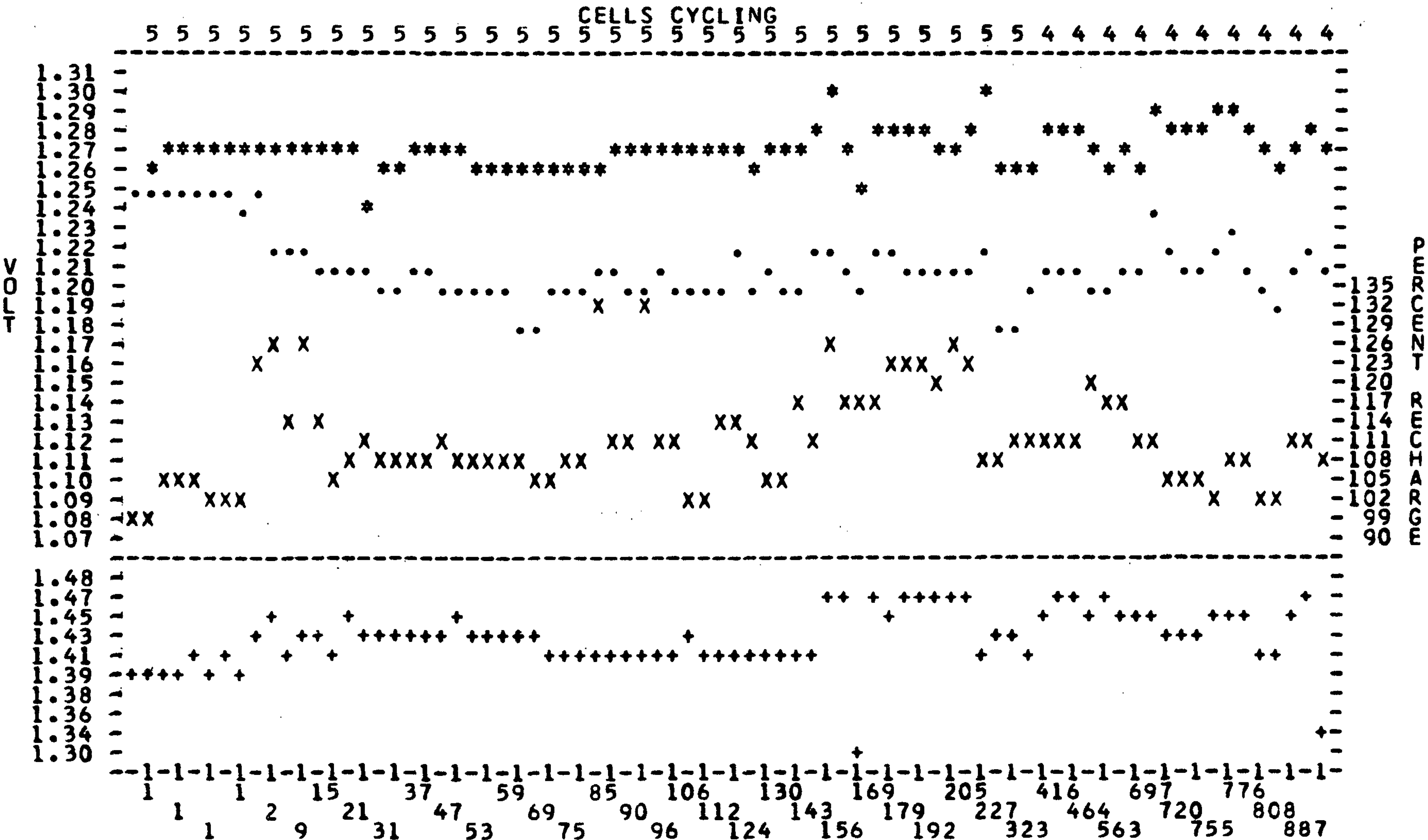


FIGURE 25

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

PACK 106B MANF. GE 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 40
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

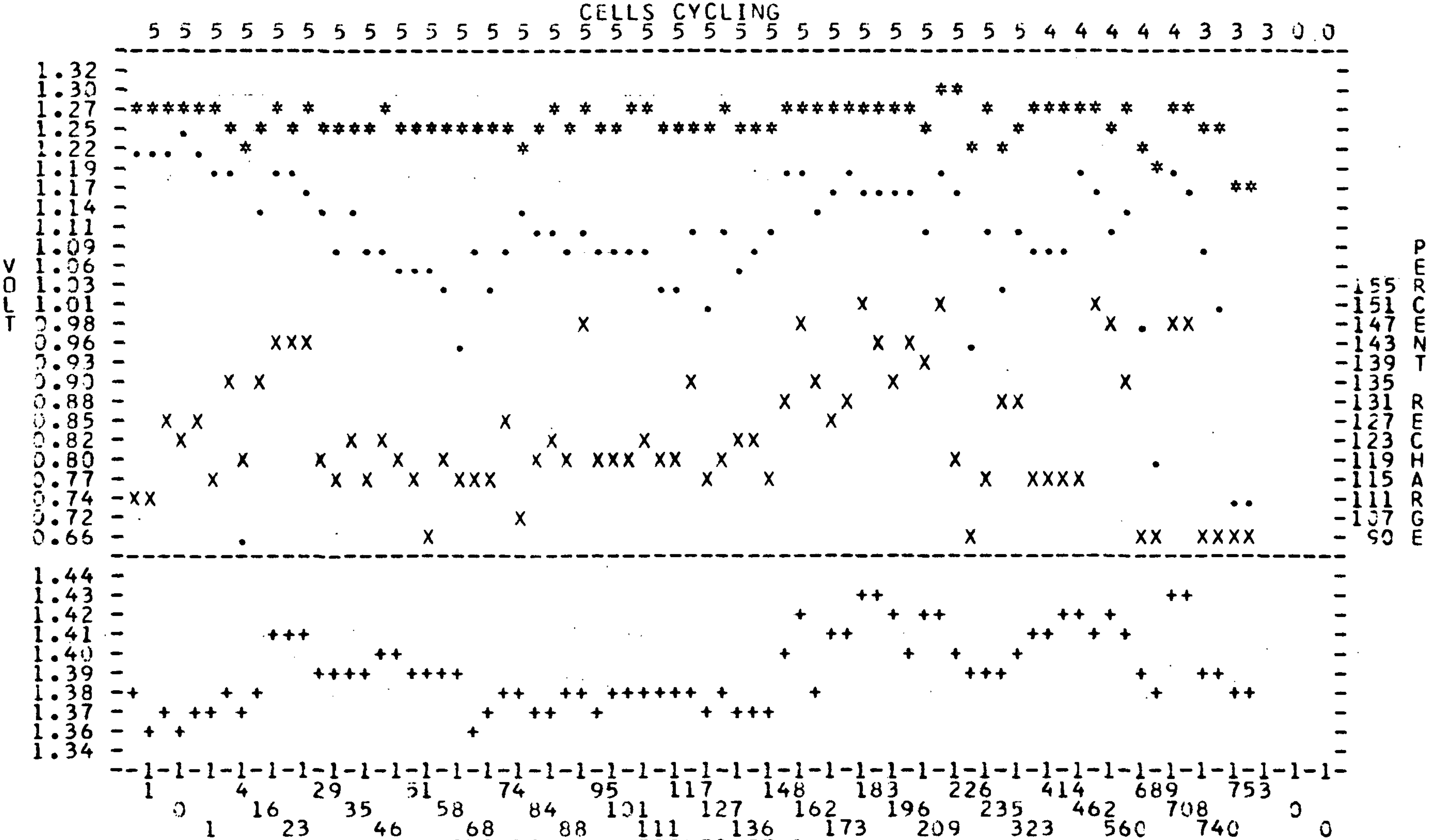


FIGURE 26

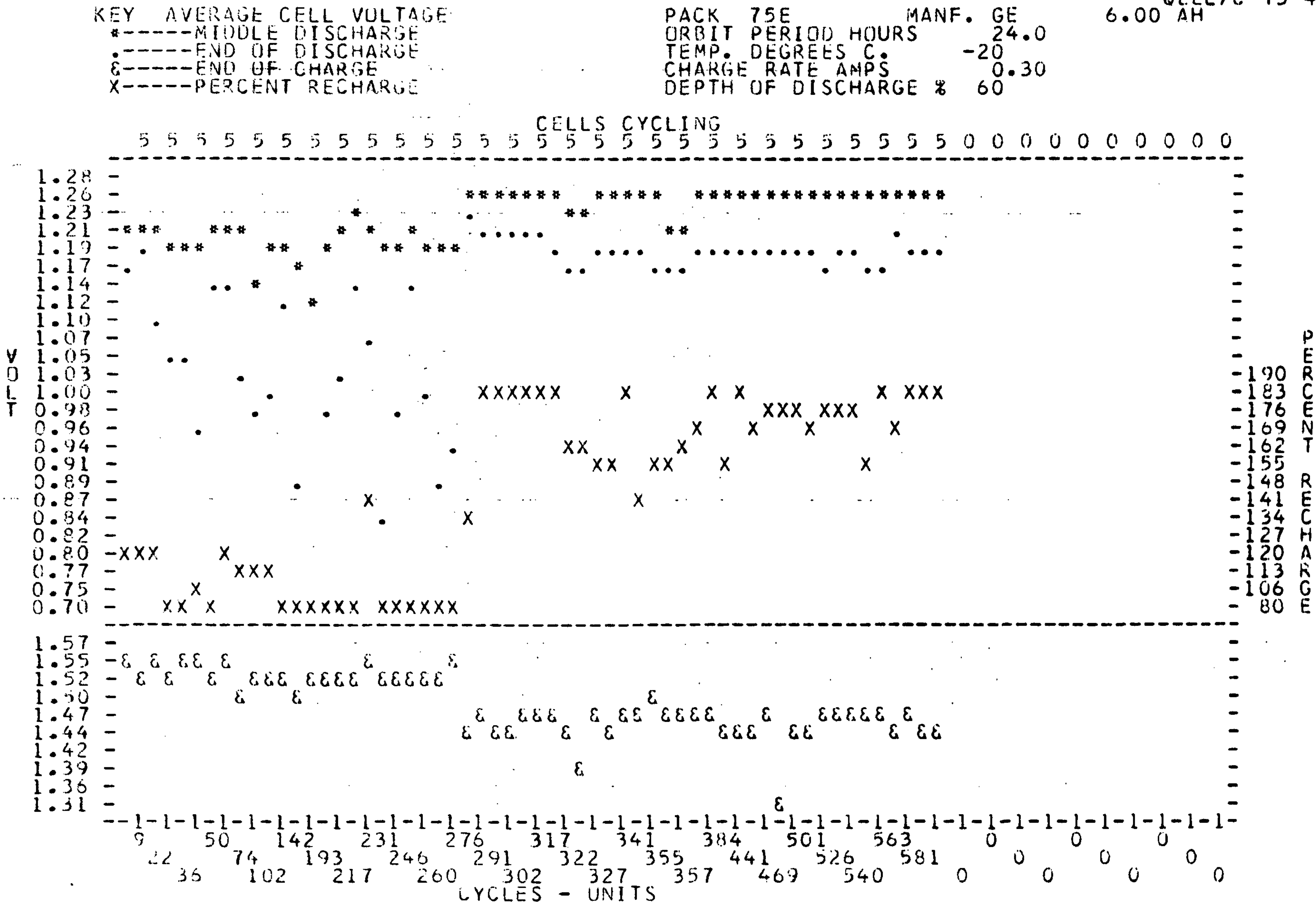


FIGURE 27

NOTE: Temperature 10°C after 270 cycles.

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

PACK 123B MANF. GE 6.00 AH
ORBIT PERIOD HOURS 24.
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.30
DEPTH OF DISCHARGE % 60

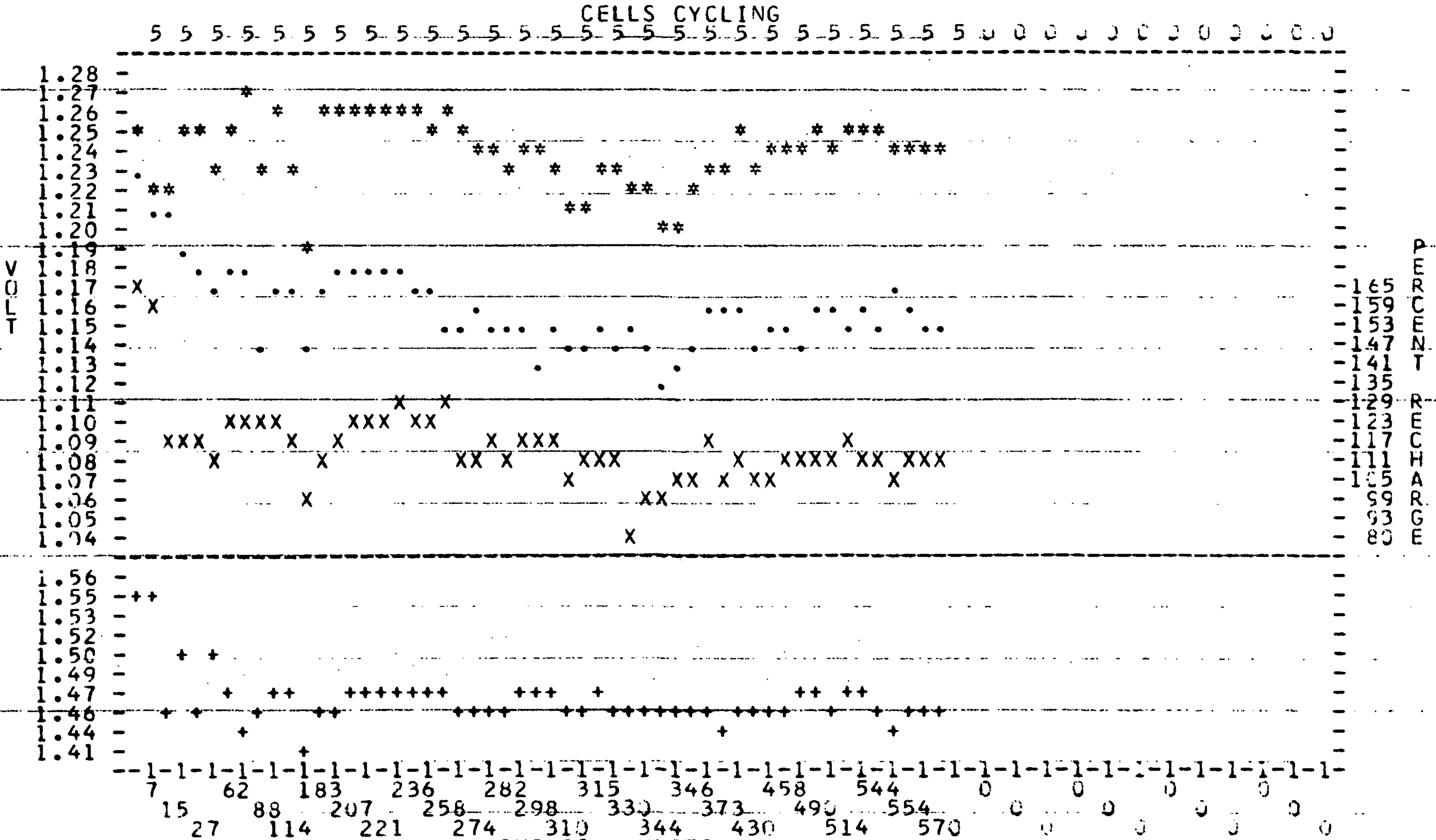


FIGURE 28

NOTE: Charge current .2A after 15 cycles.

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

PACK 109B MANF. GE 6.00 AH
ORBIT PERIOD HOURS 24.
TEMP. DEGREES C. 20
CHARGE RATE AMPS 0.30
DEPTH OF DISCHARGE % 60

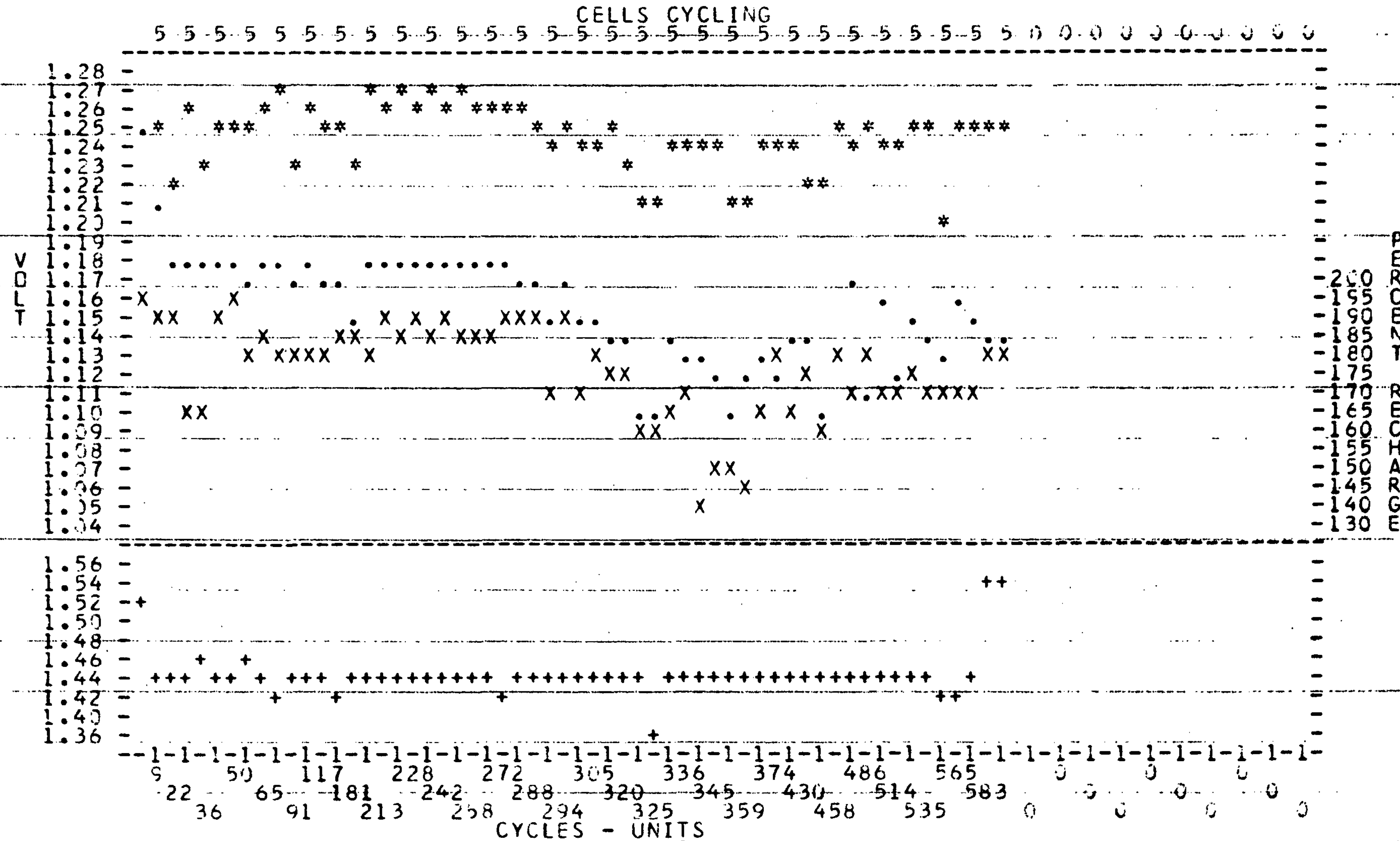


FIGURE 29

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

PACK 918 MANF. GE 6.00 AH
ORBIT PERIOD HOURS 24.0
TEMP. DEGREES C. 40
CHARGE RATE AMPS 0.30
DEPTH OF DISCHARGE % 60

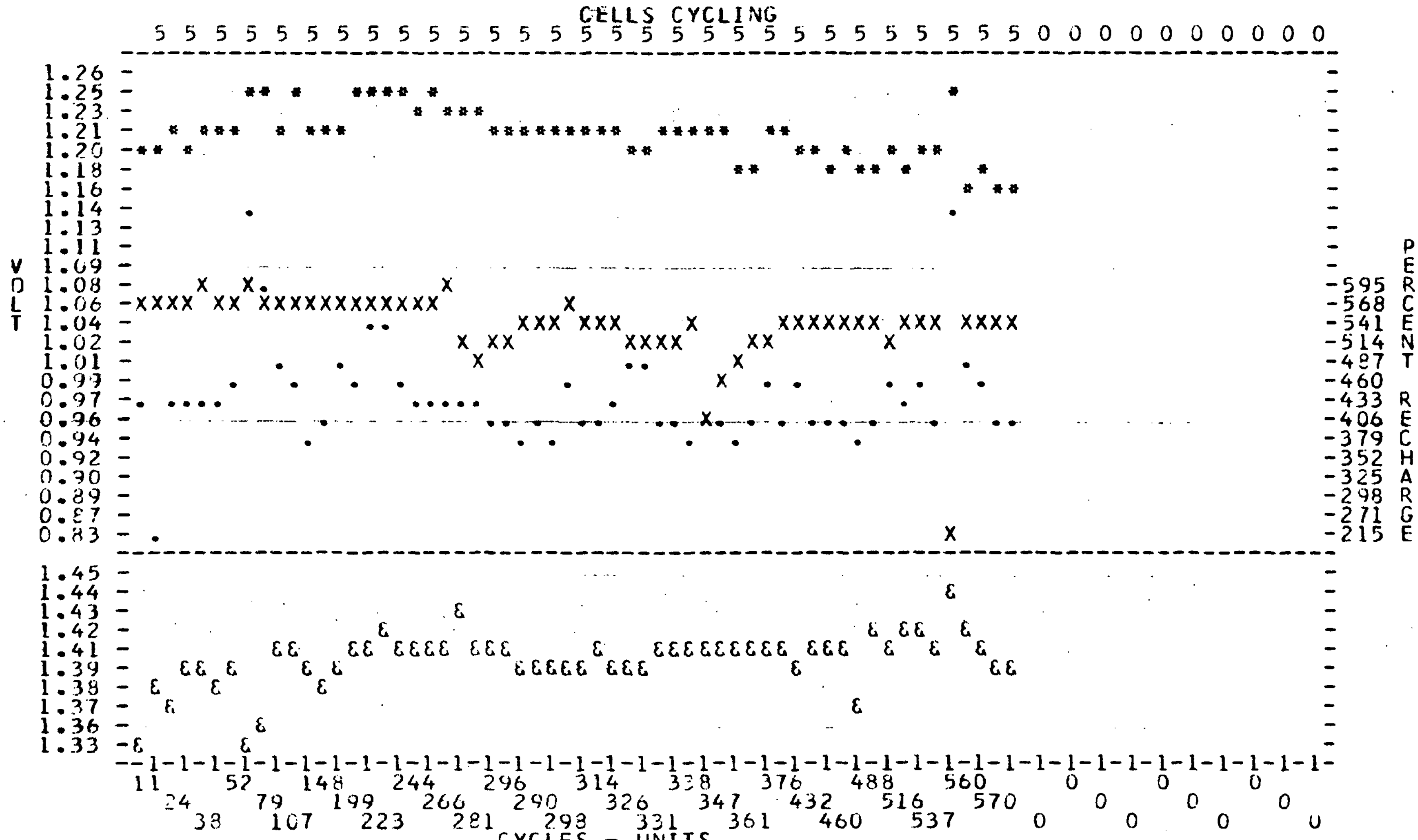


FIGURE 30

NOTE: Charge current changed to .6A (16 cycles), .9A (27 cycles), and 1.2A (585 cycles).

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

a. Cell Description: See paragraph II.A.

b. Parameters and Capacity Checks:

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

F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 31) Cycling was started in March 1972. This pack failed after completing 2903 cycles. No failure analysis data is available at this time. One cell was shipped to Heliotek, one to be analyzed by NAD Crane, and the remainder to go to Goddard Space Flight Center.

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

PACK 34D MANF. HELIOTEK20. AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 16.00
DEPTH OF DISCHARGE % 40

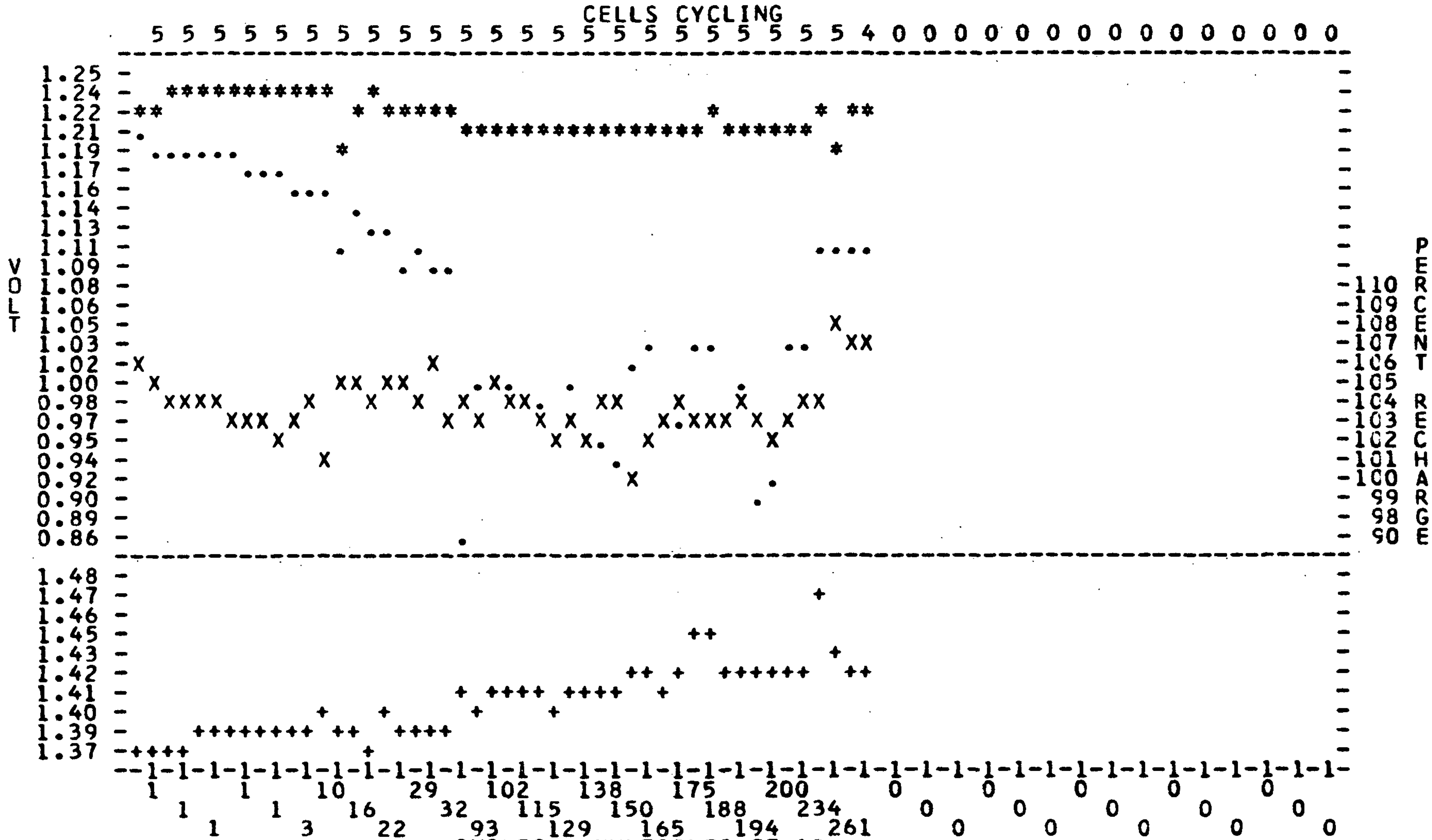


FIGURE 31

13. 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 F	0.90 F	1.05 F
440 Days Disch #2	3.27	2.12	1.28			
616 Days Disch #2	3.00	2.67	1.30 F			
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 F				

F - Failed.

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 D					

D - Discontinued.

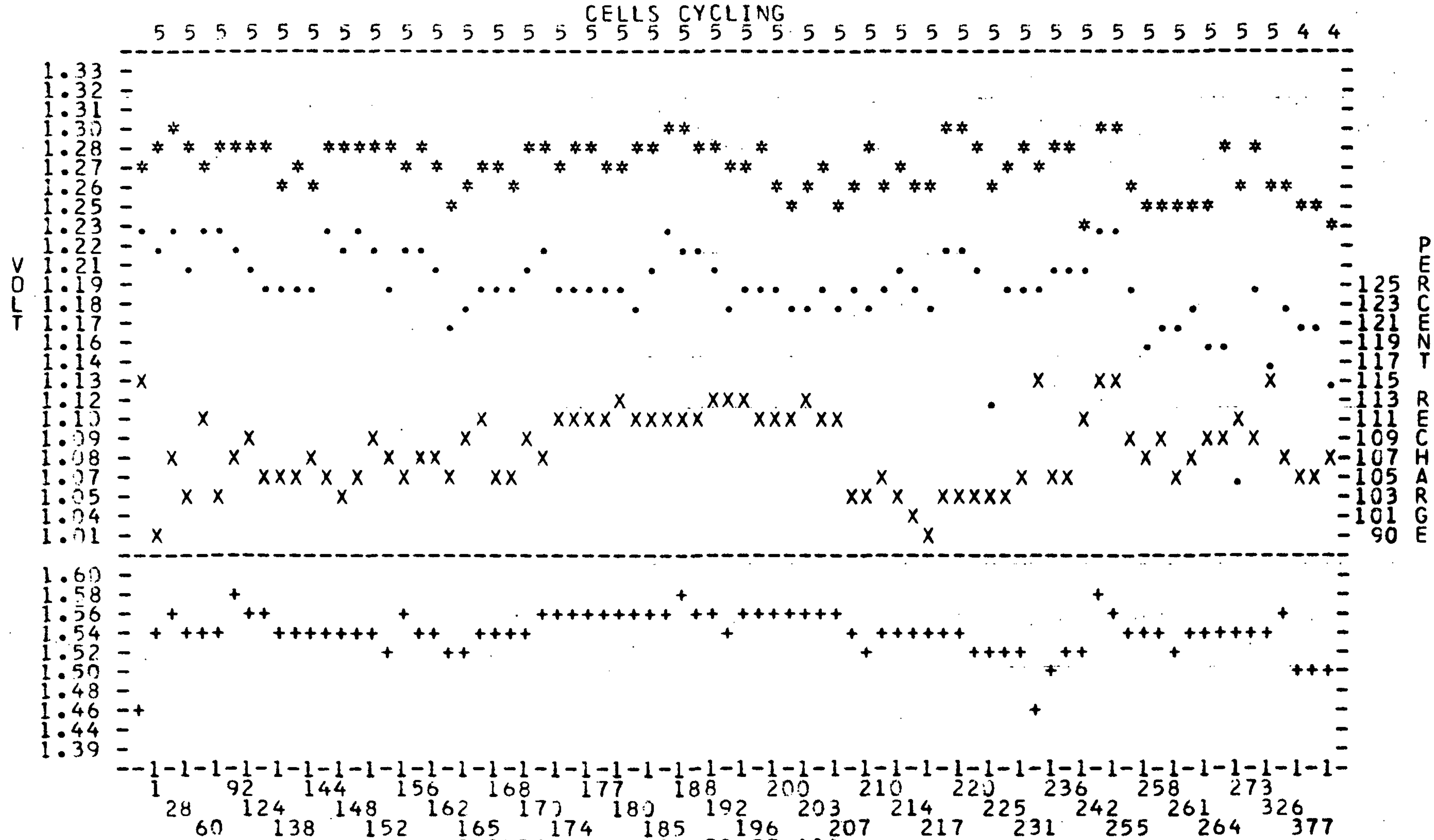
c. Test Results:

(1) Performance on Cycling: (Figure 32) 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.

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

PACK 438 MANF. SONOTONE03.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.52
DEPTH OF DISCHARGE % 15



CYCLES - MULTIPLES OF 100
FIGURE 32

14. 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 D

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

D - Discontinued.

C2

c. Test Results:

(1) Performance on Cycling: (Figure 33) 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.

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

PACK 15B MANF. SONOTONE03.5 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.39
DEPTH OF DISCHARGE % 10

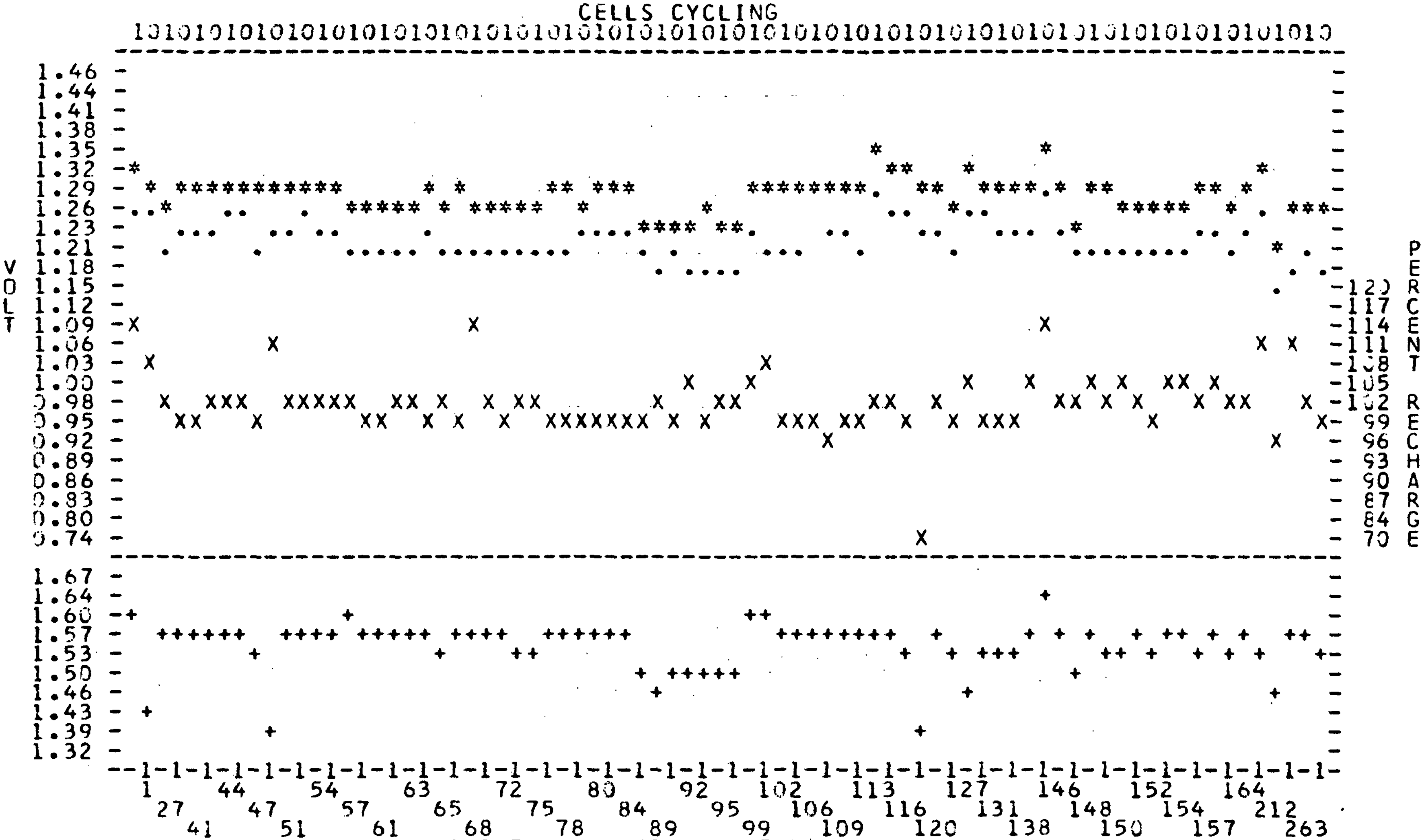


FIGURE 33

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 D

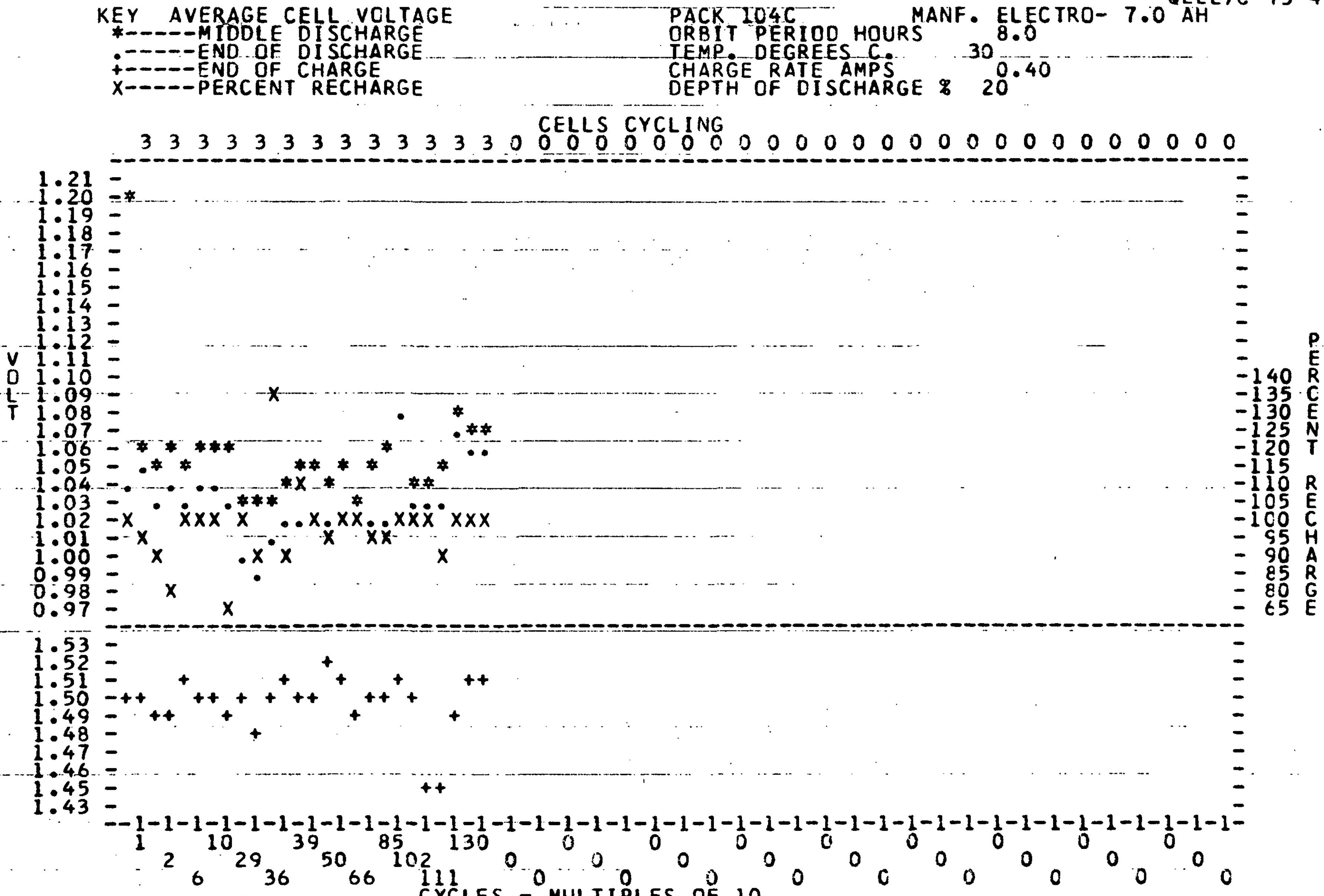
D - Discontinued

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: (Figure 34) 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.



KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
+-----END OF CHARGE
X-----PERCENT RECHARGE
PACK 104C
MANF. ELECTRO- 7.0 AH
ORBIT PERIOD HOURS 8.0
TEMP. DEGREES C. 30
CHARGE RATE AMPS 0.40
DEPTH OF DISCHARGE % 20
CELLS CYCLING
3 3 3 3 3 3 3 3 3 3 3 3 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
VOLT
1.21 1.20 1.19 1.18 1.17 1.16 1.15 1.14 1.13 1.12 1.11 1.10 1.09 1.08 1.07 1.06 1.05 1.04 1.03 1.02 1.01 1.00 0.99 0.98 0.97
1.53 1.52 1.51 1.50 1.49 1.48 1.47 1.46 1.45 1.43
PERCENT RECHARGE
140 135 130 125 120 115 110 105 100 95 90 85 80 65
1 2 6 10 29 36 39 50 66 85 102 111 130 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
CYCLES - MULTIPLES OF 10

FIGURE 34

D. Silver-Zinc Types:

1. Astropower Division of McDonnell-Douglas (VENUS Orbiter), 40 ah, Two 10-cell Packs:

a. Cell Description: These heat sterilized cells are sealed in moulded epoxy cases with threaded terminals protruding through the tops. The zinc electrodes are encapsulated in an inorganic separator. The silver electrodes are separated from the inorganic separator by pellon. Prior to testing, electrolyte leakage was noted around the threaded terminals. To further seal the cells, the terminals were extended upward by attaching metal tabs to the threaded studs and then pouring another 0.5-inch layer of epoxy over the cell top.

b. Parameters and Capacity Checks:

Orbit Period	4-hour	
Temperature	20°	20°
Depth of Discharge	20%	20%
Charge Control	*	*
Pack Number	20C	33E
Precycling Capacity	28.58 D	28.94 D

* Pack charges at 3.0 amperes to an upper voltage limit of 19.8 volts; when the current tapers to 400 milliamperes, the pack voltage trips to 18.6 volts.

D - Discontinued.

c. Test Results:

(1) Performance on Cycling: (Figures 35 and 36) Cycling was started in October 1971. Packs 20C and 33E completed 519 and 502 cycles, respectively prior to discontinuation in February and May of 1972.

(2) Analysis: Failure modes were mainly the sloughing of the zinc material out of its bag and migrating to the positive plates. Also, some negative bags were split along their sides and some cell cases were cracked leading to KOH leaking and a drying of the cell.

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

PACK 20C MANF. ASTRO 40.0 AH
ORBIT PERIOD HOURS 4.0
TEMP. DEGREES C. 20
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 20

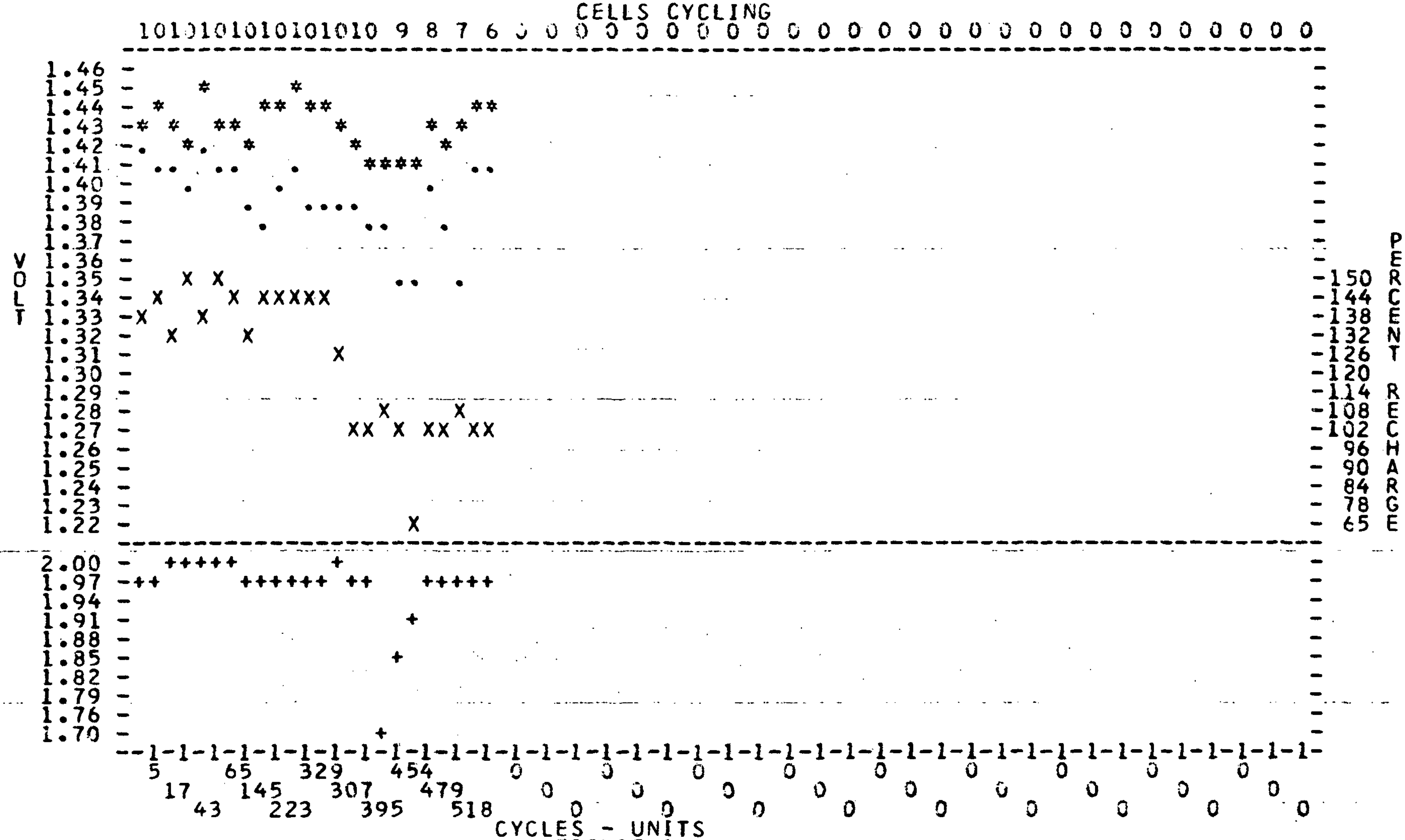


FIGURE 35

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

PACK 33E MANF. ASTRO 20. AH
ORBIT PERIOD HOURS 4.0
TEMP. DEGREES C. 20
CHARGE RATE AMPS 0.0
DEPTH OF DISCHARGE % 20

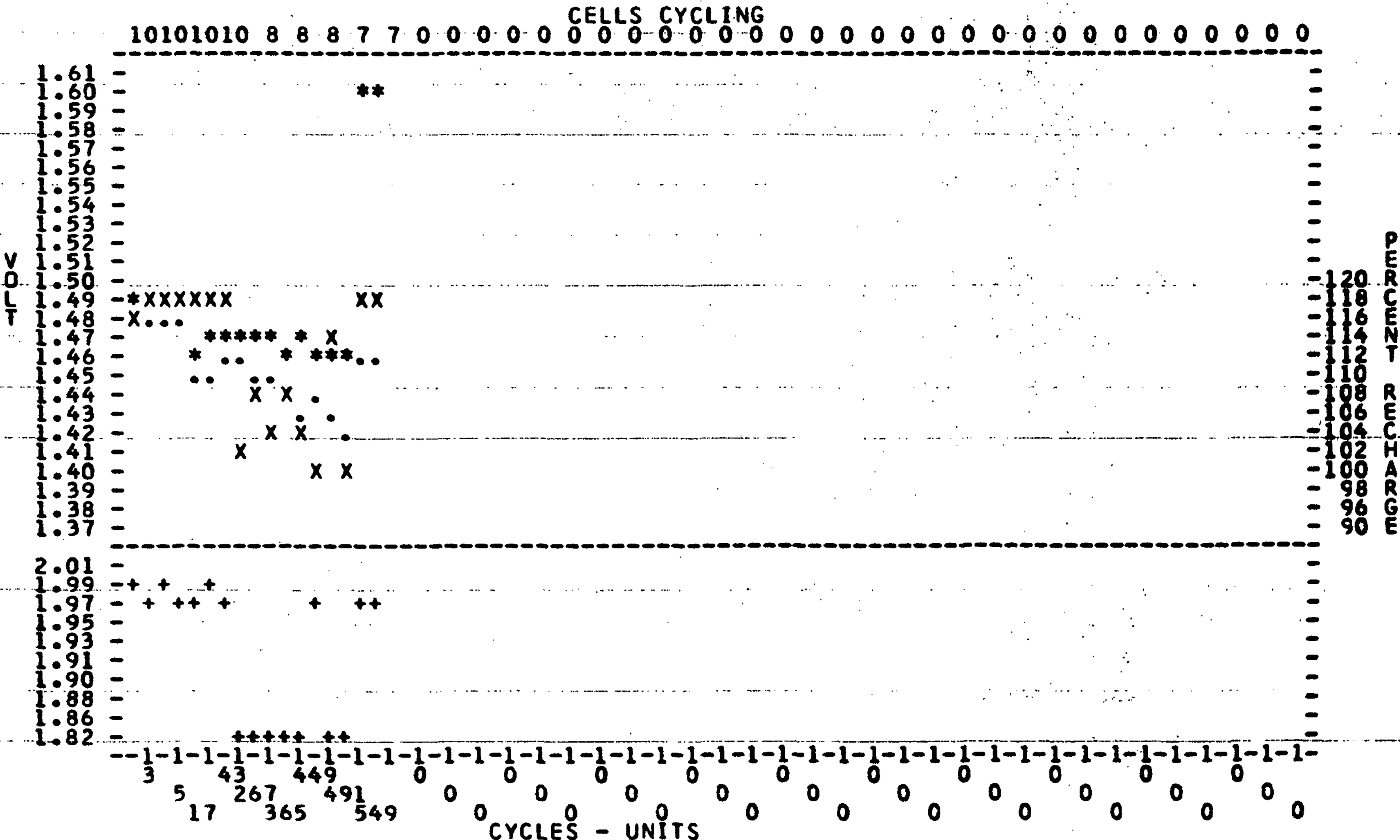


FIGURE 36

II. CELLS USING SOPHISTICATED CHARGE CONTROL METHODS AND DEVICES:

As a continuous effort to improve cells and cell life, new types of charge control methods and devices are being developed. Charge control methods being tested at NAD Crane are as follows: high overcharge current capabilities, auxiliary electrode, thermistor, voltage limit dependent upon auxiliary electrode trip level, coulometer, the two-step regulator and internal mechanical pressure devices. Sherfey upside-down cycling and stabistor charge control methods have been used in the past.

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 description are separately described as they are encountered in the following paragraphs.

B. 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 F
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 D	0.43 F	0.30 D	

* Depth of discharge was reduced to 25% after 46 cycles.

F - Failed.
D - Discontinued.

c. Test Results:

(1) Performance on Cycling: (Figures 37 through 39) Cycling was started in March 1966. Packs 74B (discontinued), 88D (failed) and 108B (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.

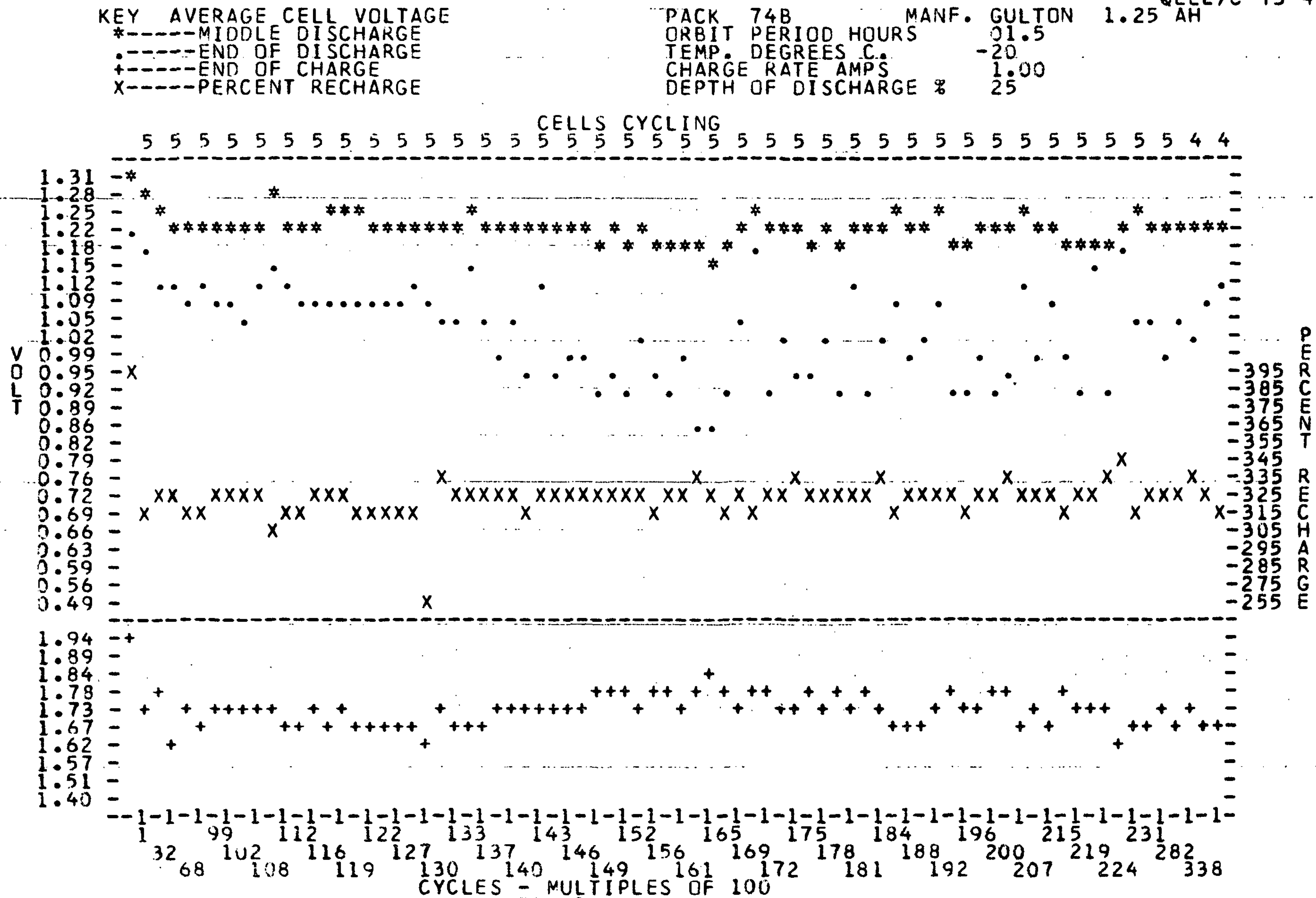

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
+-----END OF CHARGE
X-----PERCENT RECHARGE
PACK 74B MANF. GULTON 1.25 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. -20
CHARGE RATE AMPS 1.00
DEPTH OF DISCHARGE % 25
CELLS CYCLING
VOLT
PERCENT RECHARGE
CYCLES - MULTIPLES OF 100

FIGURE 37

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

PACK 88D MANF. GULTON 1.25 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. -20
CHARGE RATE AMPS 1.00
DEPTH OF DISCHARGE % 25

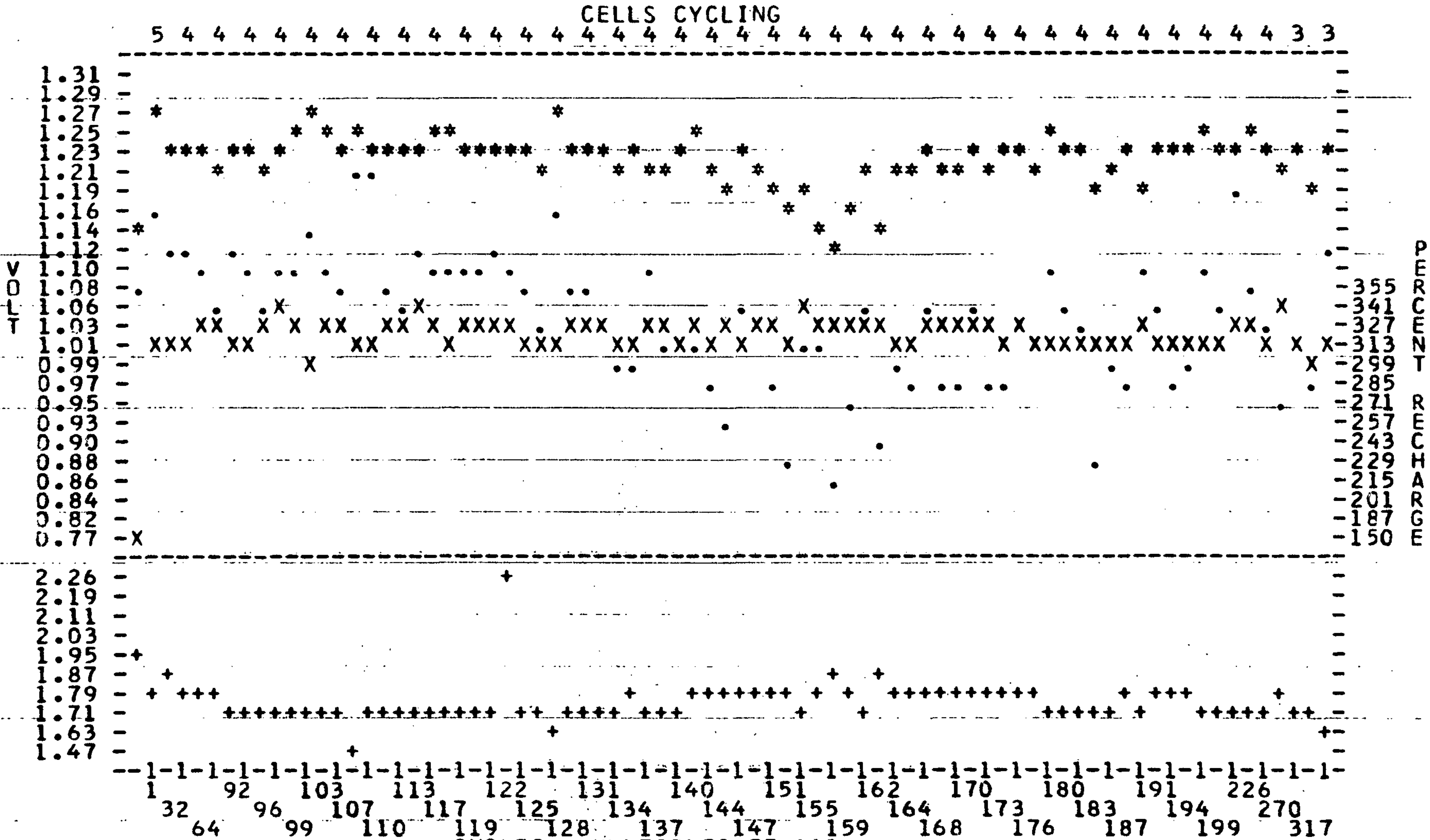


FIGURE 38

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

PACK 108B MANF. GULTON 1.25 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 1.25
DEPTH OF DISCHARGE % 25

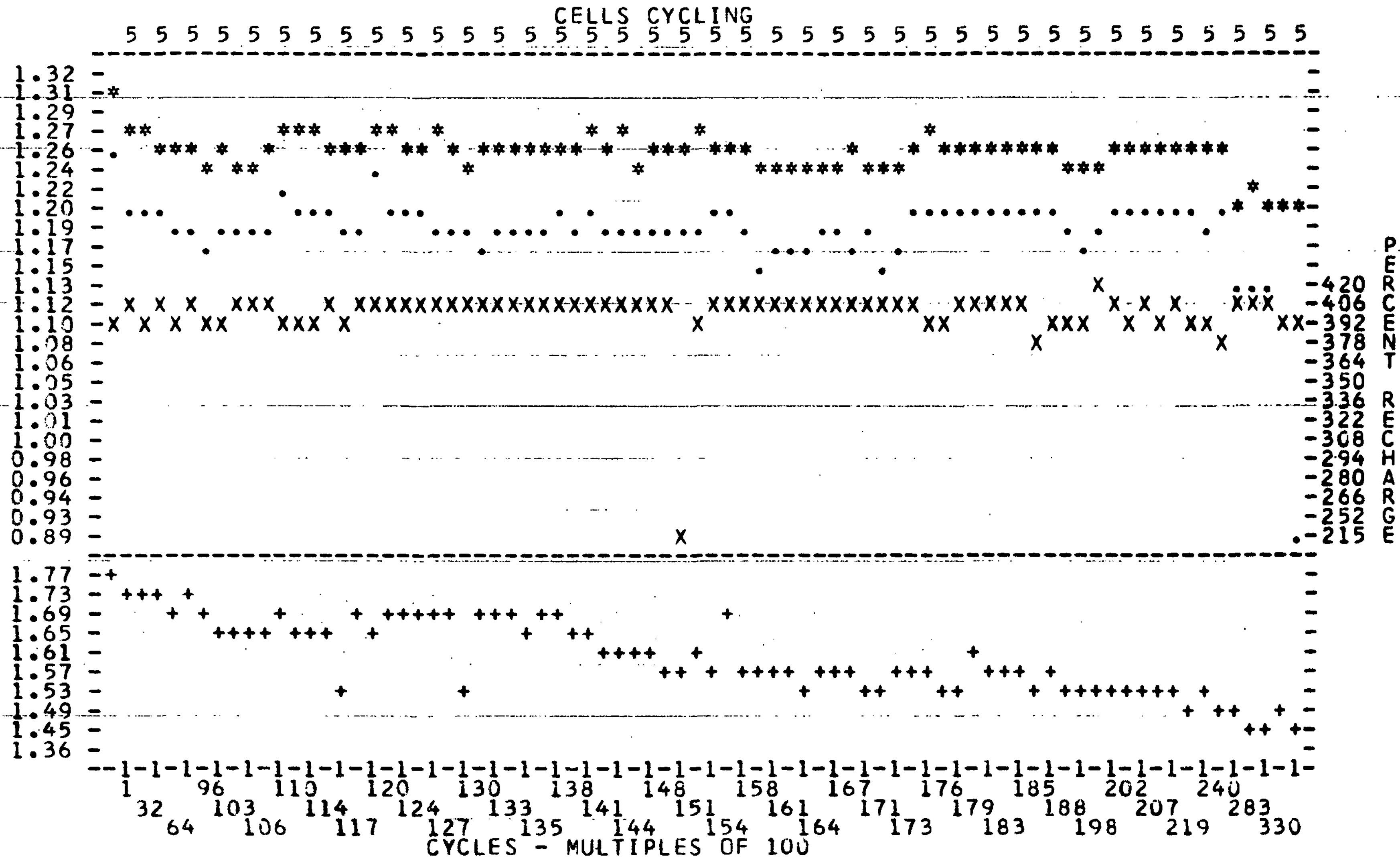


FIGURE 39

C. Auxiliary Electrode: Nickel-cadmium cells have been developed with an auxiliary electrode whose voltage, with respect to the negative terminal, is dependent upon the partial pressure of oxygen in the cell. When a nickel-cadmium cell is being charged, it generates oxygen very slowly until it nears 80 percent of the required recharge; then suddenly, the amount of oxygen generated internally increases rapidly. The increased oxygen pressure causes a fast rise in voltage between the auxiliary electrode and the negative terminal. This increasing voltage is used to signal a control circuit to reduce or terminate the charge current. The charge-current control circuit utilizes the auxiliary electrode voltage of each cell in the pack to reduce the charging rate after the cells have received the desired amount of recharge. The circuit is designed to monitor the auxiliary electrode voltage of each cell while the 5-cell pack is being charged. As the auxiliary electrode voltage of any one cell of the pack approaches a preset value, the circuit begins to reduce the charge current. When the auxiliary electrode voltage of any cell reaches the predetermined voltage (trip voltage), the charge current will be reduced to a preset trickle or to zero.

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

a. Cell Description: See paragraph II.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 Resistors (Ohms)	680	680	680
Pack Number	53C	65C*	42D
Precycling Capacity	8.26	8.40	8.54 F
152 Days	7.12	3.04 F	
330 Days	8.48		

* Percent recharge set at 102.5.
F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figures 40 through 42) Cycling was started in September 1971. Packs 42D and 65C failed after 95 and 4227 cycles, respectively. Pack 53C has completed 7260 cycles with no cell failures.

(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.

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

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

PACK 53C MANF. EP 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 4.80
DEPTH OF DISCHARGE % 25

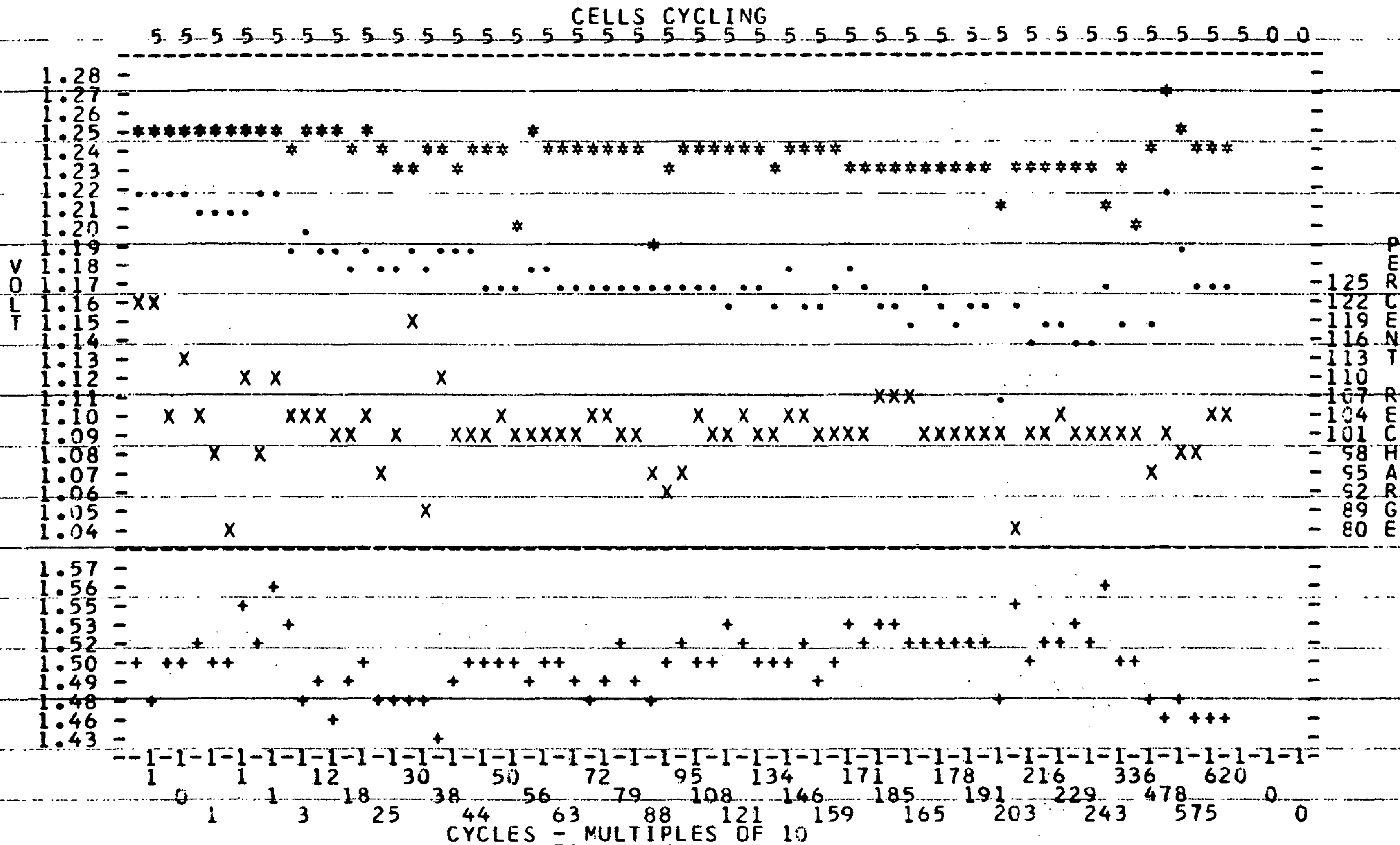


FIGURE 40

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

PACK 65C MANF. EP 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 4.80
DEPTH OF DISCHARGE % 25

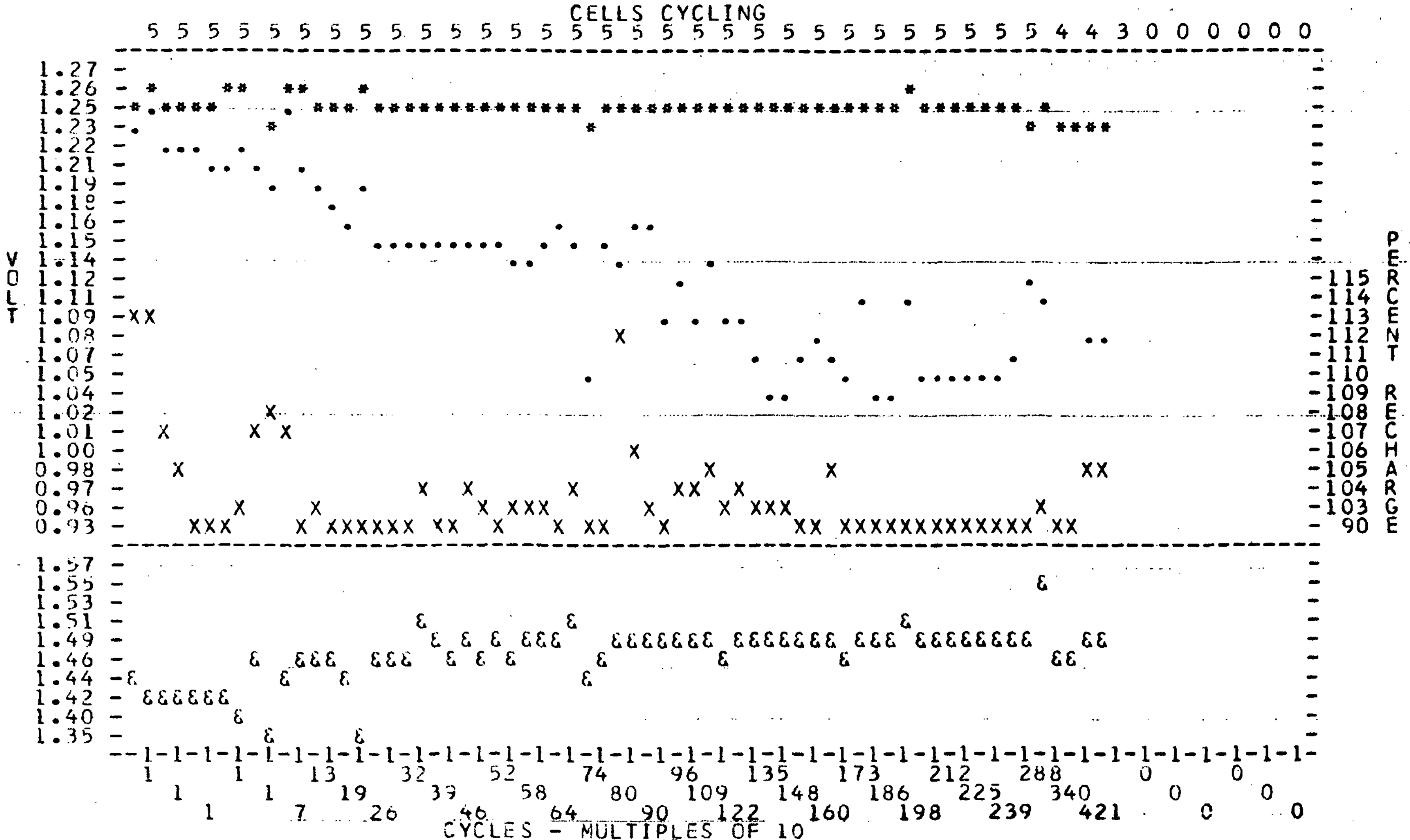


FIGURE 41

NOTE: Charge current adjusted to provide selected % recharges after 5 cycles.

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

PACK 42D MANF. EP 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 40
CHARGE RATE AMPS 4.80
DEPTH OF DISCHARGE % 25

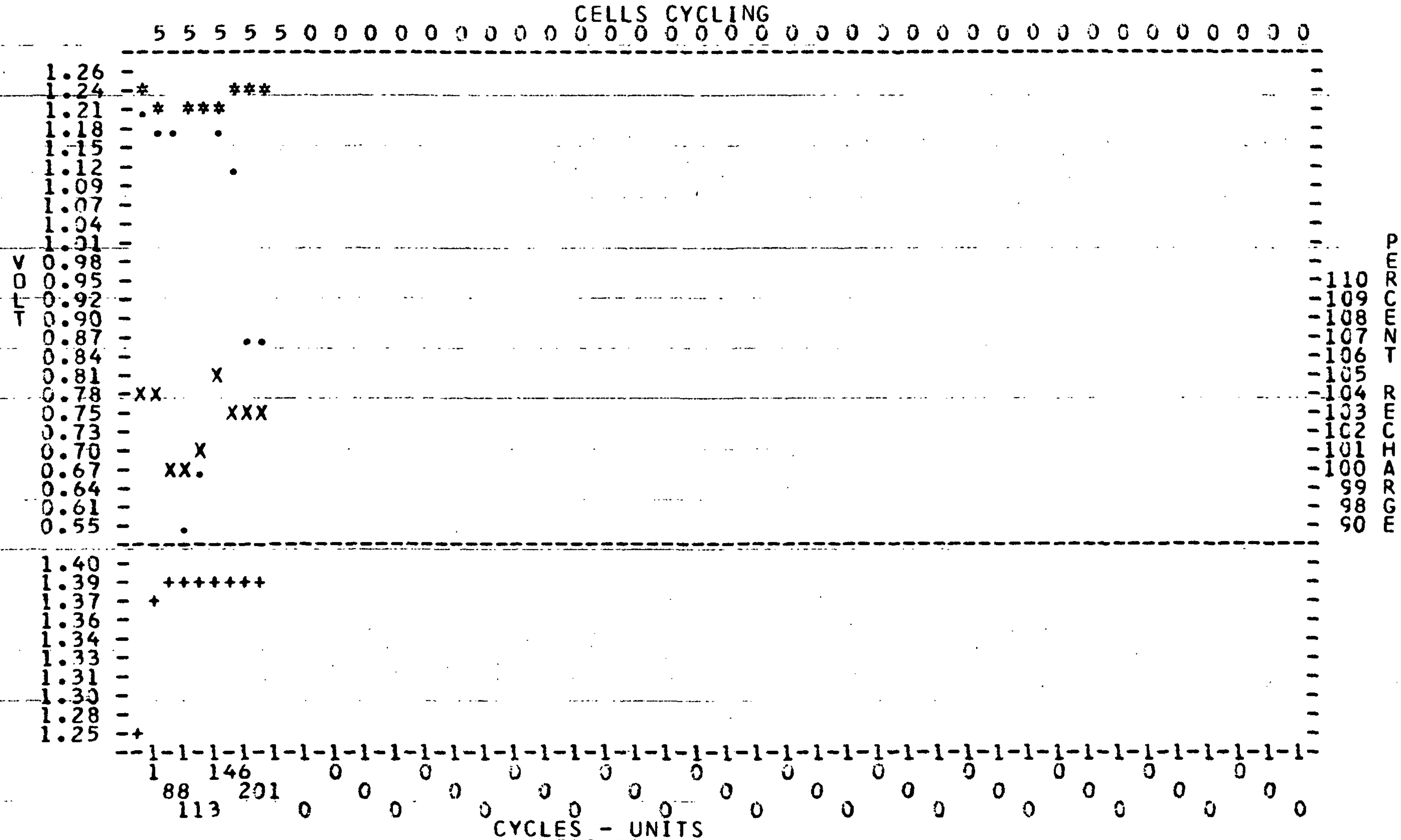


FIGURE 42

NOTE: Charge current adjusted to provide selected % recharges after 5 cycles.

2. 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 II.A.

b. Purpose of Test: This experiment is designed to test various types of separator material (listed in the table below) 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	F	6.45	F	F	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
		D			D	D	D	D	D	D

(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.

F - Failed.
D - Discontinued.

d. Test Results:

(1) Performance on Cycling: (Figures 43 through 49) 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

6000 CYCLES	2E	38F	22C	46C	49B	31C	25D
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

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

PACK 002E MANF. EP 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 1.65
DEPTH OF DISCHARGE % 25

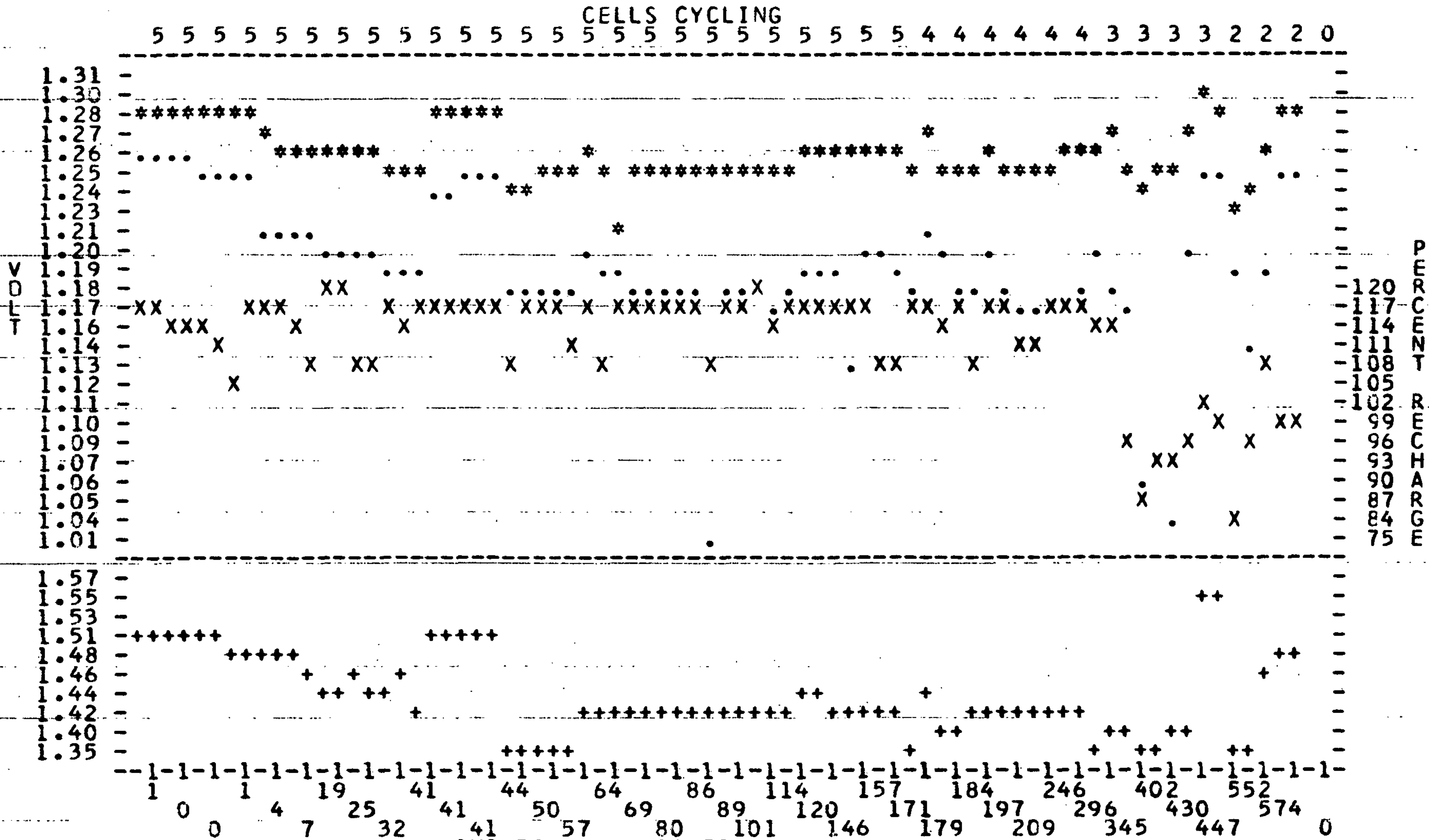


FIGURE 43

NOTE: Temperature 0°C after 4300 cycles.

QEEL/C 73-4

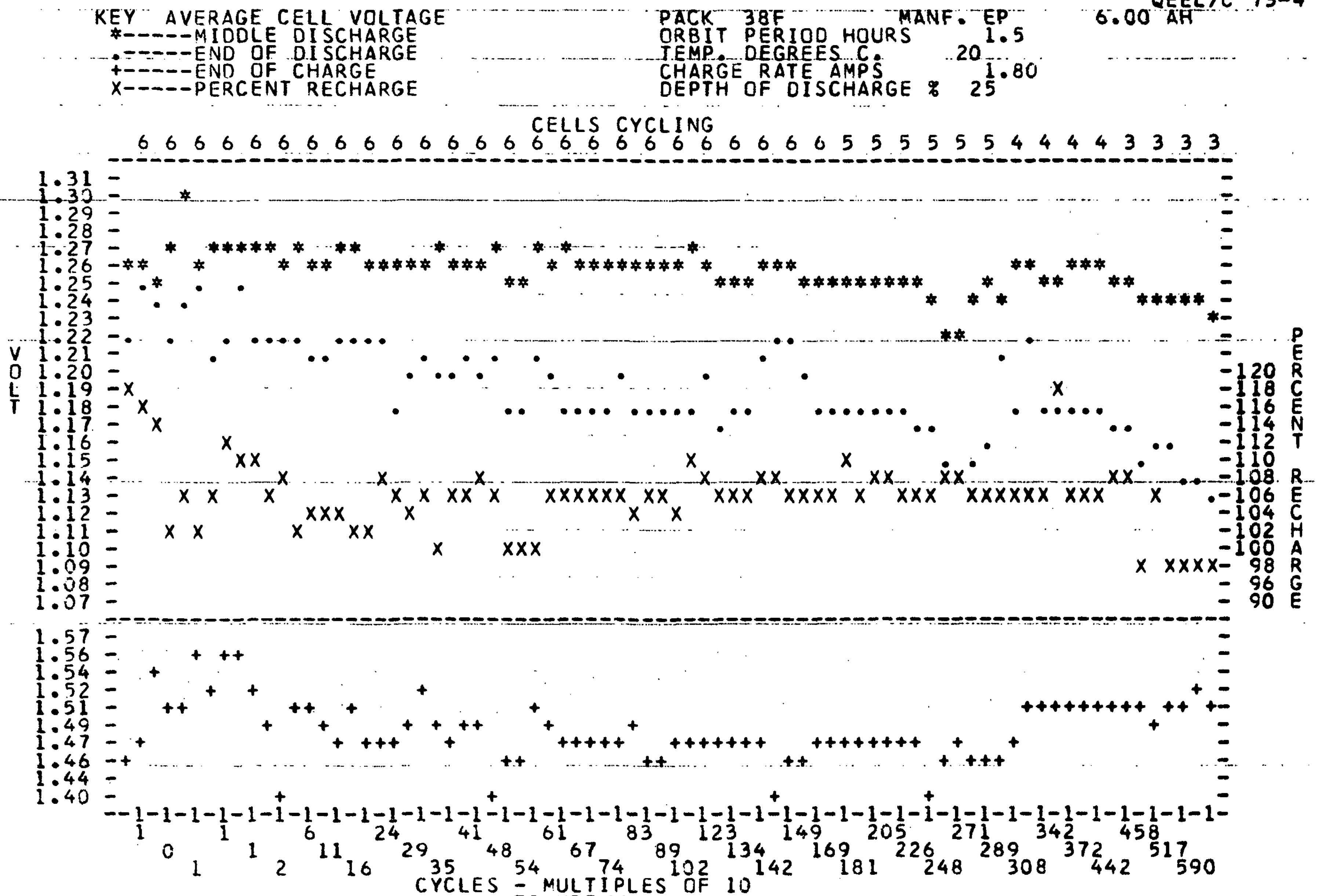


FIGURE 44

NOTE: Charge current 1.65A after 21 cycles, temperature 0°C after 4336 cycles.

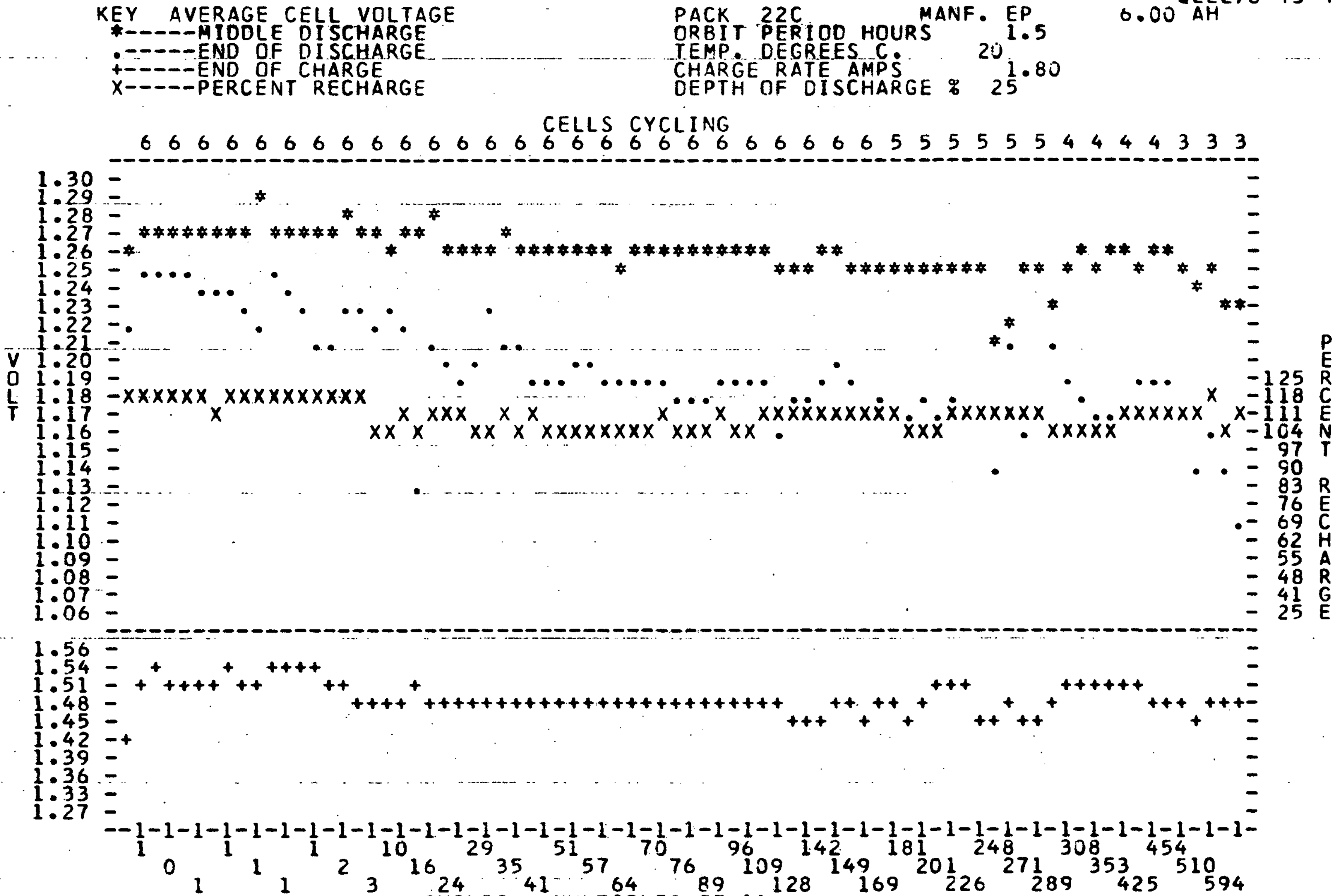


FIGURE 45

NOTE: Charge current 1.65A after 21 cycles.

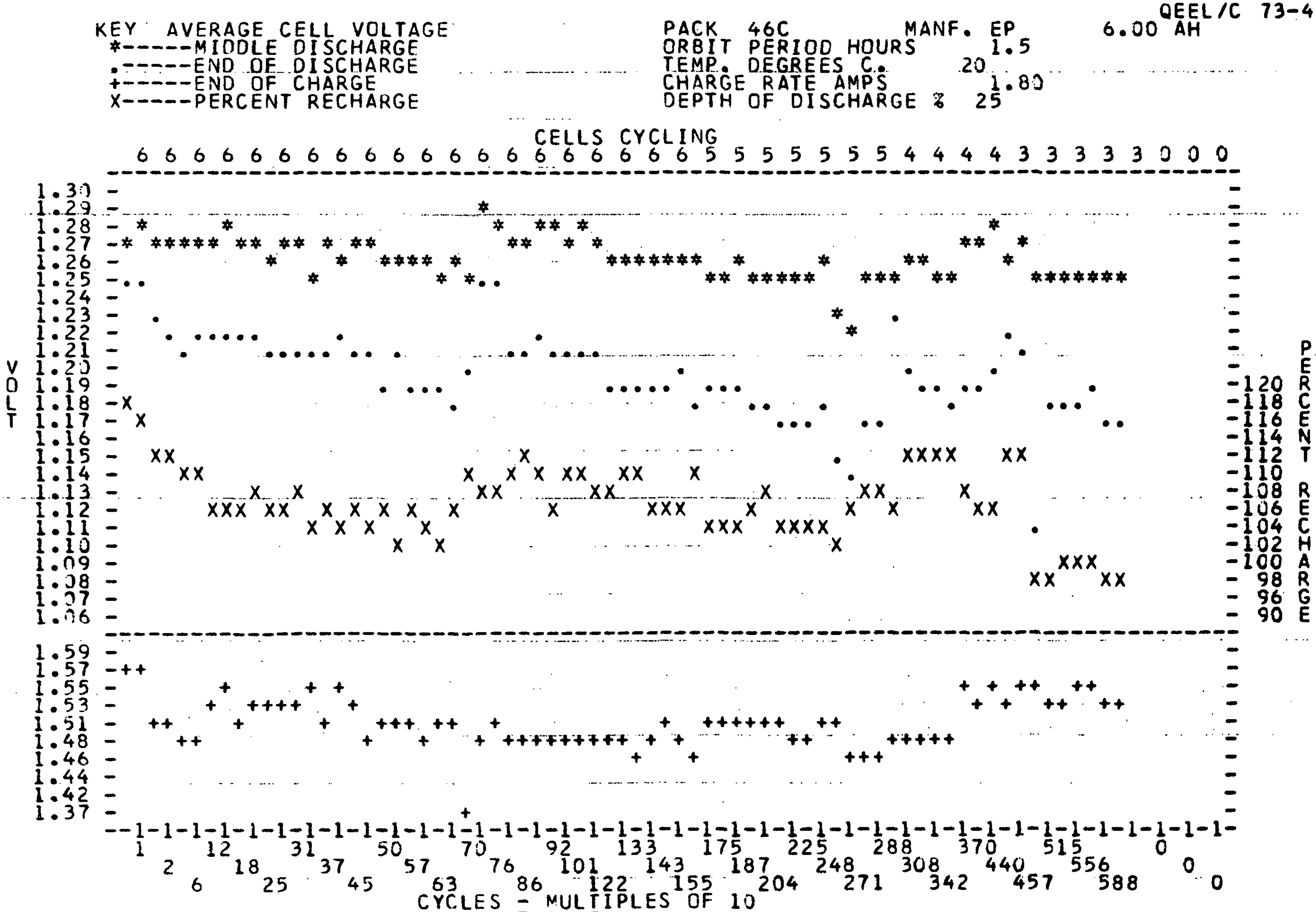


FIGURE 46

NOTE: Charge current 1.65A after 20 cycles.

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

PACK 49B MANF. EP 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 1.80
DEPTH OF DISCHARGE % 25

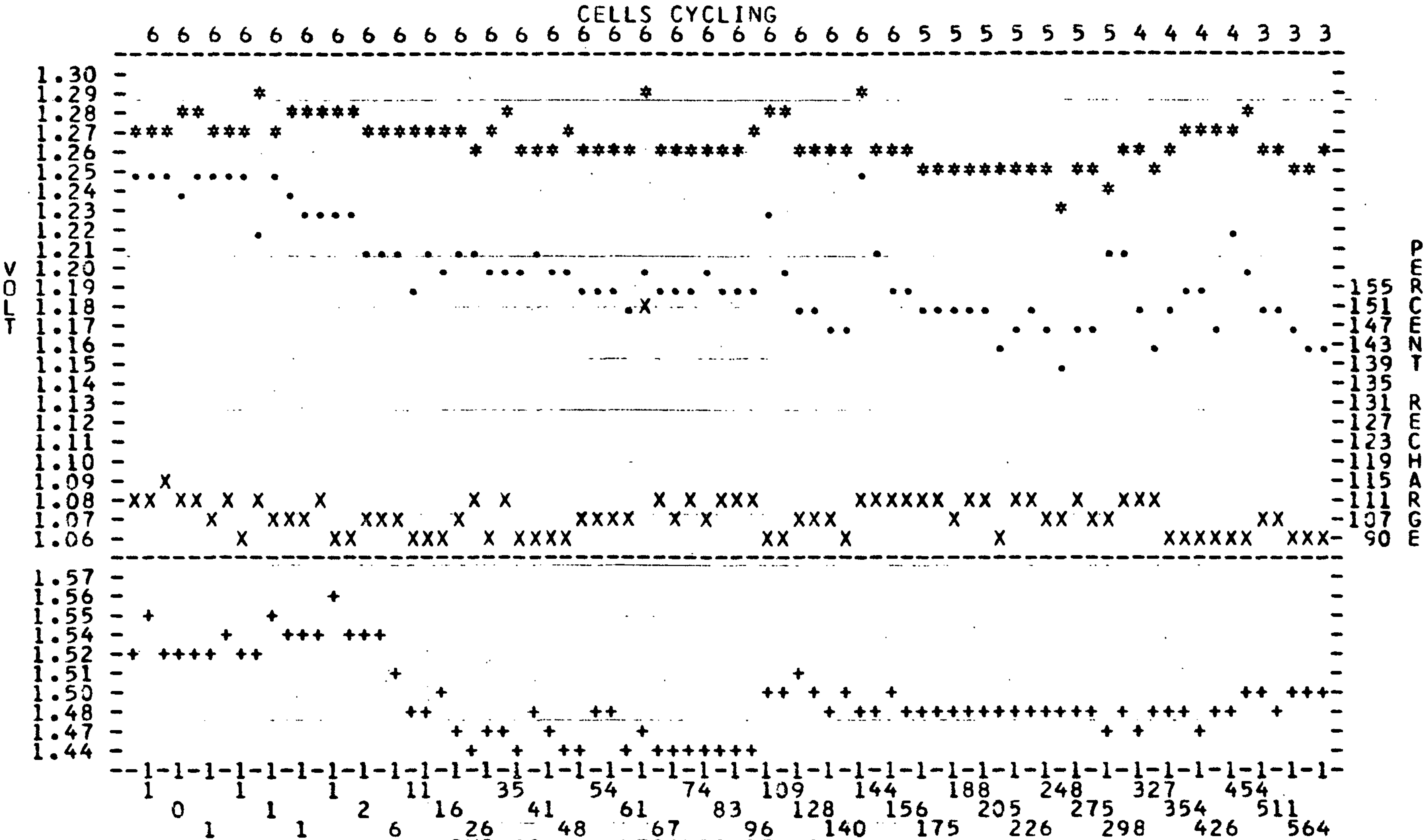


FIGURE 47

NOTE: Charge current 1.65A after 20 cycles, temperature 0°C after 4380 cycles.

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

PACK 31C MANF. EP 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 1.80
DEPTH OF DISCHARGE % 25

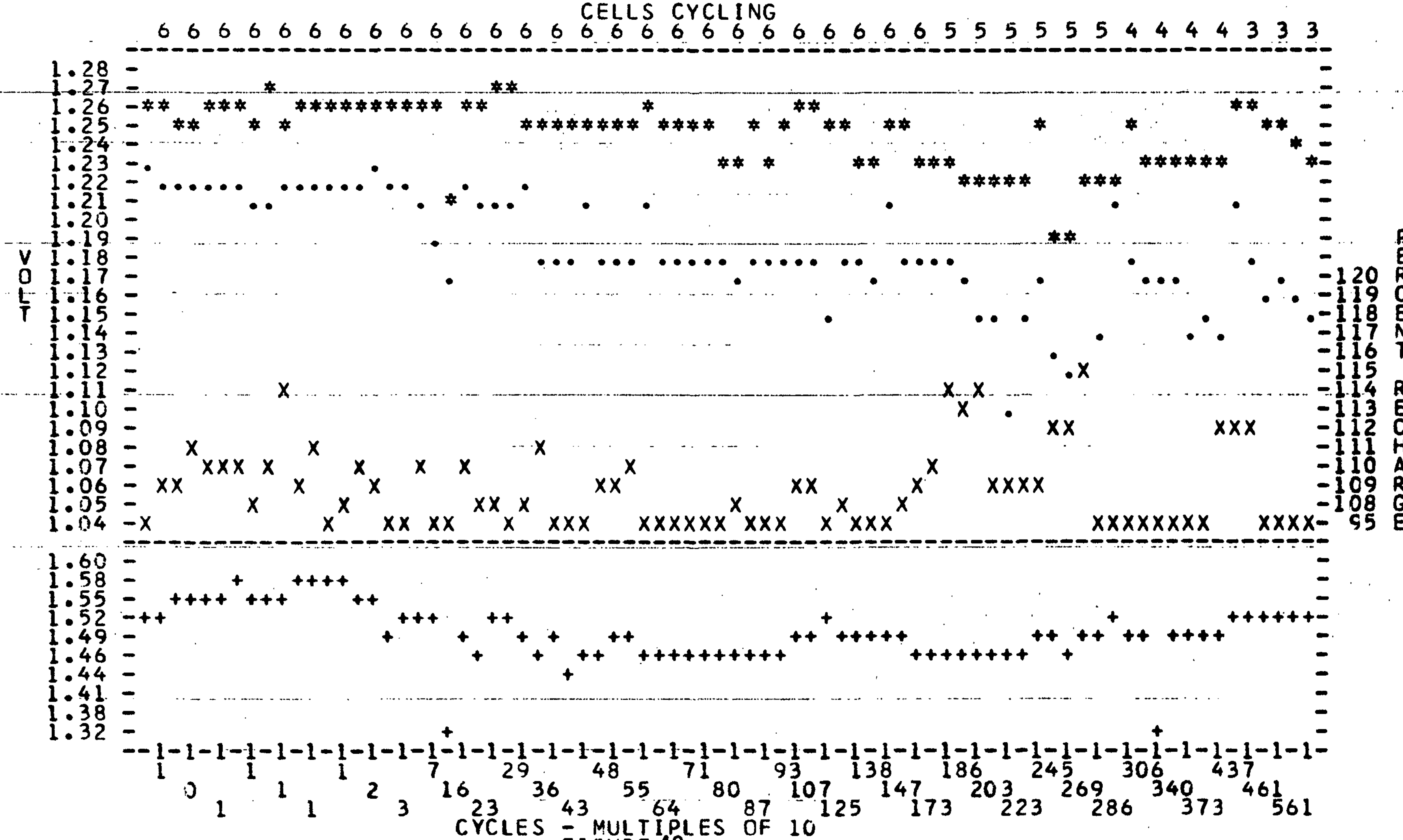


FIGURE 48

NOTE: Charge current 1.65A after 21 cycles.

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

PACK 25D MANF. EP 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 1.80
DEPTH OF DISCHARGE % 25

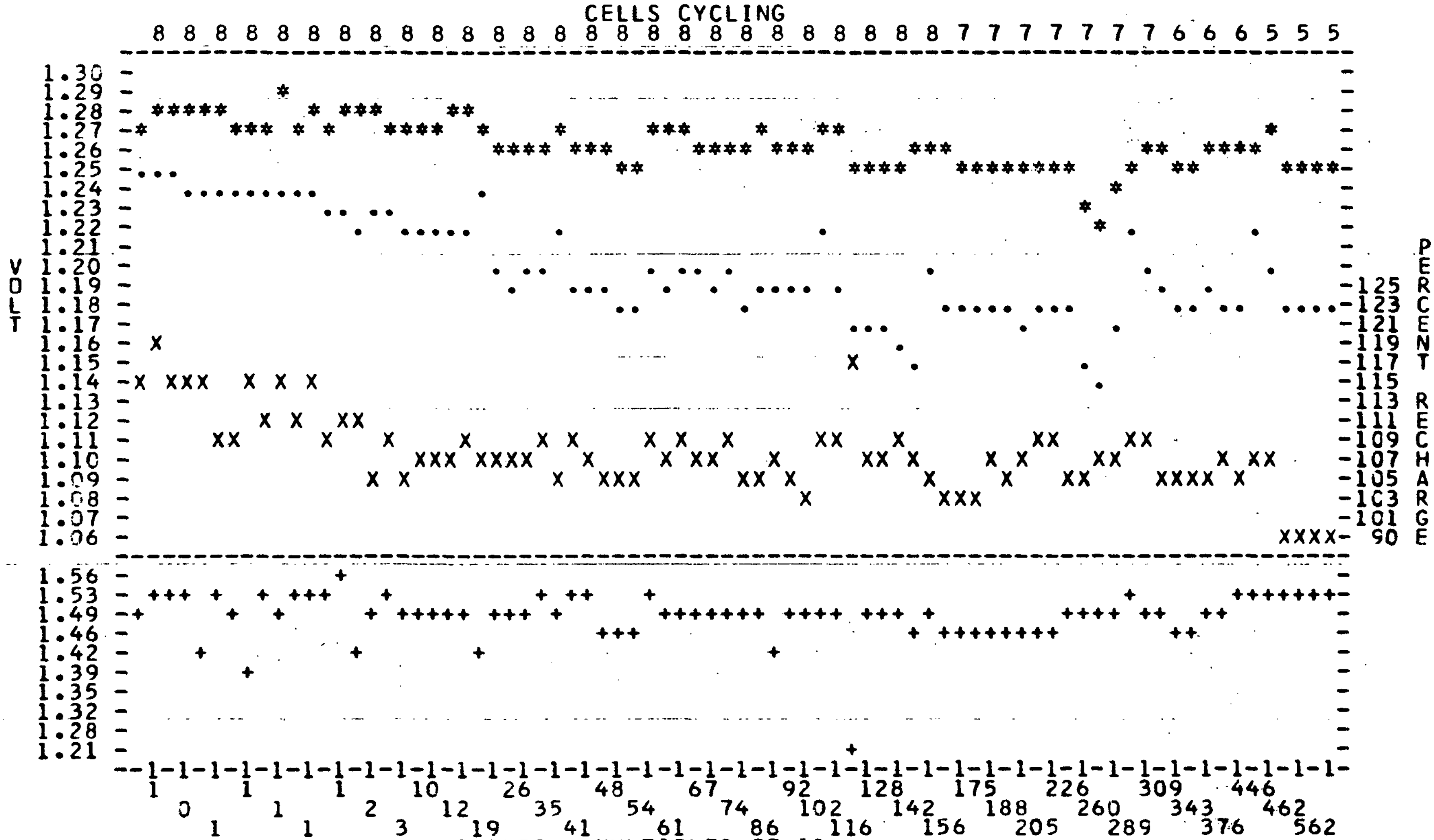


FIGURE 49

NOTE: Charge current 1.65A after 21 cycles, temperature 0°C after 4373 cycles.

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

a. Cell Description: See paragraph II.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 Resistors (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

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: (Figure 50) Cycling was started in April 1967. Packs 48B and 24C failed on cycles 6156 and 17,328, respectively. Pack 60B has completed 32,368 cycles with two 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 eight 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.

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KEY AVERAGE CELL VOLTAGE	
*-----MIDDLE DISCHARGE	PACK 60B MANF. GULTON 06.0 AH
.-----END OF DISCHARGE	ORBIT PERIOD HOURS 01.5
+-----END OF CHARGE	TEMP. DEGREES C. 0/40
X-----PERCENT RECHARGE	CHARGE RATE AMPS 1.80
	DEPTH OF DISCHARGE % 15

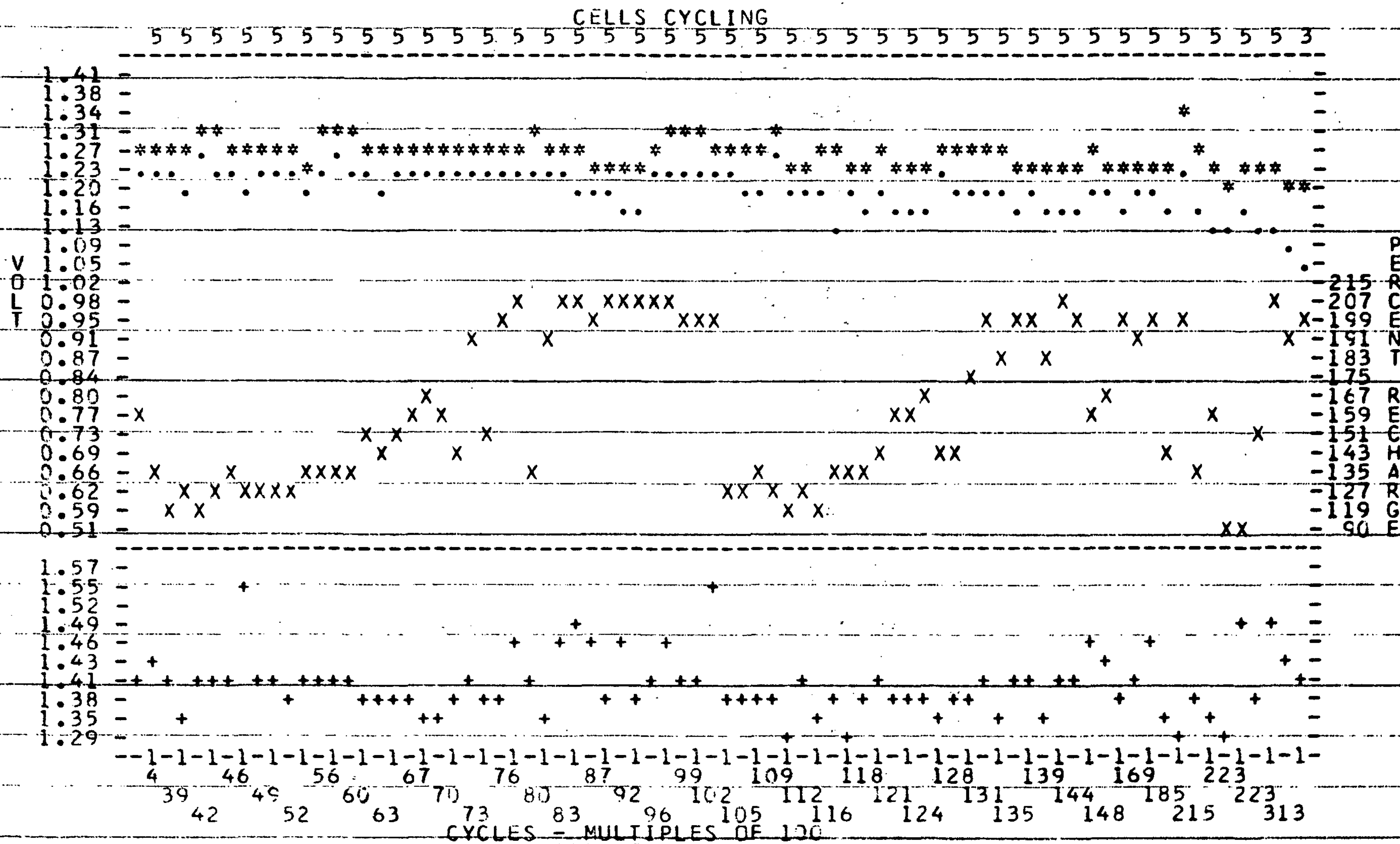

FIGURE 50

NOTE: Temperature 20°C after 22,480 cycles.

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

a. Cell Description: See paragraph II.A.

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.

c. Test Results:

(1) Performance on Cycling: (Figures 51 and 52) Cycling was started in January 1969. Packs 58D and 36D have completed 21,920 and 21,806 cycles, respectively, with no cell failures, although one cell from each pack was removed 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 do receive capacity checks every 88 days.

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

PACK 58D MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 0/40
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

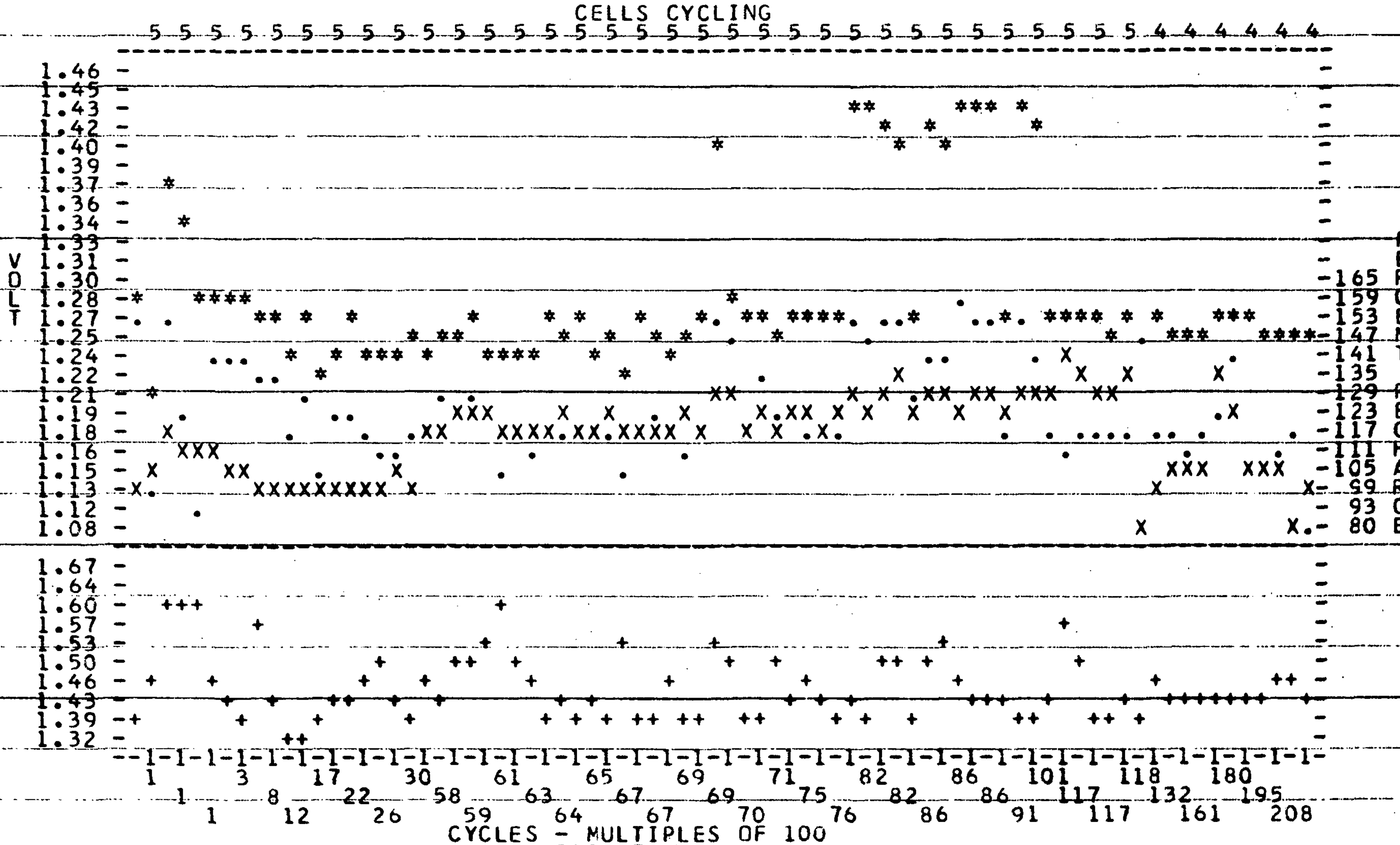

FIGURE 51

NOTE: V/L control and temperature 20°C after 11,777 cycles.

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

PACK 36D MANF. GULTON 6.0 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 0/40
CHARGE RATE AMPS 1.80
DEPTH OF DISCHARGE % 15

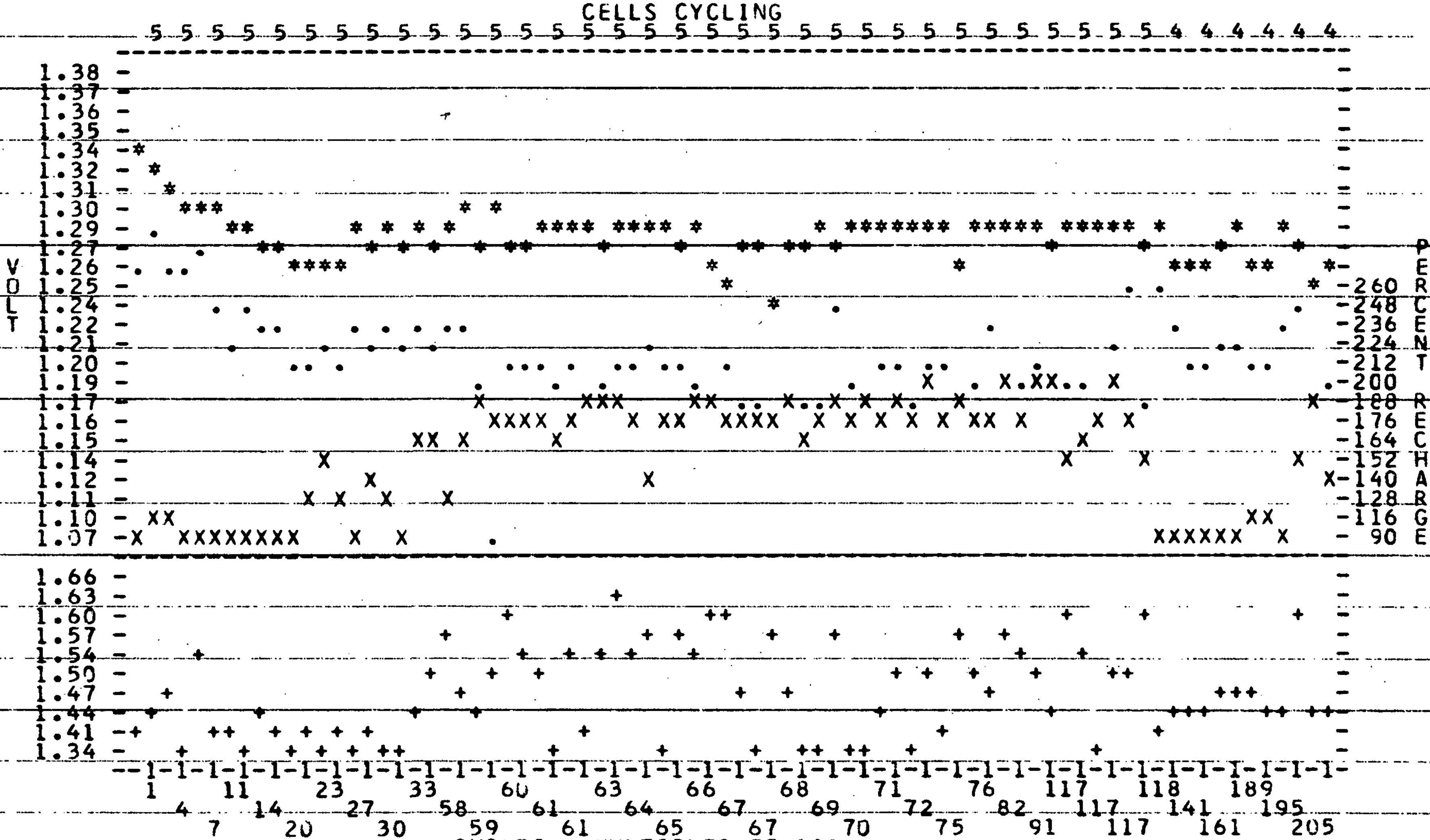

FIGURE 52

NOTE: V/L control and temperature 20°C after 11,766 cycles.

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

a. Cell Description: See paragraph II.A.

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 D	7.00 D	4.60 D

* 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: (Figures 53 through 55) 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.

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

PACK 280 MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

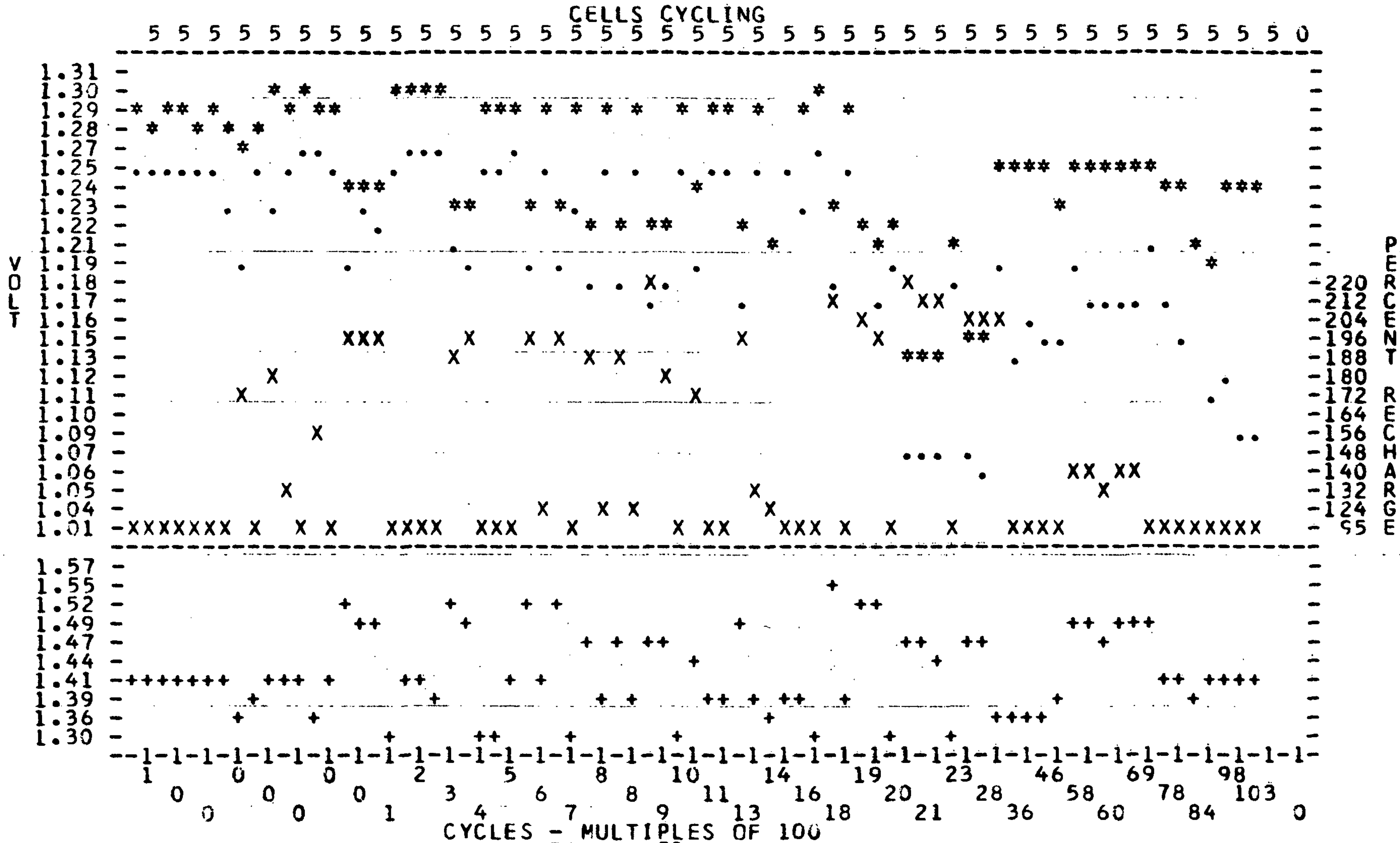

FIGURE 53

NOTE: V/L control after 5799 cycles.

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

PACK 40D MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

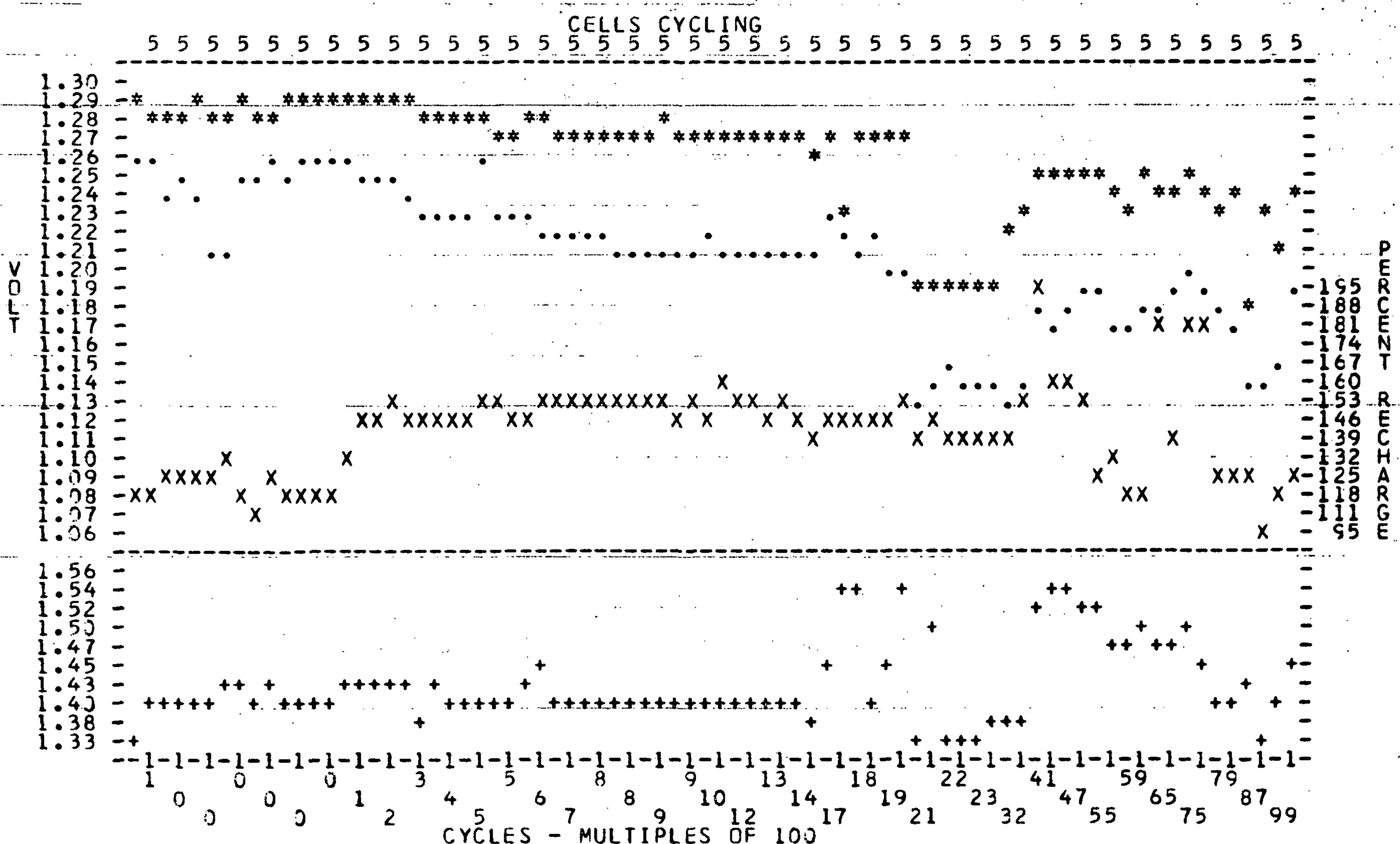

FIGURE 54

NOTE: V/L control after 5842 cycles.

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

PACK 52D MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

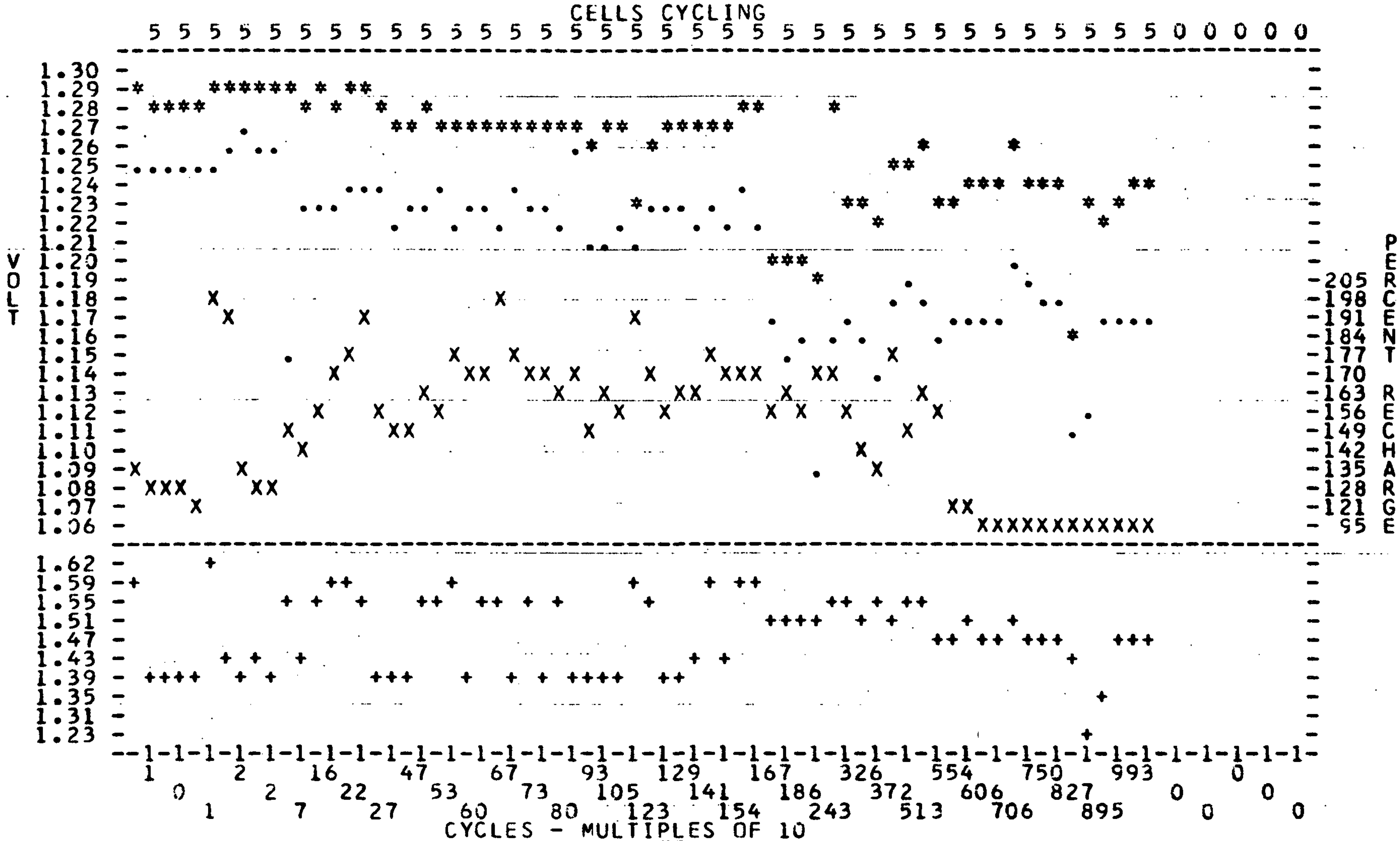

FIGURE 55

NOTE: V/L control after 5442 cycles.

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

a. Cell Description: See paragraph II.A.

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
Resistors (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			
2024 Days Disch #2	3.9			

* Capacity check not performed.

D - Discontinued.
F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 56) 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 33,065 cycles to date with no failures. Packs 71B, 11B and 47B failed on cycles 15,275, 11,933 and 6536, respectively.

(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.

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

PACK 70A MANF. GULTON 12.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 6.00
DEPTH OF DISCHARGE % 25

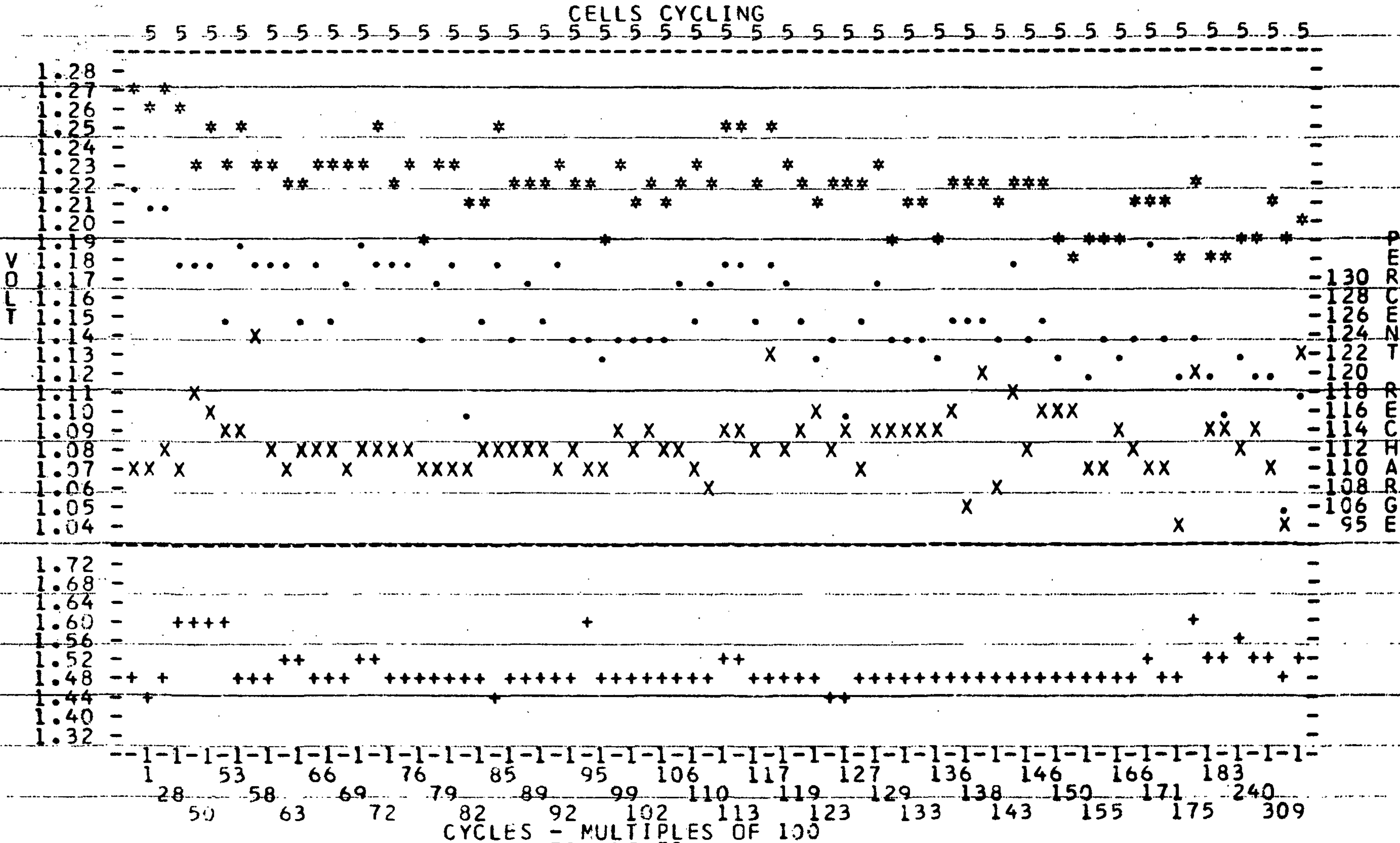

FIGURE 56

NOTE: 200% recharge from cycles 4900 to 5400 due to equipment failure - not shown in order to obtain meaningful % recharge graph.

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

a. Cell Description: See paragraph II.A.

b. Parameters and Capacity Checks:

Orbit Period		1.5-hour	
Temperature	0°	25°	40°
Depth of Discharge	15%	15%	15%
Trip Voltage (MV)	250	250*	300
Resistors (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		

* Placed on voltage limit control (3-4-71) due to both auxiliary electrode cells in the pack failed.

F - Failed.
D - Discontinued.

c. Test Results:

(1) Performance on Cycling: (Figures 57 and 58) Cycling was started in March 1968. Pack 54B has completed 27,177 cycles; pack 19B was discontinued after 24,625 cycles in March 1970; pack 38E failed after 4943 cycles due to loss of capacity at high temperature.

(2) Failure Analysis: Analysis of the five failed 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
+------END OF CHARGE
X------PERCENT RECHARGE

PACK 54B MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

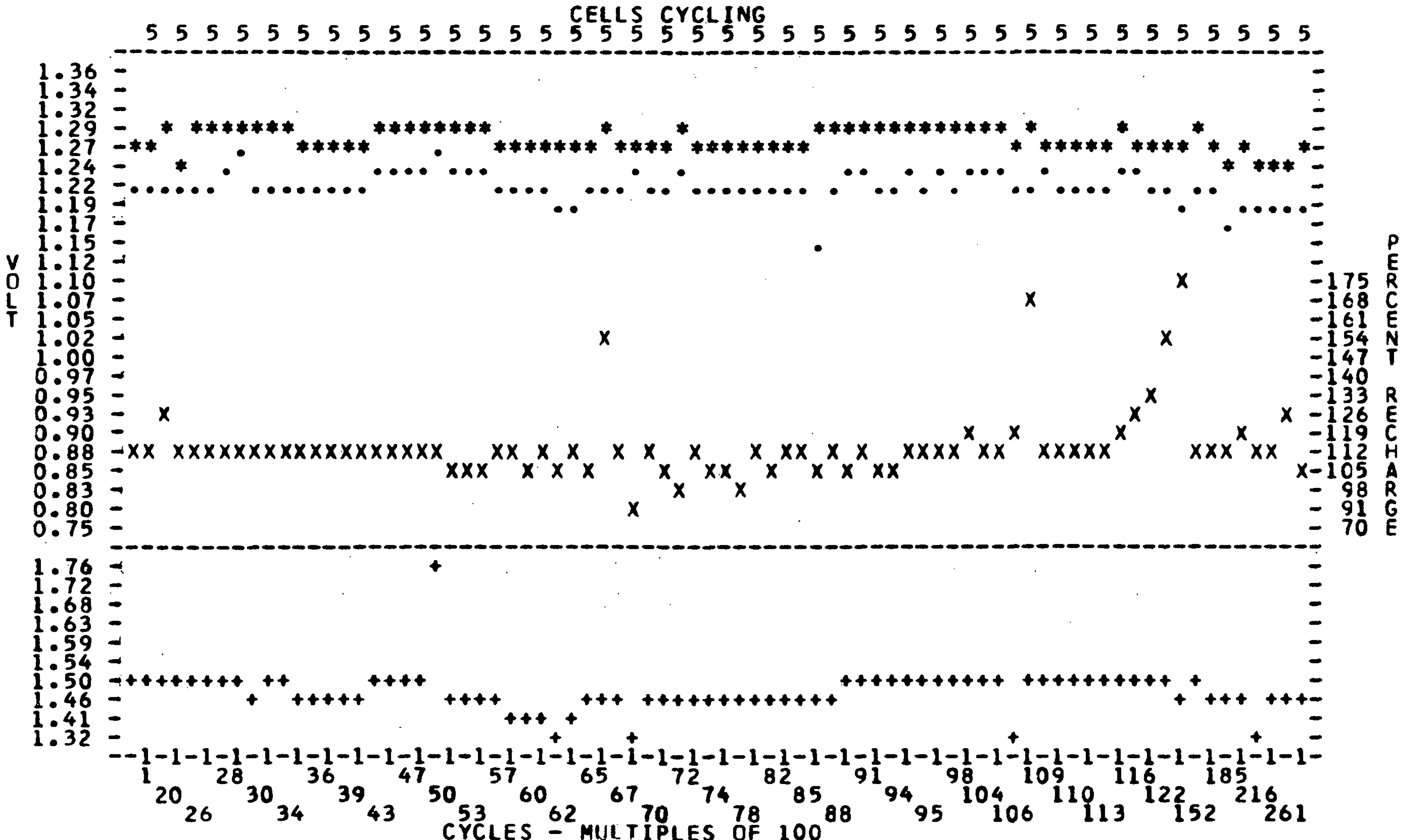

FIGURE 57

NOTE: Charge current 3.5A after 25,069 cycles.

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

PACK 19B MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

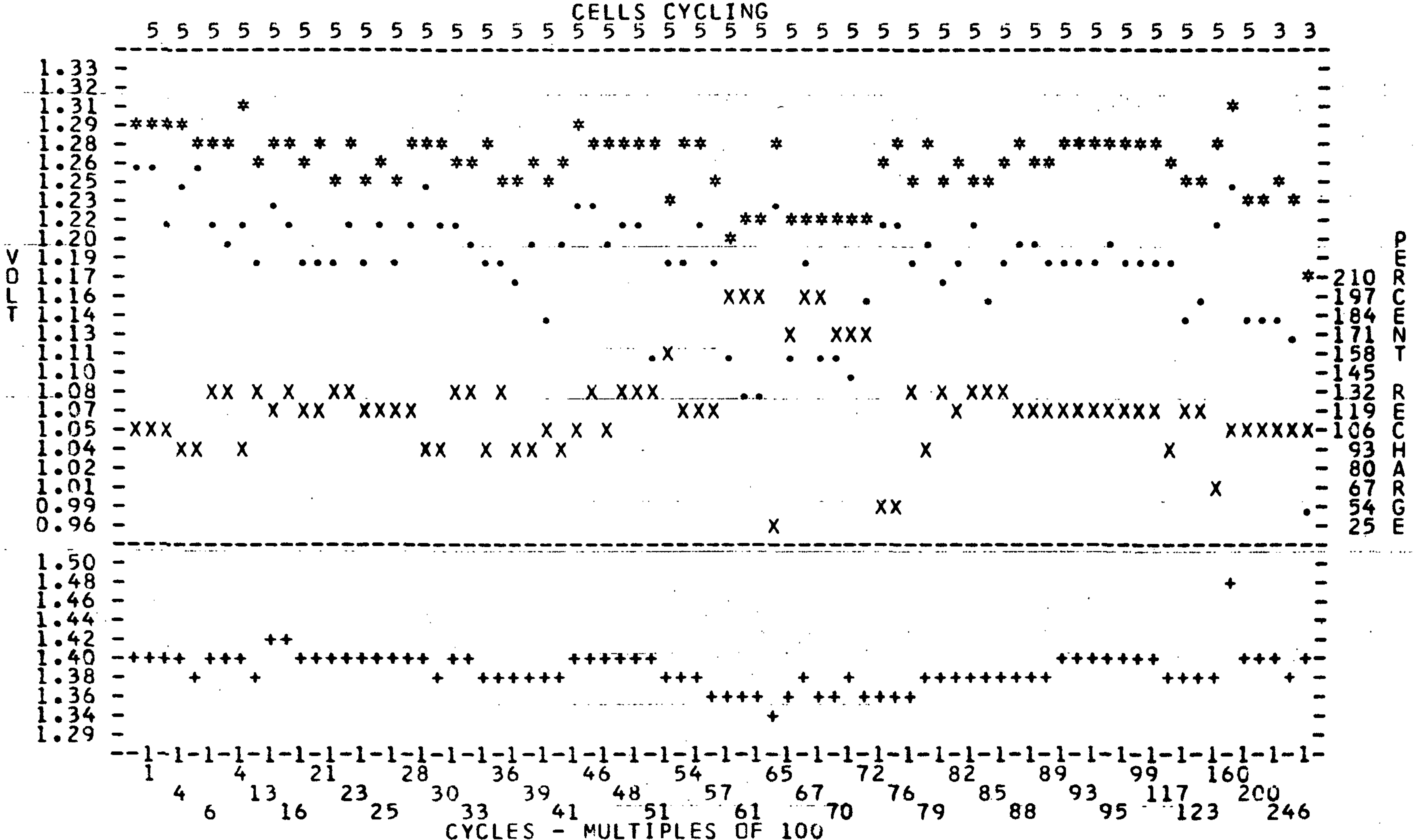

FIGURE 58

8. 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 Resistors: 47 Ohms.

	Negative Precharge		Zero Precharge		Positive Precharge	
	Cell #1 S/N 475	Cell #4 S/N 953	Cell #2 S/N 481	Cell #5 S/N 961	Cell #3 S/N 493	Cell #6 S/N 959
Precycling Capacity	25.60	25.60	25.50	24.80	25.50	25.10
88 Days	14.17	11.17	12.67	14.33	12.50	15.00
176 Days	9.20	6.80	8.80	9.00	8.30	10.20
352 Days	6.70	5.80	8.50	7.30	7.50	11.50
528 Days	6.33	5.83	7.33	7.33	7.16	9.16
704 Days	14.30	13.50	14.70	15.20 F	15.50 F	16.00 F

F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 59) Cycling was started in July 1970. Pack 48D has completed 13,404 cycles with three failures to date.

d. Failure Analysis: Cells 959, 961 and 493 all shorted out. The shorts occurred at the lower corners of the cells and were due to migration and separator deterioration.

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

PACK 48D MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 10.00
DEPTH OF DISCHARGE % 25

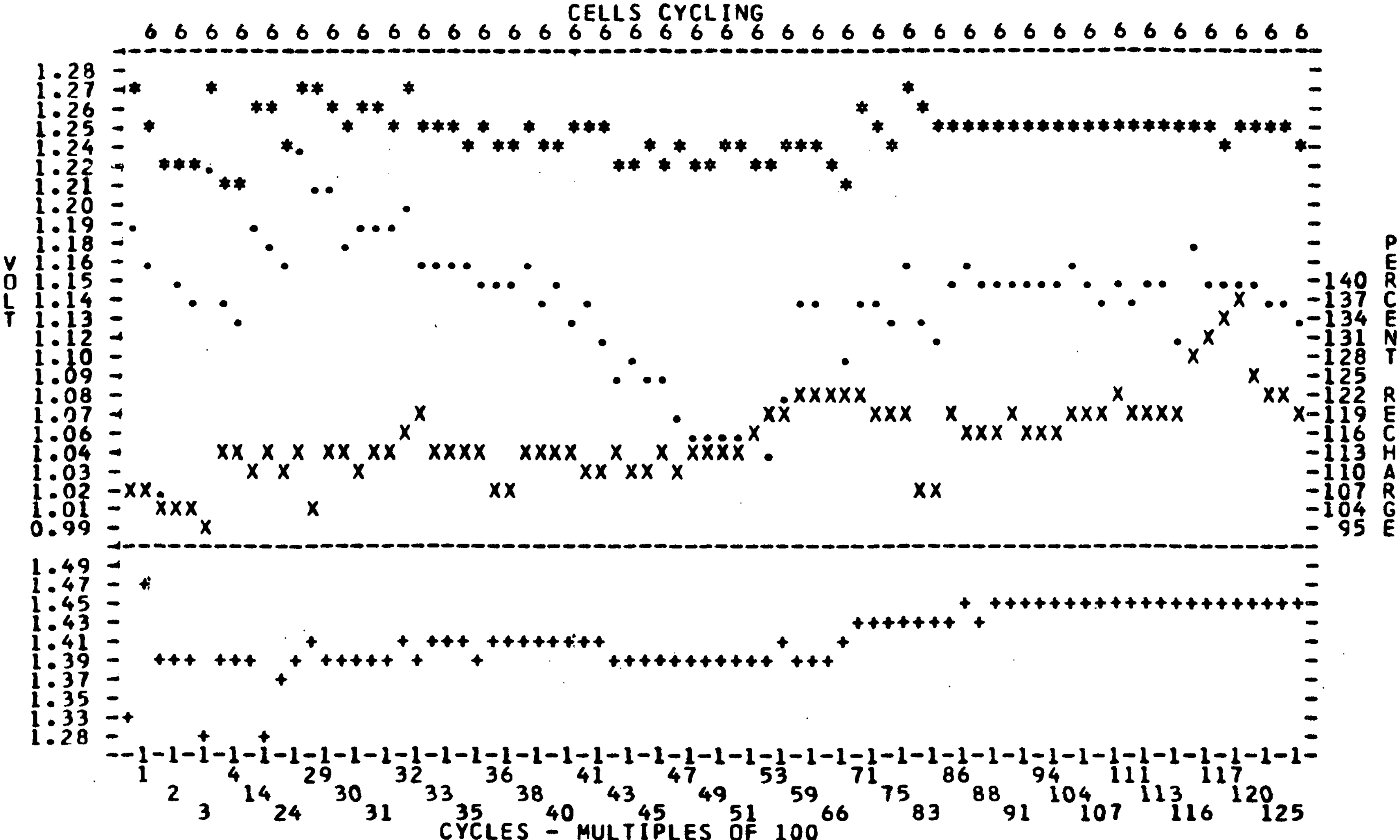

FIGURE 59

NOTE: V/L control after 2845 cycles.

9. 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. The physical description may be found in paragraph II.A.

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	
158 Days				28.17	
174 Days				26.83	

* 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 60) Cycling started in May 1970. Pack 12E has completed 14,786 cycles with two cells removed.

(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.

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

PACK 12E MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

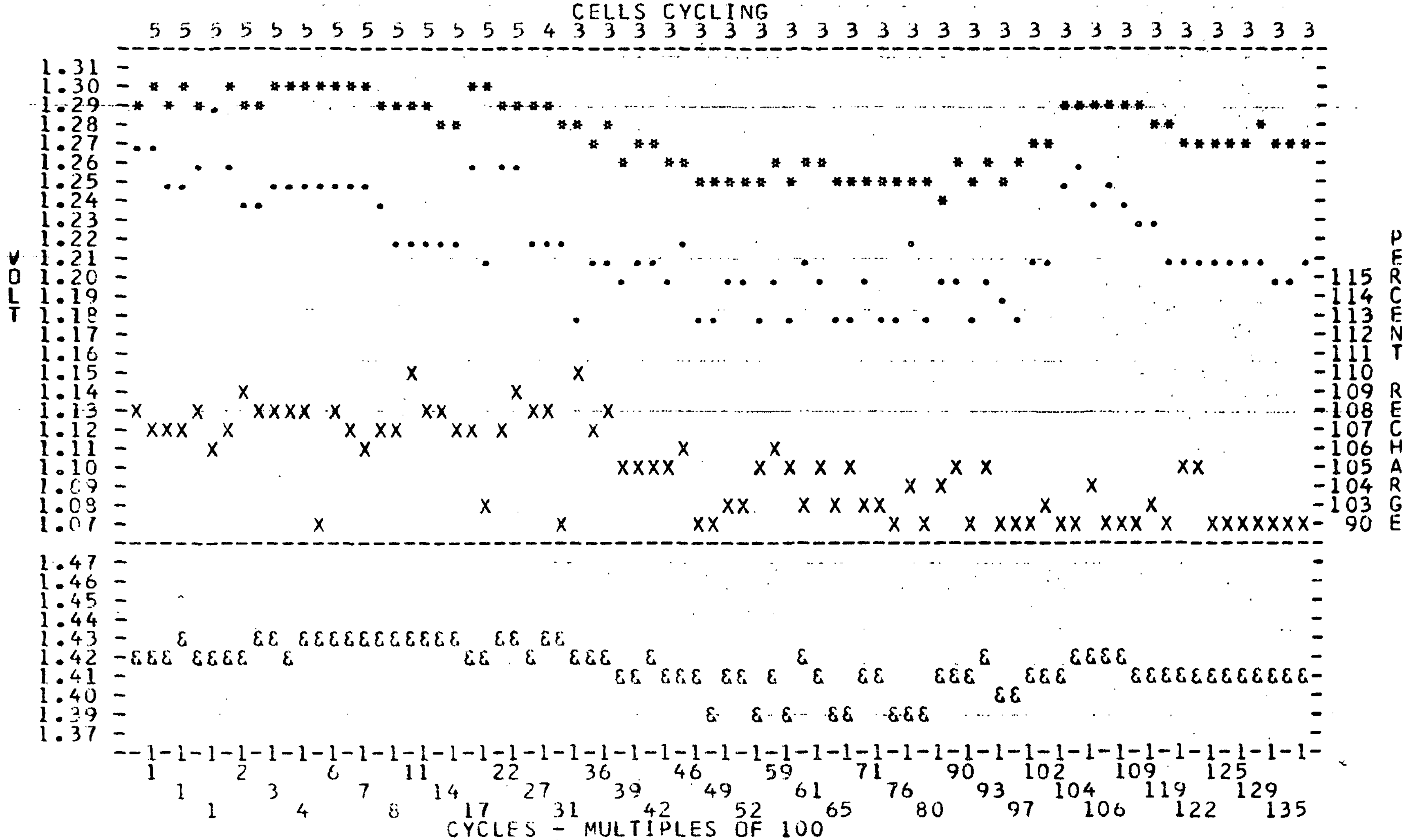

FIGURE 60

10. Gulton 20 ah (OAO), (Nickel-Cadmium), 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: 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 volt.

	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 61) Cycling was started in October 1970. Pack 68B has completed 12,397 cycles.

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

PACK 68B MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

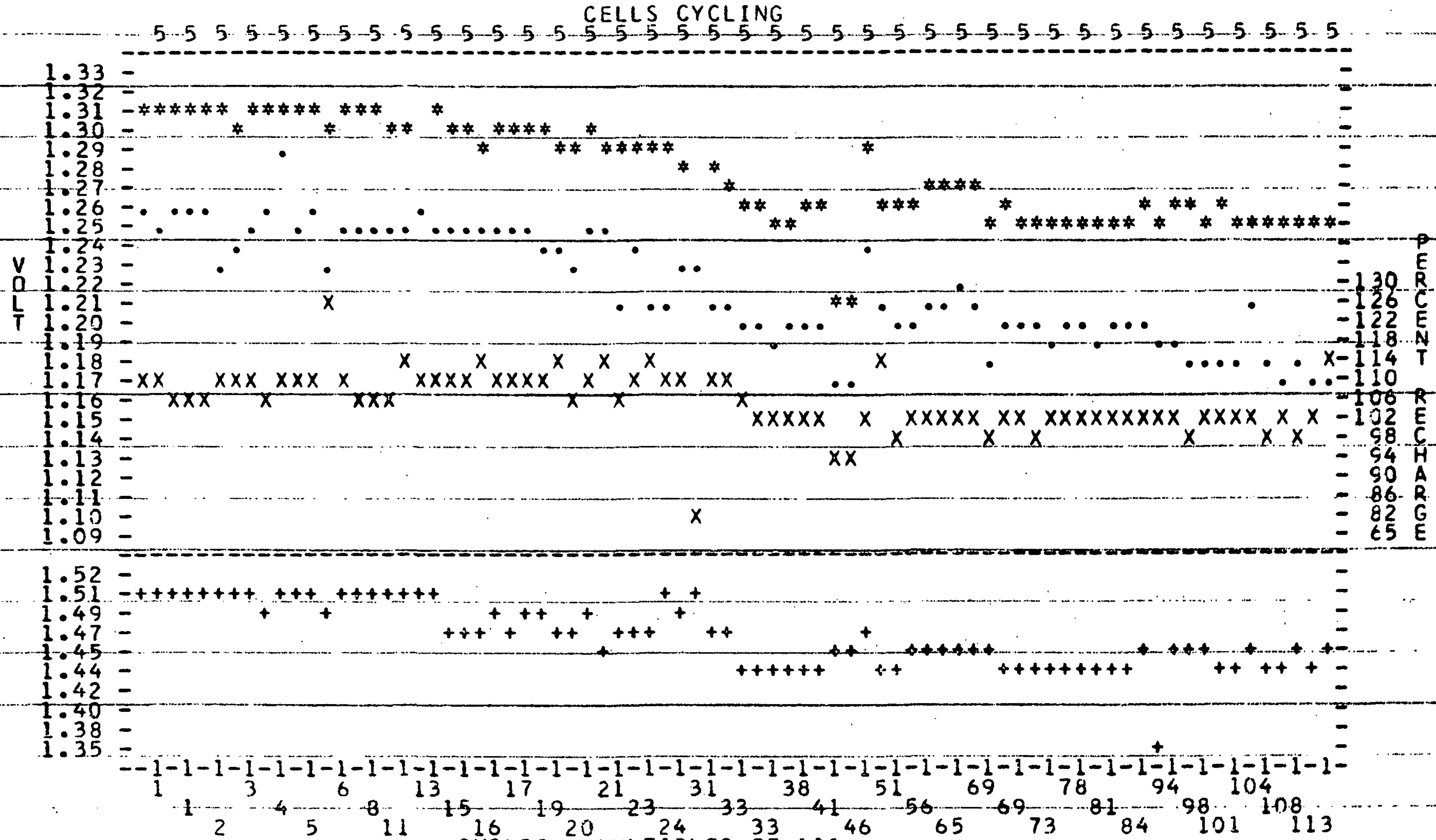

FIGURE 61

11. 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.

(5) Capacity Checks: The capacity checks are not run on a regular 88-day schedule; they are scheduled by Goddard Space Flight Center.

c. Test Results:

(1) Performance on Cycling: (Figure 62) Cycling was started in February 1971. This pack completed 10,450 cycles with no cell failures prior to its discontinuation in November 1972, as requested by Goddard Space Flight Center.

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

PACK 35B MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 10
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

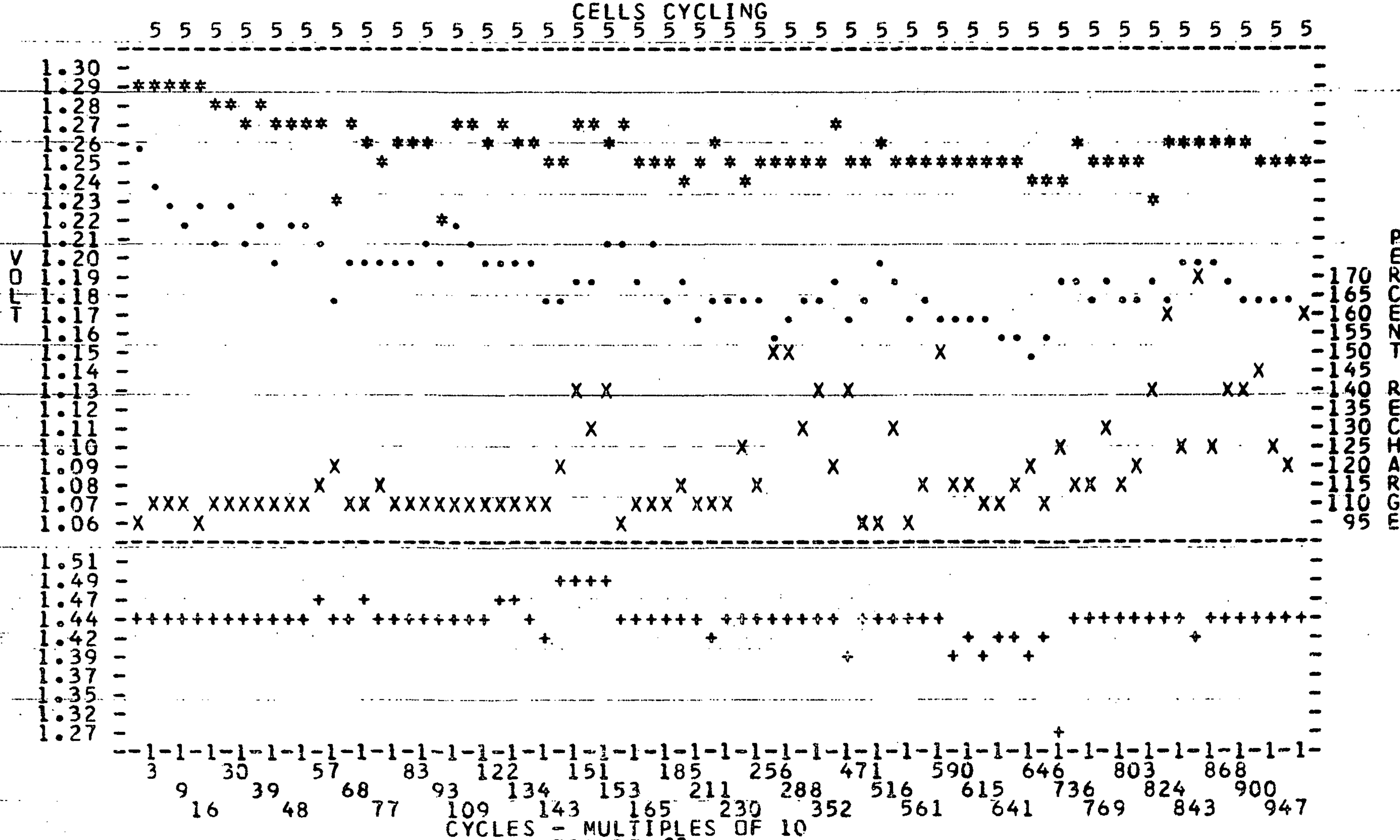


FIGURE 62

12. Gulton 20 ah, One 9-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: 4C.

(5) Capacity Checks: None.

c. Test Results:

(1) Performance on Cycling: (Figure 63) Cycling was started in May 1972. This pack has completed 3192 cycles with no cell failures.

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

PACK 4C MANF. GULTON 20.0 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 10
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

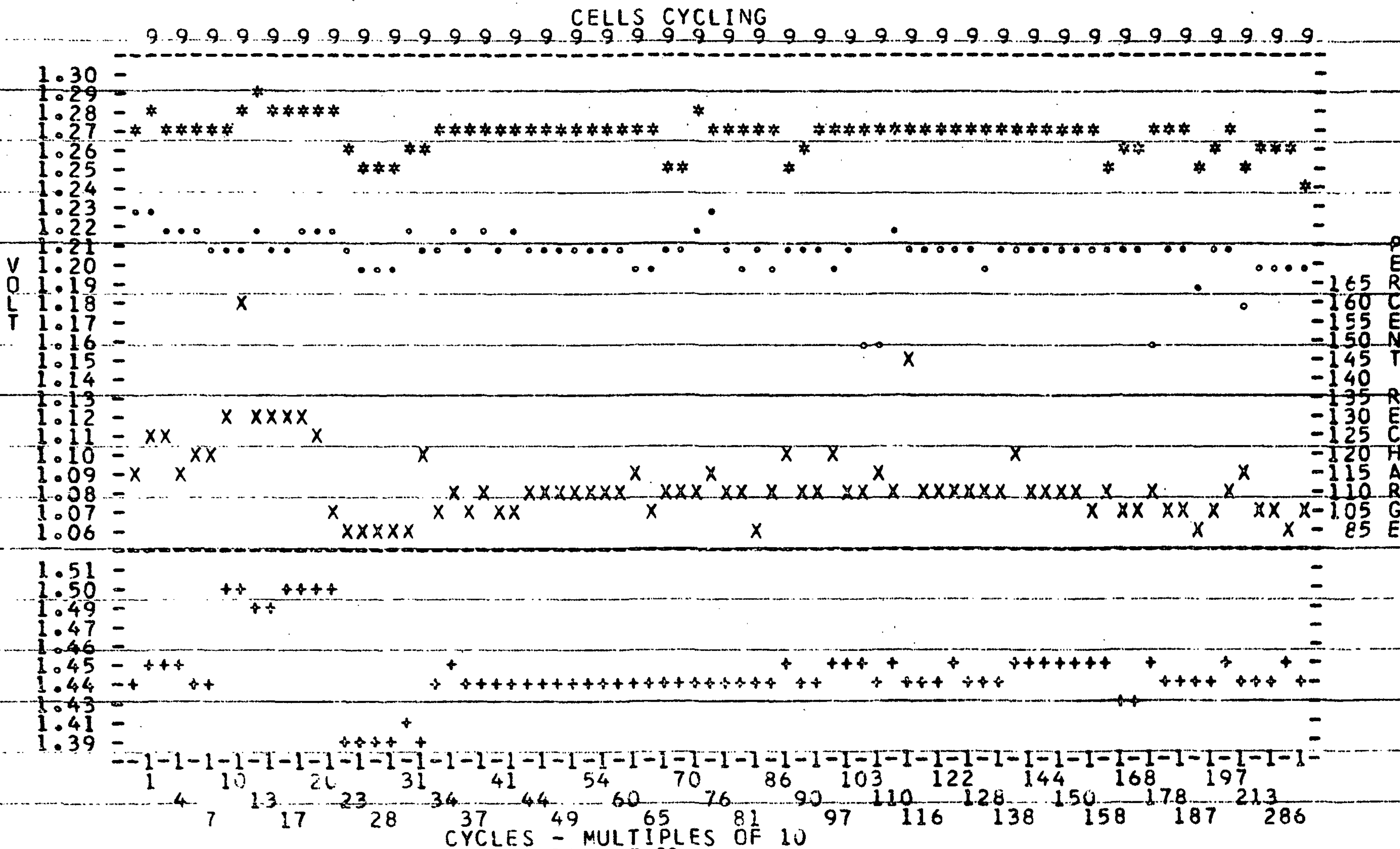


FIGURE 63

13. 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
Resistors (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				1.71 D
968 Days		6.00		1.65 F				
1144 Days		5.65						
1320 Days		4.25						
1496		3.10						

* 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: (Figures 64 and 65) Cycling started in June 1968. Pack 50B has completed 26,356 cycles with no failures. Pack 62B was discontinued after 2367 cycles and then started again using a voltage limit control and has completed 11,807 total cycles with one cell failure to date. Packs 6C, 52C and 17B failed after 8072, 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 13 cells.

(2) Failure Analysis: Analysis of eight cells showed that the major causes of failure 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.

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

PACK 50B MANF. GE 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

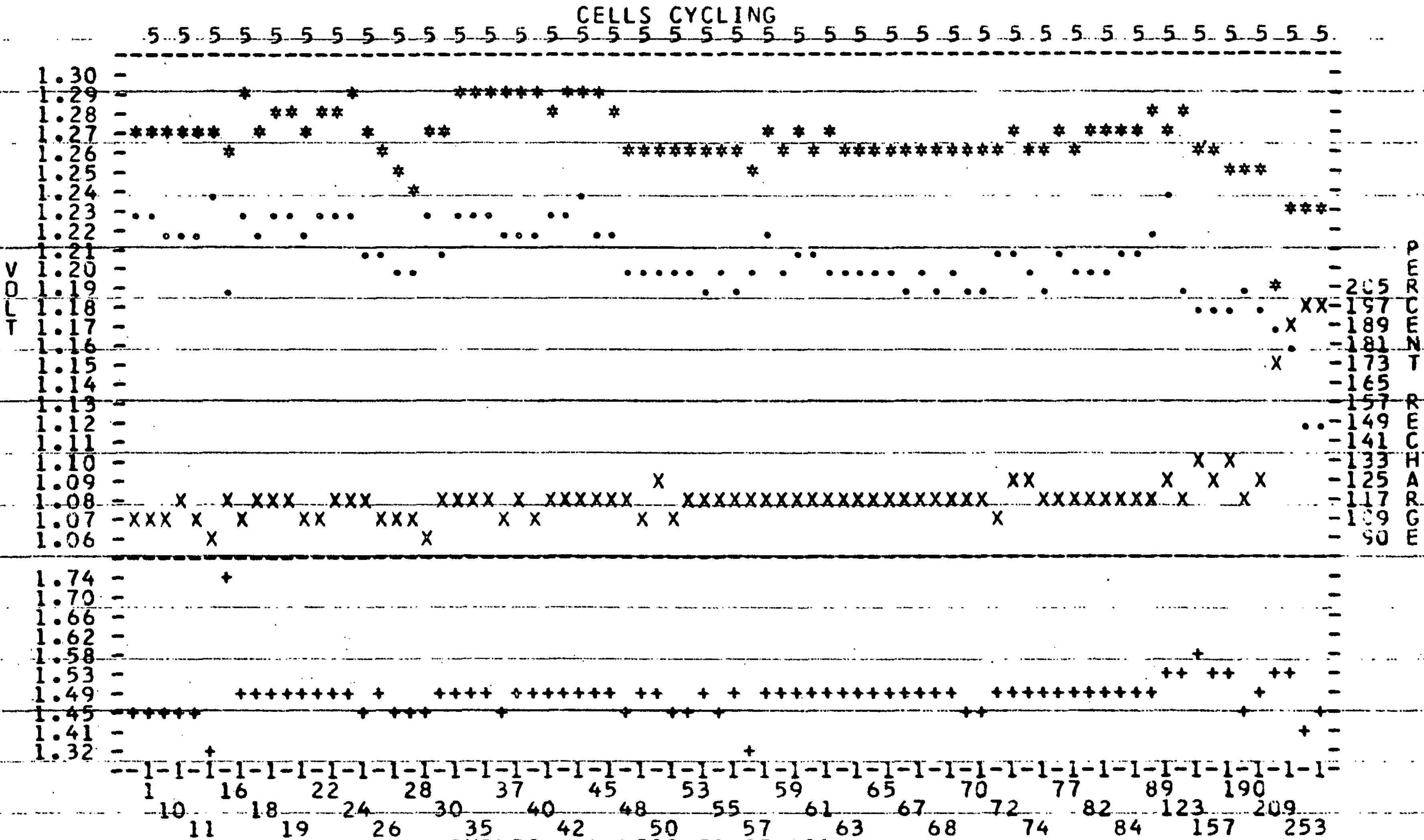


FIGURE 64

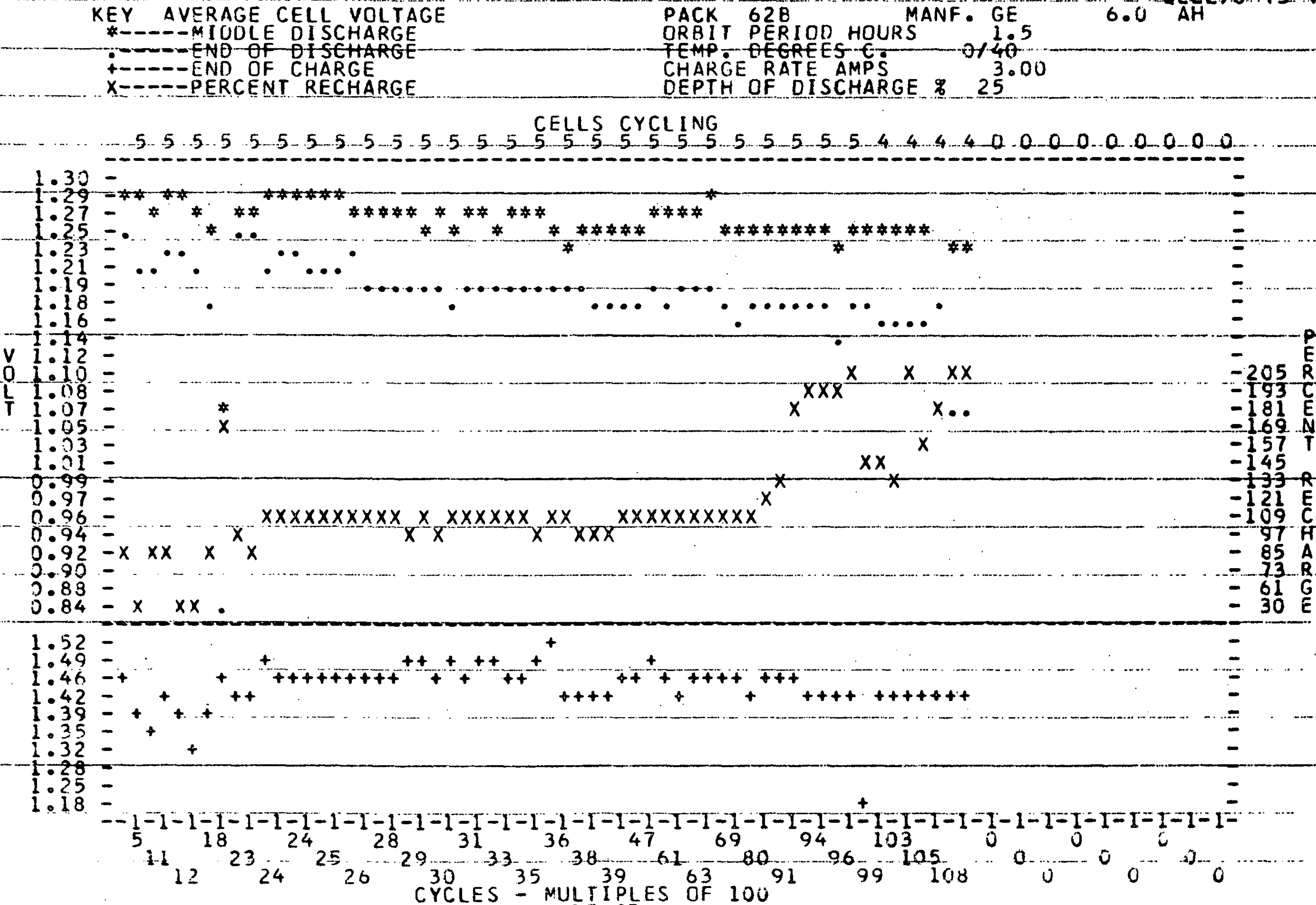


FIGURE 65

NOTE: V/L control and temperature 20°C after 2369 cycles.

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 D	3.75 F
176 Days	6.73 D		

F - Failed.
D - Discontinued.

c. Test Results:

(1) Performance on Cycling: (Figures 66 and 67) 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.

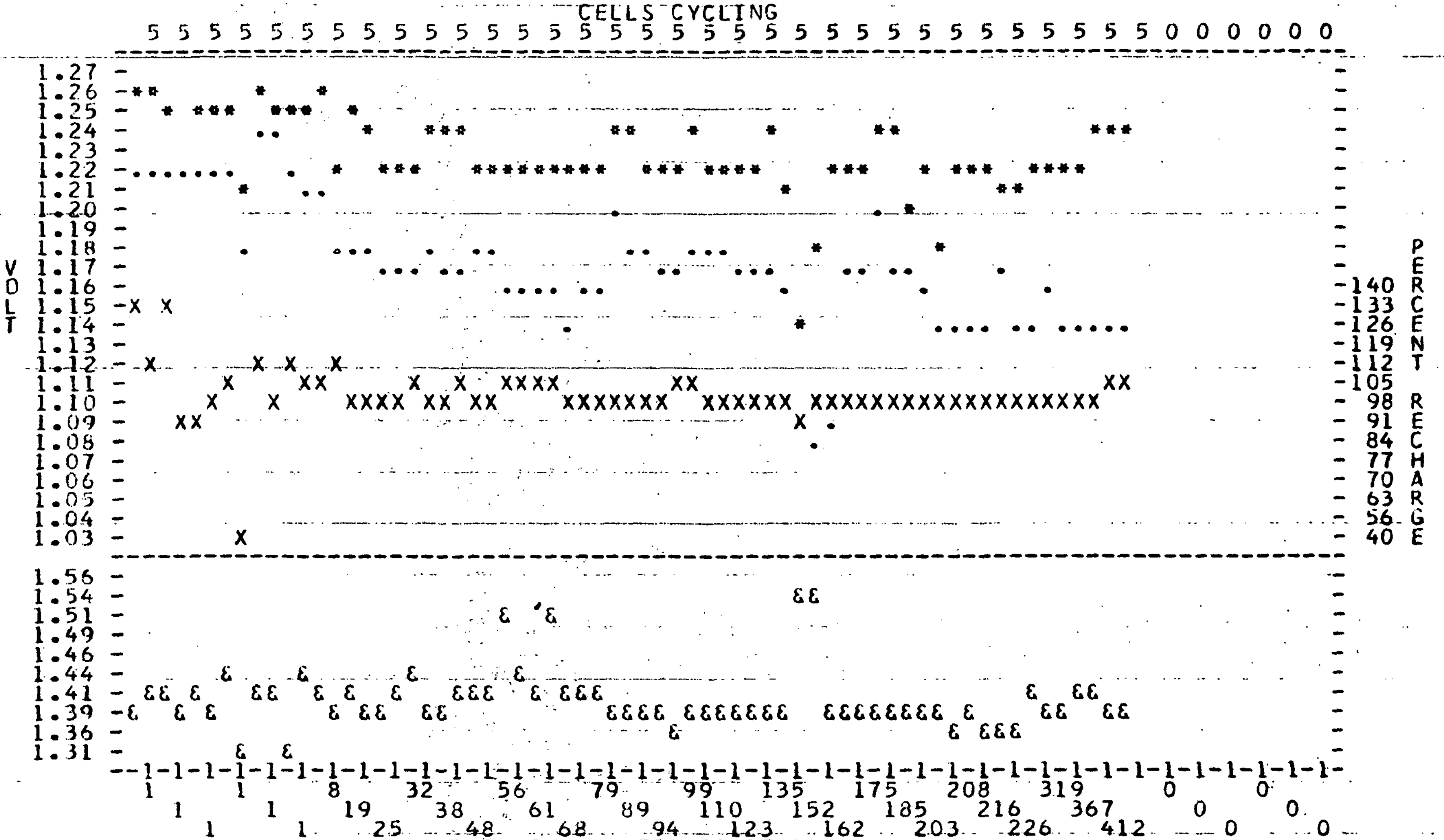
(2) Failure Analysis: Chemical Analysis of cell 1 from pack 6D revealed a high equivalence percentage of potassium carbonate--averaging 47.2 percent. Physical analysis of the same cell showed blistering of positive plates, ragged plate edges and uneven distribution of electrolyte--highest moisture content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

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

PACK 30C MANF. GE 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 4.80
DEPTH OF DISCHARGE % 25



CYCLES - MULTIPLES OF 10
FIGURE 66

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

PACK 64B MANF. GE 6.00 AH
ORBIT PERIOD HOURS 1.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 4.80
DEPTH OF DISCHARGE % 25

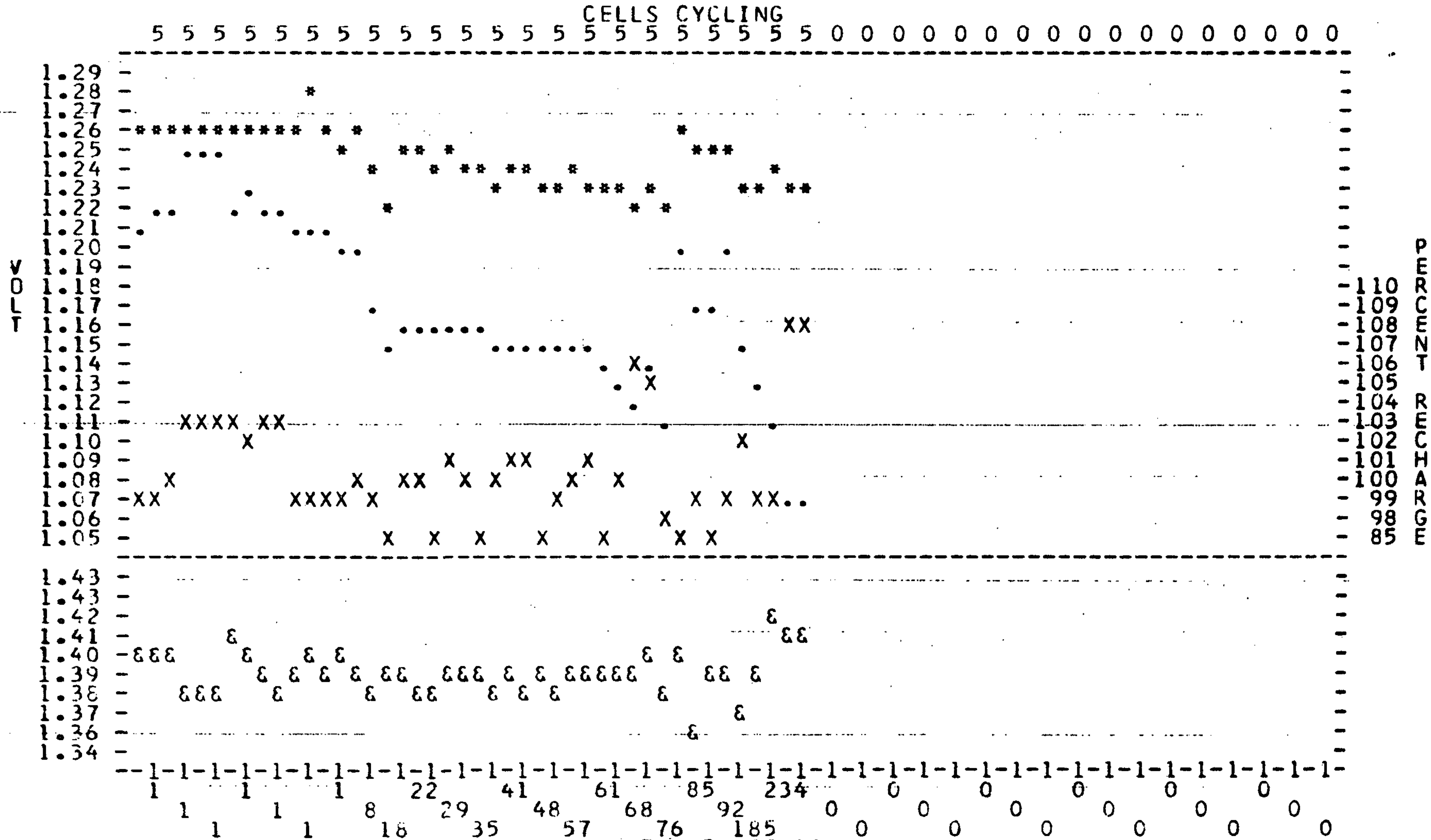


FIGURE 67

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

a. Cell Description: See paragraph II.A.

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 D	29.1 D

D - Discontinued.

c. Test Results:

(1) Performance on Cycling: (Figures 68 and 69) 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.

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

PACK 7B MANF. GE 20.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15

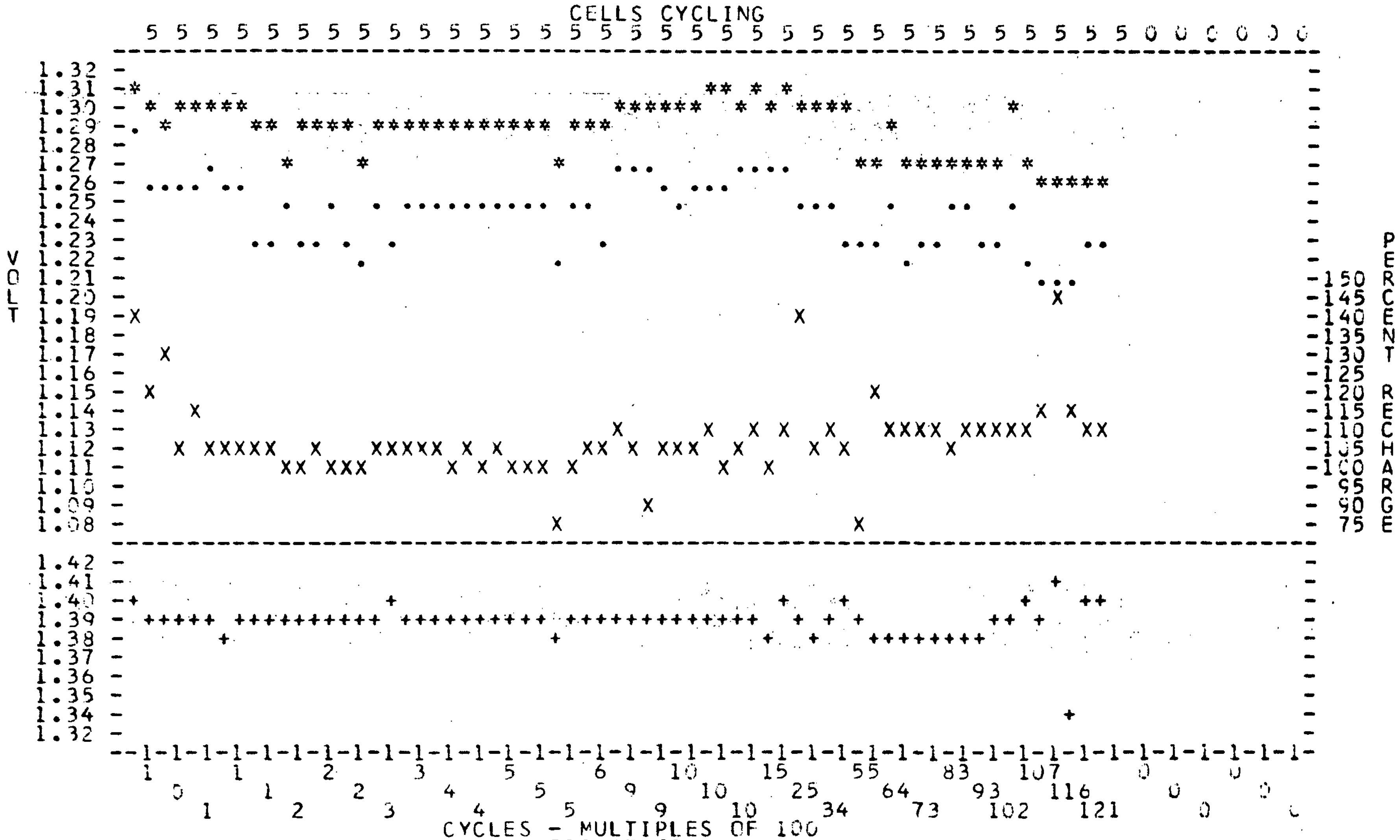
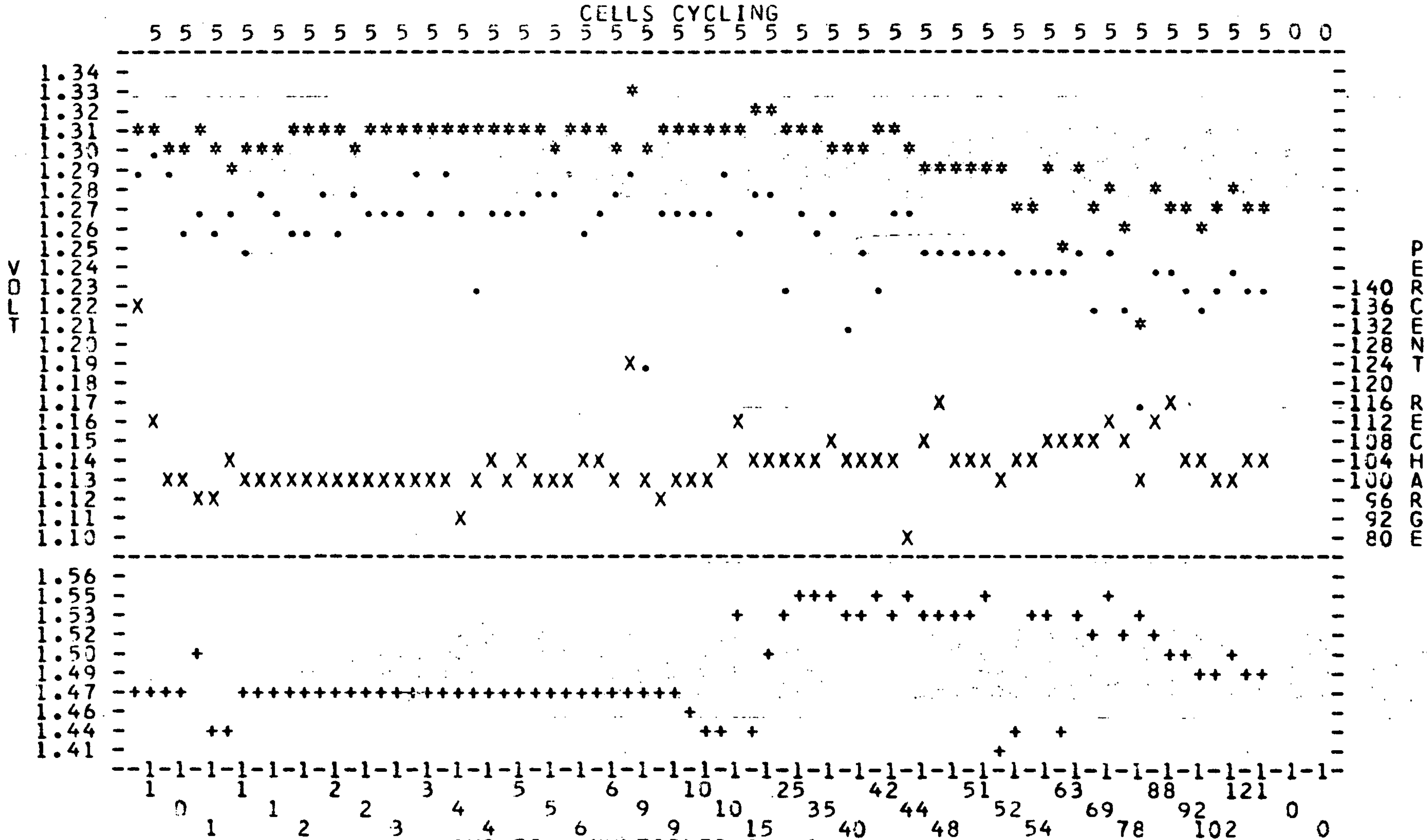


FIGURE 68

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

PACK 678 MANF. GE 20.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 8.00
DEPTH OF DISCHARGE % 15



CYCLES - MULTIPLES OF 100
FIGURE 69

16. 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 mateial 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%
Resistors (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 F
450 Days	8.35	1.85 F	
600 Days	3.95		
800 Days	2.90		
1000 Days	6.75		
1200 Days	3.00		
1400 Days	4.55		
1600 Days	3.65		

F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 70) Cycling was started in February 1968. Pack 57D has completed 1711 cycles to date with two cell failures. Packs 69B and 33C failed on cycles 507 and 447 respectively.

(2) Failure Analysis: Analysis of the seven 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.

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

PACK 57D MANF. YARDNEY 11.0 AH
ORBIT PERIOD HOURS 24.0
TEMP. DEGREES C. 00
CHARGE RATE AMPS 0.25
DEPTH OF DISCHARGE % 18

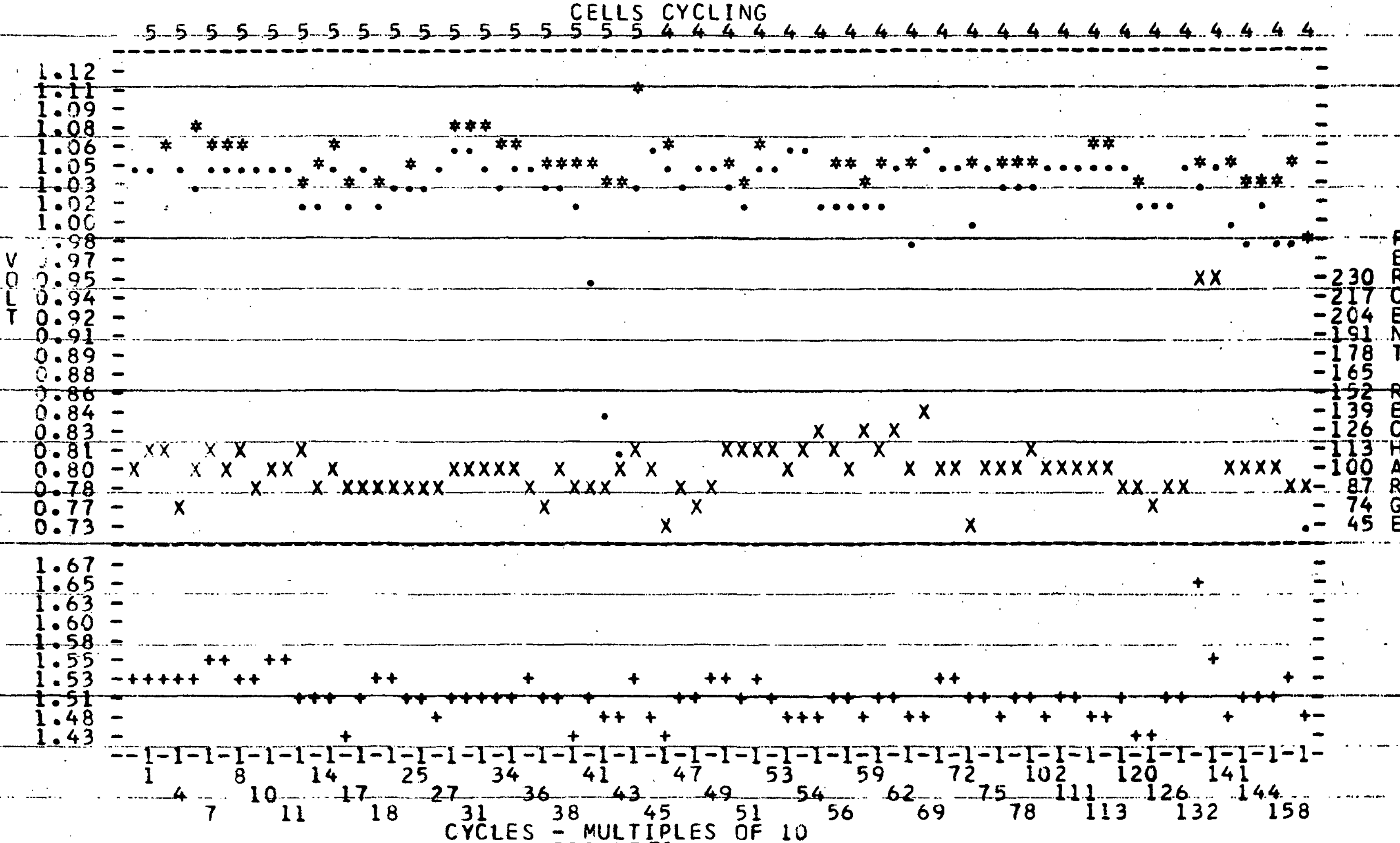


FIGURE 70

D. 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 reversable. Thus it is easy to detect when 100 percent of the discharge has been returned to the cells.

1. 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.

Orbit Period		1.5-Hour		
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	

* 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: (Figures 71 and 72) Cycling was started in September 1970. Packs 63B and 3C have completed 12,107 and 12,590 cycles, respectively, with no cell failures. Packs 27D and 39D failed after 6869 and 1376 cycles, respectively.

(2) Failure Analysis: Analysis of the six 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.

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

PACK 638 MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 00
CHARGE RATE AMPS 6.00
DEPTH OF DISCHARGE % 50

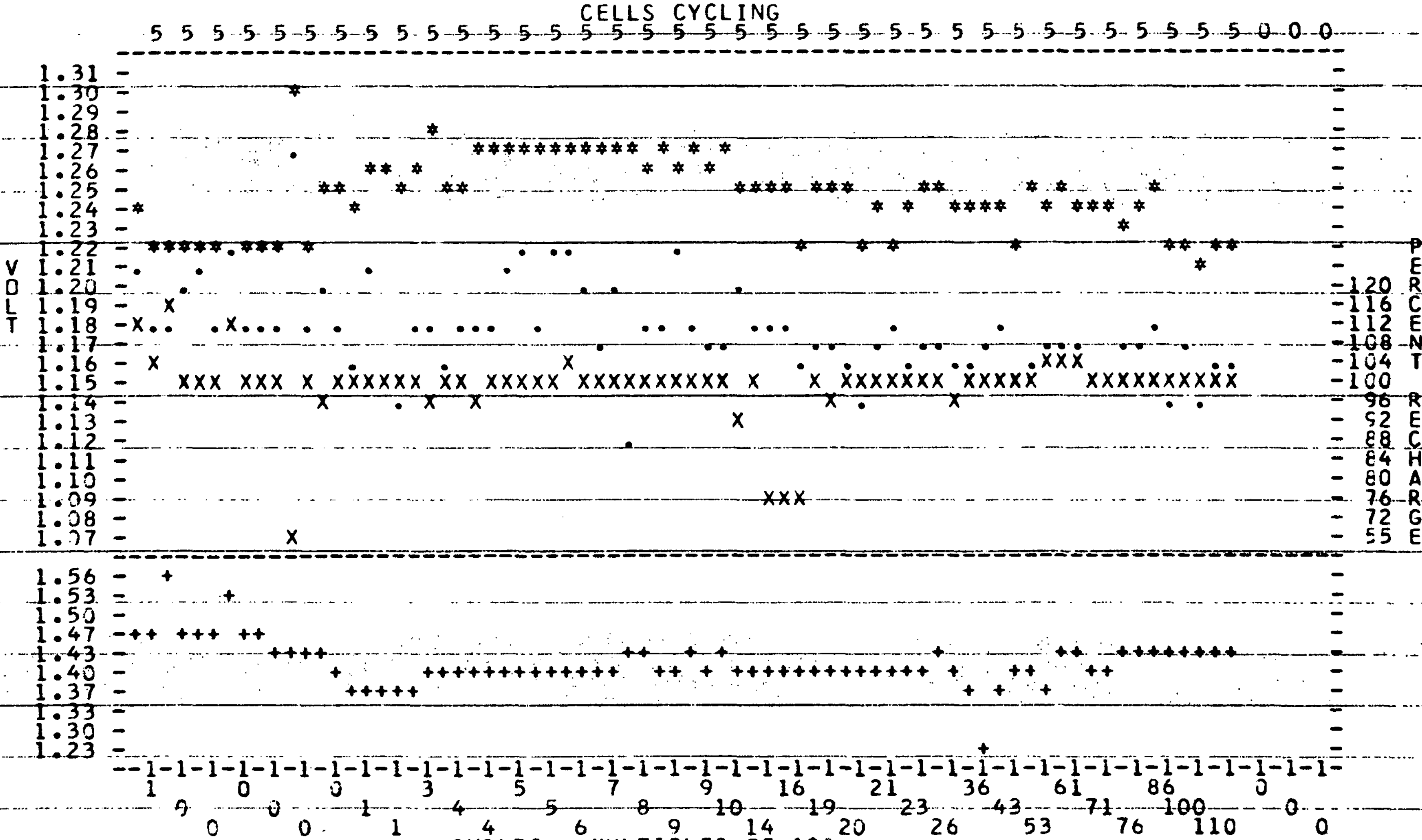


FIGURE 71

NOTE: Charge current 4.8A and 40% DOD after 41 cycles.

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

PACK 3C MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 6.00
DEPTH OF DISCHARGE % 50

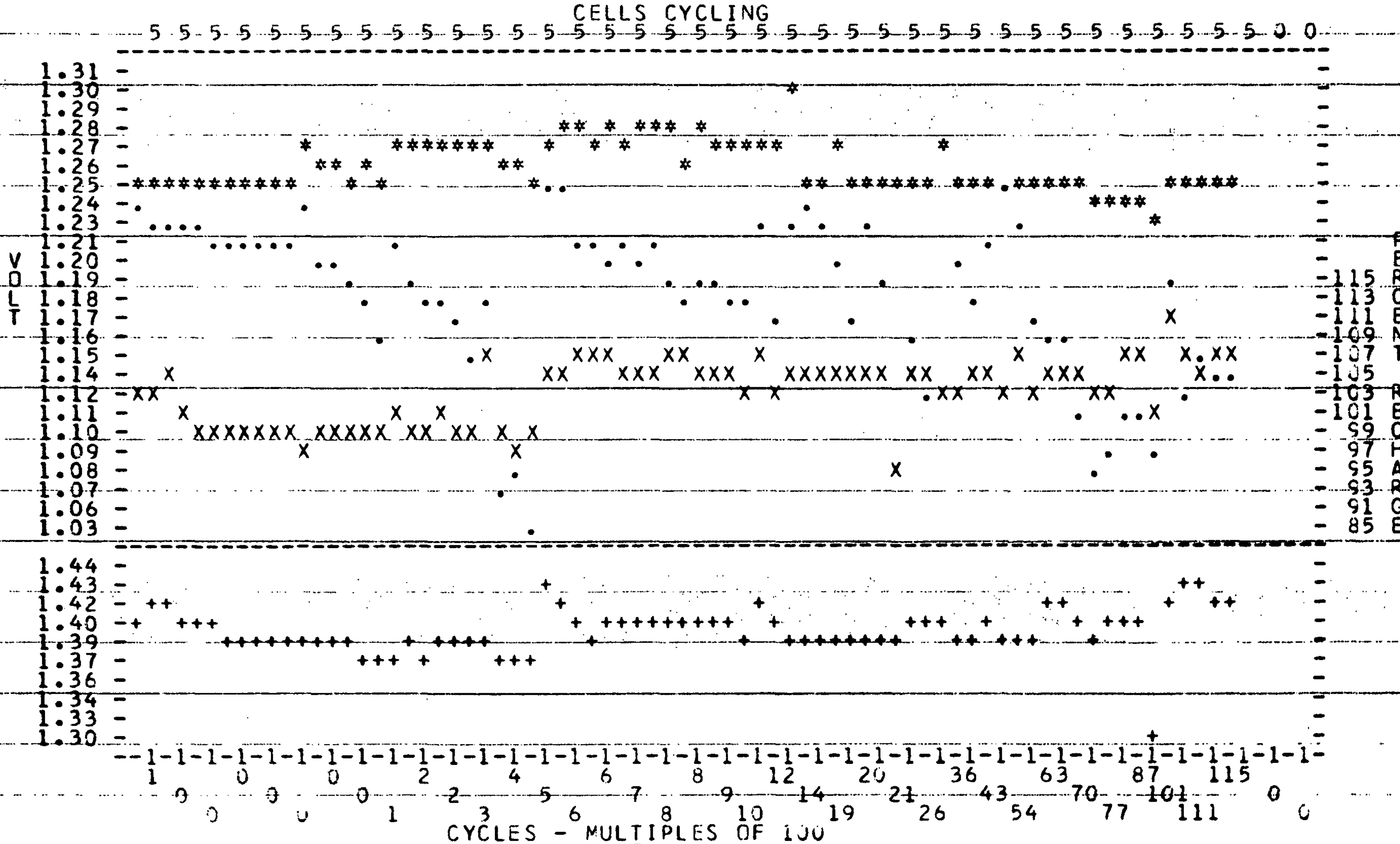


FIGURE 72

NOTE: Charge current 4.8A and 40% DOD after 70 cycles.

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

a. Cell Description: See paragraph I.A.

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 F
968 Days Disch #2	2.15	6.25	1.60	
1091 Days* Disch #2	3.30	*	* F	
1232 Days Disch #2	2.00	6.10		
1408 Days Disch #2	2.25	6.05		
1584 Days Disch #2	1.95	1.15 F		
1760 Days Disch #2	0.45 F			

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

F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 73) 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.

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

PACK 041B MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 03.0
TEMP. DEGREES C. -20
CHARGE RATE AMPS 3.00
DEPTH OF DISCHARGE % 25

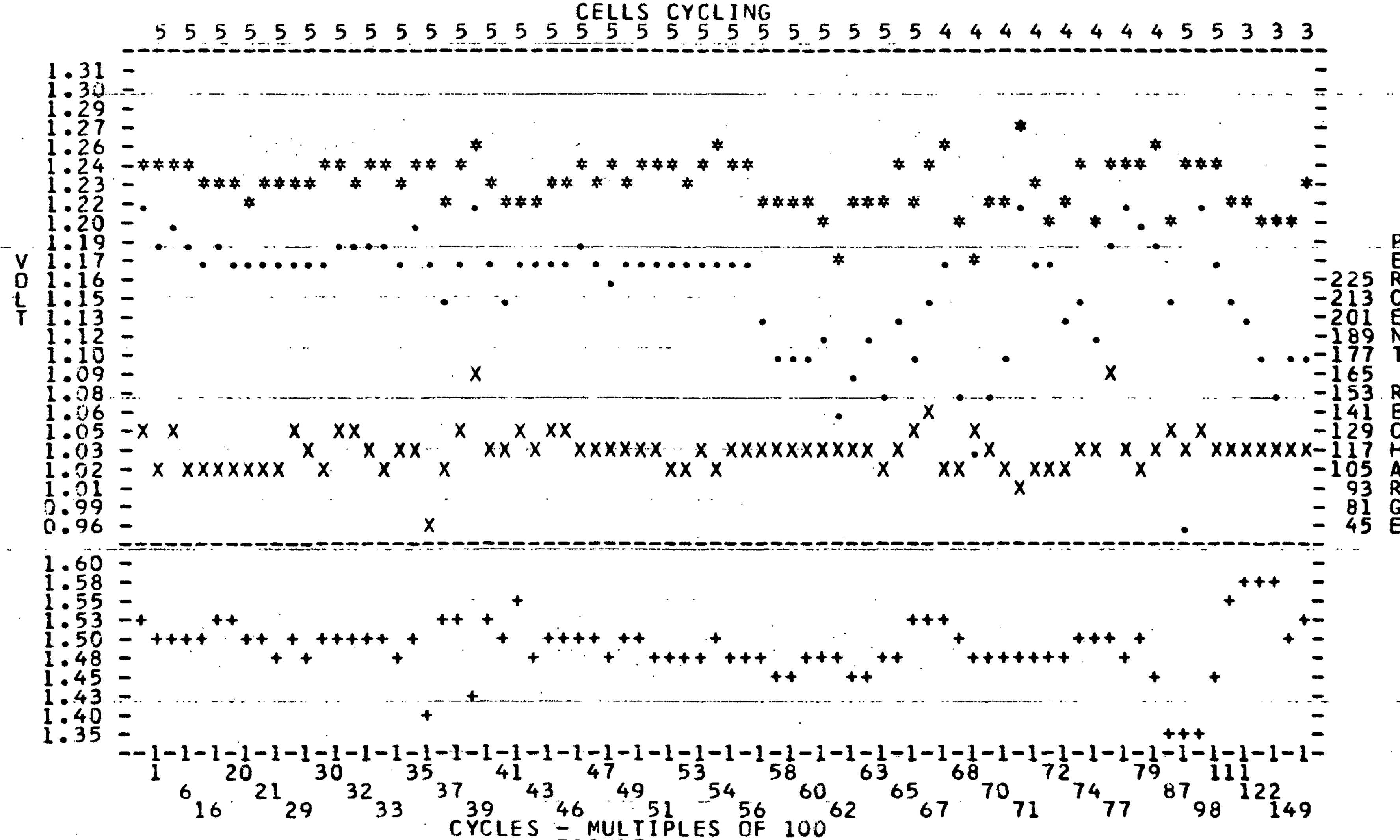


FIGURE 73

E. 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 D	18.30	22.00	9.00 D
264 Days	22.17		18.00	16.18 F	
352 Days	9.33		16.00		
440 Days	8.67		14.16 F		
616 Days	5.33				
792 Days	5.00 F				

D - Discontinued.
F - Failed.

c. Test Results:

(1) Performance on Cycling: (Figure 74) 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.

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

PACK 10B MANF. SONOTONE20.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 20
CHARGE RATE AMPS 7.00
DEPTH OF DISCHARGE % 25

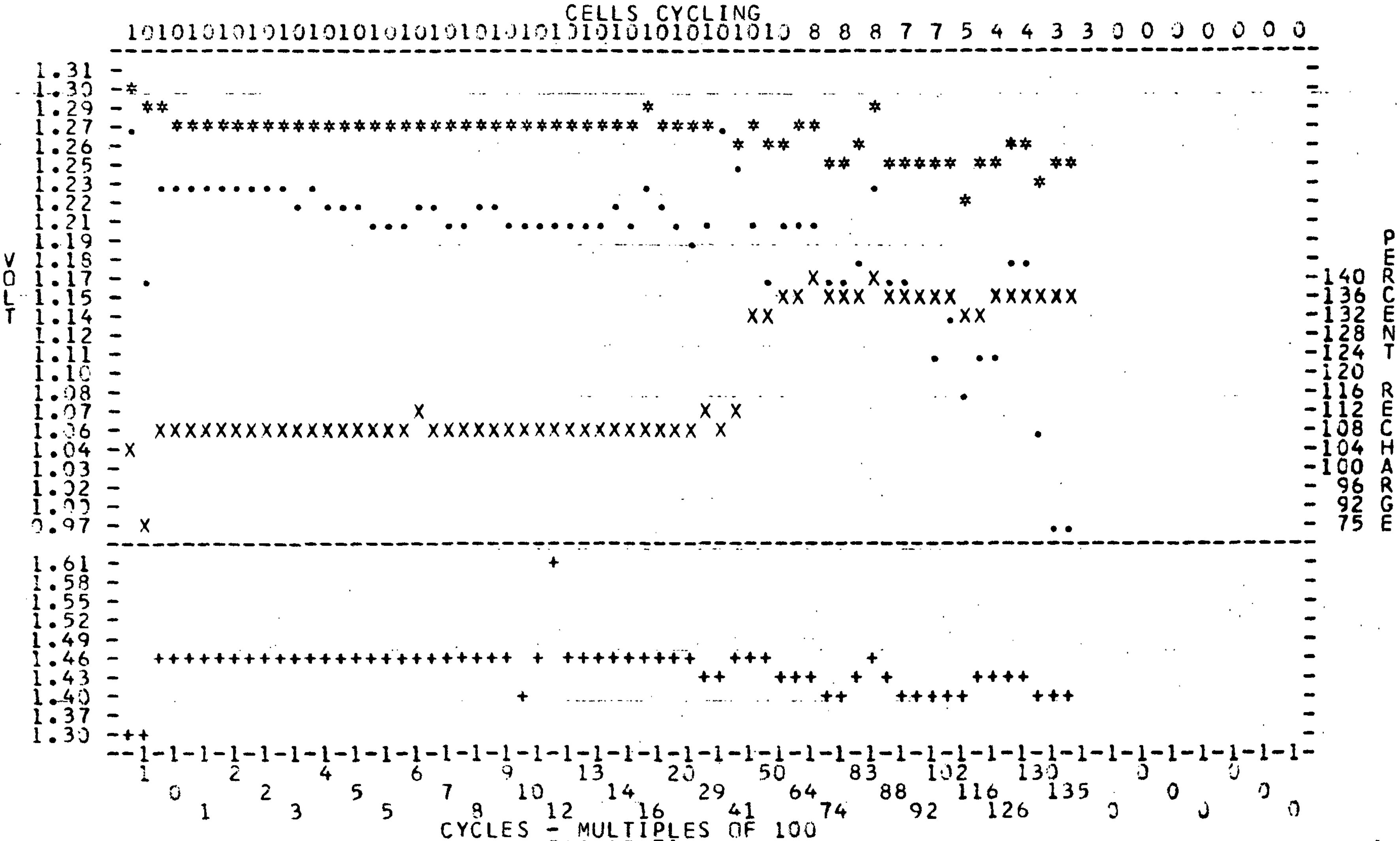


FIGURE 74

F. 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.

1. Gulton 6.0 ah (SAS A), One 8-cell Pack:

a. Cell Description: See paragraph II.A.

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

c. Test Results:

(1) Performance on Cycling: (Figure 75) Cycling started in July 1970. This pack has completed 13,565 cycles with no cell failures; although one cell was removed for analysis 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.

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

PACK 18D MANF. GULTON 06.0 AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.50
DEPTH OF DISCHARGE % 25

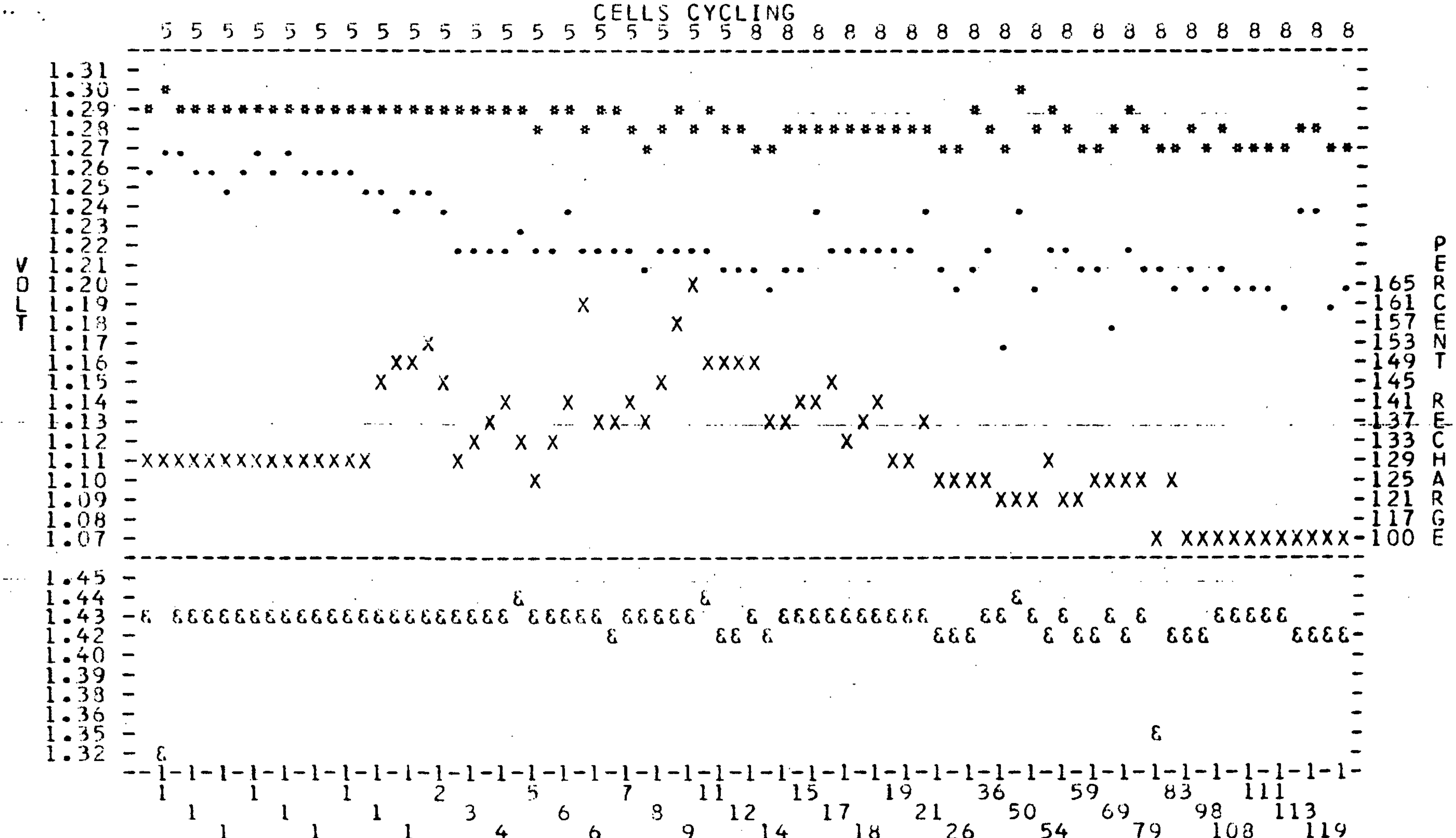


FIGURE 75

2. GE 6.0 ah (SAS B), One 8-cell Pack:

a. Cell Description: See paragraph II.A.

b. 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

c. Test Results:

(1) Performance on Cycling: (Figure 76) Cycling started in July 1970. This pack has completed 13,598 cycles with no cell failures; although one cell was removed for analysis 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.

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

PACK 1C MANF. GE 06. AH
ORBIT PERIOD HOURS 01.5
TEMP. DEGREES C. 25
CHARGE RATE AMPS 3.50
DEPTH OF DISCHARGE % 25

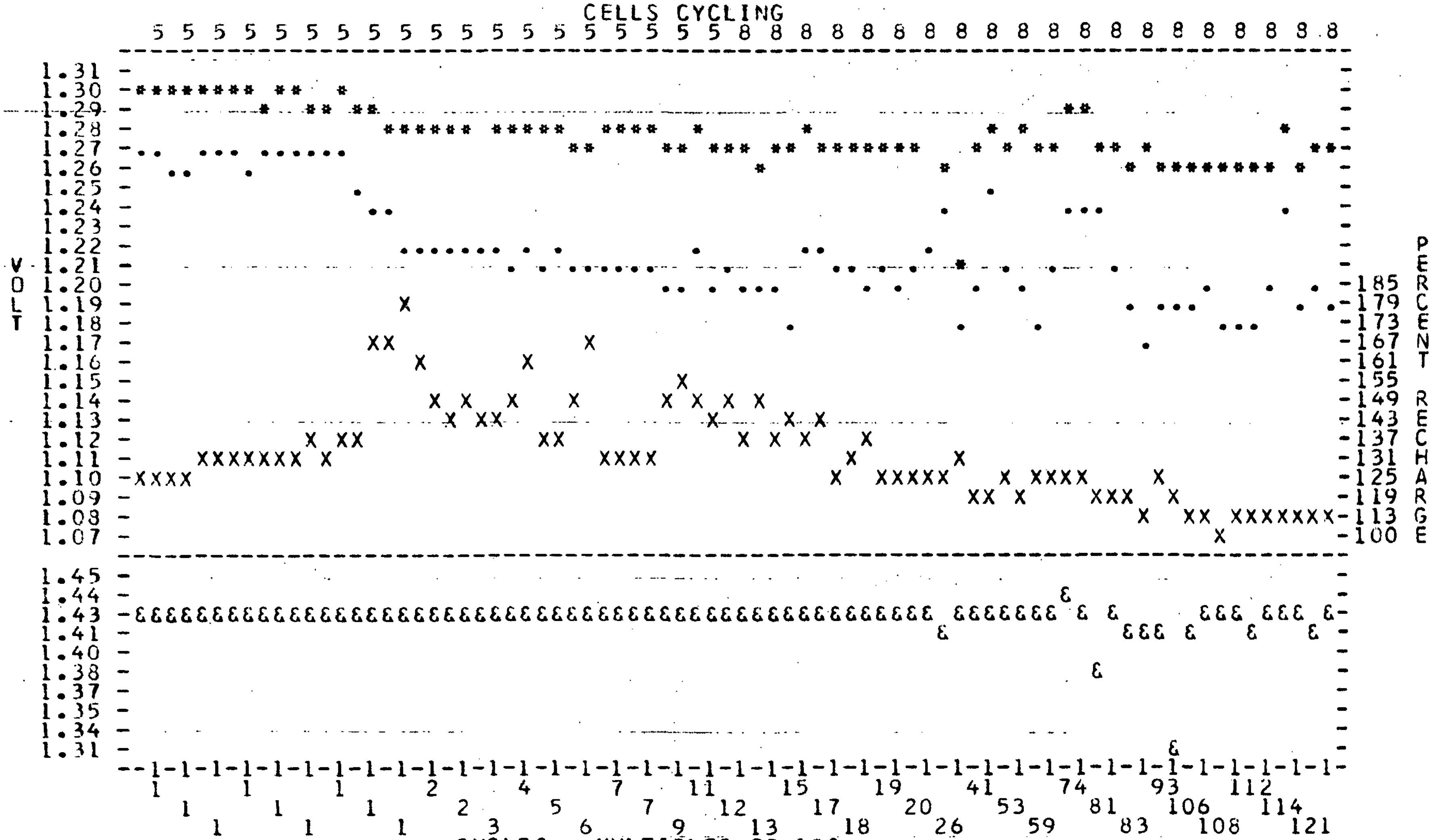


FIGURE 76

SECTION III

CELLS ON ORIGINAL TEST PROGRAM WHICH HAVE COMPLETED TEST

I. CELLS ON ORIGINAL TEST PROGRAM WHICH HAVE COMPLETED TEST

A. 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.

B. 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.

II. DESCRIPTION OF CYCLE TEST

A. 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.

III. TEST RESULTS

A. 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).

B. 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.

C. Capacity Check Results:

1. 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.

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

D. Cell Failures:

1. 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 better product with better performance characteristics.

2. Special Considerations:

a. 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.

b. 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.

3. Discussion of Failures:

a. General Observations:

(1) 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).

(2) 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.

(3) 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.

b. Discussion of Failures by Cell Type:

(1) GE:

(a) <u>3.0 ah Cells</u>: 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.

<u>1</u>. 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.

(b) <u>12 ah Cells</u>: There were 27 failures, of which three were at 0° C, 12 were at 25° C and 12 were at 50°-40° C.

1. 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.

(2) Gould:

(a) 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.

1. 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.

(b) 20 ah Cells: There were 29 cell failures, of which five were at 0° C, 12 were at 25° C and 12 were at 50°-40° C ambient temperature.

1. High internal pressure was present in almost all failures. Pierced separator was more predominant 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.

(3) Gulton:

(a) 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.

1. 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.

(b) 20 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.

1. 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 buses 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.

(4) Sonotone:

(a) 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.

1. 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	3.68	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.

SECTION IV

COMPLETED TESTS OF CELLS WHICH FOLLOWED THE ORIGINAL PROGRAM

I. COMPLETED TESTS OF CELLS WHICH FOLLOWED THE ORIGINAL PROGRAM

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.

II. 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	

C3

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 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 77). 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.

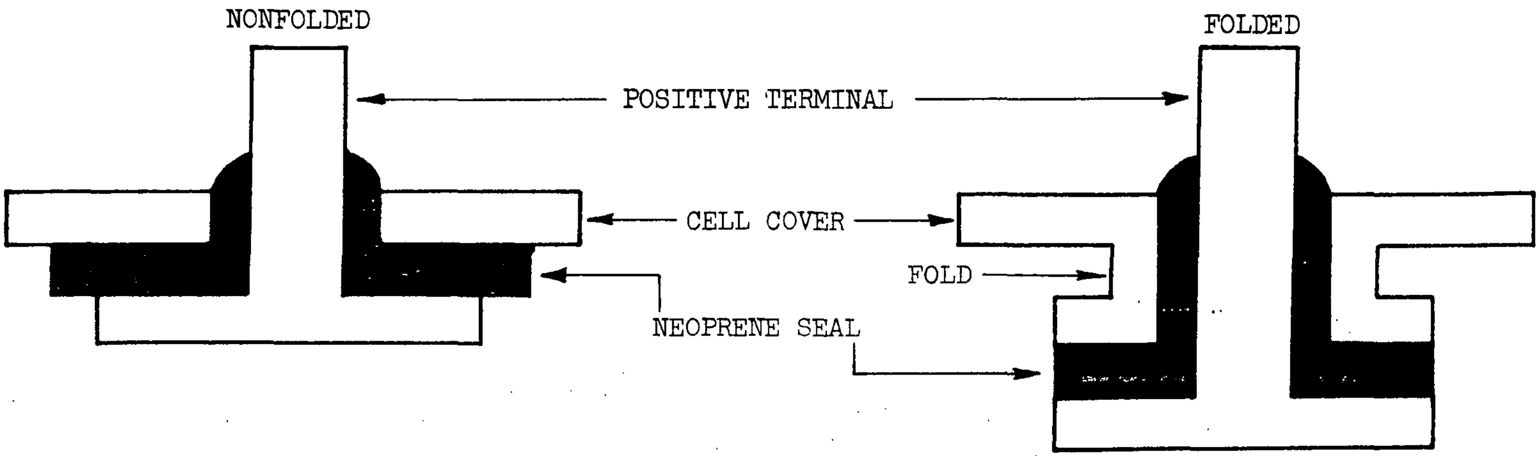
Orbit Period		1.5-hour							
Temperature		-20°	-20°	0°	0°	25°	25°	40°	40°
Depth of Discharge		25%	25%	25%	25%	25%	25%	25%	25%
Pack Number		44B (FD)	32B (NF)	100B (FD)	90C (NF)	76B (FD)	96C (NF)	42B (FD)	30B (NF)
1144 Days	Disch #2	2.66	2.33	2.05	3.17				
1320 Days	Disch #2	2.72		2.01	2.43				
1496 Days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

FIGURE 77

3. 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.

4. 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

5. 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.

6. 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

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 F	3.50
60 Days		1.25
90 Days		1.25
120 Days		1.21 F

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 F
250 Days	2.50 F	

F - Failed

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. 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 $\pm$ 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 (Failed)				

2. 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.

3. 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.

4. 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		

5. 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		

6. 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

7. 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

8. 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

9. 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	

10. 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.

11. 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

12. 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.

III. CELLS USING SOPHISTICATED CHARGE CONTROL METHODS AND DEVICES:

A. Auxiliary Electrode:

1. 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 auxililary 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. (See Section II, Paragraph II.B., for description of control unit.)

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			

2. 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. (See Section II, Paragraph II.B., for description of control unit.)

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.

3. 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. (See Section II, Paragraph II.B., for description of control unit.)

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.

4. 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.

5. 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.

6. 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. (See Section II, Paragraph II.B., for description of control unit.)

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 1968.

(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.

7. 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 plates, ragged edges of positive plates, and dry separator material. One cell from 47C which did not fail was analyzed for comparison with tne 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	

8. 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. (See Section II, Paragraph II.B., for description of control unit.)

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.

9. 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. (See Section II, Paragraph II.B., for description of control unit.)

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.

10. 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.

11. 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 II, Paragraph II.C., 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 as described in Section II, Paragraph I.A.5.a.

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. 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 II.A.4.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 ± 0.03 volts per cell, average.

(4) Low Current Level: 0.35 amps.

(5) Lower Voltage Limit: 1.87 ± 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: (See Section II, Paragraph II.D., for description of internal mechanical pressure devices.)

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 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	

SECTION V

TEST FACILITIES

I. TEST FACILITIES

A. The ambient test temperatures of -20°C, 0°C, +10°C, +20°C and +40°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 200 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 two tape transports

(e) Datum, Inc., Model 6078-H316 mass memory system with 131,000 word drum memory

(2) Auxiliary digital functions include:

(a) The real time clock, the system shut-down timer and alarm circuits, and medium speed analog input sub-system.

(b) Two John Fluke, Model 8300-A digitizers

(c) 3000-Channel reed relay scanner

(d) Computer interface

(3) Control subsystem:

(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. Temperatures; 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:

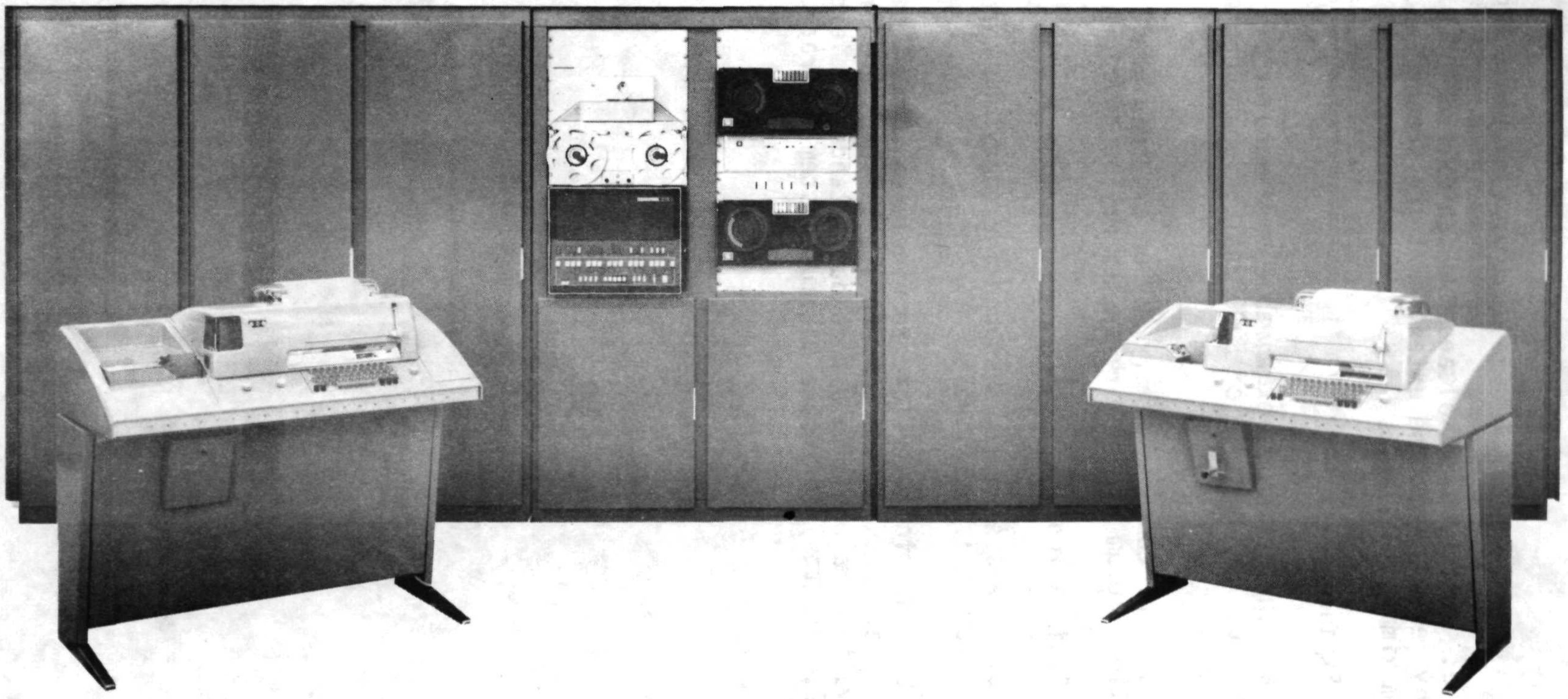
a. The system is expandable on a modular plug-in cabled-together basis up to a maximum of 5000 analog input channels, and 256 control output channels.

b. The computer memory may be expanded to 32,000 words and an additional drum mass memory system may be added.

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.



PHOTOGRAPH 1

SECTION VI

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. An additional 4K of mass memory to the Honeywell 316 computer.

2. A Centronics 101A line printer to enable report to be outputted ten times faster than with the present teletype now being used.

3. A CRT display unit with magnetic tape casettes which will provide greater flexibility in editing programs and placing the system on line following power failures, etc.

4. Fifty-six digital-to-resistance output control cards which provide the control signals to the interface between the system and the test items.

5. Power supplies, 12 and 50 ampere rating to meet requirements of new programs.

6. Environmental chambers (2), 64 cubic feet, with a temperature range of -40°C to +100°C.

B. New Programs:

1. Eagle-Picher, 3.0 ampere-hour, nickel-cadmium, Synchronous Metrological Satellite (SMS) type cells for evaluation on a synchronous orbit type regime.

2. Eagle-Picher, 20.0 ampere-hour cells for evaluation under the Process Control Program.

3. GE, 6.0 ampere-hour, nickel-cadmium cells for evaluation on the Accelerated Test Program.

4. Gulton, 15.0 ampere-hour, nickel-cadmium, ATS-F type cells for evaluation on a synchronous orbit type regime.

5. Gulton, 20.0 ampere-hour, nickel-cadmium, OAO type cells for evaluation of life-cycle capability.

6. Gulton, 100.0 ampere-hour, nickel-cadmium cells for evaluation of life-cycle capability.

7. SAFT, 20.0 ampere-hour, nickel-cadmium cells for evaluation.

8. Texas Instrument, 20.0 ampere-hour, nickel-cadmium cells for evaluation of their double seal under an OAO type test regime.

9. Yardney, 5.0 and 21.0 ampere-hour, silver-zinc cells for evaluation on a synchronous orbit type regime.

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