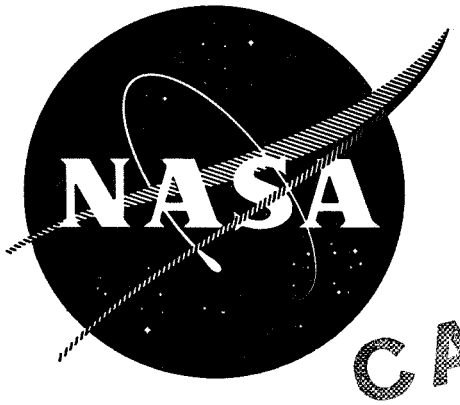

EVALUATION PROGRAM

for

SECONDARY SPACECRAFT CELLS

SIXTH ANNUAL REPORT
OF
CYCLE LIFE TEST

prepared for
GODDARD SPACE FLIGHT CENTER
CONTRACT W12,397

QUALITY EVALUATION LABORATORY
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EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

SIXTH ANNUAL REPORT OF CYCLE LIFE TEST

QE/C 70-173 6 MARCH 1970

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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 W12-397
(b) NASA ltr BRA/VBK/pad of 25 September 1961 w/BUWEPS first end FQ-1:WSK of 2 October 1961 to CO NAD Crane
(c) Preliminary Work Statement for Battery Evaluation Program of 25 August 1961
(d) NAD Crane report QE/C 69-665 of 17 October 1969

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 sixth annual report covers the cycle life test, the third phase of the evaluation program of secondary spacecraft cells, through 14 December 1969. The acceptance tests and general performance tests, the first and second phases of the evaluation program were reported earlier. 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 limited number of cells of each type (usually five) are subjected to the general performance tests to determine their actual capabilities. These 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 specific 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. Failures encountered in satellite programs such as IMP, NIMBUS, OGO, OAO, 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 731

nickel-cadmium, 174 silver-cadmium and 65 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 12 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 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 and the Sherfey upside-down cycling regime. Specially constructed cells to apply internal pressue 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 iii.

III. TEST RESULTS

A. Life cycling data shows that 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. 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 and extraneous material, both active and foreign.

C. All active and completed packs are listed on pages vi through xv. The symbols used are explained on pages iv and v.

SUMMARY IN BRIEF OF TEST PARAMETERS

MANUFACTURER	CAPACITIES TESTED	ORBIT PERIODS	PERCENT DEPTH OF DISCHARGE	TEST TEMPERATURES	SPECIAL CHARGE CONTROL	TOTAL NO. OF CELLS
			NICKEL-CADMIUM			
GE	3.0, 5.0, 6.0, 12.0	1.5, 3.0, 24.0	15, 25, 40, 50	0°, 25°, 40°, 50°-40°, *	AE, AE13, AE14	330
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, 25, 40, 50, 60	-20°, 0°, 25°, 50°-40°, 40°, *	AE, CLM, MULTI	590
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°, 25°, 50°-40°, 40°	ST, AE, IPD	255
			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
			SILVER-ZINC			
Delco	25.0, 40.0	3.0, 24.0	25, 40	25°	2SR	45
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.

   CC: Commercial cells.

   CHSP: "Chemsorb" separator.

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

   CPSP: Cellophane separator.

   C3SP: C3 separator.

   FRS: Folded seal, same type of seal as RS below.

   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.

   NB: NIMBUS cells.

   NBPT: NIMBUS cells with pressure transducers.

   PLSP: Pellon separator.

   PS: Polymerized neoprene terminal to cover seal.

   RCPSP: Radiated cellophane separator.

RS: Vulcanized neoprene terminal to cover seal.

ST: Stabistors used for charge control of cells.

TETR: Test and training satellite.

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

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
NICD	3.00	1.5	15%	0°	GE		63A	115	0.52	0.90	1.55	10	12-6-63	22,923	2-15-68	D
NICD	3.00	3.0	15%	0°	GE		67A	115	0.21	0.90	1.55	10	12-20-63	11,532	2-15-68	D
NICD	3.00	1.5	25%	0°	GE		64A	115	0.86	1.50	1.55	10	12-5-63	23,441	2-14-68	D
NICD	3.00	3.0	25%	0°	GE		68A	115	0.34	1.50	1.55	10	12-20-63	11,740	2-13-68	D
NICD	3.00	1.5	25%	25°	GE		15A	125	0.94	1.50	1.49	10	12-6-63	10,382	11-6-65	F
NICD	3.00	3.0	25%	25°	GE		19A	125	0.38	1.50	1.49	10	12-20-63	10,768	2-12-68	D
NICD	3.00	1.5	40%	25°	GE		16A	125	1.50	2.40	1.49	10	12-5-63	5,014	11-18-64	F
NICD	3.00	3.0	40%	25°	GE		20A	125	0.60	2.40	1.49	10	12-20-63	5,410	1-8-66	F
NICD	3.00	1.5	15%	40°	GE		39A	160	0.72	0.90	1.45	10	12-12-63	8,109	6-19-65	F
NICD	3.00	3.0	15%	40°	GE		43A	160	0.29	0.90	1.45	10	12-20-63	2,656	12-26-64	F
NICD	3.00	1.5	25%	40°	GE		40A	160	1.20	1.50	1.45	10	12-12-63	2,511	7-9-64	F
NICD	3.00	3.0	25%	40°	GE		44A	160	0.48	1.50	1.45	10	12-20-63	4,487	9-14-65	F
NICD	5.00	1.5	15%	0°	GE	NB	103A	110	0.83	1.50	1.49	5	4-24-65	26,111		
NICD	5.00	1.5	25%	0°	GE	NBPT	107A	110	1.38	2.50	1.49	5	6-5-65	25,482		
NICD	5.00	1.5	15%	25°	GE	NB	106A	120	0.90	1.50	1.49	5	4-24-65	26,013		
NICD	5.00	1.5	25%	25°	GE	NBPT	104B	120	1.50	2.50	1.49	5	6-10-65	13,149	11-15-67	F
NICD	5.00	1.5	15%	40°	GE	NB	113A	130	0.98	1.50	1.49	5	4-24-65	4,998	3-15-66	F
NICD	5.00	1.5	25%	40°	GE	NBPT	114A	130	1.63	2.50	1.49	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	8,784		
NICD	6.00	1.5	25%	0°	GE	AE-14	50B		3.00	3.00		5	5-20-68	9,057		
NICD	6.00	1.5	25%	25°	GE	AE-13	5B		3.00	3.00		5	5-20-68	8,198		
NICD	6.00	1.5	25%	25°	GE	AE-14	17B		3.00	3.00		5	5-20-68	9,082		
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		
NICD	6.00	1.5	25%	*	GE	AE-13	62B		3.00	3.00		5	7-3-68	2,316		
NICD	6.00	1.5	25%	*	GE	AE-14	65B		3.00	3.00		5	7-3-68	8,270		

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	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	8,080		
NICD	6.00	1.5	15%	25°	GE	AE	28C		1.80	1.80		5	7-18-68	8,168		
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	12.00	1.5	15%	0°	GE		110A	115	2.07	3.60	1.55	5	1-4-64	32,108		
NICD	12.00	3.0	15%	0°	GE		111A	115	0.83	3.60	1.55	5	1-4-64	16,284		
NICD	12.00	1.5	25%	0°	GE		124A	115	3.45	6.00	1.55	5	1-4-64	34,343	11-5-69	F
NICD	12.00	3.0	25%	0°	GE		125A	115	1.38	6.00	1.55	5	1-4-64	16,593		
NICD	12.00	1.5	25%	25°	GE		82A	125	3.75	6.00	1.49	5	1-4-64	10,878	12-30-65	F
NICD	12.00	3.0	25%	25°	GE		83A	125	1.50	6.00	1.49	5	1-4-64	13,897	1-24-69	F
NICD	12.00	1.5	40%	25°	GE		96A	125	6.00	9.60	1.49	5	1-4-64	4,020	10-2-64	F
NICD	12.00	3.0	40%	25°	GE		97A	125	2.40	9.60	1.49	5	1-4-64	5,002	11-8-65	F
NICD	12.00	1.5	15%	40°	GE		85A	160	2.88	3.60	1.45	5	1-9-64	9,710	11-8-65	F
NICD	12.00	3.0	15%	40°	GE		86A	160	1.15	3.60	1.45	5	1-4-64	10,661	1-2-68	F
NICD	12.00	1.5	25%	40°	GE		99A	160	4.80	6.00	1.45	5	1-9-64	4,853	1-5-65	F
NICD	12.00	3.0	25%	40°	GE		100A	160	1.92	6.00	1.45	5	1-4-64	4,424	9-24-65	F
NICD	12.00	24.0	50%	25°	GE		93A	150	0.52	6.00	1.49	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

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
NICD	12.00	1.5	25%	40°	GE	AE	36A		6.00	6.00		5	1-27-67	75	2-3-67	D
NICD	12.00	1.5	40%	40°	GE	AE	34A		6.00	9.60		5	1-27-67	65	2-3-67	D
NICD	3.50	1.5	15%	0°	GOULD		51A	115	0.60	1.05	1.55	10	12-5-63	22,364	2-15-68	D
NICD	3.50	3.0	15%	0°	GOULD		55A	115	0.24	1.05	1.55	10	12-20-63	11,546	2-15-68	D
NICD	3.50	1.5	25%	0°	GOULD		52A	115	1.00	1.75	1.55	10	12-5-63	13,730	6-11-66	F
NICD	3.50	3.0	25%	0°	GOULD		56A	115	0.40	1.75	1.55	10	12-20-63	11,897	2-15-68	D
NICD	3.50	1.5	25%	25°	GOULD		3A	125	1.09	1.75	1.49	10	12-6-63	4,751	10-31-64	F
NICD	3.50	3.0	25%	25°	GOULD		7A	125	0.44	1.75	1.49	10	12-20-63	4,173	7-26-65	F
NICD	3.50	1.5	40%	25°	GOULD		4A	125	1.75	2.80	1.49	10	12-5-63	3,164	7-9-64	F
NICD	3.50	3.0	40%	25°	GOULD		8A	125	0.70	2.80	1.49	10	12-20-63	2,494	11-29-64	F
NICD	3.50	1.5	15%	40°	GOULD		27A	160	0.84	1.05	1.45	10	12-12-63	4,485	11-6-64	F
NICD	3.50	3.0	15%	40°	GOULD		31A	160	0.34	1.05	1.45	10	12-20-63	2,517	1-3-65	F
NICD	3.50	1.5	25%	40°	GOULD		28A	160	1.40	1.75	1.45	10	12-12-63	1,811	5-29-64	F
NICD	3.50	3.0	25%	40°	GOULD		32A	160	0.56	1.75	1.45	10	12-20-63	975	6-10-64	F
NICD	20.00	1.5	15%	0°	GOULD		84A	115	3.45	6.00	1.55	5	1-16-64	22,448	2-13-68	D
NICD	20.00	3.0	15%	0°	GOULD		80A	115	1.38	6.00	1.55	5	1-21-64	11,378	2-13-68	D
NICD	20.00	1.5	25%	0°	GOULD		98A	115	5.75	10.00	1.55	5	1-21-64	10,641	1-14-66	F
NICD	20.00	3.0	25%	0°	GOULD		94A	115	2.30	10.00	1.55	5	1-24-64	11,162	2-13-68	D
NICD	20.00	1.5	25%	25°	GOULD		104A	125	6.25	10.00	1.49	5	1-16-64	2,980	8-20-64	F
NICD	20.00	3.0	25%	25°	GOULD		105A	125	2.50	10.00	1.49	5	1-21-64	5,690	3-17-66	F
NICD	20.00	1.5	40%	25°	GOULD		118A	125	10.00	16.00	1.49	5	2-1-64	2,937	9-7-64	F
NICD	20.00	3.0	40%	25°	GOULD		119A	125	4.00	16.00	1.49	5	2-1-64	1,793	9-27-64	F
NICD	20.00	1.5	15%	40°	GOULD		112A	160	4.80	6.00	1.45	5	1-16-64	5,213	2-15-65	F
NICD	20.00	3.0	15%	40°	GOULD		108A	160	1.92	6.00	1.45	5	1-24-64	4,273	8-31-65	F
NICD	20.00	1.5	25%	40°	GOULD		126A	160	8.00	10.00	1.45	5	1-16-64	1,574	5-23-64	F
NICD	20.00	3.0	25%	40°	GOULD		122A	160	3.20	10.00	1.45	5	1-24-64	983	7-2-64	F

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
NICD	1.25	1.5	25%	-20°	GULTON		74B		1.00	0.63		5	3-3-66	21,006		
NICD	1.25	1.5	60%	-20°	GULTON		88D		1.00	0.63		5	3-3-66	20,397		
NICD	1.25	1.5	25%	0°	GULTON		108B		1.25	0.63		5	3-4-66	21,311		
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	110	0.96	1.75	1.56	5	12-24-66	16,738		
NICD	3.50	1.5	40%	-20°	GULTON	PS	75D	110	1.54	2.80	1.56	5	12-24-66	14,197	9-28-69	F
NICD	3.50	1.5	25%	0°	GULTON	PS	122C	115	1.01	1.75	1.55	5	12-24-66	23,817		
NICD	3.50	1.5	40%	0°	GULTON	PS	99C	115	1.61	2.80	1.55	5	12-24-66	16,821		
NICD	3.50	1.5	25%	25°	GULTON	PS	87C	125	1.09	1.75	1.49	5	12-23-66	16,815		
NICD	3.50	1.5	25%	40°	GULTON	PS	112C	160	1.40	1.75	1.45	5	1-2-67	11,155	1-3-69	F
NICD	3.50	1.5	40%	25°	GULTON	PS	73C	125	1.75	2.80	1.49	5	12-23-66	9,978	10-28-68	F
NICD	3.60	1.5	40%	25°	GULTON	CLM	39B		3.60	2.88	1.49	10	11-11-65	5,399	12-6-66	F
NICD	4.00	1.5	15%	0°	GULTON	CC	115B	115	0.69	1.20	1.55	5	7-25-64	29,929		
NICD	4.00	1.5	25%	0°	GULTON	CC	126B	115	1.15	2.00	1.55	5	7-25-64	30,330		
NICD	4.00	1.5	25%	25°	GULTON	CC	4B	125	1.25	2.00	1.49	5	8-4-64	30,335		
NICD	4.00	1.5	40%	25°	GULTON	CC	14B	125	2.00	3.20	1.49	5	8-4-64	8,474	3-19-66	F
NICD	4.00	1.5	15%	40°	GULTON	CC	28B	160	0.96	1.20	1.45	5	8-4-64	20,227	7-6-68	F
NICD	4.00	1.5	25%	40°	GULTON	CC	40B	160	1.60	2.00	1.45	5	8-4-64	10,360	6-22-66	F
NICD	4.00	1.5	25%	-20°	GULTON	CLM	40C		2.00	2.00	1.56	5	3-4-67	2	3-4-67	F
NICD	4.00	1.5	25%	0°	GULTON	CLM	52B		2.00	2.00	1.48	5	3-3-67	5,685	3-5-68	F
NICD	4.00	1.5	15%	25°	GULTON	CLM	26C		1.20	1.20	1.44	5	2-18-67	11,455	2-28-69	F
NICD	4.00	1.5	25%	25°	GULTON	CLM	14C		2.00	2.00	1.44	5	3-3-67	2,428	8-8-67	F
NICD	4.00	1.5	40%	25°	GULTON	CLM	37C		4.80	4.80	1.44	5	3-4-67	790	5-5-67	F
NICD	4.00	1.5	60%	25°	GULTON	CLM	38D		3.20	3.20	1.44	5	2-18-67	1,927	6-27-67	F
NICD	4.00	1.5	25%	40°	GULTON	CLM	39C		2.00	2.00	1.38	5	3-3-67	1,508	6-20-67	F
NICD	5.00	1.5	15%	0°	GULTON	NB	117A	110	0.83	1.50	1.49	5	5-8-65	25,681		

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
NICD	5.00	1.5	25%	0°	GULTON	NBPT	121A	110	1.38	2.50	1.49	5	6-5-65	20,861	3-5-69	F
NICD	5.00	1.5	15%	25°	GULTON	NB	120A	120	0.90	1.50	1.49	5	5-2-65	24,716		
NICD	5.00	1.5	25%	25°	GULTON	NBPT	118B	120	1.50	2.50	1.49	5	6-10-65	8,108	11-22-66	F
NICD	5.00	1.5	15%	40°	GULTON	NB	127A	130	0.98	1.50	1.49	5	4-29-65	10,638	5-24-67	F
NICD	5.00	1.5	25%	40°	GULTON	NBPT	128A	130	1.63	2.50	1.49	5	6-21-65	6,345	8-18-66	F
NICD	5.60	1.5	25%	-20°	GULTON	FRS	44B	115	1.61	2.80	1.55	5	1-2-66	22,152		
NICD	5.60	1.5	25%	-20°	GULTON	RS	32B	115	1.61	2.80	1.55	5	1-2-66	22,040		
NICD	5.60	1.5	25%	0°	GULTON	FRS	100B	115	1.61	2.80	1.55	5	12-17-65	22,369		
NICD	5.60	1.5	25%	0°	GULTON	RS	90C	115	1.61	2.80	1.55	5	12-17-65	22,454		
NICD	5.60	1.5	25%	25°	GULTON	FRS	76B	125	1.75	2.80	1.49	5	12-10-65	11,158	1-2-68	F
NICD	5.60	1.5	25%	25°	GULTON	RS	96C	125	1.75	2.80	1.49	5	12-10-65	9,791	9-19-67	F
NICD	5.60	1.5	25%	40°	GULTON	FRS	42B	160	2.24	2.80	1.45	5	12-3-65	3,798	9-10-66	F
NICD	5.60	1.5	25%	40°	GULTON	RS	30B	160	2.24	2.80	1.45	5	12-3-65	1,275	3-8-66	F
NICD	6.00	1.5	15%	0°	GULTON		61A	115	1.04	1.80	1.55	10	12-31-63	10,146	12-17-65	F
NICD	6.00	3.0	15%	0°	GULTON		65A	115	0.41	1.80	1.55	10	12-31-63	11,208	2-15-68	D
NICD	6.00	1.5	25%	0°	GULTON		62A	115	1.72	3.00	1.55	10	12-30-63	22,779	2-15-68	D
NICD	6.00	3.0	25%	0°	GULTON		66A	115	0.69	3.00	1.55	10	12-31-63	4,414	8-31-65	F
NICD	6.00	1.5	25%	25°	GULTON		13A	125	1.88	3.00	1.49	10	12-31-63	4,021	11-11-64	F
NICD	6.00	3.0	25%	25°	GULTON		17A	125	0.75	3.00	1.49	10	12-20-63	2,885	1-31-65	F
NICD	6.00	1.5	25%	25°	GULTON		14A	125	3.00	4.80	1.49	10	12-30-63	2,086	6-19-64	F
NICD	6.00	3.0	40%	25°	GULTON		18A	125	1.20	4.80	1.49	10	12-31-63	1,500	8-18-64	F
NICD	6.00	1.5	15%	40°	GULTON		37A	160	1.44	1.80	1.45	10	12-31-63	6,064	4-14-65	F
NICD	6.00	3.0	15%	40°	GULTON		41A	160	0.58	1.80	1.45	10	12-31-63	1,689	9-14-64	F
NICD	6.00	1.5	25%	40°	GULTON		38A	160	2.40	3.00	1.45	10	12-30-63	1,377	5-22-64	F
NICD	6.00	3.0	25%	40°	GULTON		42A	160	0.96	3.00	1.45	10	12-31-63	4,133	8-23-65	F
NICD	6.00	24.0	50%	25°	GULTON		79A	115	0.20	3.00	1.49	5	3-28-64	545	10-13-65	F

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
NICD	6.00	1.5	25%	0°	GULTON	IM	13B	115	1.73	3.00	1.55	5	2-22-65	27,157		
NICD	6.00	1.5	40%	25°	GULTON	IM	18B	125	3.00	4.80	1.49	5	2-22-65	7,577	7-21-66	F
NICD	6.00	1.5	25%	40°	GULTON	IM	38B	160	2.40	3.00	1.45	5	2-22-65	5,766	3-31-66	F
NICD	6.00	1.5	10%	0°	GULTON		61B	110	0.66	1.20	1.55	10	6-7-67	14,217		
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	15,272		
NICD	6.00	1.5	25%	*	GULTON	AE	24C		3.00	3.00		5	4-25-67	15,253		
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	8,310		
NICD	6.00	3.0	25%	0°	GULTON	CLM	66B		3.00	3.00		5	11-18-66	8,717		
NICD	6.00	3.0	25%	25°	GULTON	CLM	18C		3.00	3.00		5	11-18-66	8,288		
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	5,377		
NICD	6.00	1.5	25%	*	GULTON	AE	58D		3.00	3.00		5	1-8-69	5,374		
NICD	6.00	1.5	0.8%	20°	GULTON	TETR	51B		0.30	0.10		10	2-26-69	4,541		
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	115	2.07	3.60	1.55	5	2-20-65	27,018		
NICD	12.00	1.5	25%	0°	GULTON		101B	115	3.45	6.00	1.55	5	12-19-64	27,808		
NICD	12.00	1.5	25%	25°	GULTON		27B	125	3.75	6.00	1.49	5	1-28-65	14,250	9-5-67	F

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
NICD	12.00	1.5	40%	25°	GULTON		96B	125	6.00	9.60	1.49	5	12-2-64	5,152	11-9-65	F
NICD	12.00	1.5	15%	40°	GULTON		78A	160	2.88	3.60	1.45	5	12-22-64	11,081	1-4-66	F
NICD	12.00	1.5	25%	40°	GULTON		90B	160	8.00	10.00	1.45	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	16,062		
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	115	3.45	6.00	1.55	5	1-16-64	3,629	9-20-64	F
NICD	20.00	3.0	15%	0°	GULTON		102A	115	1.38	6.00	1.55	5	1-21-64	11,212	2-13-68	D
NICD	20.00	1.5	25%	0°	GULTON		115A	115	5.75	10.00	1.55	5	1-16-64	2,291	6-24-64	F
NICD	20.00	3.0	25%	0°	GULTON		116A	115	2.30	10.00	1.55	5	2-11-64	10,971	2-13-68	D
NICD	20.00	1.5	25%	25°	GULTON		73A	125	6.25	10.00	1.49	5	1-16-64	7,763	6-30-65	F
NICD	20.00	3.0	25%	25°	GULTON		74A	125	2.50	10.00	1.49	5	1-21-64	1,754	9-27-64	F
NICD	20.00	1.5	40%	25°	GULTON		87A	125	10.00	16.00	1.49	5	2-1-64	627	4-7-64	F
NICD	20.00	3.0	40%	25°	GULTON		88A	125	4.00	16.00	1.49	5	2-1-64	358	3-21-64	F
NICD	20.00	1.5	15%	40°	GULTON		76A	160	4.80	6.00	1.45	5	1-18-64	9,348	10-15-65	F
NICD	20.00	3.0	15%	40°	GULTON		77A	160	1.92	6.00	1.45	5	1-21-64	6,032	4-20-66	F
NICD	20.00	1.5	25%	40°	GULTON		90A	160	8.00	10.00	1.45	5	1-18-64	4,045	11-12-64	F
NICD	20.00	3.0	25%	40°	GULTON		91A	160	3.20	10.00	1.45	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	9,993		

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
NICD	20.00	1.5	15%	25°	GULTON	AE	19B		8.00	6.00		5	3-23-68	10,004		
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	1,360		
NICD	50.00	1.5	25%	0°	GULTON		95A	115	14.38	25.00	1.55	5	6-8-64	3,227	2-9-65	F
NICD	50.00	1.5	15%	40°	GULTON		123A	160	12.00	15.00	1.45	5	6-8-64	1,873	11-11-64	F
NICD	3.90	1.5	25%	0°	NIFE		97C	107	1.07	2.00	1.47	5	9-29-67	12,560		
NICD	3.90	1.5	25%	25°	NIFE		85C	107	1.07	2.00	1.47	5	9-29-67	9,356	6-19-69	F
NICD	3.00	1.5	15%	0°	SONOTONE	3S	43B	115	0.52	0.90	1.55	5	6-24-65	24,682		
NICD	3.00	1.5	25%	0°	SONOTONE	3S	31B	115	0.86	1.50	1.55	5	6-24-65	24,359		
NICD	3.00	1.5	25%	25°	SONOTONE	3S	3B	125	0.94	1.50	1.49	5	6-25-65	11,726	8-23-67	F
NICD	3.00	1.5	40%	25°	SONOTONE	3S	2B	125	1.50	2.40	1.49	5	7-10-65	5,399	7-26-66	F
NICD	3.00	1.5	15%	40°	SONOTONE	3S	26B	160	0.72	0.90	1.45	5	7-10-65	6,289	10-4-66	F
NICD	3.00	1.5	25%	40°	SONOTONE	3S	37B	160	1.20	1.50	1.45	5	7-10-65	5,625	8-4-66	F
NICD	3.50	1.5	10%	0°	SONOTONE		15B	110	0.39	0.70	1.55	10	6-7-67	14,284		
NICD	5.00	1.5	15%	0°	SONOTONE		49A	115	0.86	1.50	1.55	10	12-31-63	23,112	2-15-68	D
NICD	5.00	3.0	15%	0°	SONOTONE		53A	115	0.35	1.50	1.55	10	12-31-63	11,427	2-13-68	D
NICD	5.00	1.5	25%	0°	SONOTONE		50A	115	1.44	2.50	1.55	10	12-17-63	22,525	2-15-68	D
NICD	5.00	3.0	25%	0°	SONOTONE		54A	115	0.58	2.50	1.55	10	12-31-63	11,331	2-7-68	D
NICD	5.00	1.5	25%	25°	SONOTONE		1A	125	1.56	2.50	1.49	10	12-17-63	11,745	2-27-66	F
NICD	5.00	3.0	25%	25°	SONOTONE		5A	125	0.62	2.50	1.49	10	12-31-63	11,092	2-12-68	D
NICD	5.00	1.5	40%	25°	SONOTONE		2A	125	2.50	4.00	1.49	10	12-17-63	6,671	4-24-65	F
NICD	5.00	3.0	40%	25°	SONOTONE		6A	125	1.00	4.00	1.49	10	1-2-64	5,211	12-13-65	F
NICD	5.00	1.5	15%	40°	SONOTONE		25A	160	1.20	1.50	1.45	10	12-17-63	9,328	10-31-65	F
NICD	5.00	3.0	15%	40°	SONOTONE		29A	160	0.48	1.50	1.45	10	12-31-63	5,975	4-17-66	F
NICD	5.00	1.5	25%	40°	SONOTONE		26A	160	2.00	2.50	1.45	10	12-17-63	3,625	10-15-64	F
NICD	5.00	3.0	25%	40°	SONOTONE		30A	160	0.80	2.50	1.45	10	12-31-63	4,141	8-7-65	F

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
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
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	1.50	5	11-7-67	1,179	2-7-68	F
NICD	20.00	1.5	25%	25°	SONOTONE	IPD	22A		20.00	10.00	1.50	10	9-20-67	6,664	10-7-69	D
NICD	20.00	1.5	25%	25°	SONOTONE	IPD	10A		7.00	10.00	1.50	10	9-20-67	7,188	10-7-69	D
NICD	20.00	1.5	40%	25°	SONOTONE	IPD	34B		20.00	16.00	1.50	10	9-20-67	5,634	7-3-69	F
NICD	20.00	3.0	40%	25°	SONOTONE	IPD	46A		20.00	16.00	1.50	10	9-20-67	3,501	10-7-69	D
NICD	20.00	1.5	75%	25°	SONOTONE	IPD	72B		20.00	30.00	1.50	10	9-20-67	1,143	4-5-69	F
AGCD	8.00	8.0	25%	25°	ESB	AE	1B		0.50	2.00	1.51	5	9-9-66	3,387		
AGCD	3.00	1.5	16%	25°	YARDNEY		2C		1.30	1.00	1.52	9	9-16-66	7,039	12-12-67	F
AGCD	5.00	24.0	20%	0°	YARDNEY	C3SP	57B		0.30	1.00	1.50	5	9-17-65	267	6-17-66	F
AGCD	5.00	24.0	20%	25°	YARDNEY	C3SP	21A		0.30	1.00	1.50	5	9-17-65	98	12-25-65	F
AGCD	5.00	24.0	20%	40°	YARDNEY	C3SP	45A		0.30	1.00	1.50	5	9-27-65	61	11-16-65	F
AGCD	5.00	24.0	20%	25°	YARDNEY	RCPSP	9C		0.30	1.00	1.50	10	10-27-65	34	12-1-65	D
AGCD	5.00	24.0	20%	25°	YARDNEY	CPSP	33B		0.30	1.00	1.50	5	10-17-65	720	11-4-67	F
AGCD	5.00	24.0	20%	25°	YARDNEY	PLSP	69A		0.30	1.00	1.50	5	10-27-65	595	7-17-67	F
AGCD	5.00	24.0	20%	0°	YARDNEY		113B		0.30	1.00	1.50	5	1-22-67	1,053		
AGCD	5.00	24.0	20%	25°	YARDNEY		77B		0.30	1.00	1.50	5	1-12-67	661	11-12-68	F
AGCD	5.00	24.0	20%	25°	YARDNEY		105B		0.30	1.00	1.50	5	1-12-67	77	4-19-67	F
AGCD	5.00	24.0	20%	40°	YARDNEY		128B		0.30	1.00	1.50	5	1-19-67	269	11-4-67	F

TYPE	AMPERE-HOUR	ORBIT PERIOD	DEPTH OF DISCHARGE	TEMP (°C)	MANUFACTURER	SPECIAL SYMBOL	PACK NO.	PERCENT CHARGE	CHARGE CURRENT	DISCHARGE CURRENT	VOLTAGE LIMIT	NO. CELLS IN PACK	DATE STARTED	CYCLES COMPLETED	DATE COMPLETED	
AGCD	5.00	8.0	20%	0°	YARDNEY	PLCPSP	114B		0.30	1.00	1.50	5	1-22-67	1,496	6-25-68	F
AGCD	5.00	8.0	20%	25°	YARDNEY	PLCPSP	118C		0.30	1.00	1.50	5	1-17-67	1,505	7-9-68	F
AGCD	10.00	8.0	30%	25°	YARDNEY		45D		0.50	3.00	1.51	5	5-3-67	1,759	11-19-68	F
AGCD	11.00	24.0	40%	0°	YARDNEY		45B		0.30	4.40	1.51	10	11-5-66	121	3-13-67	F
AGCD	11.00	24.0	40%	25°	YARDNEY		21B		0.30	4.40	1.51	10	11-5-66	69	1-13-67	F
AGCD	11.00	8.0	27%	25°	YARDNEY	PLSP	21C		0.50	3.00	1.51	5	3-28-67	37	4-9-67	F
AGCD	11.00	8.0	27%	25°	YARDNEY	WNSP	45C		0.50	3.00	1.51	5	3-28-67	70	4-22-67	F
AGCD	11.00	24.0	18%	0°	YARDNEY	AE-GU	57D		0.25	2.00	1.51	5	2-14-68	651		
AGCD	11.00	24.0	18%	25°	YARDNEY	AE-GU	69B		0.25	2.00	1.51	5	2-14-68	507	7-13-69	F
AGCD	11.00	24.0	18%	40°	YARDNEY	AE-GU	33C		0.25	2.00	1.51	5	2-14-68	447	5-15-69	F
AGCD	12.00	24.0	50%	0°	YARDNEY		57A		0.60	6.00	1.50	10	2-14-64	168	9-3-64	F
AGCD	12.00	24.0	50%	40°	YARDNEY		33A		0.60	6.00	1.50	10	2-14-64	210	9-20-64	F
AGCD	12.00	1.5	25%	-20°	YARDNEY		85B		3.90	6.00	1.60	5	1-19-66	2,375	3-25-67	F
AGCD	12.00	1.5	25%	0°	YARDNEY		97B		3.90	6.00	1.58	5	1-19-66	4,481	3-15-67	F
AGCD	12.00	1.5	25%	25°	YARDNEY		82B		3.90	6.00	1.55	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	1.51	5	6-16-67	60	8-13-67	F
AGCD	12.00	24.0	43%	40°	YARDNEY	AE-GE	9F		0.50	5.20	1.51	5	6-16-67	310	5-28-68	F
AGZN	25.00	24.0	40%	25°	DELCO-REMY		89A		15.00	10.00	1.97	5	9-18-64	80	12-8-64	D
AGZN	25.00	24.0	40%	25°	DELCO-REMY		75A		15.00	10.00	1.97	5	8-18-64	32	9-18-64	F
AGZN	25.00	3.0	40%	25°	DELCO-REMY		88B		15.00	20.00	1.97	5	3-1-65	120	3-16-65	D
AGZN	25.00	3.0	40%	25°	DELCO-REMY		88C		15.00	20.00	1.97	5	3-26-65	325	5-6-65	D
AGZN	25.00	24.0	40%	25°	DELCO-REMY	2SR	9D		1.00	10.00	1.97	10	12-13-65	121	4-18-66	D
AGZN	25.00	24.0	40%	25°	DELCO-REMY	2SR	9E		1.00	10.00	1.97	10	10-5-66	90	1-4-67	D
AGZN	40.00	24.0	25%	25°	DELCO-REMY		75B		25.00	10.00	1.97	5	10-28-64	139	3-15-65	D
AGZN	12.00	24.0	42%	25°	YARDNEY		9A		0.50	5.00	1.97	10	5-7-65	58	7-7-65	D
AGZN	16.00	24.0	31%	25°	YARDNEY	2SR	57C		0.50	5.00	1.98	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 sixth annual report covers the cycle life test, the third phase of the evaluation program of secondary spacecraft cells, through 14 December 1969. 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.

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 731 nickel-cadmium, 174 silver-cadmium and 65 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 12 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 and 24 hours; and depths of discharge ranging from 10 to 75 percent. The charge control methods used are voltage limit, auxiliary electrode, coulometer, stabistor, two-step regulator 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 cycling temperature of 0° to 40° C within a period of 48 hours.

Data is recorded on each pack every 32 cycles for the 1.5 and 3.0 hour orbit periods, every 24 cycles for the 8.0 hour orbit period, and every 8 cycles for the 24 hour orbit period. The data consists of individual cell voltage, individual cell temperature, total voltage, current, and ambient temperature. Also when appropriate, data is collected 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.

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.

The ampere-hour capacity of each pack, at its specified test temperature, is measured initially and every 88 days of continuous cycling. 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, whichever occurs first. The pack is then recharged at the c/10 rate for 16 hours and discharged again as above. Before being returned to regular cycling, the pack is given a 48-hour charge 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). 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 and then recharged at the regular cycle rate prior to being returned to automatic cycling.

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 the recorded cycle. The cells remaining in the pack continue test until two-thirds 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 according to their use in this report. These are our definitions, and they may differ somewhat from usage elsewhere.

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. Deposits may or may not be accompanied by a weight loss as defined above. Deposits are not removed prior to weighing.

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 when the plates are unrolled for failure analysis, and may come off in large, intact pieces. This condition is not noticed on flat plates, which are not flexed in the analysis.

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 only to short circuits between plates, when caused by either a grid wire or a tab at the tab-to-plate connection piercing the separator and contacting the adjacent plate.

Excess Scoring: The two indentations which encircle the cell case put increased pressure on the outside layer of the plates and separators at these points. Usually this results only in increased

migration of negative active material, but in some cases the scoring is deep enough to damage the wrap, plate, or separator just beneath the scoring marks. It may result in a short circuit between the case and the adjacent plate.

Burned Positive Tab: The positive tab, above the plates, is burned and sometimes broken. The broken tab may fall against the case and cause a short circuit. In all cases the tape with which the positive tab had been wrapped was also burned. At times the corrosion is such that the tab crumbles when the cell is opened, so that its prior configuration cannot be determined. The burned positive tab has been attributed to an insufficient area of welding between the tab and the positive terminal, causing a high-resistance contact. However, with two exceptions, this condition was found only among cells tested at 50°-40° C temperature where it was the predominant mode of failure. This suggests that additional factors are involved.

Short Separator: Related to the 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 5.0 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 invariable 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. The results of those failed and discontinued packs are covered in Section IV. The following information covers those packs held in the cycling program.

B. The five packs maintained on cycling contained five GE 12 ampere-hour, nickel-cadmium, cells per pack. These cells are rectangular in shape. 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	Percent of Recharge	Charge Voltage Limit, Per Cell
110A*	0° C	15	115	1.55
111A	0° C	15	115	1.55
124A*	0° C	25	115	1.55
125A	0° C	25	115	1.55
83A	25° C	25	125	1.49

* These packs are cycled at 1.5-hour orbit period, all others at 3.0-hour orbit period.

D. Cycling was started in January 1964. Packs 110A, 111A, and 125A have completed 32,108, 16,284 and 16,593 cycles, respectively, with no cell failures. Packs 124A and 83A failed on cycles 34,343 and 13,897, respectively, with a total of six cell failures (three from each pack). (See Figures 1 through 5)

1. Analysis of the six failed cells showed heavy migration of negative plate material, severe separator deterioration, and high internal pressure (as indicated by bulged cases and the escape of

gas when the cells were opened). Two cells, one from each pack, had electrolyte leakage around the ceramic-to-metal seal as evidenced by carbonate deposits.

E. The ampere-hour capacities on the precycling and capacity check cycles varied with ambient test temperature. The capacity of packs tested at 0° C, initially, averaged 14.2 ampere-hours, at 25° C averaged 15.0 ampere-hours, and at 40° C averaged 6.95 ampere-hours. At the present time or just prior to pack failure the average capacities are 9.40 ampere-hours at 0° C, 5.28 ampere-hours at 25° C and 3.55 at 40° C. More comparative information may be found in Section IV, Paragraph D.

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

PACK 110A, MANUFACTURE GE 12.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 2.07
DEPTH OF DISCHARGE IN % 15

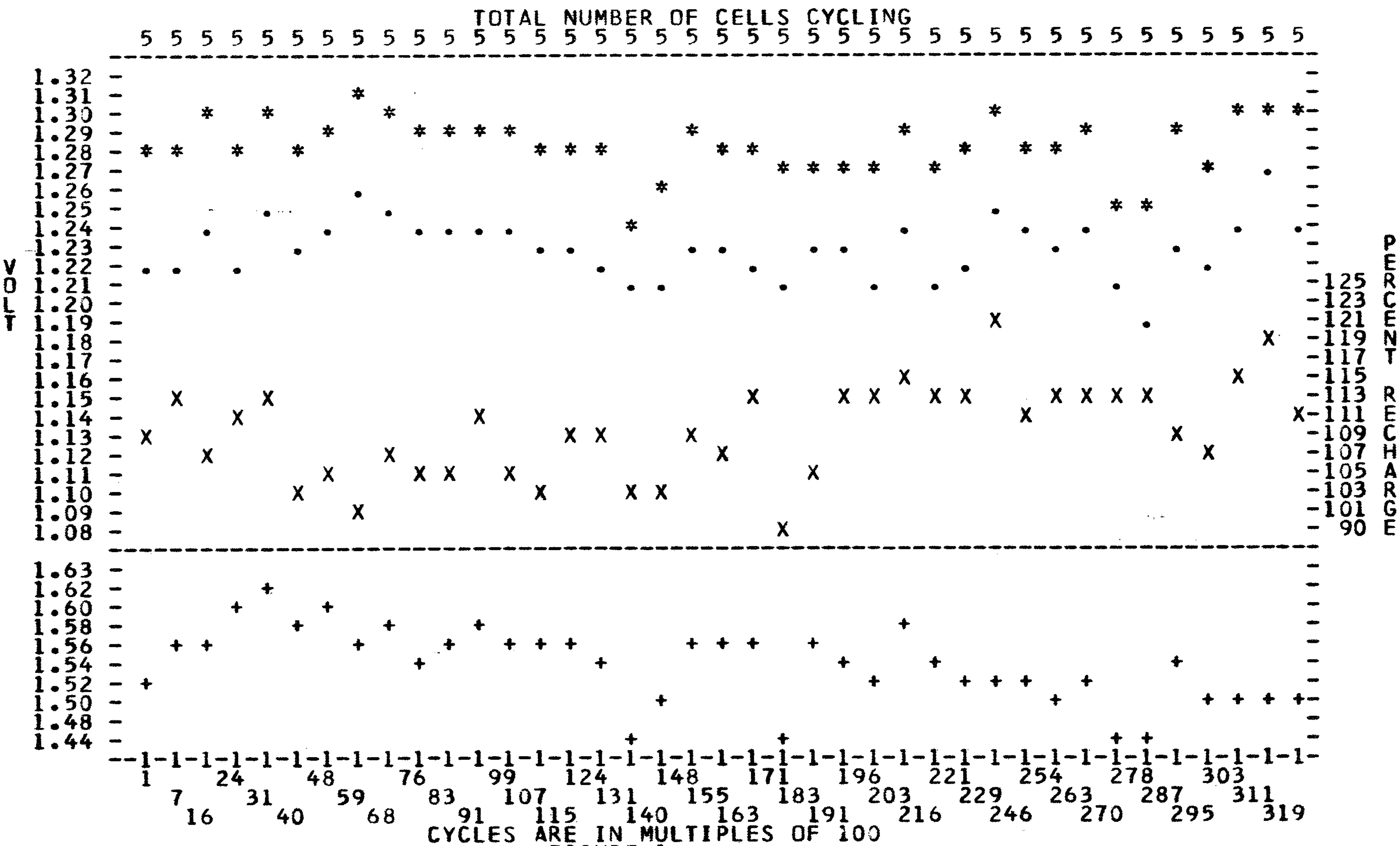


FIGURE 1

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

PACK 111A, MANUFACTURE GE 12.0 AH
ORBIT PERIOD IN HOURS 03.0
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.83
DEPTH OF DISCHARGE IN % 15

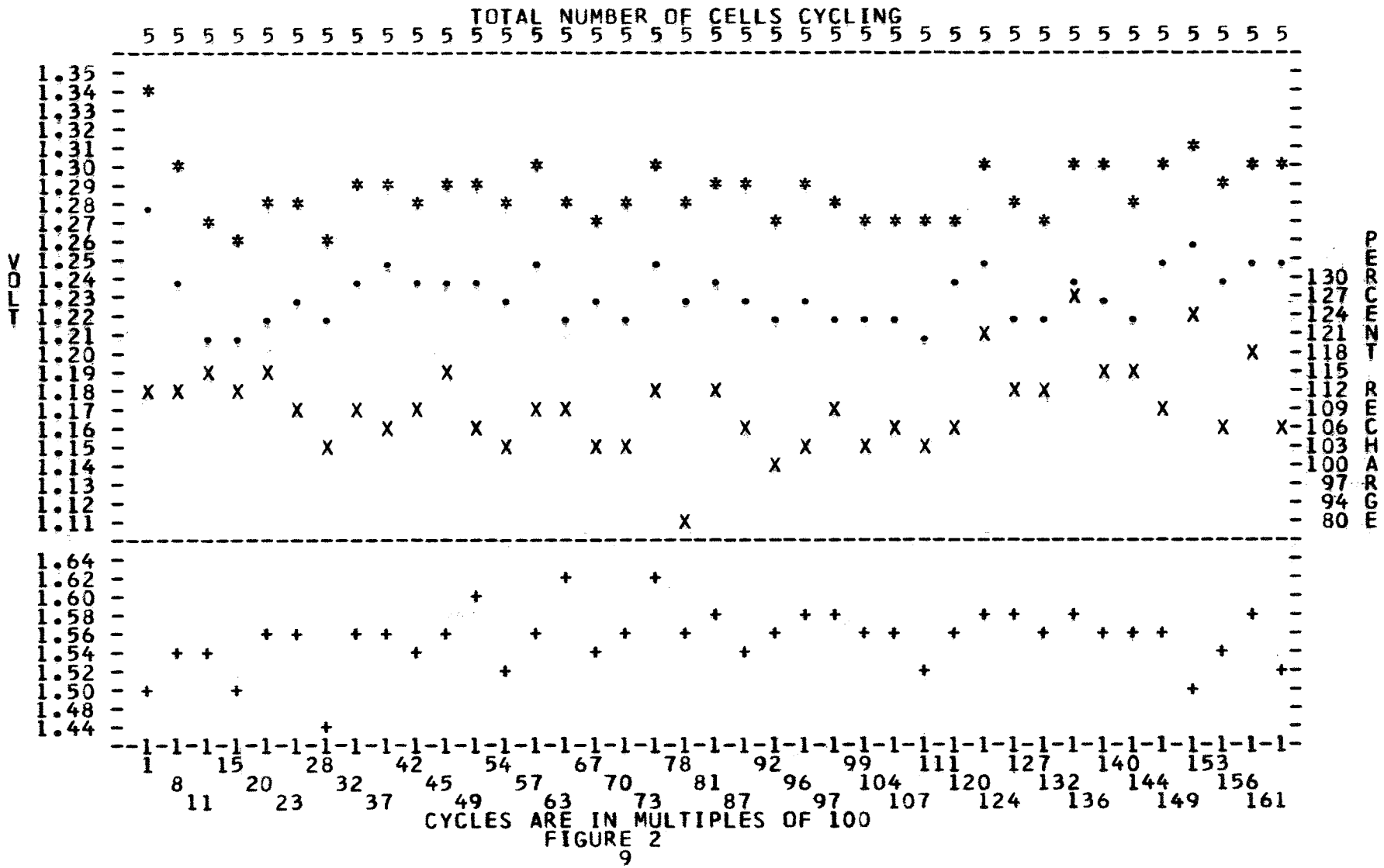


FIGURE 2

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

PACK 124A, MANUFACTURE GE 12.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 3.45
DEPTH OF DISCHARGE IN % 25

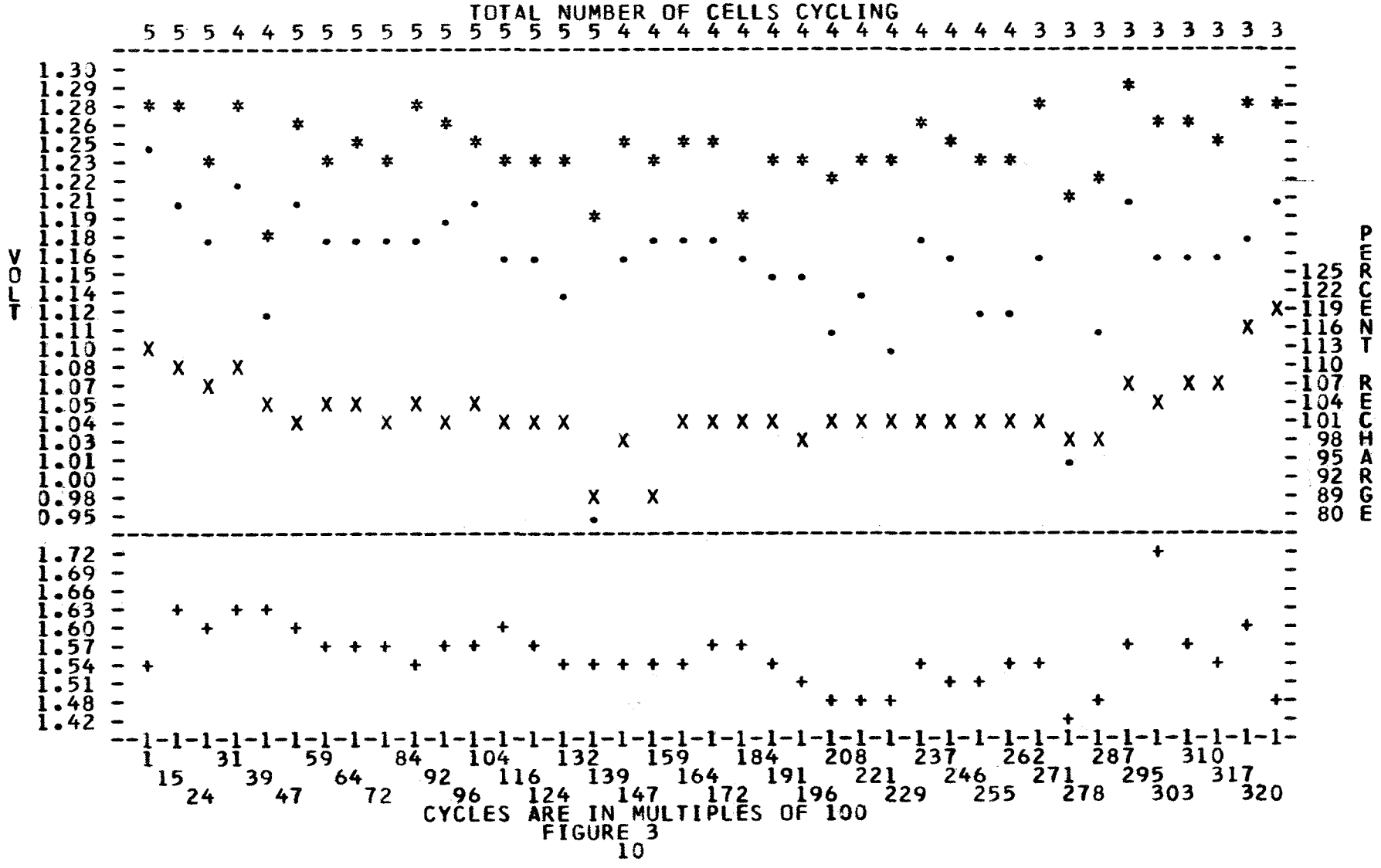
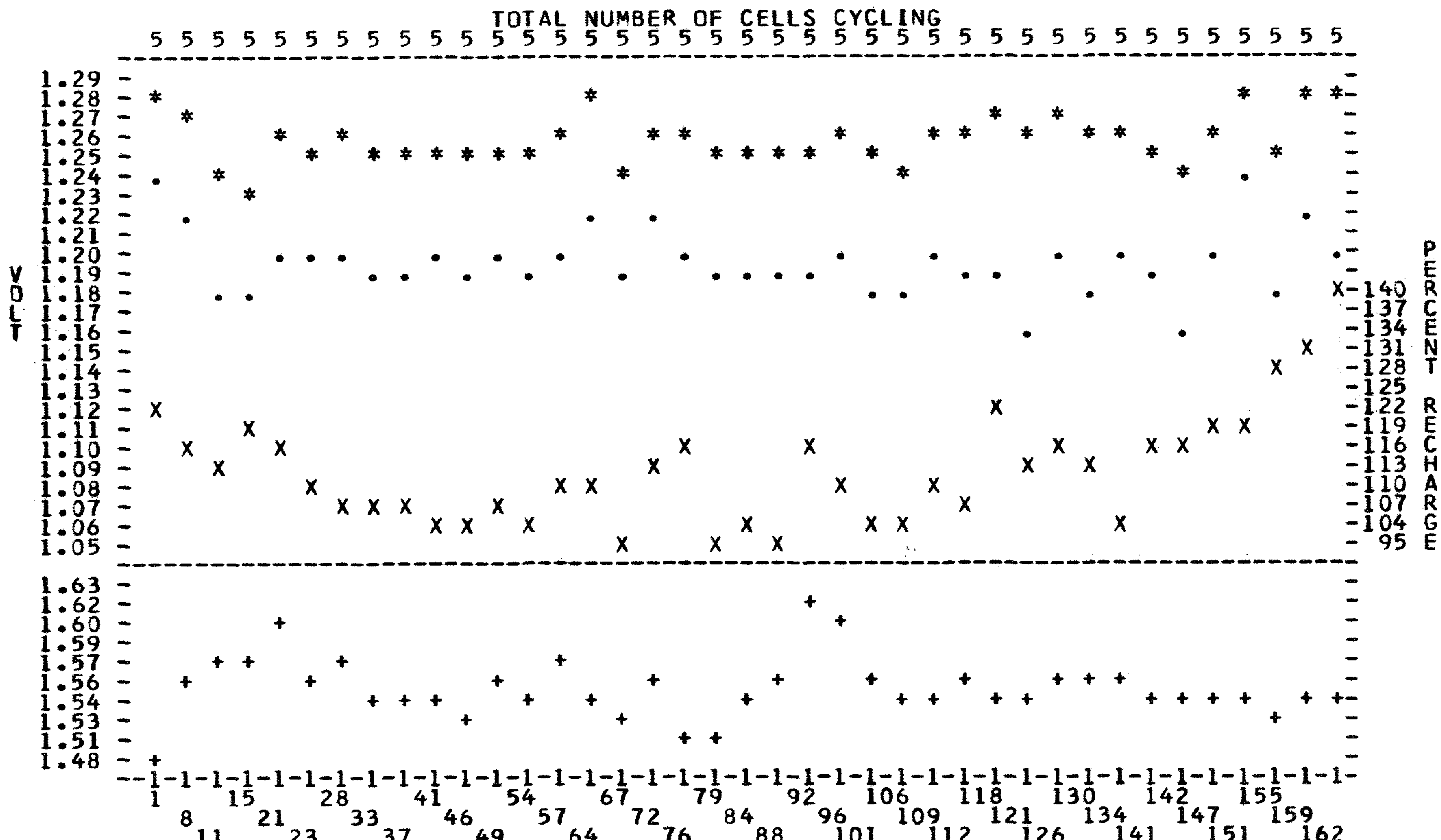


FIGURE 3

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

PACK 125A, MANUFACTURE GE 12.0 AH
ORBIT PERIOD IN HOURS 03.0
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.38
DEPTH OF DISCHARGE IN % 25



CYCLES ARE IN MULTIPLES OF 100
FIGURE 4

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

PACK 083A, MANUFACTURE GE 12.0 AH
ORBIT PERIOD IN HOURS 03.0
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 1.50
DEPTH OF DISCHARGE IN % 25

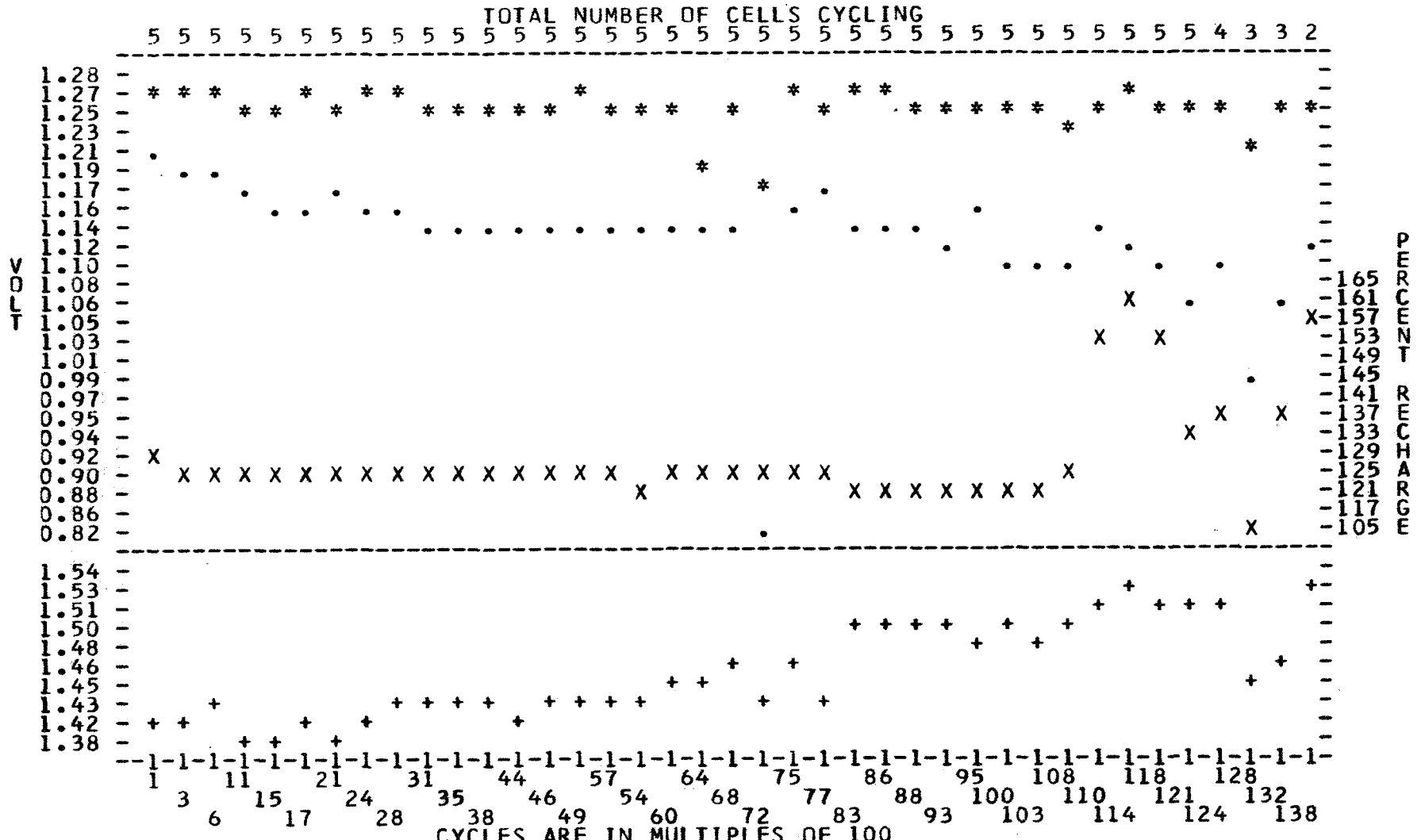


FIGURE 5

SECTION II

CELLS USING CONSTANT CURRENT CHARGE WITH VOLTAGE LIMIT CONTROL

I. CELLS USING CONSTANT CURRENT CHARGE WITH VOLTAGE LIMIT CONTROL

Because of the continuing effort to extend the performance life, new cells are added to the cycle program for evaluation as modifications; such as, nickel plating the silver braze area or new seals, are made, or when new environmental conditions; such as, -20° C or temperature cycling, are encountered. Each pack is cycled until more than two-thirds of the cells have failed. A cell is considered a failure when its terminal voltage drops below 0.5 volt during cycling.

A. Nickel-Cadmium Types:

1. Gulton 3.5 ah (Polymerized Neoprene Seal), Seven 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are cylindrical in shape. The cell containers and covers are 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.

b. Test Parameters:

(1) Cells Cycling:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
89C	-20° C	25	110	1.56 ± 0.03
75D	-20° C	40	110	1.56 ± 0.03
122C	0° C	25	115	1.55 ± 0.03
99C	0° C	40	115	1.55 ± 0.03
87C	25° C	25	125	1.49 ± 0.03
73C	25° C	40	125	1.49 ± 0.03
112C	40° C	25	160	1.45 ± 0.03

(2) 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.

c. Test Results:

(1) Performance on Cycling: (Figures 6 through 11) Cycling was started in December 1966. Packs 89C, 122C, 99C and 87C have completed 16,738, 23,817, 16,821 and 16,815 cycles, respectively, with one cell failure in pack 87C. Packs 75D, 73C and 112C failed on cycles 14,197, 9978 and 11,155, respectively, with a total of nine cell failures (three cells from each pack).

(2) Failure Analysis:

(a) Anlysis of nine 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 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.

(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°	-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
176 Days	Disch #2	2.33	3.35	3.21	4.20	3.27	2.22	1.20
264 Days	Disch #2	2.25	2.80	3.00	4.03	2.95	2.33	1.23
352 Days	Disch #2	2.33	3.03	2.86	3.94	2.48	1.84	1.08
440 Days	Disch #2	2.33	3.30	2.65	3.65	2.01	1.87	1.05
528 Days	Disch #2	3.79	3.94	2.57	3.35	3.21	1.98	1.25
616 Days	Disch #2	1.72	2.77	2.45	3.12	1.17	1.60 F	1.08
704 Days	Disch #2	1.49	2.60	2.33	2.95	1.17		1.08 F
792 Days	Disch #2	1.60	2.80	2.33	2.97	1.11		
880 Days	Disch #2	1.46	2.60 F	2.45	2.54	1.40		
968 Days	Disch #2	1.25		2.27	2.97	0.93		

F - Failed

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

PACK 089C, MANUFACTURE GULTON 03.5 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. -20
CHARGE RATE IN AMPS 0.96
DEPTH OF DISCHARGE IN % 25

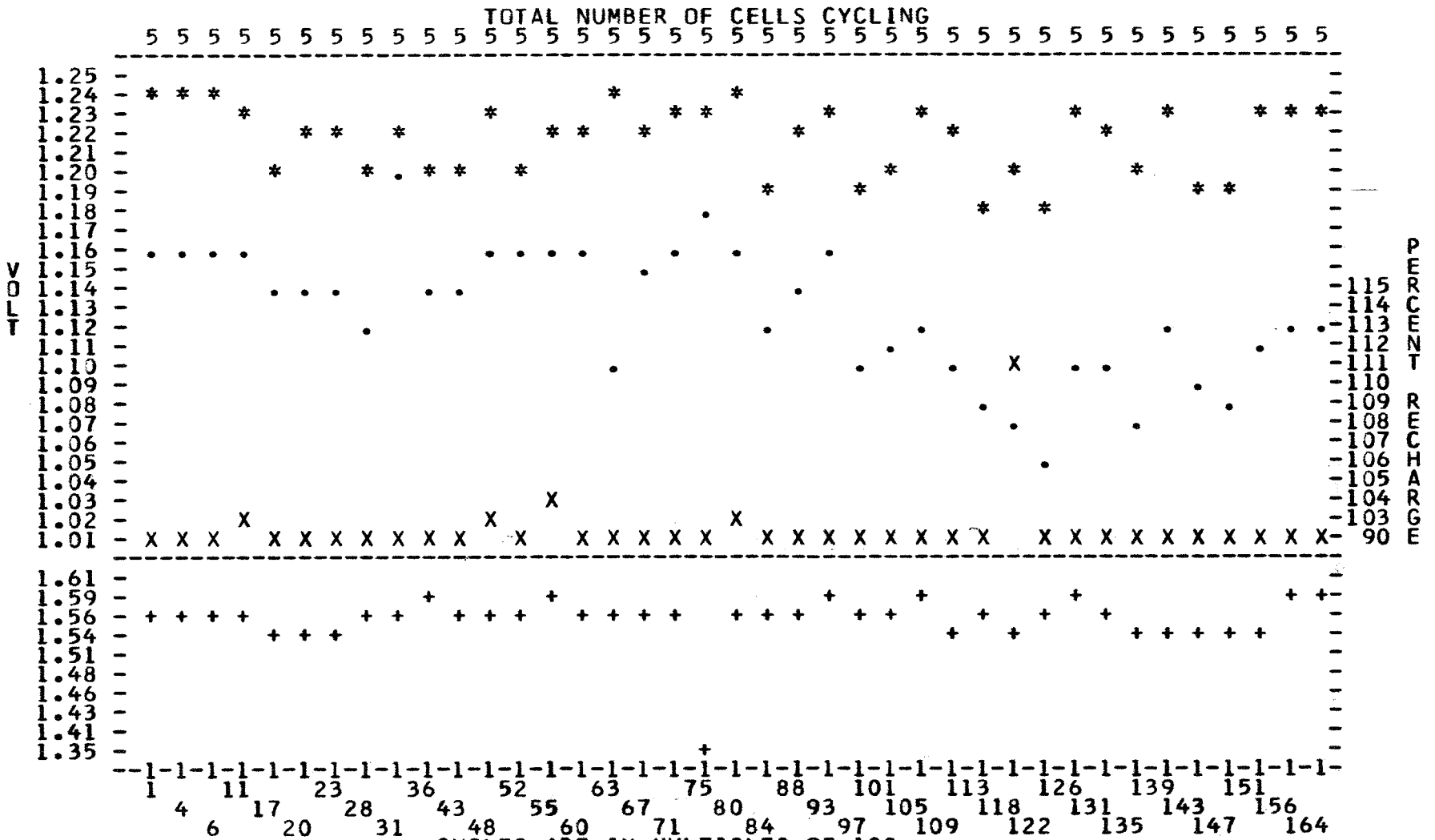


FIGURE 6

QE/C 70-173

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

PACK 075D, MANUFACTURE GULTON 03.5 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. -20
CHARGE RATE IN AMPS 1.54
DEPTH OF DISCHARGE IN % 40

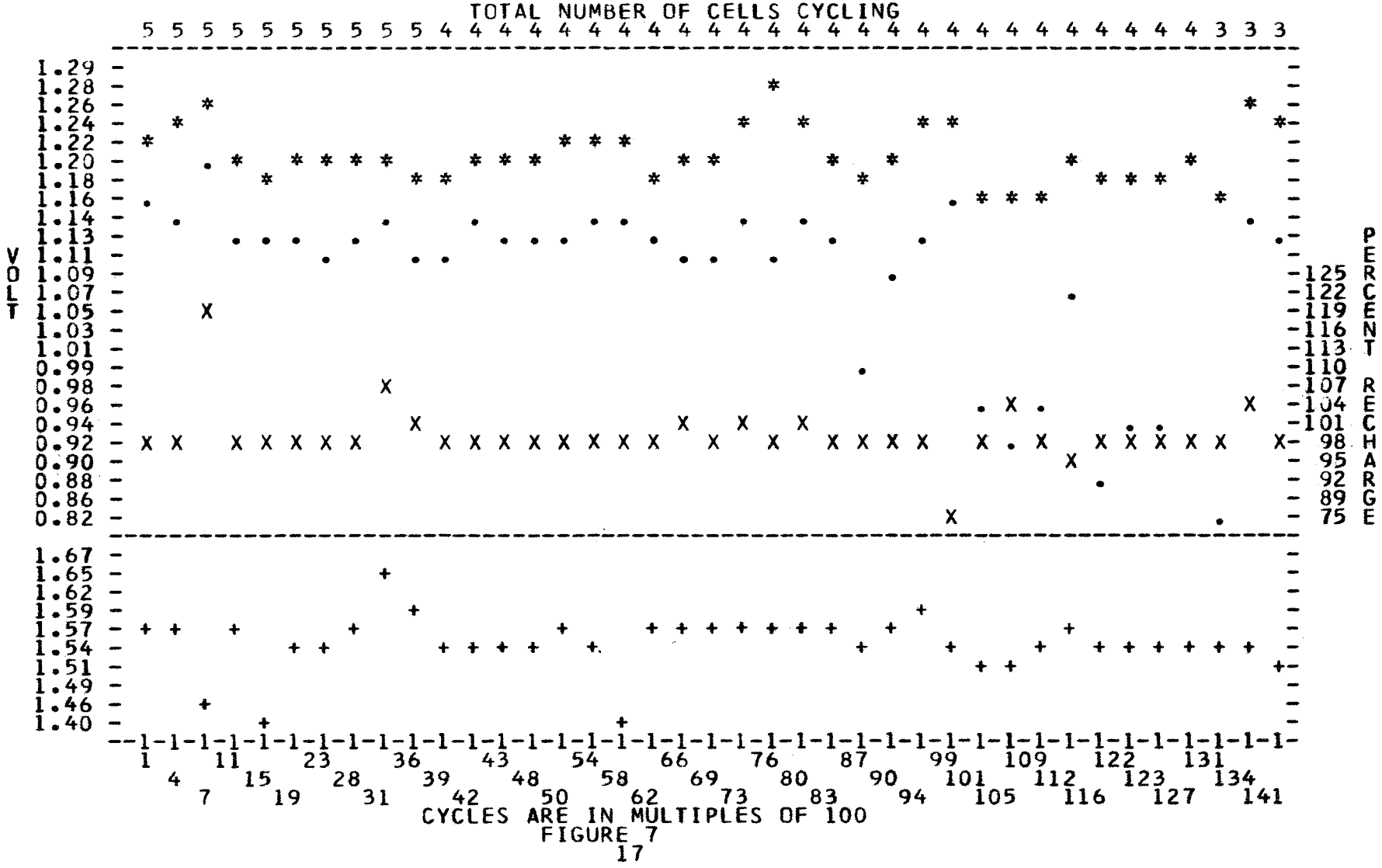


FIGURE 7

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

PACK 122C, MANUFACTURE GULTON 03.5 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.01
DEPTH OF DISCHARGE IN % 25

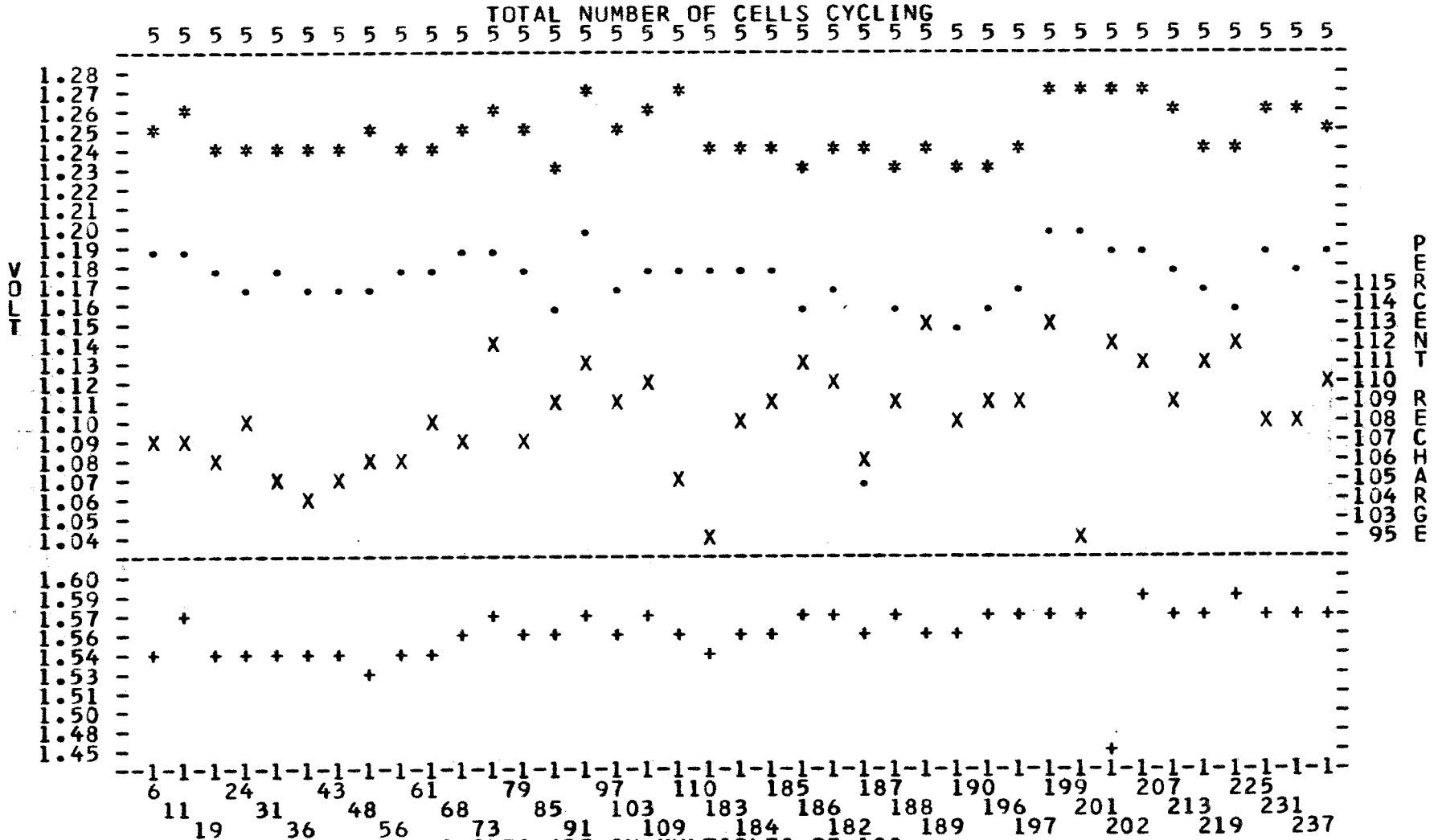


FIGURE 8

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

PACK 099C, MANUFACTURE GULTON 03.5 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.61
DEPTH OF DISCHARGE IN % 40

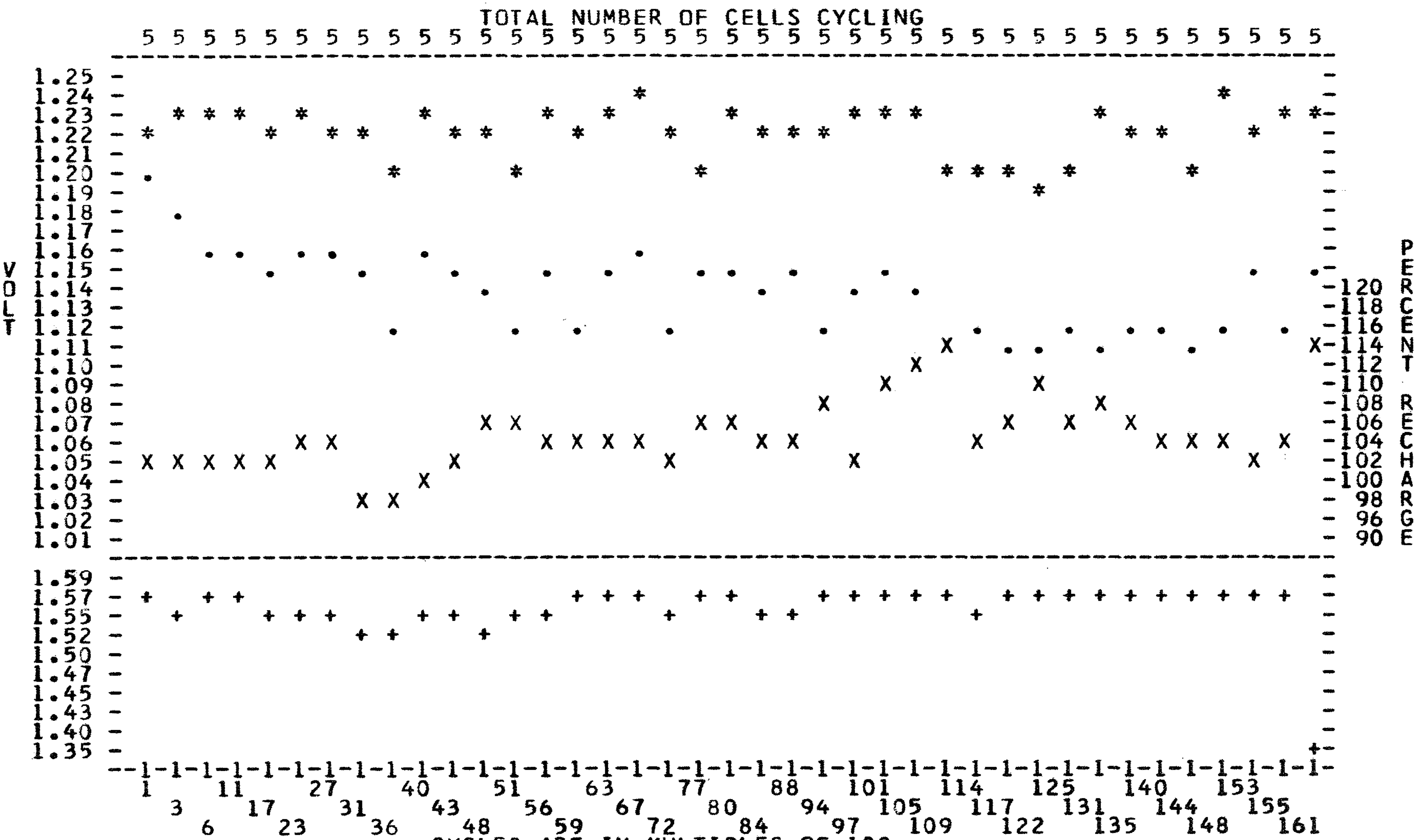


FIGURE 9

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

PACK 087C, MANUFACTURE GULTON 03.5 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 1.09
DEPTH OF DISCHARGE IN % 25

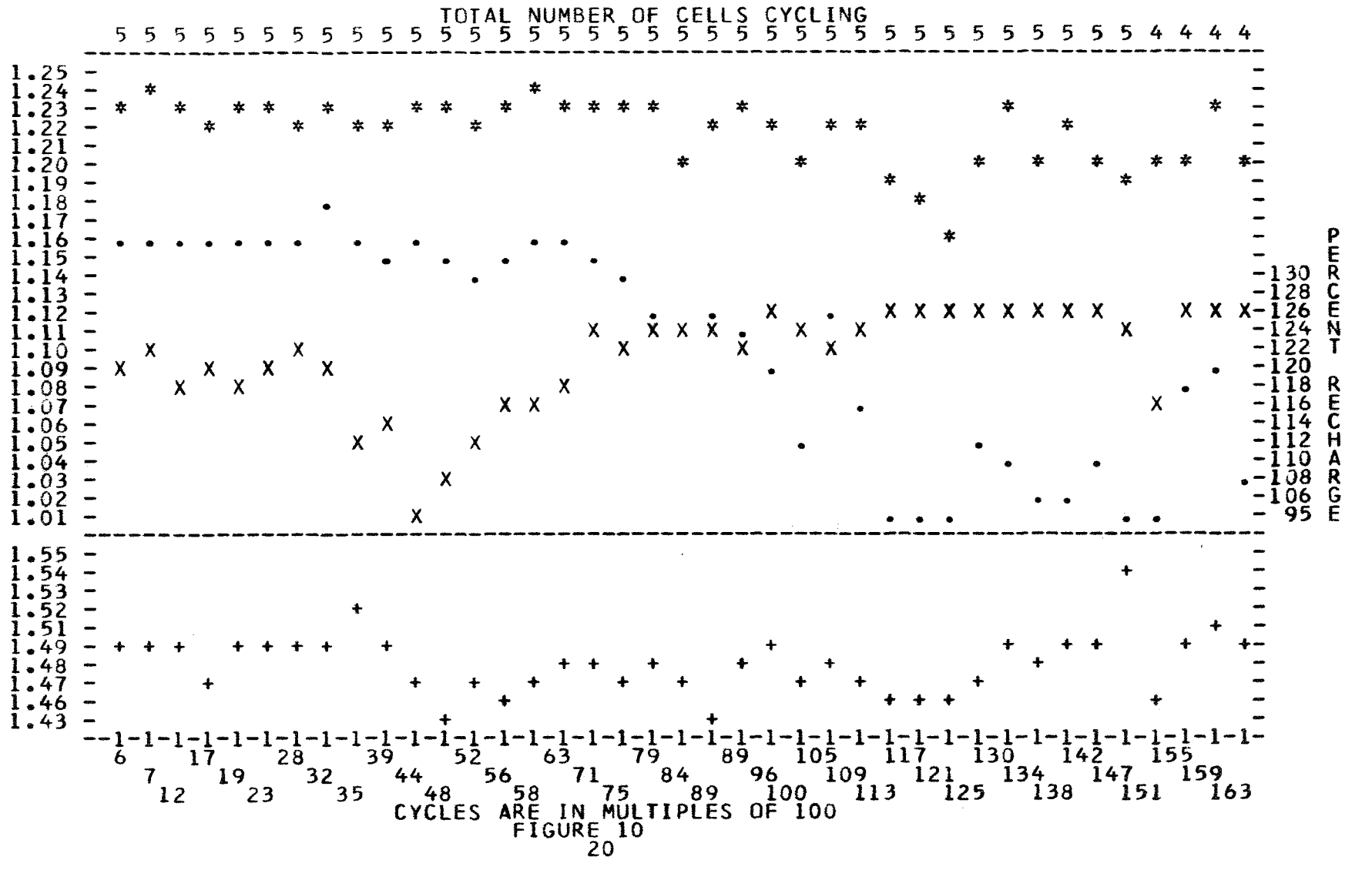


FIGURE 10

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

PACK 112C, MANUFACTURE GULTON 03.5 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 40
CHARGE RATE IN AMPS 1.40
DEPTH OF DISCHARGE IN % 25

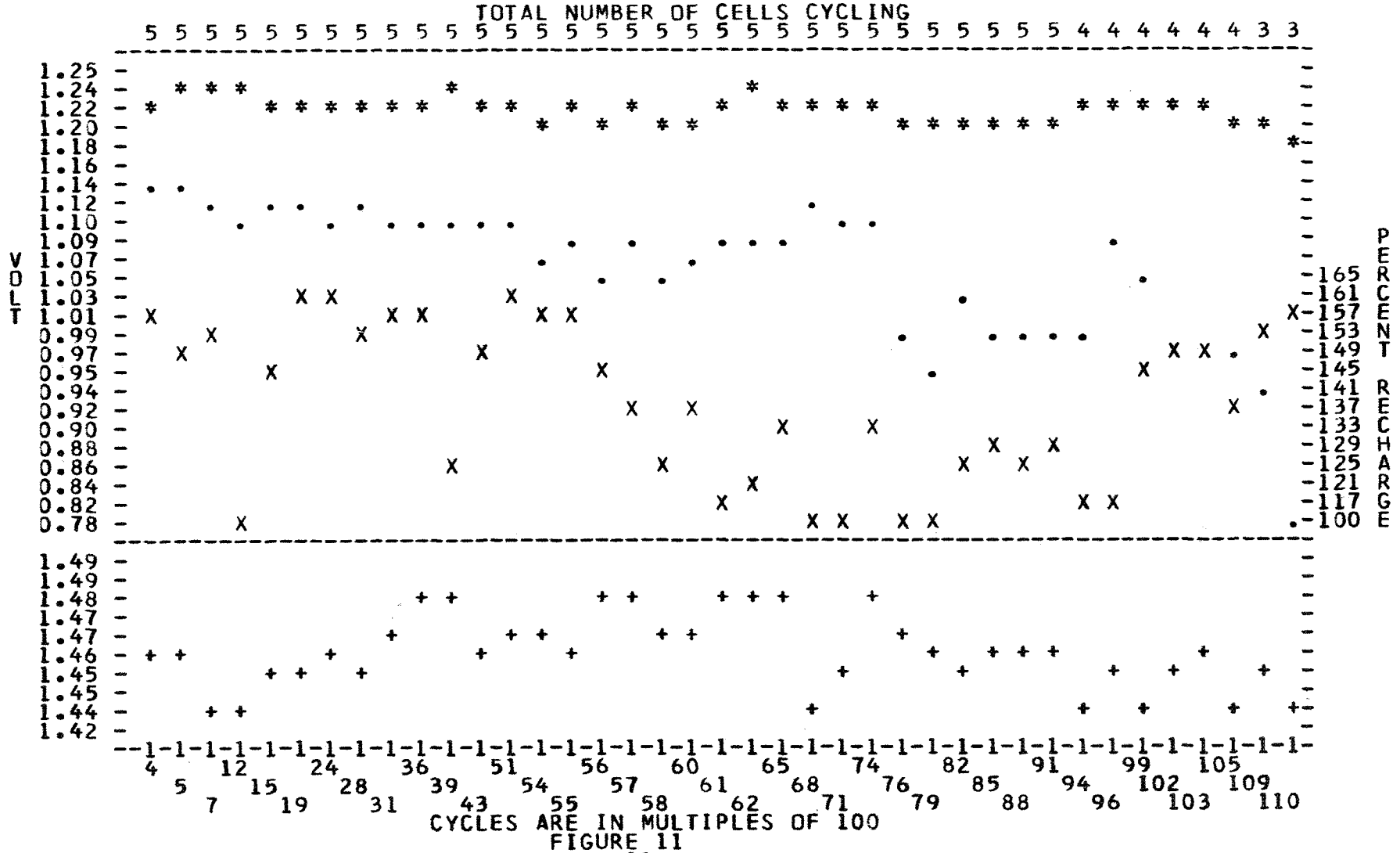


FIGURE 11

2. Gulton 4.0 ah (Commercial), Six 5-cell Packs, 1.5-hour Orbit Period:

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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
115B	0° C	15	115	1.55 ± 0.03
126B	0° C	25	115	1.55 ± 0.03
4B	25° C	25	125	1.49 ± 0.03
14B	25° C	40	125	1.49 ± 0.03
28B	40° C	15	160	1.45 ± 0.03
40B	40° C	25	160	1.45 ± 0.03

c. Test Results:

(1) Performance on Cycling: (Figures 12 through 14) Cycling was started in August 1964. Packs 115B, 126B and 4B have completed 29,929, 30,330 and 30,335 cycles, respectively, with one cell failure in Pack 4B. Pack 14B failed on cycle 8474, pack 28B on cycle 20,227 and pack 40B on cycle 10,360.

(2) Failure Analysis: The analysis of 10 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. Failure analysis has not been performed on the eleventh cell because of the pack construction.

(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	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
176 Days Disch #2	4.03	3.87	2.07	2.07	1.67	1.13
264 Days Disch #2	4.00	3.73	1.80	1.87	1.43	1.30
352 Days Disch #2	3.50	3.67	1.83	1.93	1.53	0.96
440 Days Disch #2	4.07	3.60	1.67	1.93	1.53	1.17
528 Days Disch #2	4.03	3.93	1.60	1.67 F	1.75	0.93
616 Days Disch #2	4.60	3.03	1.60		1.67	0.76 F
704 Days Disch #2	4.07	3.63	1.63		1.70	
792 Days Disch #2	4.33	3.63	1.67		1.77	
880 Days Disch #2	3.77	3.50	1.63		1.87	
968 Days Disch #2	4.03	3.37	1.67		2.07	
1056 Days Disch #2	3.80	3.30	1.57		1.97	
1144 Days Disch #2	3.67	3.37	1.30		0.47	
1232 Days Disch #2	3.50	3.37	1.70		2.10	
1320 Days Disch #2	3.63	3.27	1.47		1.73 F	
1408 Days Disch #2	3.47	3.33	1.50			
1496 Days Disch #2	3.40	3.10	1.33			
1584 Days Disch #2	3.27	3.03	1.40			
1672 Days Disch #2	3.17	3.00	1.70			
1760 Days Disch #2	3.23		1.27			

F - Failed

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

PACK 115B, MANUFACTURE GULTON 04.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.69
DEPTH OF DISCHARGE IN % 15

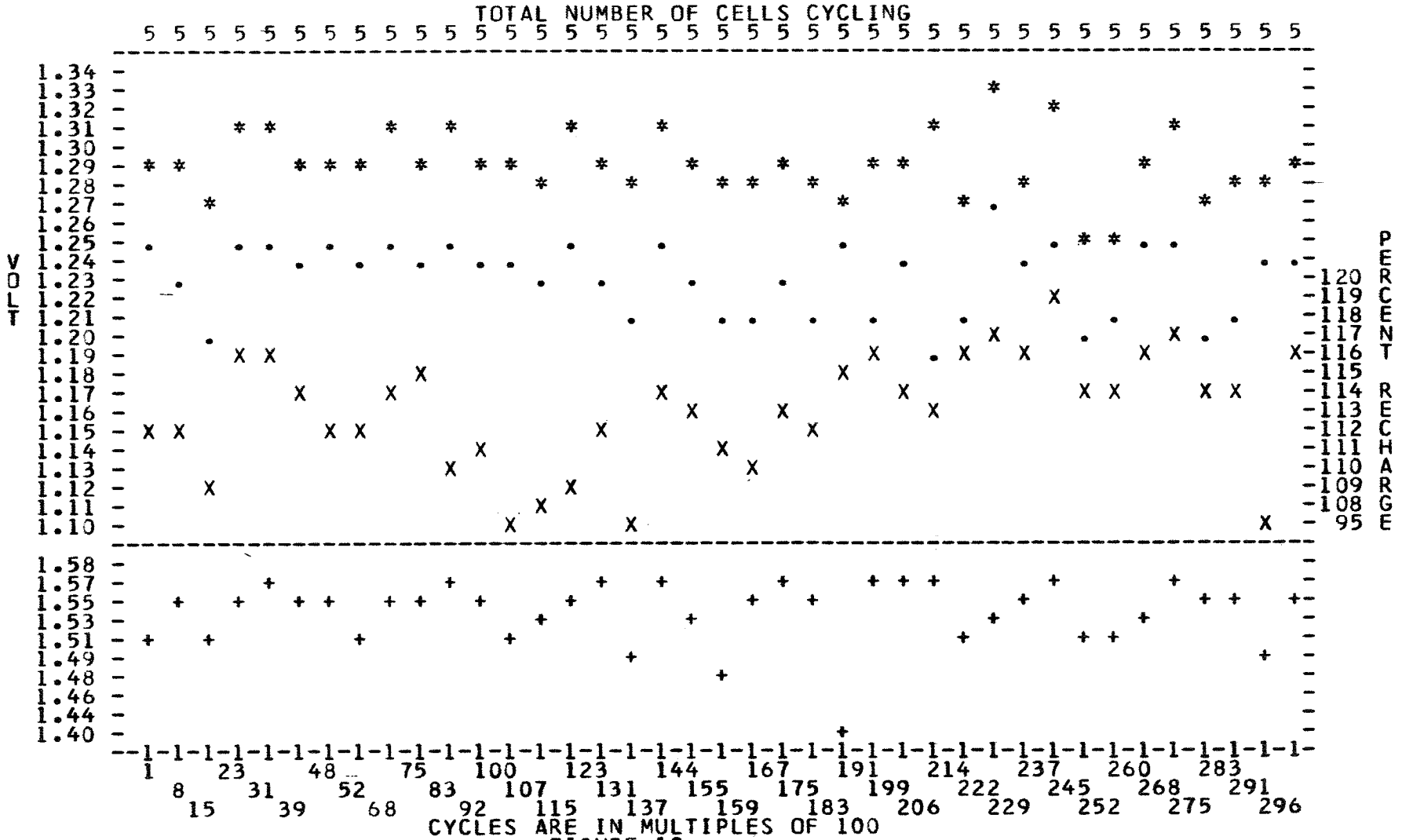


FIGURE 12

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

PACK 126B, MANUFACTURE GULTON 04.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.15
DEPTH OF DISCHARGE IN % 25

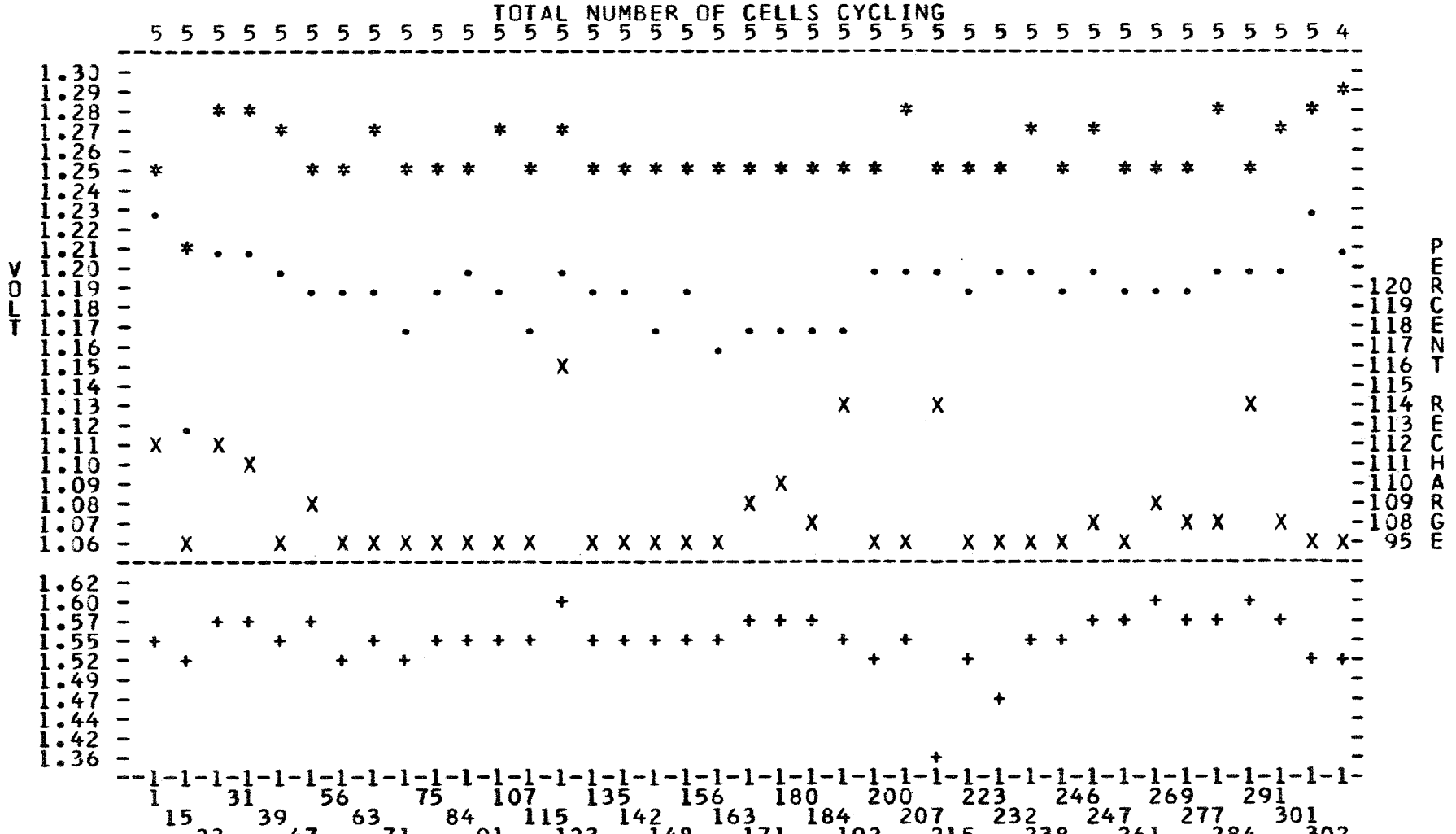


FIGURE 13

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

PACK 004B, MANUFACTURE GULTON 04.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 1.25
DEPTH OF DISCHARGE IN % 25

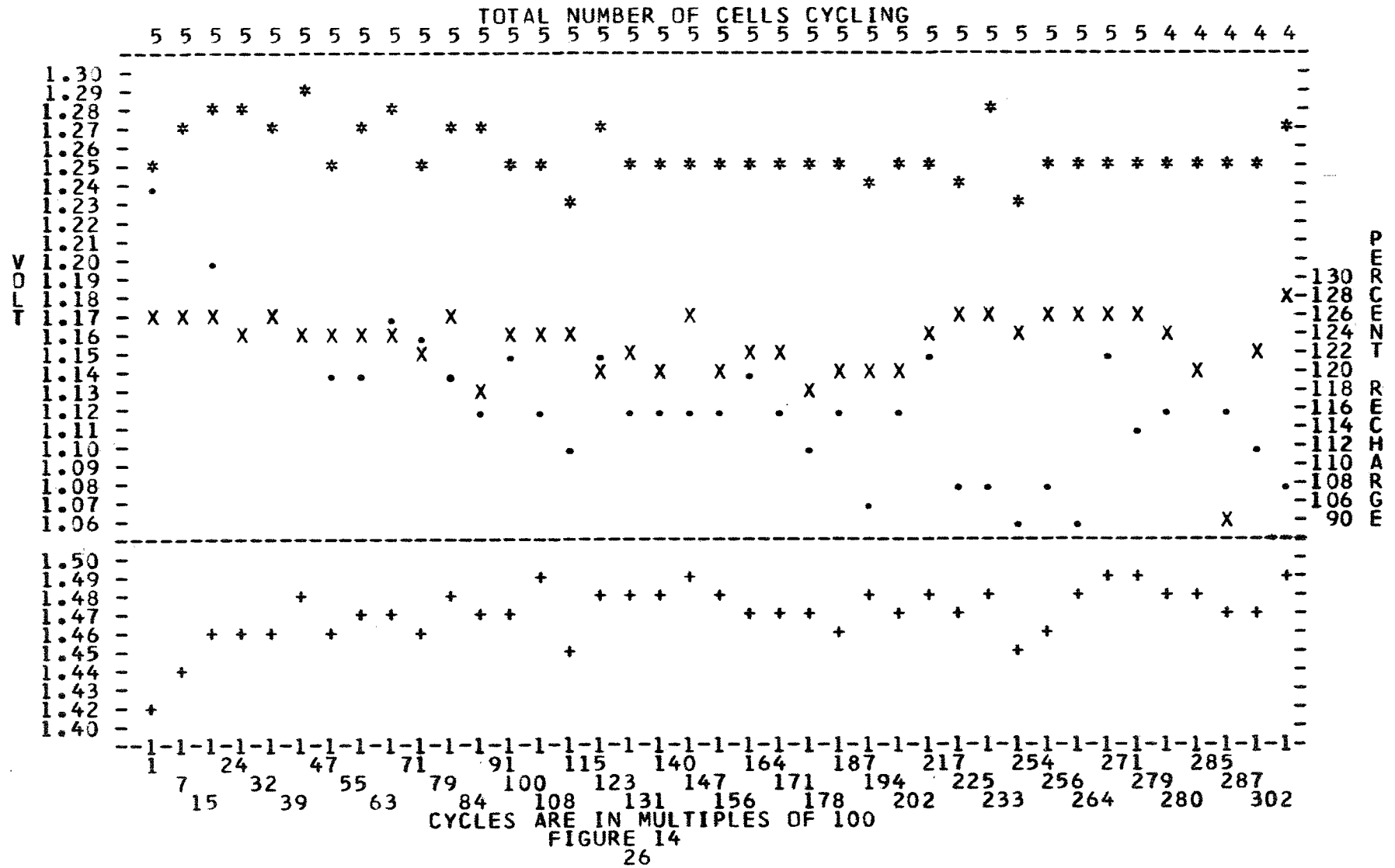


FIGURE 14

3. Gulton 5.0 ah (NIMBUS), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are cylindrical in shape 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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
117A	0° C	15	110	1.49 ± 0.03
121A*	0° C	25	110	1.49 ± 0.03
120A	25° C	15	120	1.49 ± 0.03
118B*	25° C	25	120	1.49 ± 0.03
127A	40° C	15	130	1.49 ± 0.03
128A	40° C	25	130	1.49 ± 0.03

* One cell in each of these packs is equipped with a pressure transducer.

c. Test Results:

(1) Performance on Cycling: (Figures 15 and 16) Cycling was started in May 1965. Packs 117A and 120A have completed 25,681 and 24,716 cycles, respectively, with one cell failure in Pack 120A. Packs 121A, 118B, 127A and 128A failed on cycles 20,861, 8108, 10,638 and 6345, respectively.

(2) Failure Analysis: Analysis of the 12 failed 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 material, pierced separators material by the positive tab, short (vertical height) separators and high internal pressure.

(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		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
176 Days	Disch #2	5.46	5.33	4.17	1.67	1.50	1.54
264 Days	Disch #2	5.17	5.00	2.79	1.50	1.38	1.71
352 Days	Disch #2	4.75	4.46	2.33	1.67	1.42	1.83 F
440 Days	Disch #2	4.75	4.29	2.08	2.00 F	1.71	
528 Days	Disch #2	4.50	3.96	*		2.25	
616 Days	Disch #2	4.70	3.96	*		2.04 F	
704 Days	Disch #2	4.42	3.96	3.58			
792 Days	Disch #2	4.08	4.08	3.21			
880 Days	Disch #2	4.04	3.96	3.00			
968 Days	Disch #2	4.17	3.79	2.58			
1056 Days	Disch #2	4.04	3.83	2.37			
1144 Days	Disch #2	3.83	3.67	2.37			
1232 Days	Disch #2	4.62	3.54 F	2.42			
1320 Days	Disch #2	4.46		2.12			
1408 Days	Disch #2	4.17		2.12			
1496 Days	Disch #2	4.50		1.79			

* Capacity check not performed
F - Failed

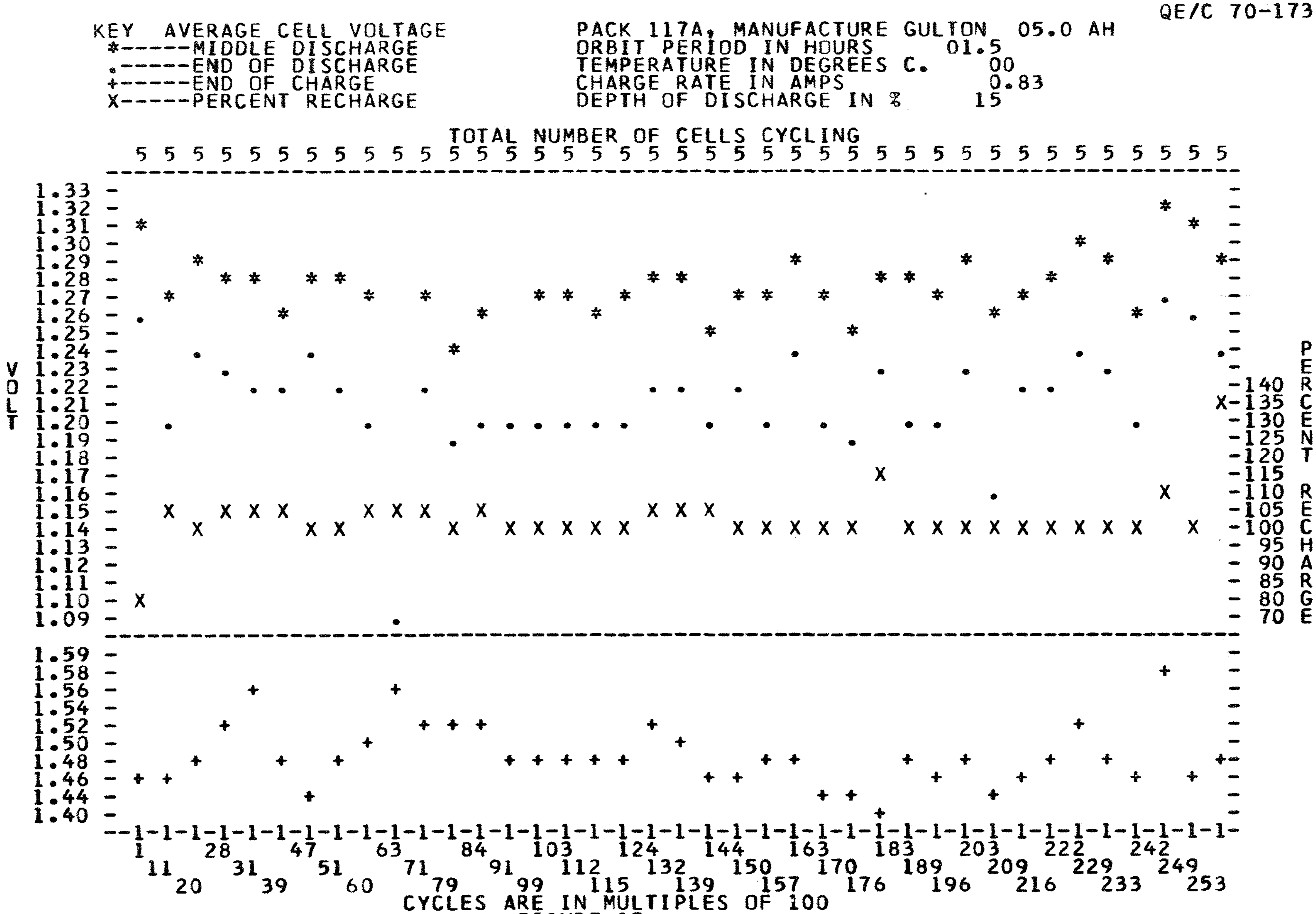
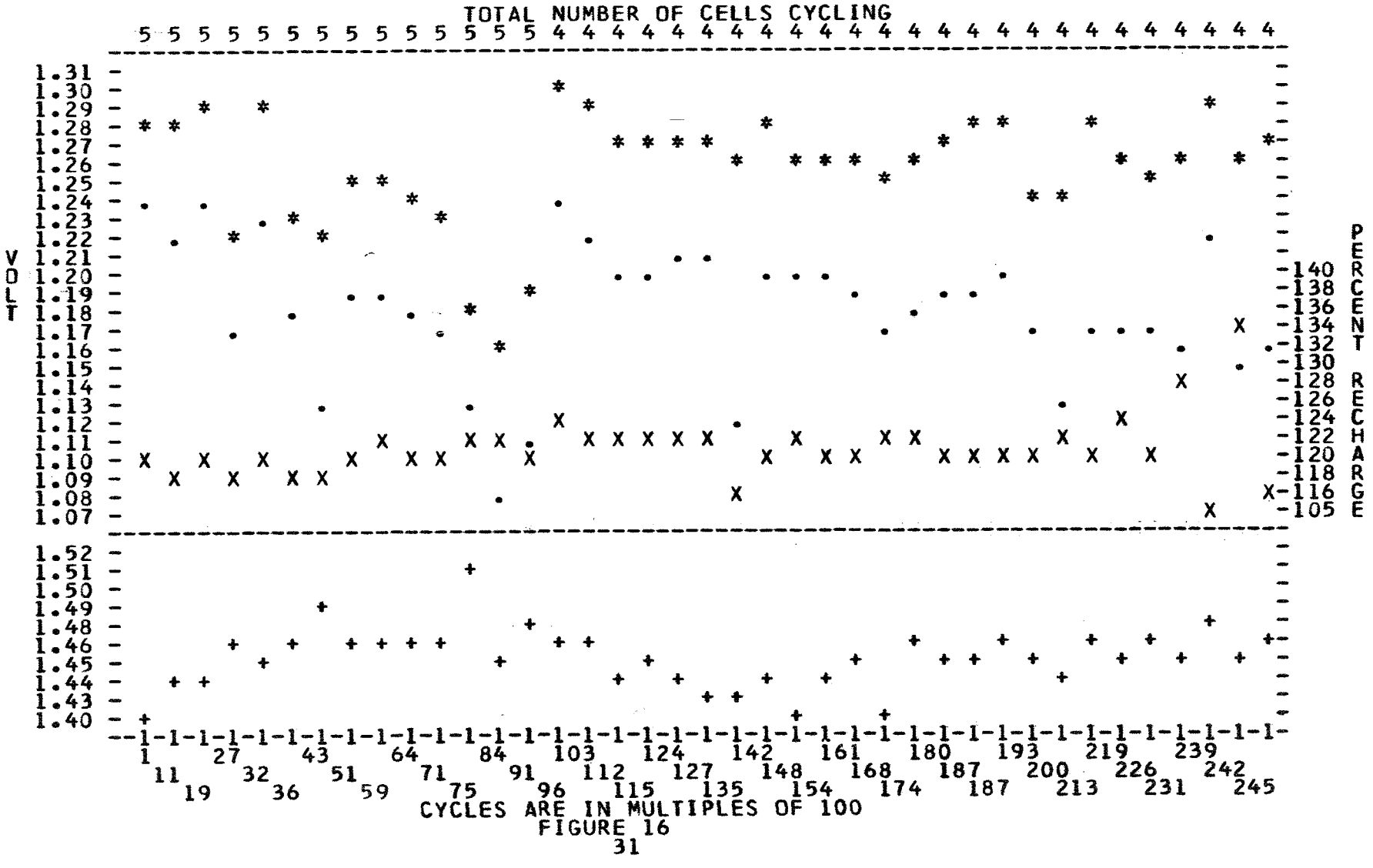

KEY AVERAGE CELL VOLTAGE
*-----MIDDLE DISCHARGE
.-----END OF DISCHARGE
+-----END OF CHARGE
X-----PERCENT RECHARGE
PACK 117A, MANUFACTURE GULTON 05.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.83
DEPTH OF DISCHARGE IN % 15
TOTAL NUMBER OF CELLS CYCLING
5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
VOLT
1.33 1.32 1.31 1.30 1.29 1.28 1.27 1.26 1.25 1.24 1.23 1.22 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
1.59 1.58 1.56 1.54 1.52 1.50 1.48 1.46 1.44 1.40
PERCENT RECHARGE
140 135 130 125 120 115 110 105 100 95 90 85 80 70
1 11 20 28 31 39 47 51 60 63 71 79 84 91 99 103 112 115 124 132 139 144 150 157 163 170 176 183 189 196 203 209 216 222 229 233 242 249 253
CYCLES ARE IN MULTIPLES OF 100

FIGURE 15

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

PACK 120A, MANUFACTURE GULTON 05.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 0.90
DEPTH OF DISCHARGE IN % 15



CYCLES ARE IN MULTIPLES OF 100

FIGURE 16

4. Gulton 5.6 ah (Neoprene Seal), Eight 5-cell Packs, 1.5-hour Orbit Period:

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 17). 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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell	Seal
44B	-20° C	25	115	1.55 ± 0.03	Folded
32B	-20° C	25	115	1.55 ± 0.03	Nonfolded
100B	0° C	25	115	1.55 ± 0.03	Folded
90C	0° C	25	115	1.55 ± 0.03	Nonfolded
76B	25° C	25	125	1.49 ± 0.03	Folded
96C	25° C	25	125	1.49 ± 0.03	Nonfolded
42B	40° C	25	160	1.45 ± 0.03	Folded
30B	40° C	25	160	1.45 ± 0.03	Nonfolded

c. Test Results:

(1) Performance on Cycling: (Figures 18 through 21) Cycling was started in December 1965. Packs 44B, 32B, 100B and 90C have completed 22,152, 22,040, 22,369 and 22,454 cycles,

respectively with a total of four cell failures. Pack 76B failed on cycle 11,158, pack 96C on cycle 9791, pack 42B on cycle 3798 and pack 30B on cycle 1275.

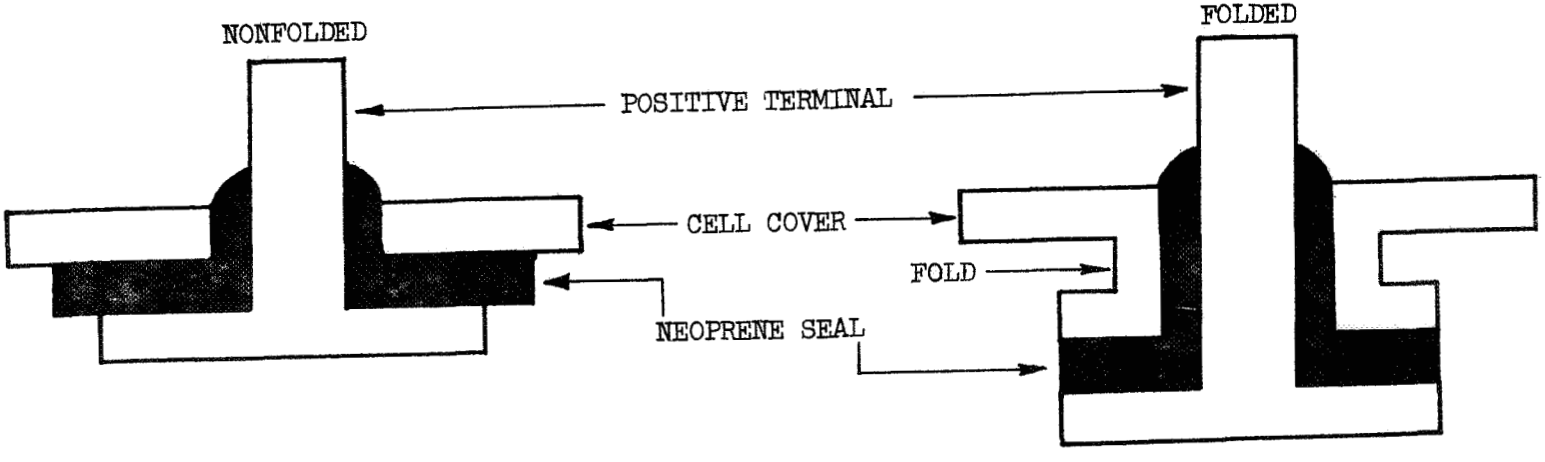
(2) Failure Analysis: Failure analysis of the 16 failed cells showed the major cause to be separator deterioration, migration of the negative plate material, electrolyte leakage, and burned positive tabs. Other conditions found were weak positive tab-to-plate welds, burned positive tabs, and high internal pressure.

(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°	-20°	0°	0°	25°	25°	40°	40°
Depth of Discharge		25%	25%	25%	25%	25%	25%	25%	25%
Pack Number		44B	32B	100B	90C	76B	96C	42B	30B
Precycling Capacity		4.01	4.53	6.25	6.58	5.60	6.30	4.39	4.90 F
88 Days	Disch #2	4.67	4.57	5.32	5.88	1.63	2.33	1.49	
176 Days	Disch #2	4.34	4.67	4.85	5.50	1.59	2.24	1.35 F	
264 Days	Disch #2	3.36	3.64	4.39	5.27	1.59	1.87		
352 Days	Disch #2	3.36	3.45	4.25	4.85	1.63	2.85		
440 Days	Disch #2	3.64	3.64	3.83	4.48	2.10	2.33		
528 Days	Disch #2	3.27	3.27	3.64	3.97	1.49	2.38 F		
616 Days	Disch #2	3.41	3.17	3.50	3.64	1.17 F			
704 Days	Disch #2	4.48	2.99	2.75	3.27				
792 Days	Disch #2	3.87	2.85	2.75	3.08				
880 Days	Disch #2	4.53	2.95	2.61	2.75				
968 Days	Disch #2	2.66	2.10	2.33	2.57				
1056 Days	Disch #2	2.85	2.61	2.05	3.22				
1144 Days	Disch #2	2.71	2.33	2.24	3.17				
1232 Days	Disch #2			2.01	2.89				

F - Failed



CROSS SECTION OF NEOPRENE SEAL

FIGURE 17

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

PACK 044B, MANUFACTURE GULTON 05.6 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. -20
CHARGE RATE IN AMPS 1.61
DEPTH OF DISCHARGE IN % 25

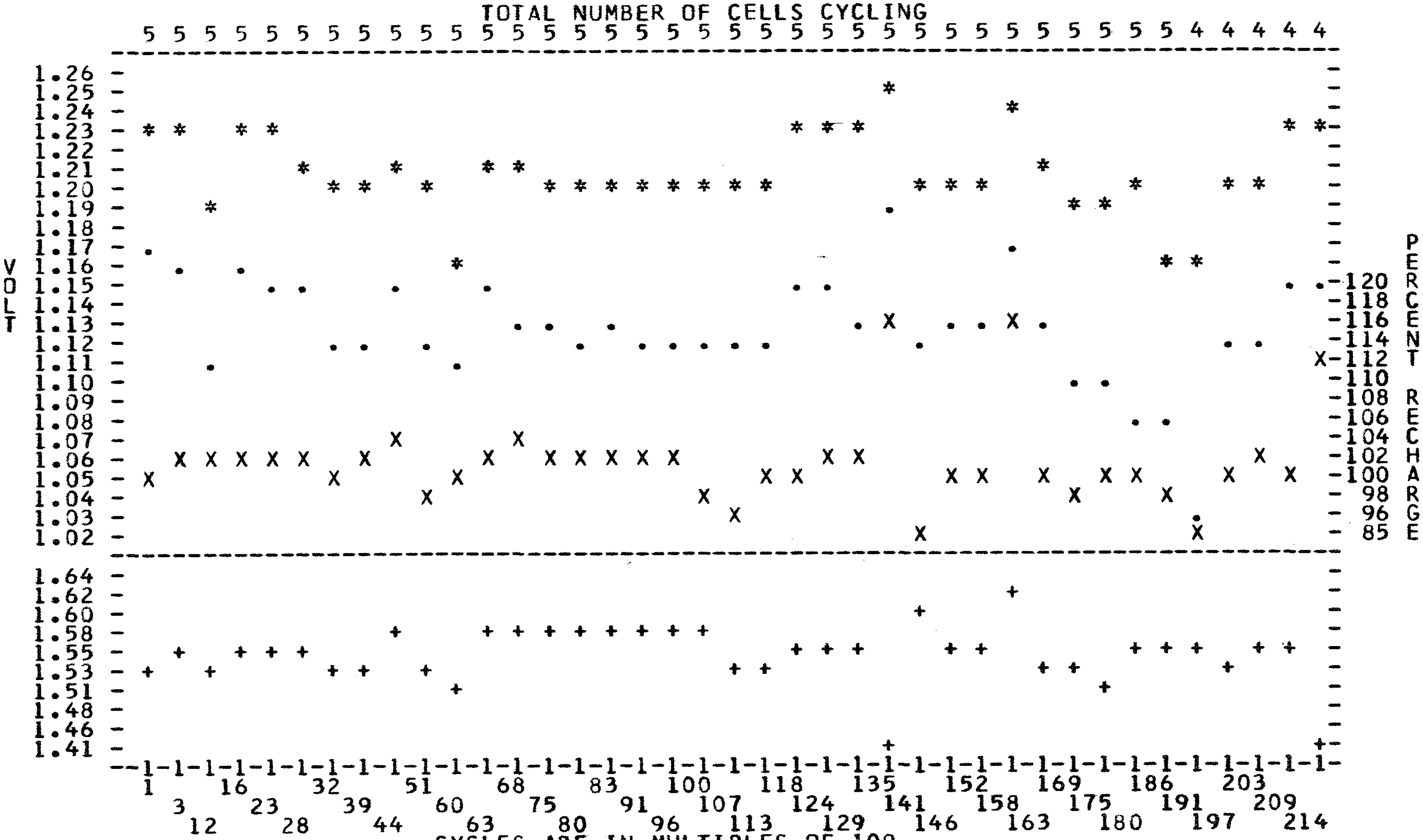


FIGURE 18

QE/C 70-173

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

PACK 032B, MANUFACTURE GULTON 05.6 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. -20
CHARGE RATE IN AMPS 1.61
DEPTH OF DISCHARGE IN % 25

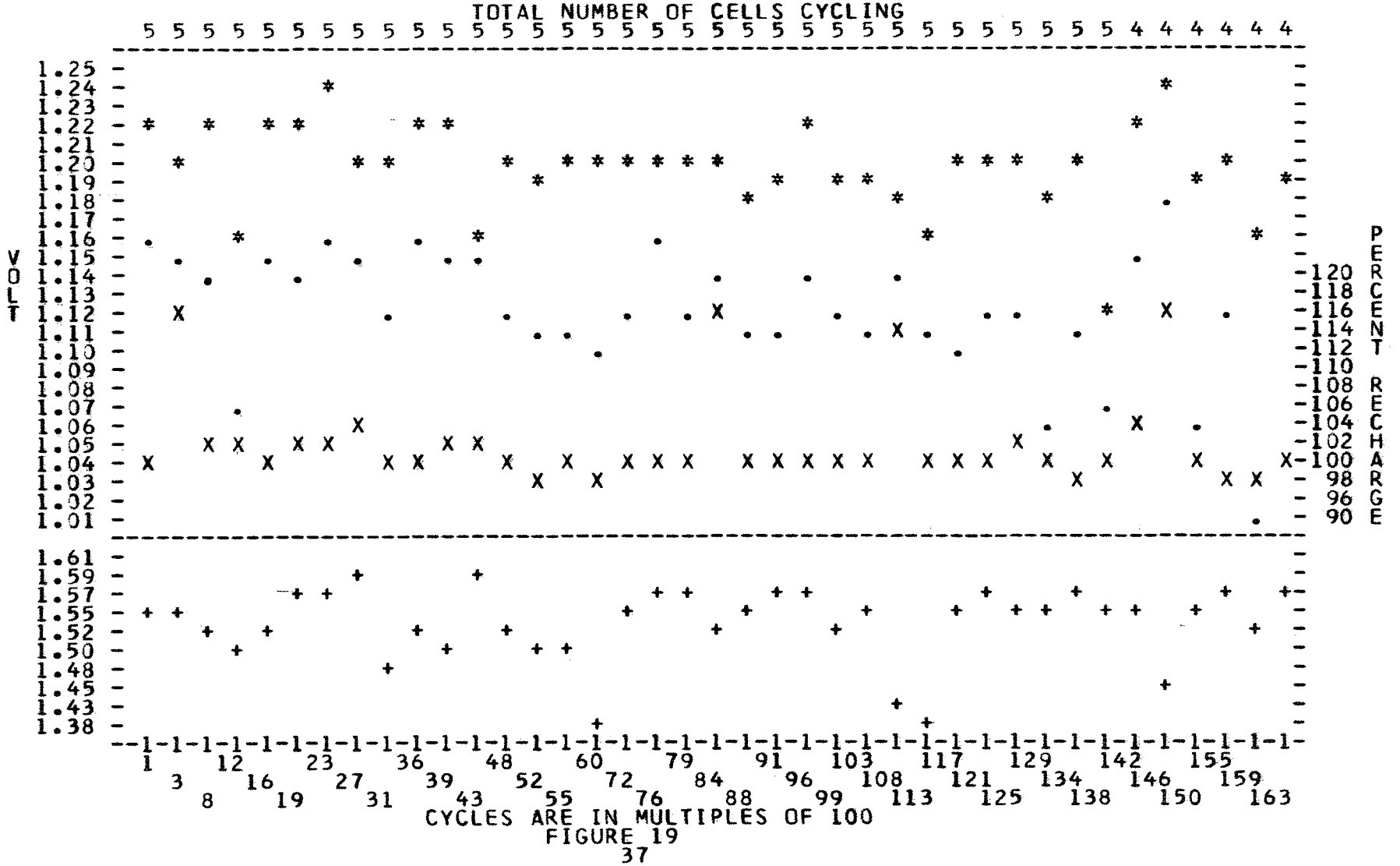


FIGURE 19

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

PACK 100B, MANUFACTURE GULTON 05.6 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.61
DEPTH OF DISCHARGE IN % 25

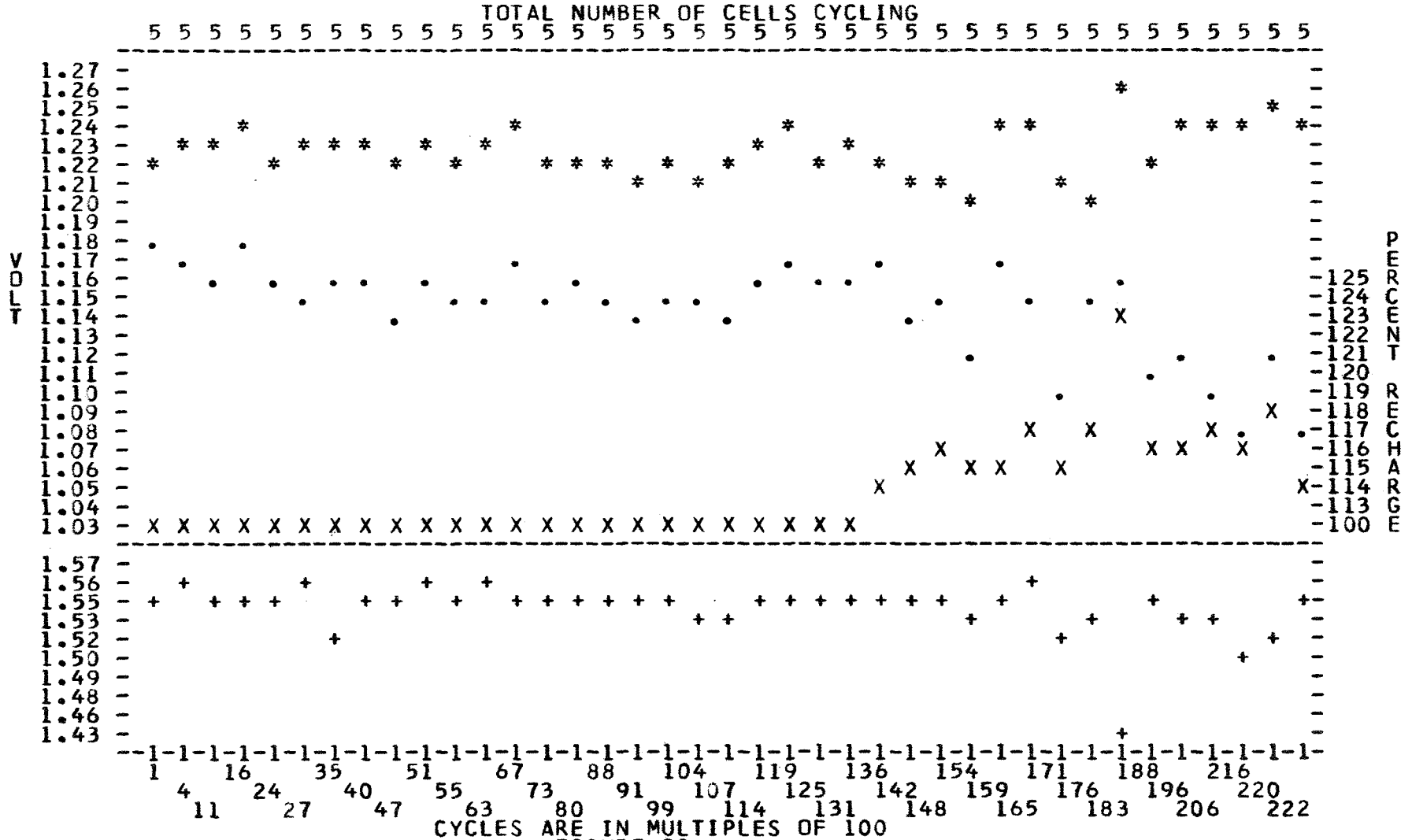


FIGURE 20

QE/C 70-173

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

PACK 090C, MANUFACTURE GULTON 05.6 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.61
DEPTH OF DISCHARGE IN % 25

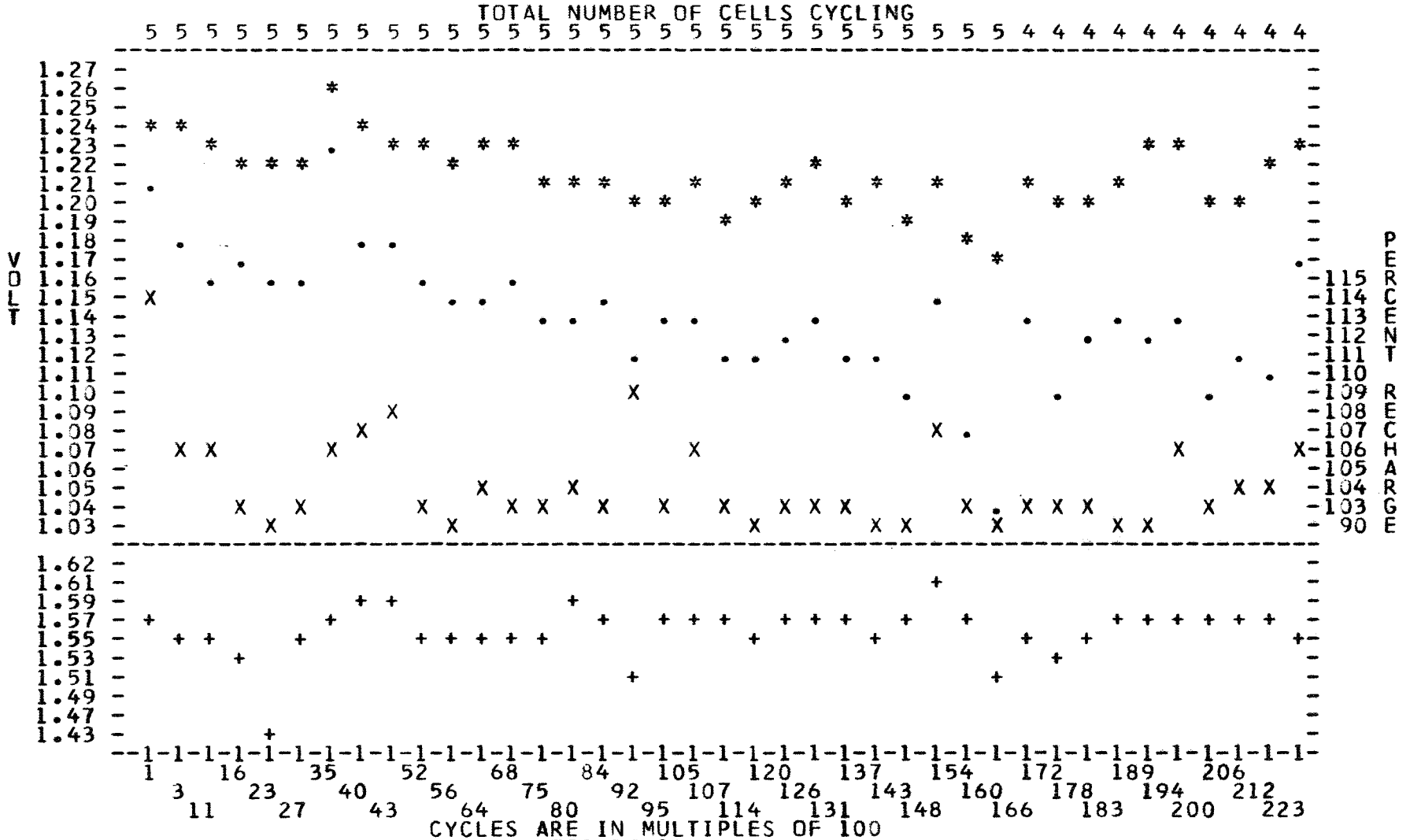


FIGURE 21

5. Gulton 6.0 ah (Improved), Three 5-cell Packs, 1.5-hour Orbit Period:

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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
13B	0° C	25	115	1.55 ± 0.03
18B	25° C	40	125	1.49 ± 0.03
38B	40° C	25	160	1.45 ± 0.03

c. Test Results:

(1) Performance on Cycling: (Figure 22) Cycling started in February 1965. Pack 13B has completed 27,157 cycles to date with one cell failure. Packs 18B and 38B failed on cycles 7577 and 5766, respectively.

(2) Failure Analysis: Failure analysis of seven 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 and high internal pressure.

(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		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
176 Days	Disch #2	7.25	3.60	2.00
264 Days	Disch #2	7.20	3.80	1.50
352 Days	Disch #2	7.00	3.05 F	2.80 F
440 Days	Disch #2	6.75		
528 Days	Disch #2	6.75		
616 Days	Disch #2	*		
704 Days	Disch #2	6.25		
792 Days	Disch #2	5.65		
880 Days	Disch #2	5.15		
968 Days	Disch #2	5.00		
1056 Days	Disch #2	4.80		
1144 Days	Disch #2	4.05		
1232 Days	Disch #2	4.15		
1320 Days	Disch #2	4.00		
1408 Days	Disch #2	*		
1496 Days	Disch #2	3.75		

* Capacity check not performed
F - Failed

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

PACK 013B, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.73
DEPTH OF DISCHARGE IN % 25

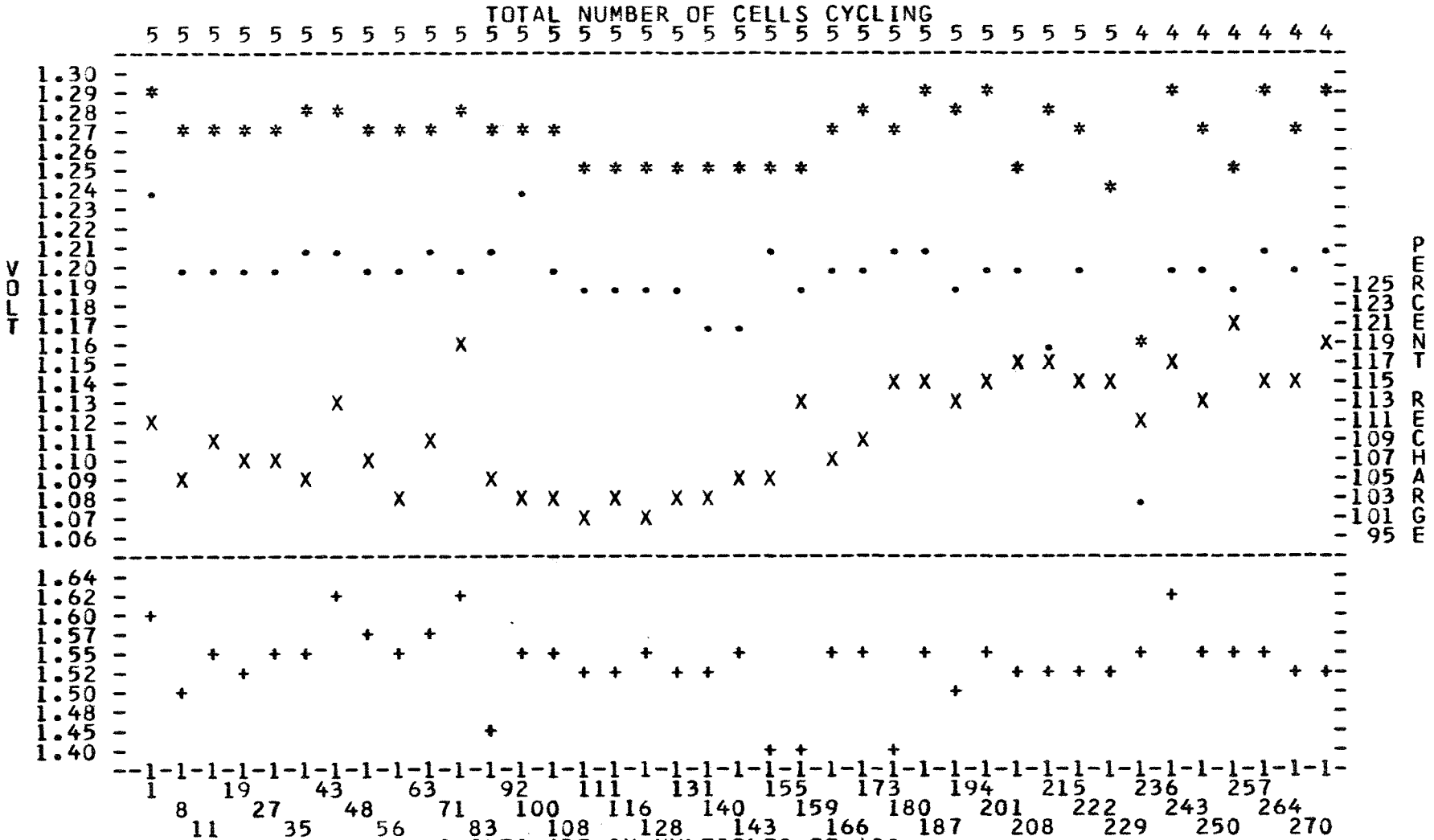


FIGURE 22

6. Gulton 6.0 ah, One 5-cell Pack, 1.5-hour Orbit Period (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) Percent of Recharge: 110%.

(d) Charge Voltage: 1.55 $\pm$ 0.03 volts per cell, average.

(e) 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. Test Results:

(1) Performance on Cycling: (Figure 23) Cycling started at NAD Crane in June 1967. This pack has completed 14,217 additional cycles at 0° C with no cell failures.

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

(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	0°
Depth of Discharge	10%
Pack Number	61B
Precycling Capacity	5.30
88 Days Disch #2	5.40
176 Days Disch #2	5.50
264 Days Disch #2	5.45
352 Days Disch #2	4.95
440 Days Disch #2	4.70
528 Days Disch #2	3.95
616 Days Disch #2	3.75
704 Days Disch #2	3.35
792 Days Disch #2	3.40

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

PACK 061B, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.66
DEPTH OF DISCHARGE IN % 10

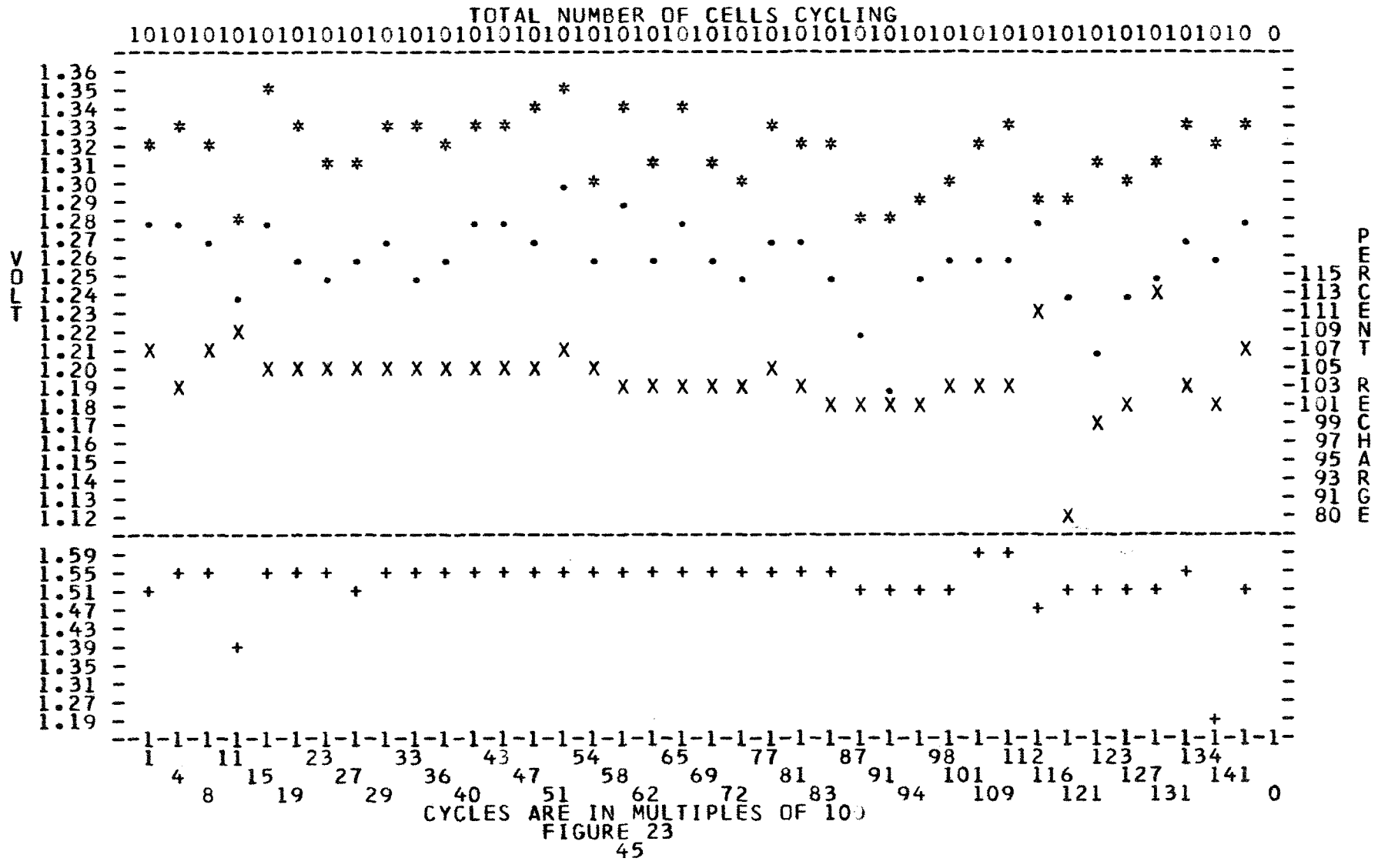

FIGURE 23

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

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. Four of the 10 cells are from the same lot of cells used for the Test and Training (TETR) satellite.

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 24) Cycling started in February 1969. This pack has completed 4541 cycles. The 1.5-ampere discharge has been 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 are run on these cells.

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

PACK 051B, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 20
CHARGE RATE IN AMPS 0.30
DEPTH OF DISCHARGE IN % .8

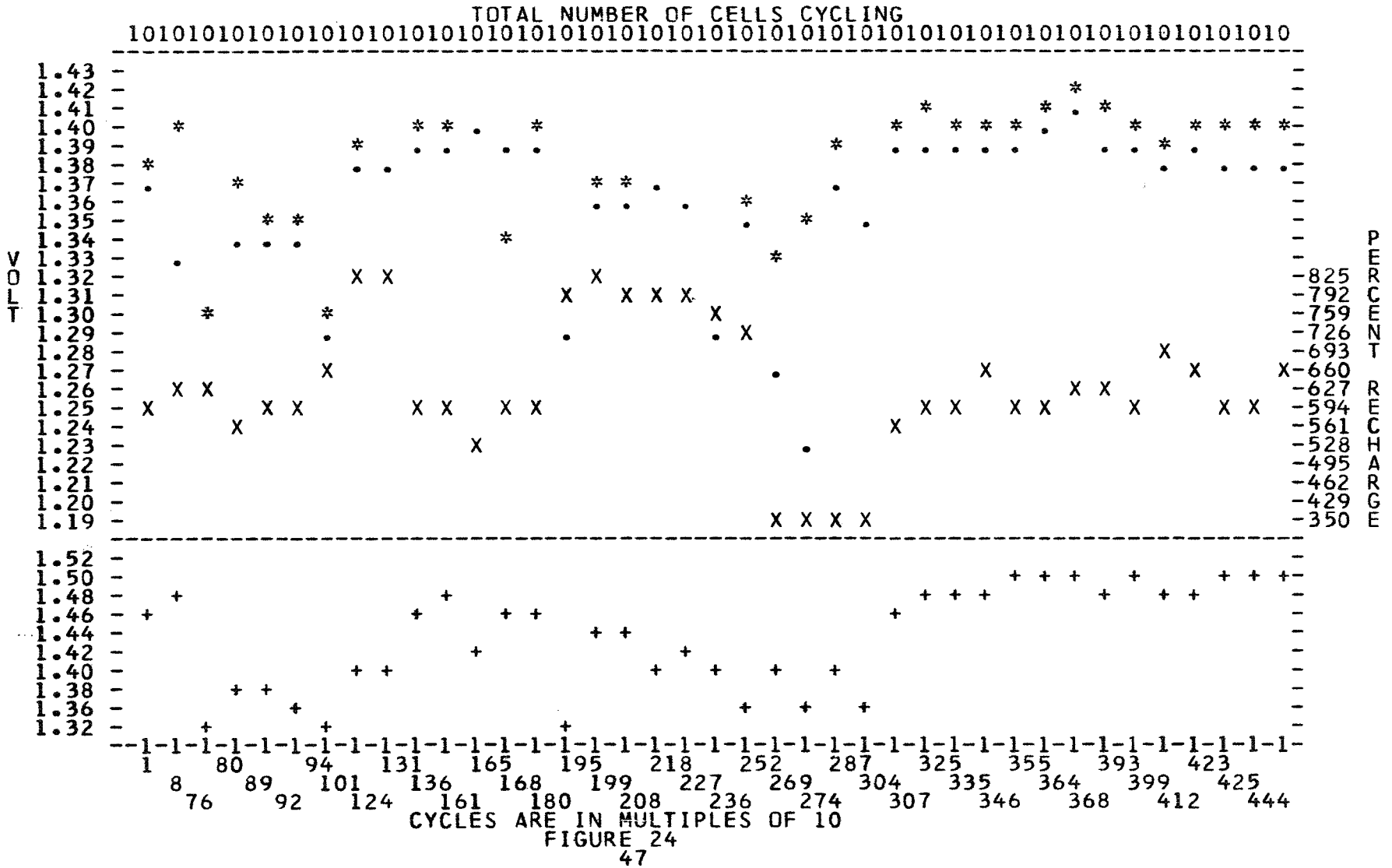

FIGURE 24

8. Gulton 12.0 ah (OGO), 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 a ceramic seal and protrude through the cover as solder type terminals. These cells were designed for use in the OGO Satellite.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
16B	0° C	15	115	1.55 ± 0.03
101B	0° C	25	115	1.55 ± 0.03
27B	25° C	25	125	1.49 ± 0.03
96B	25° C	40	125	1.49 ± 0.03
78A	40° C	15	160	1.45 ± 0.03
90B	40° C	25	160	1.45 ± 0.03

c. Test Results:

(1) Performance on Cycling: (Figures 25 and 26) Cycling was started in January 1966. Packs 16B and 101B have completed 27,018 and 27,808 cycles, respectively. Packs 27B, 96B, 78A and 90B failed on cycles 14,250, 5152, 11,081 and 5124, respectively.

(2) Failure Analysis: Analysis of the 13 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 and extraneous active material.

(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		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
176 Days	Disch #2	14.10	14.40	3.50	5.40	3.10	3.60
264 Days	Disch #2	14.20	12.90	4.10	5.00 F	3.30	3.70 F
352 Days	Disch #2	13.70	13.00	4.20		3.40	
440 Days	Disch #2	13.70	11.90	4.80		3.40	
528 Days	Disch #2	12.40	11.00	5.10		3.20	
616 Days	Disch #2	13.10	10.60	4.00		5.30 F	
704 Days	Disch #2	12.80	10.20	4.30			
792 Days	Disch #2	12.70	9.00	3.90 F			
880 Days	Disch #2	12.30	8.88				
968 Days	Disch #2	11.80	9.00				
1056 Days	Disch #2	11.60	8.40				
1144 Days	Disch #2	11.50	8.80				
1232 Days	Disch #2	11.00	8.40				
1320 Days	Disch #2	10.50	8.10				
1408 Days	Disch #2	10.50	7.70				
1496 Days	Disch #2	10.30	7.80				
1584 Days	Disch #2	9.80	8.00				

F - Failed

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

PACK 0168, MANUFACTURE GULTON 12.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 2.07
DEPTH OF DISCHARGE IN % 15

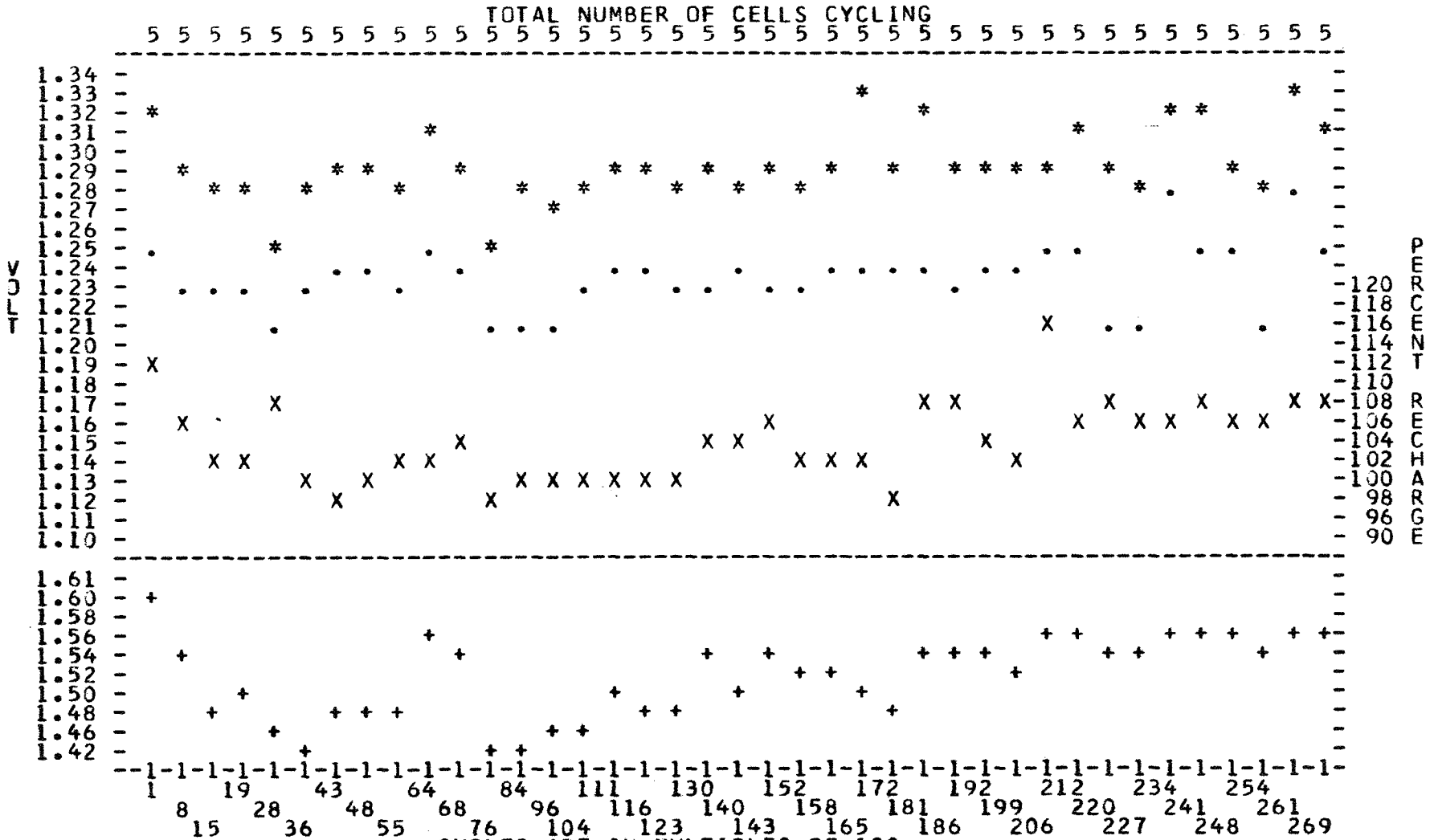

FIGURE 25

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

PACK 101B, MANUFACTURE GULTON 12.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 3.45
DEPTH OF DISCHARGE IN % 25

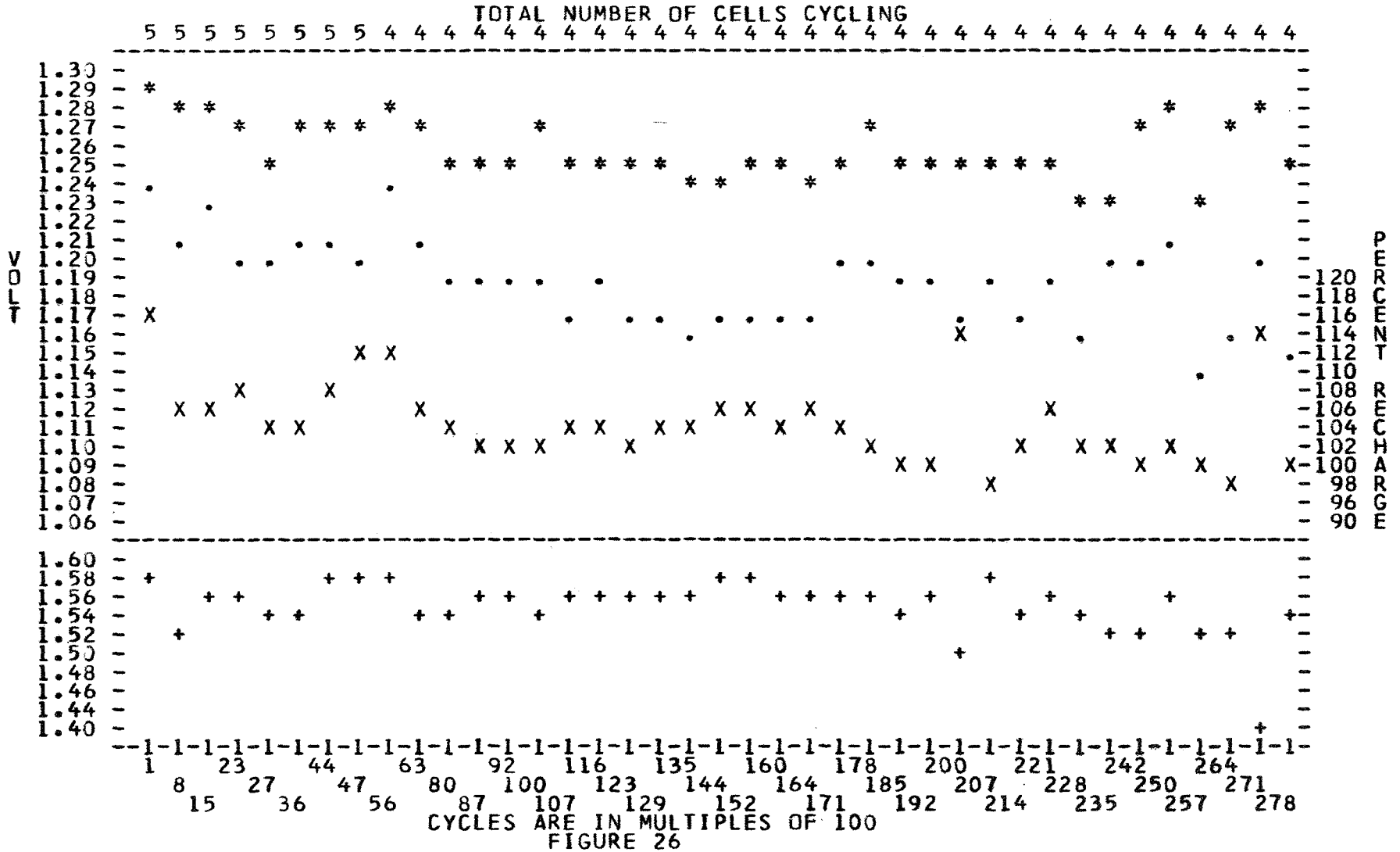

FIGURE 26

9. GE 5.0 ah (NIMBUS), Six 5-cell Packs, 1.5-hour Orbit Period:

a. Cell Description: These cells are cylindrical in shape 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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
103A	0° C	15	110	1.49 ± 0.03
107A*	0° C	25	110	1.49 ± 0.03
106A	25° C	15	120	1.49 ± 0.03
104B*	25° C	25	120	1.49 ± 0.03
113A	40° C	15	130	1.49 ± 0.03
114A*	40° C	25	130	1.49 ± 0.03

* One cell in these packs is equipped with a pressure transducer.

c. Test Results:

(1) Performance on Cycling: (Figures 27 through 29) Cycling was started in May 1965. Packs 103A, 107A and 106A have completed 26,111, 25,482 and 26,013 cycles, respectively. Packs 104B, 113A and 114A failed on cycles 13,149, 4998 and 8273, respectively.

(2) Failure Analysis: Analysis of the nine 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, and blistering on the positive plates. 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.

(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		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
176 Days	Disch #2	5.38	5.46	4.13	2.54	2.25	1.71
264 Days	Disch #2	5.58	5.33	3.50	1.75	1.83 F	1.63
352 Days	Disch #2	5.42	5.17	3.21	2.04		1.21
440 Days	Disch #2	5.54	5.42	3.08	2.00		1.00 F
528 Days	Disch #2	5.13	4.83	3.04	1.46		
616 Days	Disch #2	4.75	4.58	3.25	1.83		
704 Days	Disch #2	5.00	4.25	3.42	1.38 F		
792 Days	Disch #2	5.08	5.25	3.13			
880 Days	Disch #2	5.04	4.46	3.00			
968 Days	Disch #2	5.17	4.46	2.92			
1056 Days	Disch #2	4.87	4.37	3.00			
1144 Days	Disch #2	5.08	4.21	2.58			
1232 Days	Disch #2	4.79	4.29	2.92			
1320 Days	Disch #2	4.75	4.42	2.46			
1408 Days	Disch #2	4.21	4.08	2.37			
1496 Days	Disch #2	4.67	4.37	1.21			

F - Failed

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

PACK 103A, MANUFACTURE GE 05.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.83
DEPTH OF DISCHARGE IN % 15

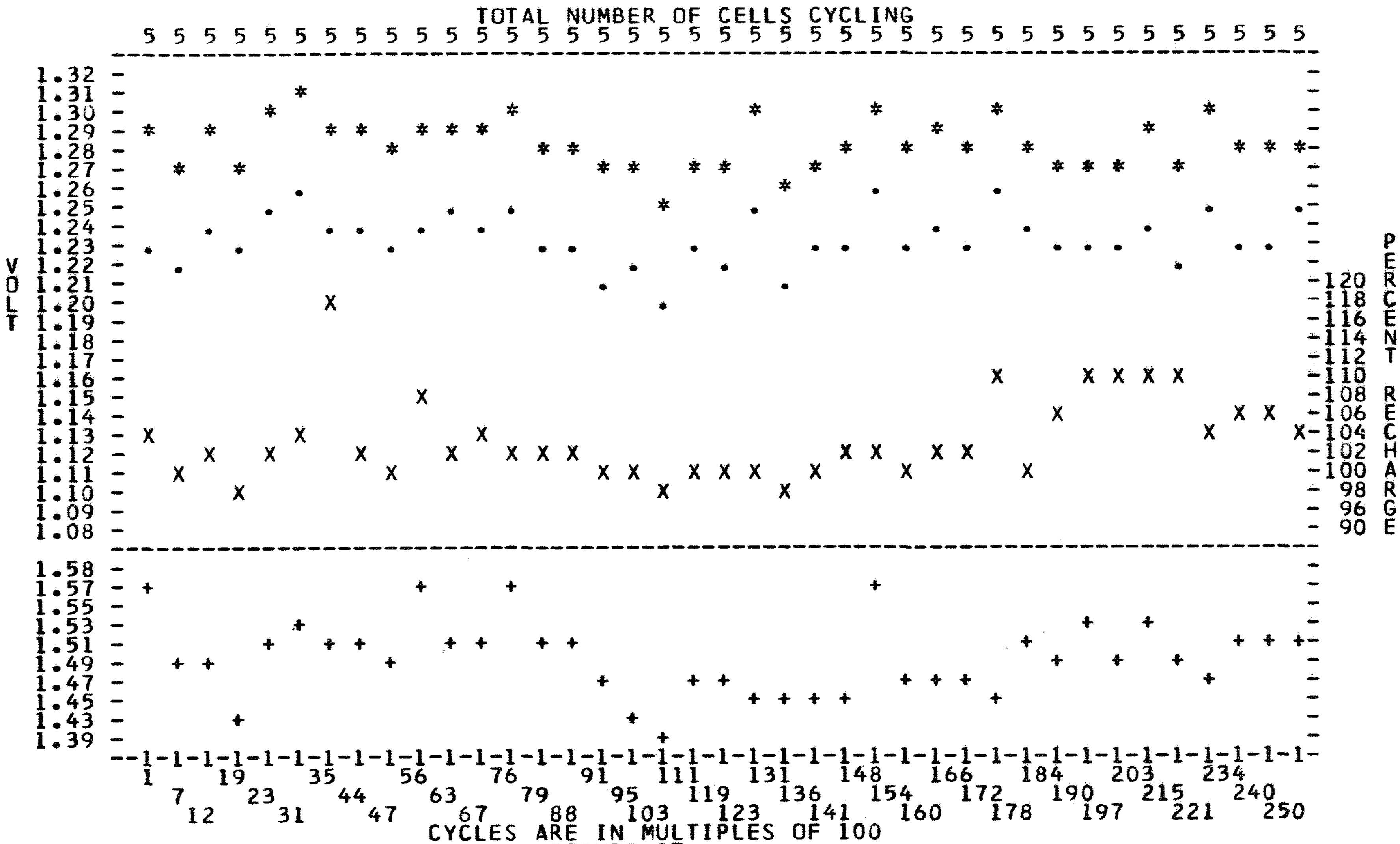

FIGURE 27

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

PACK 107A, MANUFACTURE GE 05.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.38
DEPTH OF DISCHARGE IN % 25

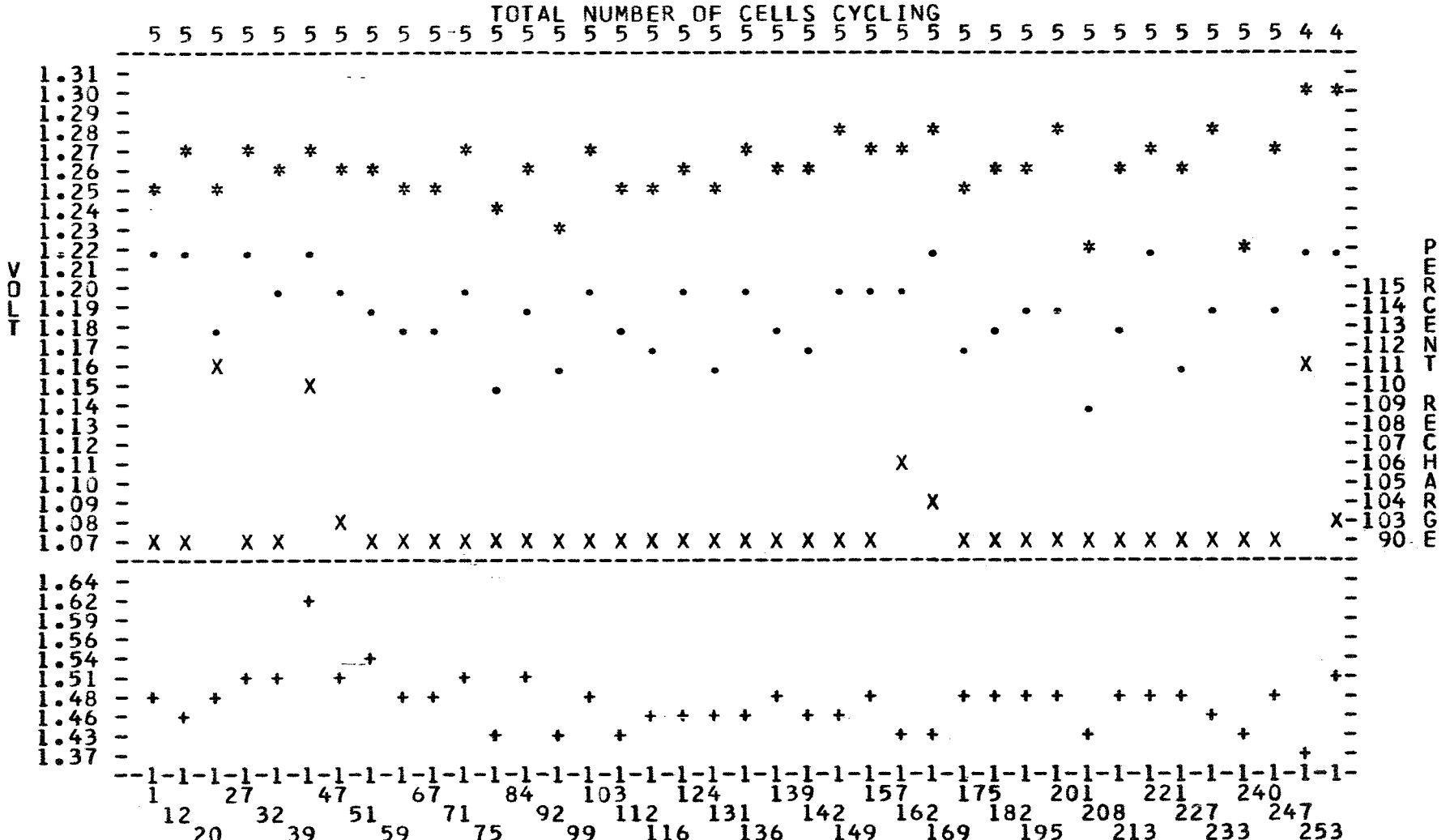

FIGURE 28

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

PACK 106A, MANUFACTURE GE 05.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 0.90
DEPTH OF DISCHARGE IN % 15

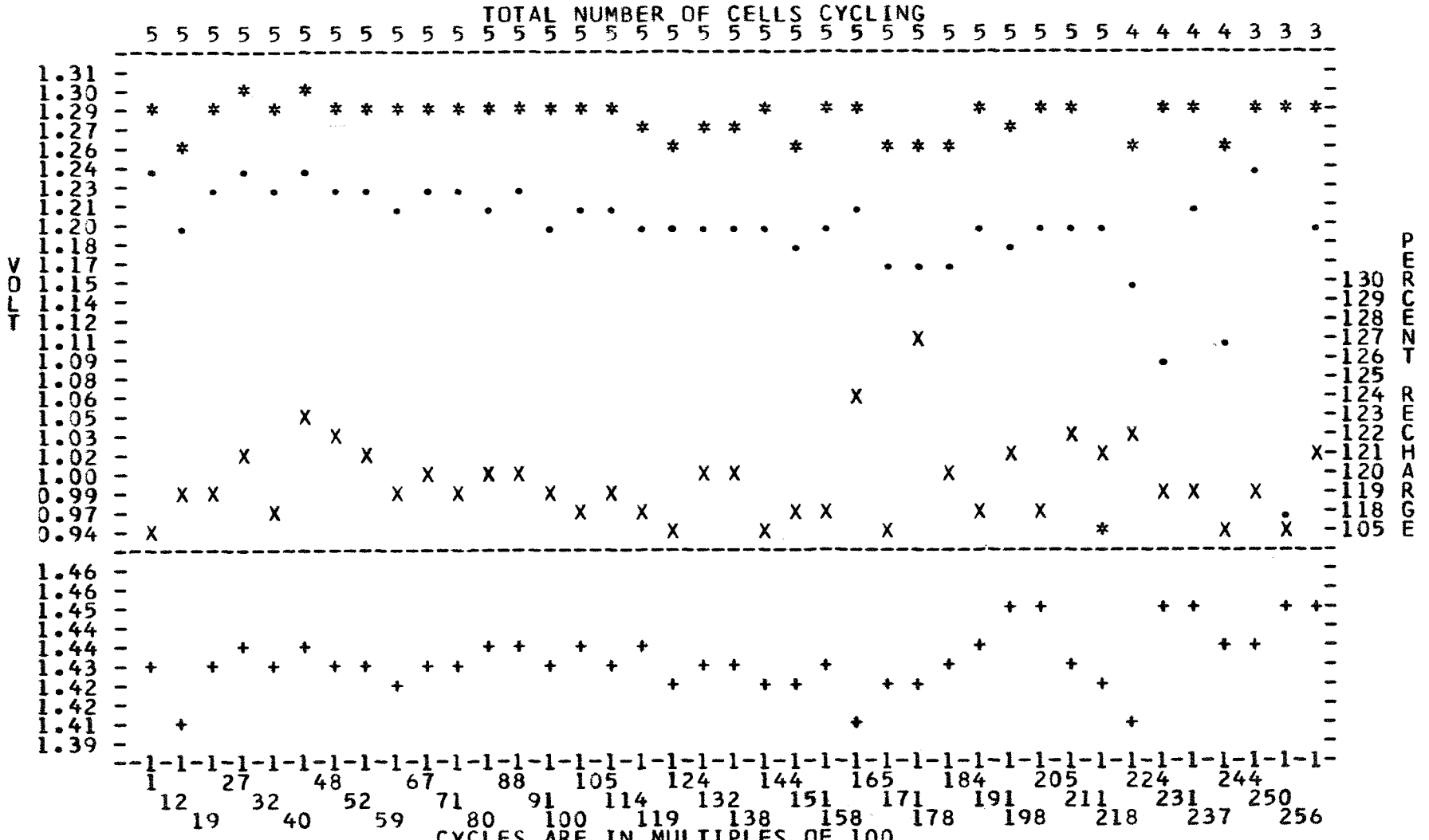


FIGURE 29

10. Sonotone 3.0 ah (Triple Seal), Six 5-cell Packs, 1.5-hour Orbit Period:

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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
43B	0° C	15	115	1.55 ± 0.03
31B	0° C	25	115	1.55 ± 0.03
3B	25° C	25	125	1.49 ± 0.03
2B	25° C	40	125	1.49 ± 0.03
26B	40° C	15	160	1.45 ± 0.03
37B	40° C	25	160	1.45 ± 0.03

c. Test Results:

(1) Performance on Cycling: (Figures 30 and 31) Cycling was started in July 1965. Packs 43B and 31B have completed 24,682 and 24,359 cycles, respectively. Packs 3B, 2B, 26B and 37B failed on cycles 11,726, 5399, 6289 and 5625, respectively.

(2) Failure Analysis: Analysis of the 13 failed 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.

(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	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
176 Days Disch #2	3.47	2.78	1.17	1.45	1.40	1.05
264 Days Disch #2	3.50	2.72	1.50	1.62 F	0.90	1.05 F
352 Days Disch #2	2.63	2.67	1.45		0.47 F	
440 Days Disch #2	3.42	2.27	1.28			
528 Days Disch #2	3.27	2.12	1.00			
616 Days Disch #2	3.00	2.60	1.30			
704 Days Disch #2	3.00	2.67	0.40 F			
792 Days Disch #2	2.75	2.52				
880 Days Disch #2	2.50	2.37				
968 Days Disch #2	2.50	2.48				
1056 Days Disch #2	2.32	2.27				
1144 Days Disch #2	2.15	2.20				
1232 Days Disch #2	2.10	2.10				
1320 Days Disch #2	2.00	1.97				
1408 Days Disch #2	2.35	1.85				
1496 Days Disch #2	2.42	1.62				

F - Failed

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

PACK 043B, MANUFACTURE SONOTONE03.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.52
DEPTH OF DISCHARGE IN % 15

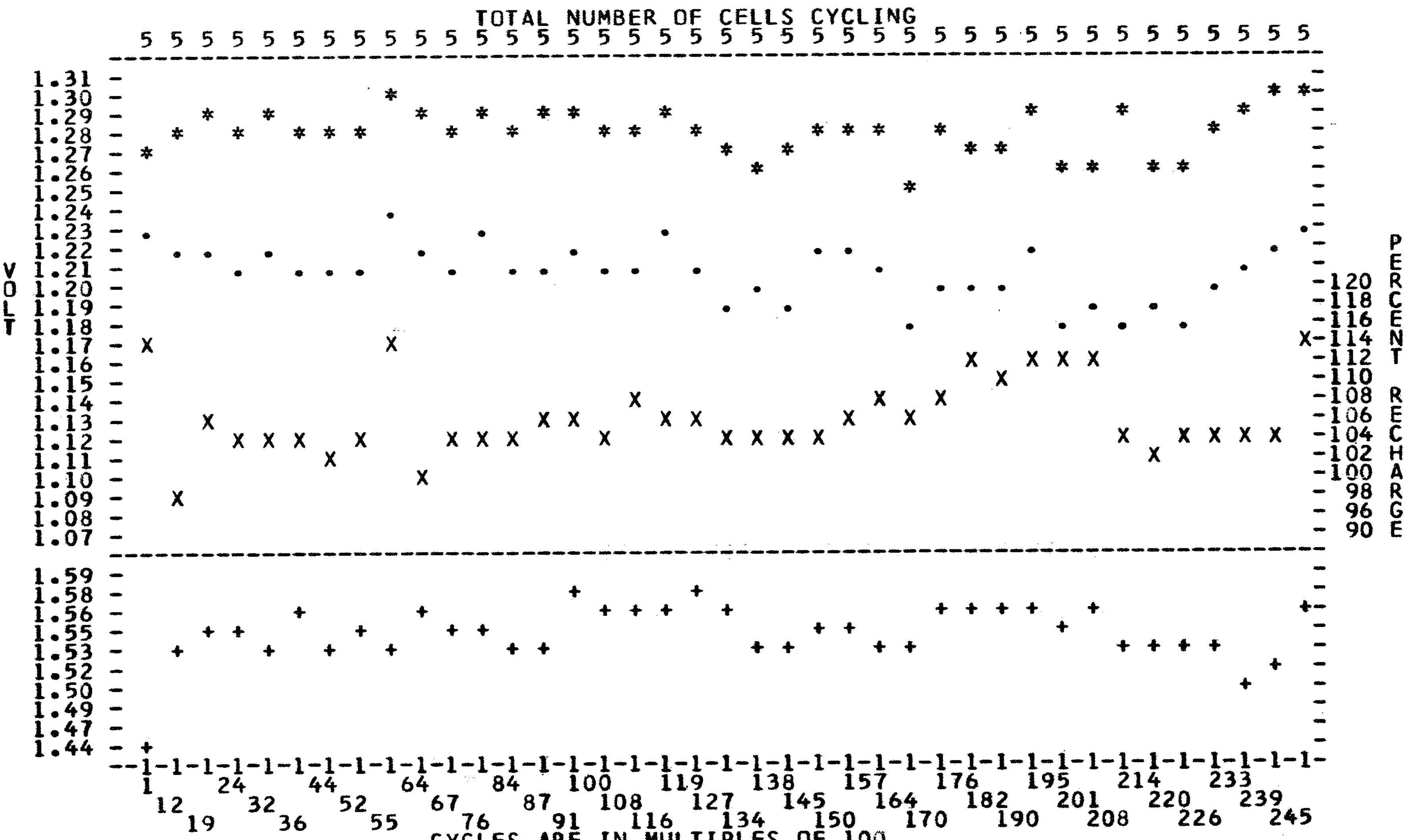
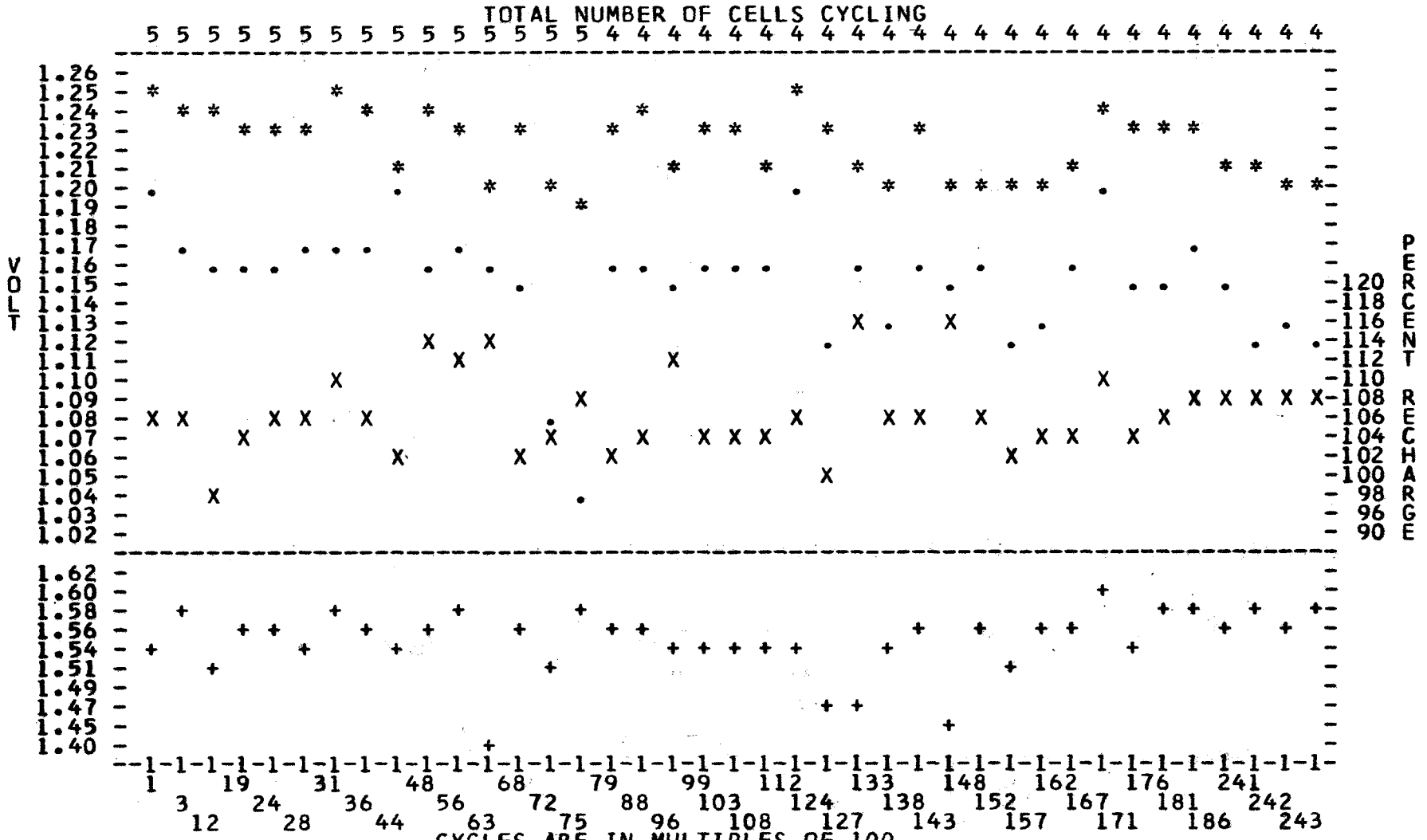


FIGURE 30

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

PACK 031B, MANUFACTURE SONOTONE03.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.86
DEPTH OF DISCHARGE IN % 25



CYCLES ARE IN MULTIPLES OF 100

FIGURE 31

11. Sonotone 3.5 ah, One 10-cell Pack, 1.5-hour Orbit Period (Pack 15B):

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. Test Parameters:

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

(a) Test Temperature: -10° C.

(b) Depth of Discharge: 10%.

(c) Percent of Recharge: 110%.

(d) Charge Voltage Limit: 1.55 $\pm$ 0.03 volts per cell, average.

(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. Test Results:

(1) Performance on Cycling: (Figure 32) This pack has completed 14,284 additional cycles at 0° C 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.

(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	0°
Depth of Discharge	10%
Pack Number	15B
Precycling Capacity	3.18
88 Days Disch #2	3.09
176 Days Disch #2	2.86
264 Days Disch #2	2.95
352 Days Disch #2	2.77
440 Days Disch #2	2.60
528 Days Disch #2	2.71
616 Days Disch #2	2.77
704 Days Disch #2	2.74
792 Days Disch #2	3.06

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

PACK 015B, MANUFACTURE SONOTONE03.5 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.39
DEPTH OF DISCHARGE IN % 10

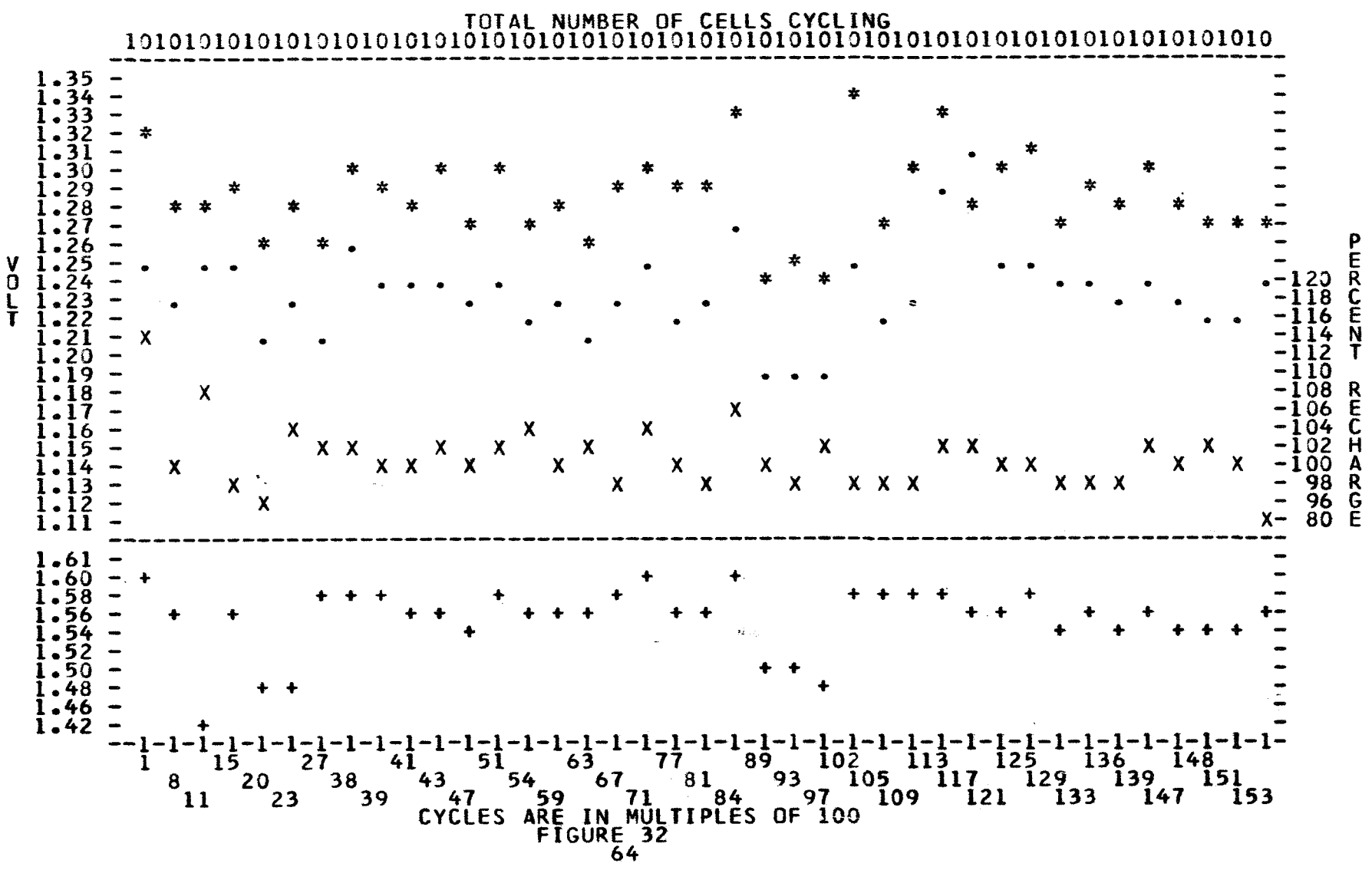


FIGURE 32

12. NIFE 3.9 ah, Two 5-cell Packs, 1.5-hour Orbit Period:

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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
97C	0° C	25	107	1.47 ± 0.03
85C	25° C	25	107	1.47 ± 0.03

c. Test Results:

(1) Performance on Cycling: (Figures 33 and 34) Cycling was started in September 1967. Pack 97C has completed 12,560 cycles to date with no cell failures. Pack 85C failed on cycle 9356 with its third cell failure. The other two cell failures occurred on cycles 8532 and 8938.

(2) Failure Analysis: The three 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) 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	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
176 Days Disch #2	3.93	3.07
264 Days Disch #2	3.33	3.33
352 Days Disch #2	3.90	3.10
440 Days Disch #2	3.27	2.90
528 Days Disch #2	3.47	2.30
616 Days Disch #2	3.60	2.20 F
704 Days Disch #2	3.73	

F - Failed

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

PACK 097C, MANUFACTURE NIFE 03.9 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.07
DEPTH OF DISCHARGE IN % 25

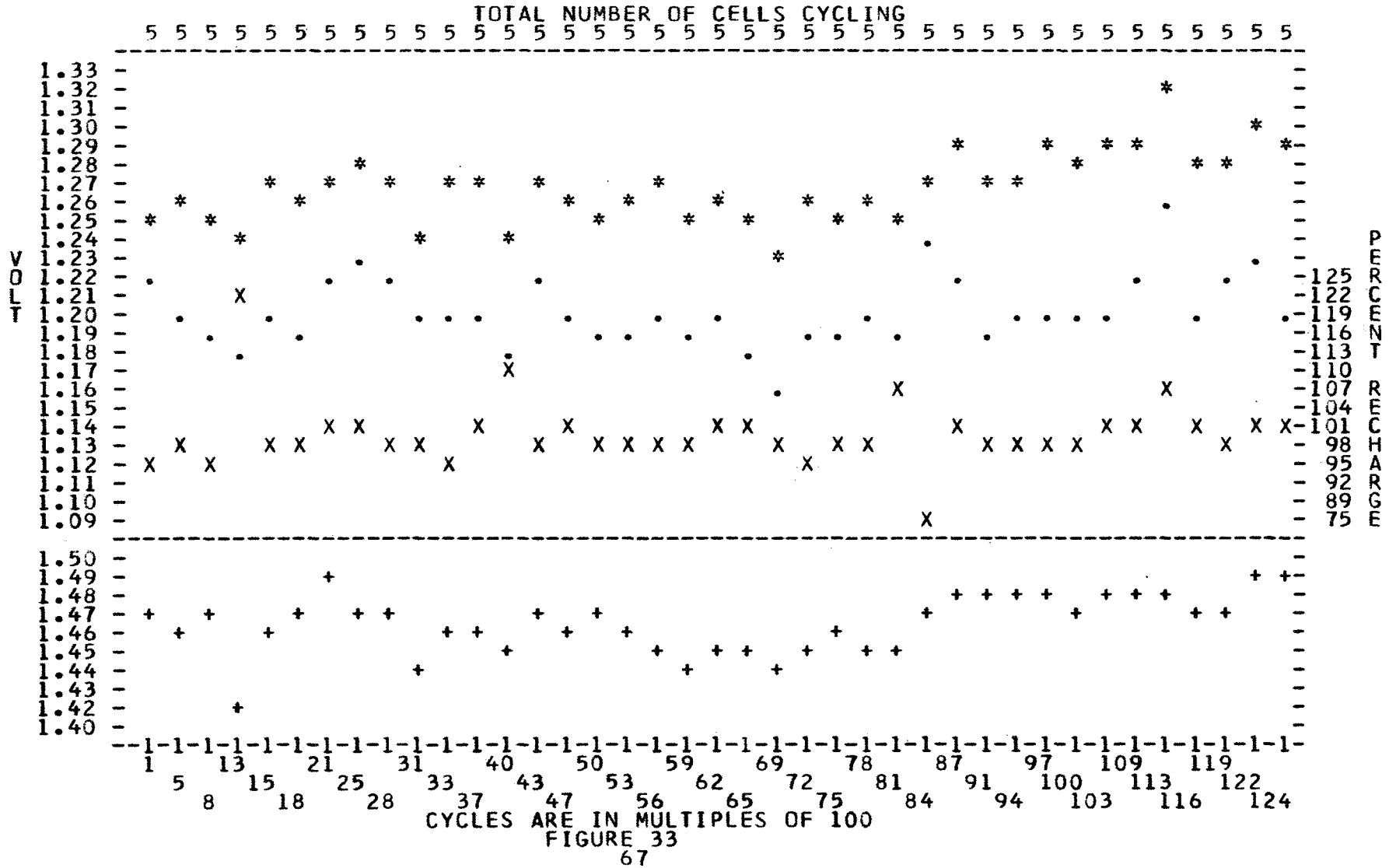


FIGURE 33

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

PACK 085C, MANUFACTURE NIFE 03.9 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 1.07
DEPTH OF DISCHARGE IN % 25

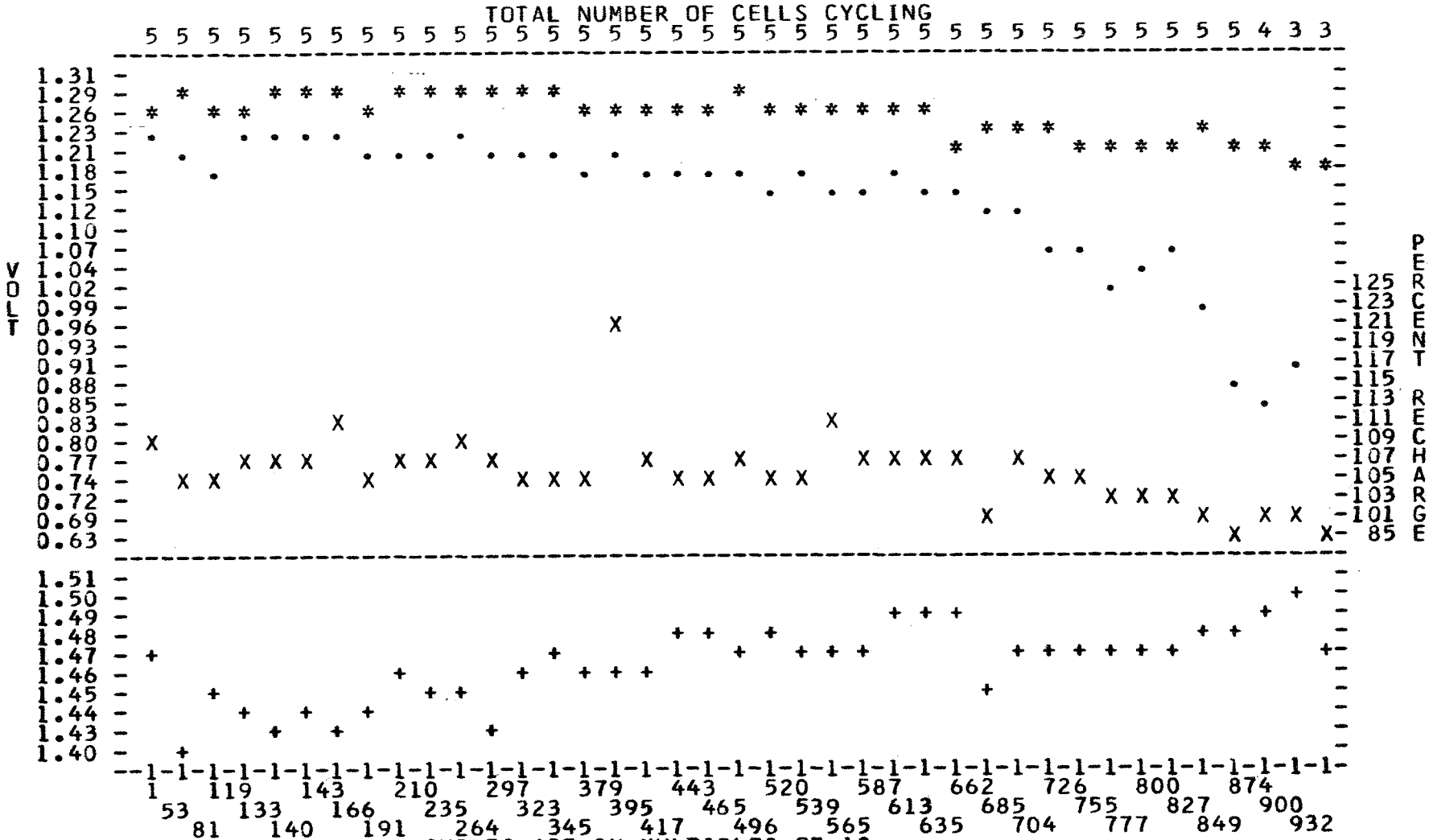


FIGURE 34

B. Silver-Cadmium Types:

1. Yardney 5.0 ah, Four 5-cell Packs, 24-hour Orbit Period:

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. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Charge Voltage Limit, Per Cell
113B	0° C	20	1.50 ± 0.03
77B	25° C	20	1.50 ± 0.03
105B	25° C	20	1.50 ± 0.03
128B	40° C	20	1.50 ± 0.03

c. Test Results:

(1) Performance on Cycling: (Figure 35) Cycling was started in January 1967. Pack 113B completed 1053 cycles to date with no cell failures. Packs 77B, 105B and 128B failed on cycles 661, 77 and 269 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 nine failed cells showed that the failures were due to silver migration and separator deterioration which resulted in internally shorted cells.

(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°	25°	40°
Depth of Discharge	20%	20%	20%	20%
Pack Number	113B	77B	105B	128B
Precycling Capacity	4.08	5.02	4.95 F	6.47
100 Days	5.27	4.92		5.53
200 Days	4.08	4.77		1.25 F
300 Days	4.67	4.67		
400 Days	5.55	4.67		
500 Days	4.03	1.25		
600 Days	5.06	2.35 F		
700 Days	4.03			
800 Days	5.15			

F - Failed

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

PACK 113B, MANUFACTURE YARDNEY 05.0 AH
ORBIT PERIOD IN HOURS 24.0
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.30
DEPTH OF DISCHARGE IN % 20

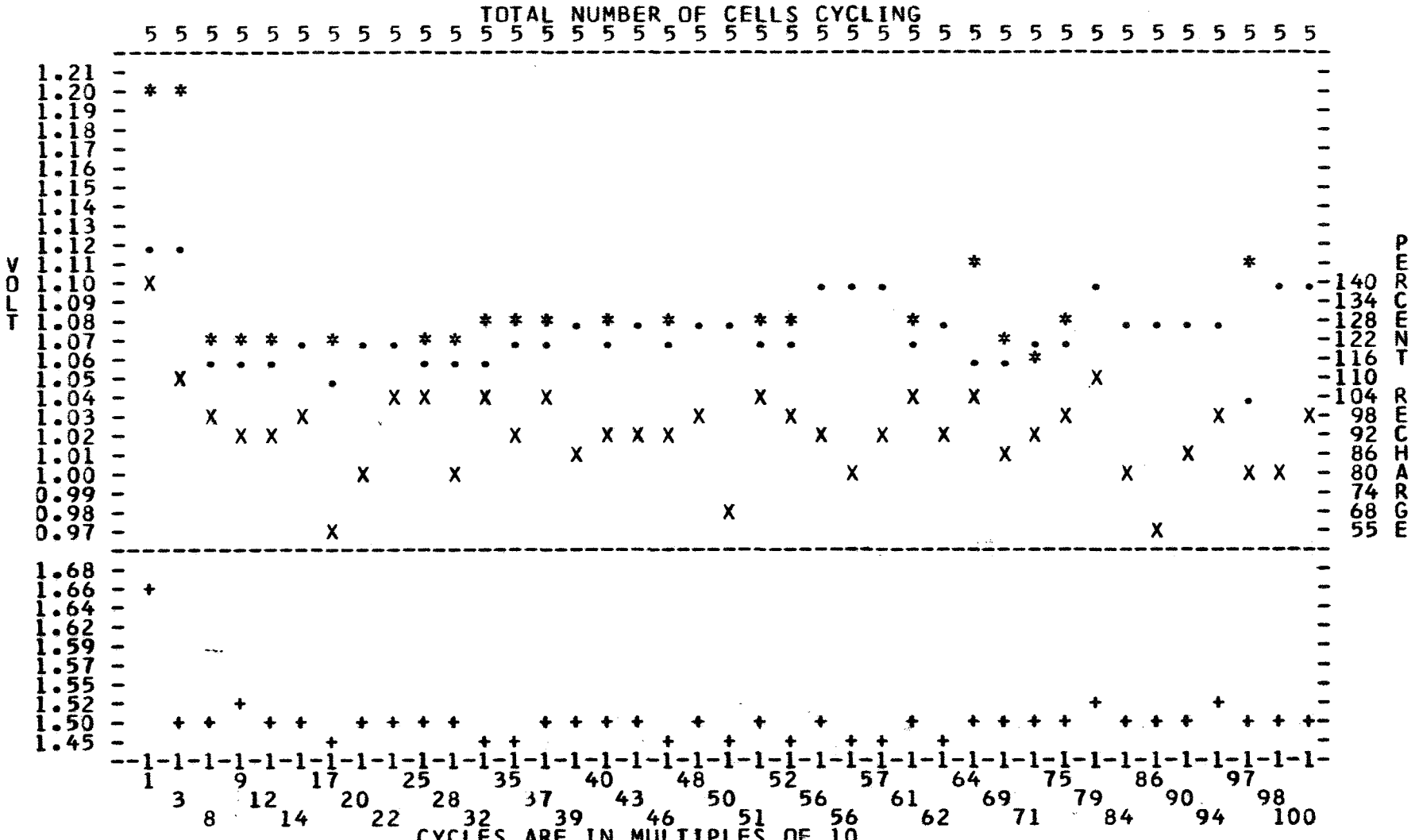


FIGURE 35

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, stabistor, coulometer, Sherfey upside-down cycling, the two-step regulator and internal mechanical pressure devices.

A. 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, 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. 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. The cell containers were somewhat larger than normally expected for a 1.25 ampere-hour cell and each cell was equipped with a pressure gage.

b. Test Parameters:

(1) Initial Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Charge Current
74B	-20° C	25	1.25 Amps
88D	-20° C	60	1.25 Amps
108B	0° C	25	1.25 Amps
98B	0° C	60	1.25 Amps

c. Test Results:

(1) Performance on Cycling: (Figures 36 through 38) Cycling was started in March 1966. Packs 74B, 88D and 108B have completed 21,006, 20,397 and 21,311 cycles, respectively. Pack 98B failed on cycle 12,247.

(a) Pack 74B: These cells developed pressures in excess of 150 psig. After release of the gas following cycles 4 and 6, and with the reduction of the charge current from 1.25 to 1.00 ampere, the internal pressure remained low for over 6000 cycles. At cycle 6294, about 8 days after the capacity checks following 352 days of cycling, the internal pressure in cell number 1 increased and the gas was released. At cycle 11,011, about 40 days after the capacity checks following 616 days of cycling, the internal pressure increased in all cells and the gas was again released. Similarly, at cycle 13,062, following the capacity checks after 792 days of cycling, the pressure in cell number 1 increased and the gas was released and that of each of the five cells was released at cycle 14,450 following the capacity checks after 880 days of cycling. There were no cell failures.

(b) Pack 88D: These cells developed pressures in excess of 150 psig. After release of the gas following cycles 3 and 5, the charge current was reduced from 1.25 to 1.00 ampere. At cycle 46 the gas was again released in cell number 2, at which time the depth of discharge was reduced from 60 to 25 percent. It was necessary to release the gas in each of the five cells at cycle 10,399, approximately 40 days after the capacity checks following 616 days of cycling; and at cycle 13,839, following the capacity checks after 880 days of cycling. The one failed cell showed severe migration of the negative plate material and blistering on the positive plates.

(c) Pack 98B: The three cells which failed at cycles 5033, 5513 and 12,247, respectively, showed severe migration of negative material and blistering of the positive plates. Two of these cells had developed high internal pressure as evidenced by bulged cases.

(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°
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
176 Days	Disch #2	0.42	0.52	1.59	1.39
264 Days	Disch #2	0.40	0.35	1.43	0.95
352 Days	Disch #2	0.47	0.40	1.35	1.05
440 Days	Disch #2	0.36	0.35	1.32	0.87
528 Days	Disch #2	0.47	0.37	1.13	0.86
616 Days	Disch #2	0.41	0.36	0.92	0.99
704 Days	Disch #2	0.34	0.31	0.55	0.81 F
792 Days	Disch #2	0.29	0.28	1.01	
880 Days	Disch #2	0.27	0.27	0.87	
968 Days	Disch #2	0.27	0.28	0.66	
1056 Days	Disch #2	0.30	0.30	0.58	
1144 Days	Disch #2	0.25	0.28	0.42	
1232 Days	Disch #2	0.30	0.29	0.61	

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

F - Failed

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

PACK 074B, MANUFACTURE GULTON 1.00 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. -20
CHARGE RATE IN AMPS 1.00
DEPTH OF DISCHARGE IN % 25

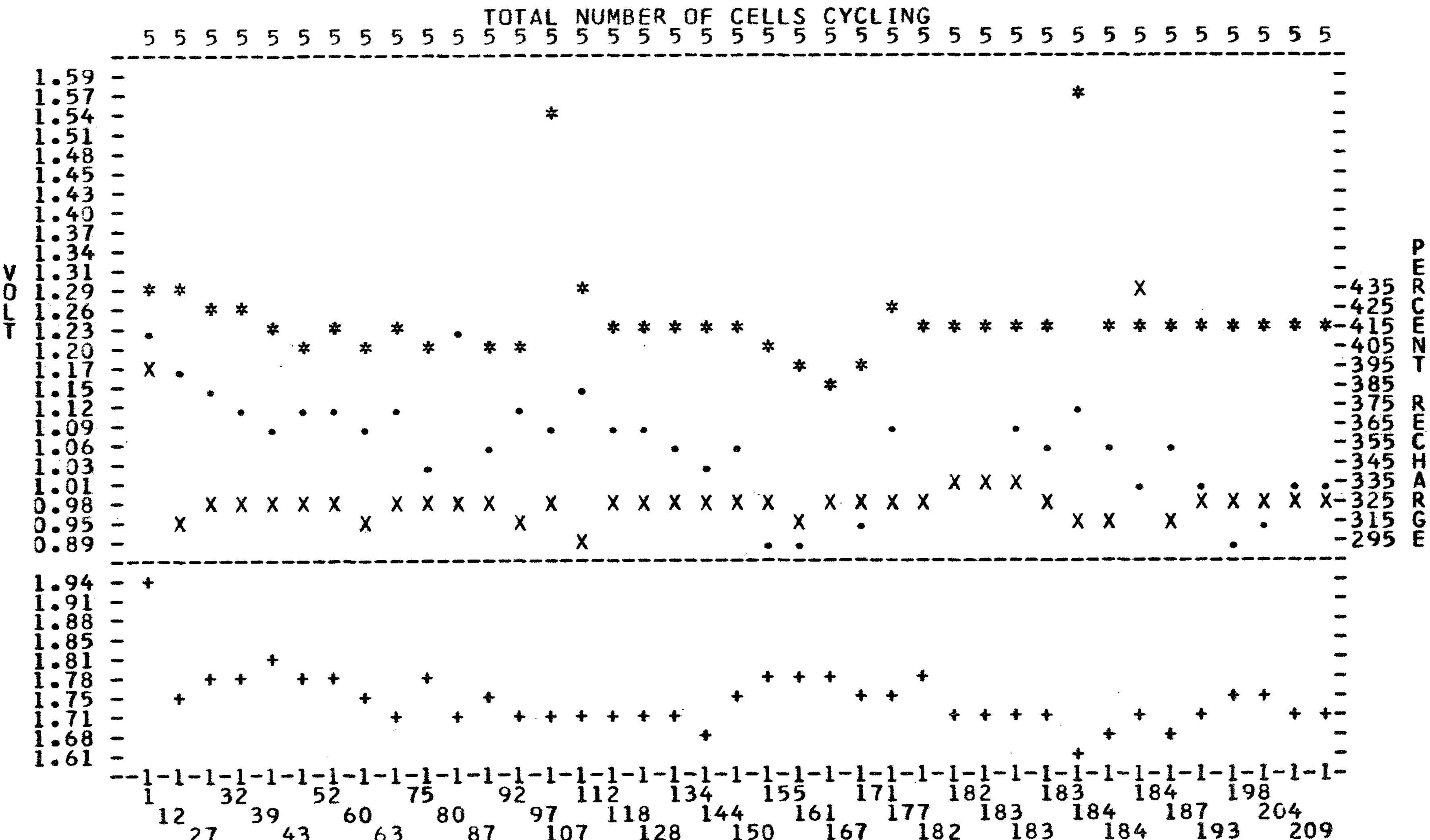


FIGURE 36

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

PACK 088D, MANUFACTURE GULTON 1.25 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. -20
CHARGE RATE IN AMPS 10.05
DEPTH OF DISCHARGE IN % 60

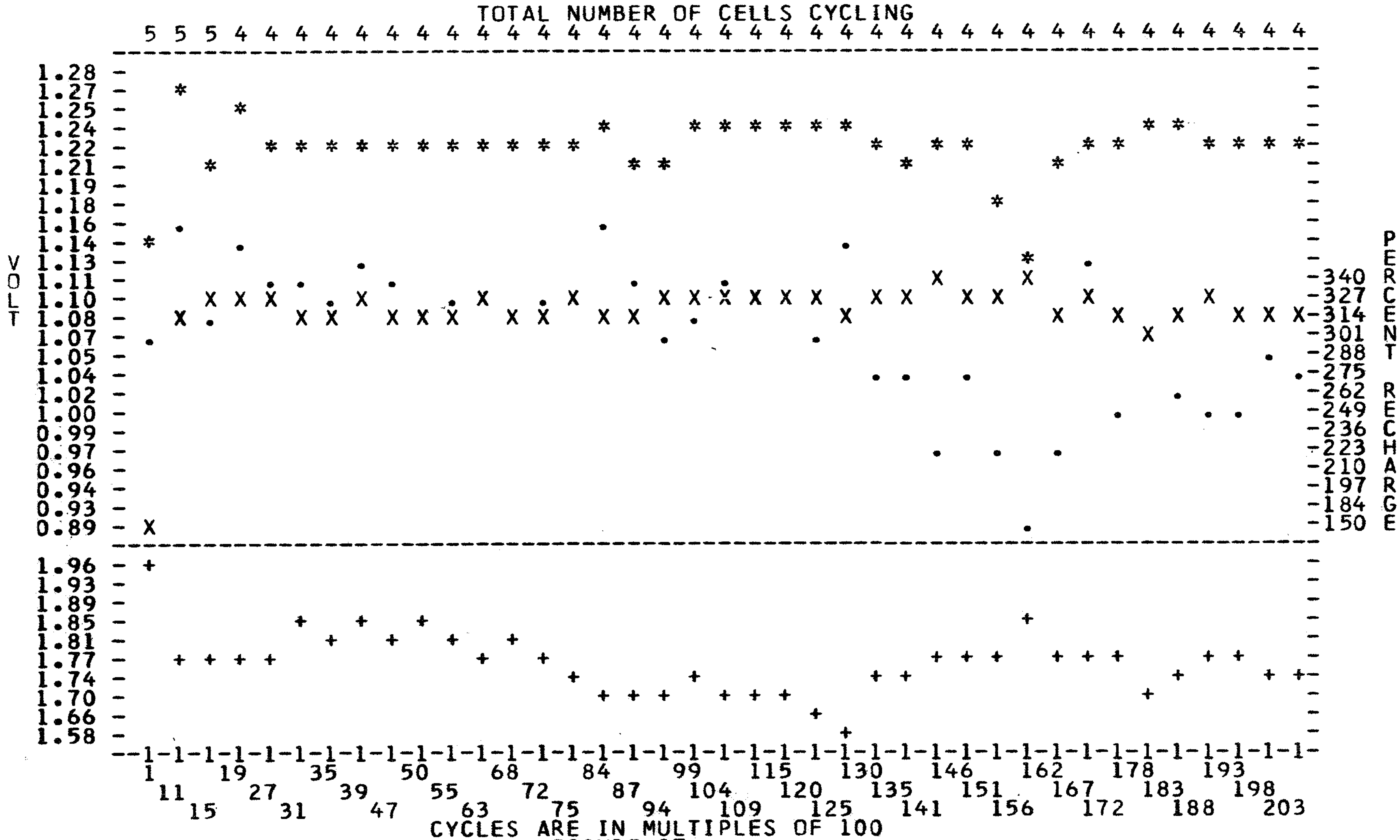
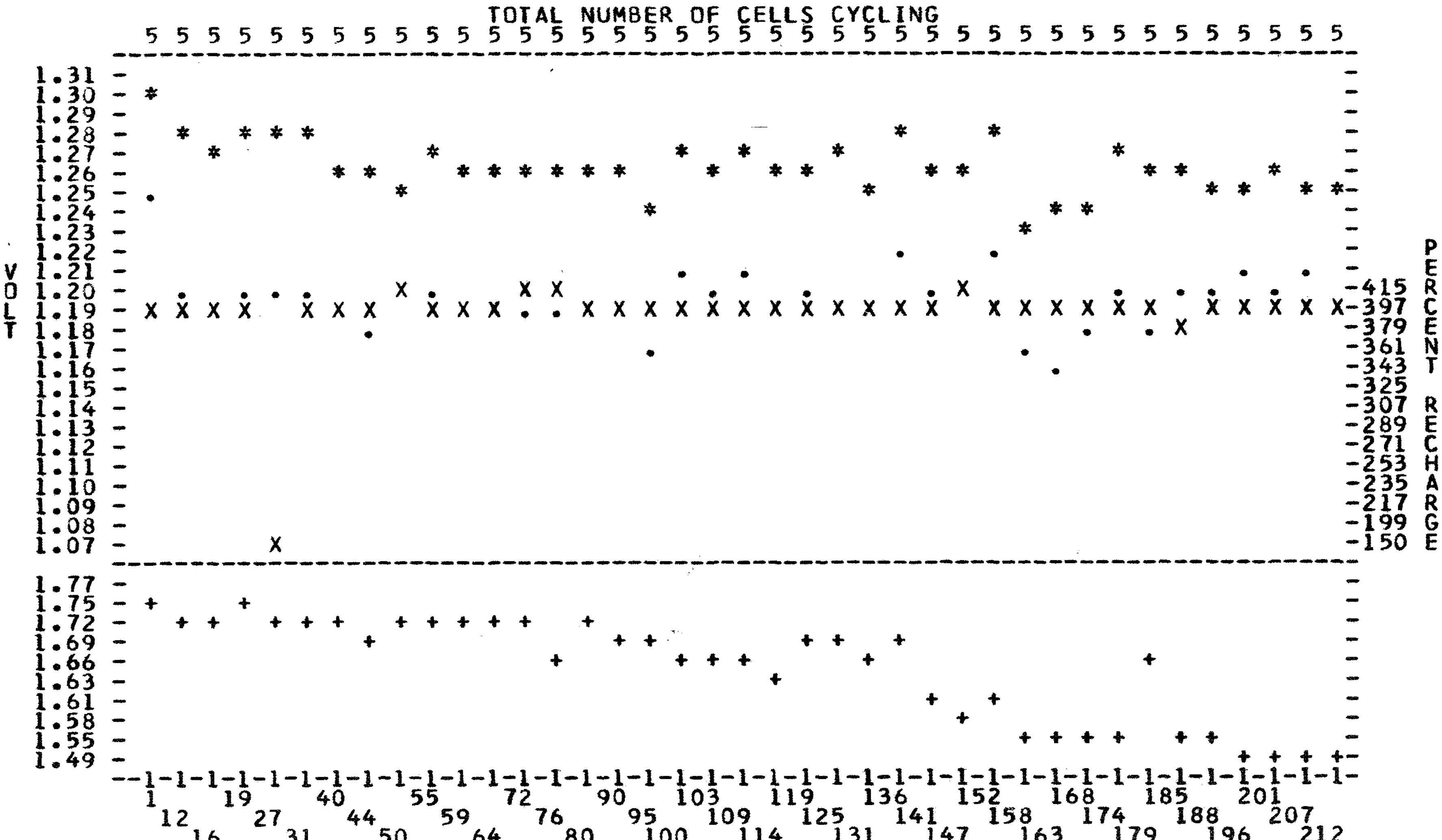


FIGURE 37

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

PACK 108B, MANUFACTURE GULTON 1.25 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.25
DEPTH OF DISCHARGE IN % 25



CYCLES ARE IN MULTIPLES OF 100

FIGURE 38

B. 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. Gulton 6.0 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 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 is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms)
48B	*	40	170	6.8
24C	*	25	170	6.8
60B	*	15	170	6.8

* 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.

c. Test Results:

(1) Performance on Cycling: (Figures 39 and 40) Cycling was started in April 1967. Pack 48B failed on cycle 6156. Packs 24C and 60B have completed 15,253 and 15,272 cycles, respectively with no 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.

(b) All cells in pack 48B, operating at 40 percent depth of discharge failed on or before cycle 6156. The first cell failure (cycle 3669) resulted from the shorting together of the positive and auxiliary electrodes due to insufficient separator between one edge of the positive plates and the auxiliary electrode. This cell also showed severe separator deterioration, migration of negative material and blistered positive plates. The second cell failure (cycle 6139) resulted from a shorting condition caused by a piece of extraneous positive material, excessive migration of negative material and separator deterioration, particularly at that point; and the positive plates were blistered. This cell also had high pressure (bulged case), leakage as evidenced by a deposit on the welded seam, and a weak weld between the auxiliary electrode and the bracket on the inside wall of the cell. The remaining three cells failed on cycle 6156, due to excessive separator deterioration, and migration of negative material. These three cells had blistered positive plates and high internal pressure as evidenced by their bulged cases. Two of these cells indicated leaks by deposits around the ceramic seals, one of which also had a weak weld between the auxiliary electrode and the bracket on the inside wall of the cell. These weak welds may be the result of failure to remove active material from the grid of the auxiliary electrode before welding it to the bracket.

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

PRECYCLING AND CAPACITY CHECKS

Orbit Period	1.5-hour		
Temperature	*	*	*
Depth of Discharge	40%	25%	15%
Pack Number	48B	24C	60B
Precycling Capacity	7.40	7.20	7.45
88 Days	3.68	6.90	7.02
176 Days	2.80	6.55	7.20
264 Days	3.76	6.30	6.45
352 Days	3.20	4.15	7.14
440 Days	3.84 F	3.25	6.33
528 Days		3.09	6.63
616 Days		3.10	5.61
704 Days		2.90	5.04
792 Days		2.55	4.68
880 Days		2.10	4.11

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

F - Failed

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

PACK 024C, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 0/40
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

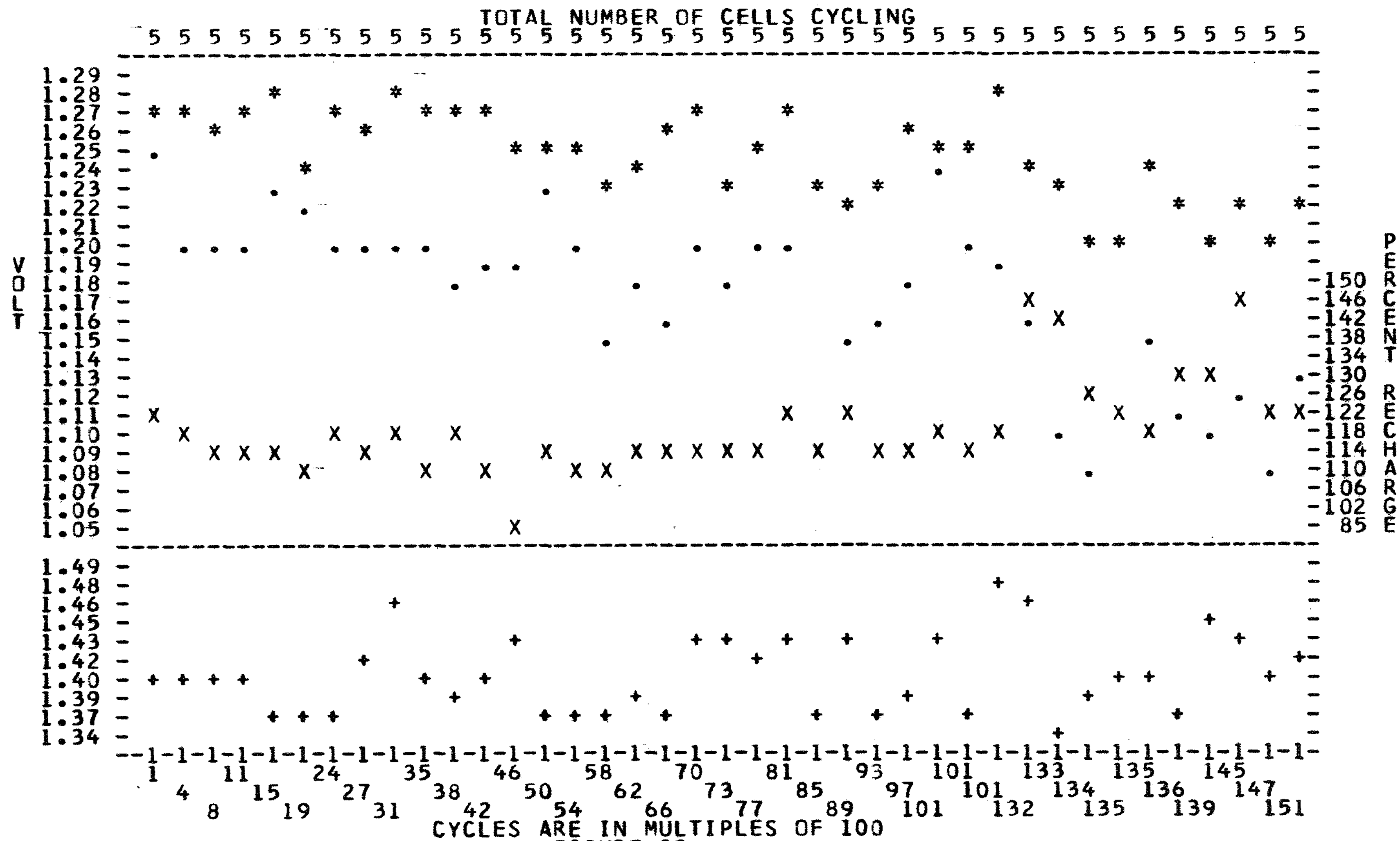


FIGURE 39

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

PACK 060B, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 0/40
CHARGE RATE IN AMPS 1.80
DEPTH OF DISCHARGE IN % 15

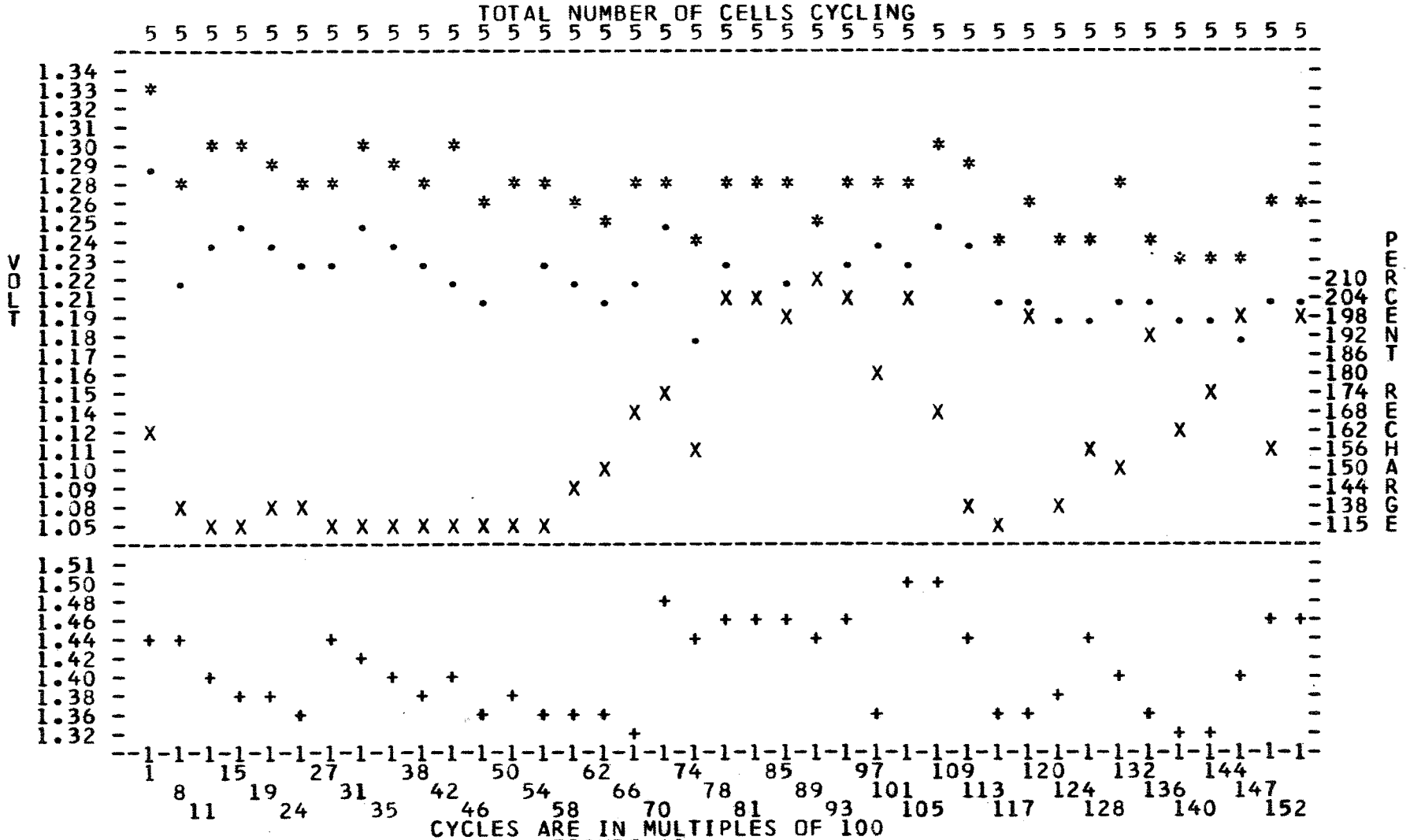


FIGURE 40

2. Gulton 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 is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal.

b. Test Parameters:

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

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

c. Test Results:

(1) Performance on Cycling: (Figures 41 and 42) Cycling was started in January 1969. Packs 58D and 36D have completed 5374 and 5377 cycles, respectively, with no cell failures. 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 058D, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 0/40
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

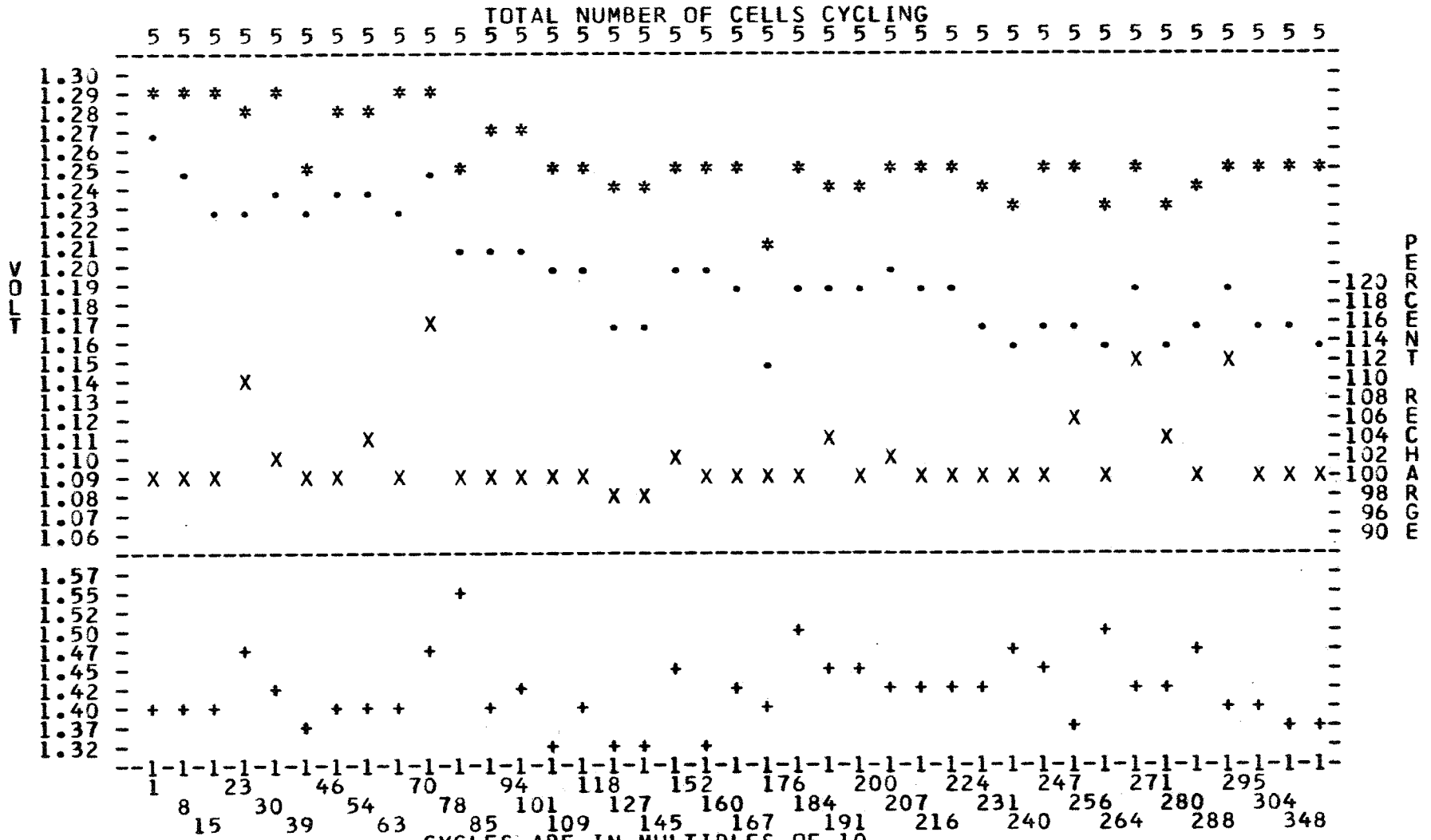


FIGURE 41

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

PACK 036D, MANUFACTURE GULTON 6.0 AH
ORBIT PERIOD IN HOURS 1.5
TEMPERATURE IN DEGREES C. 0/40
CHARGE RATE IN AMPS 1.80
DEPTH OF DISCHARGE IN % 15

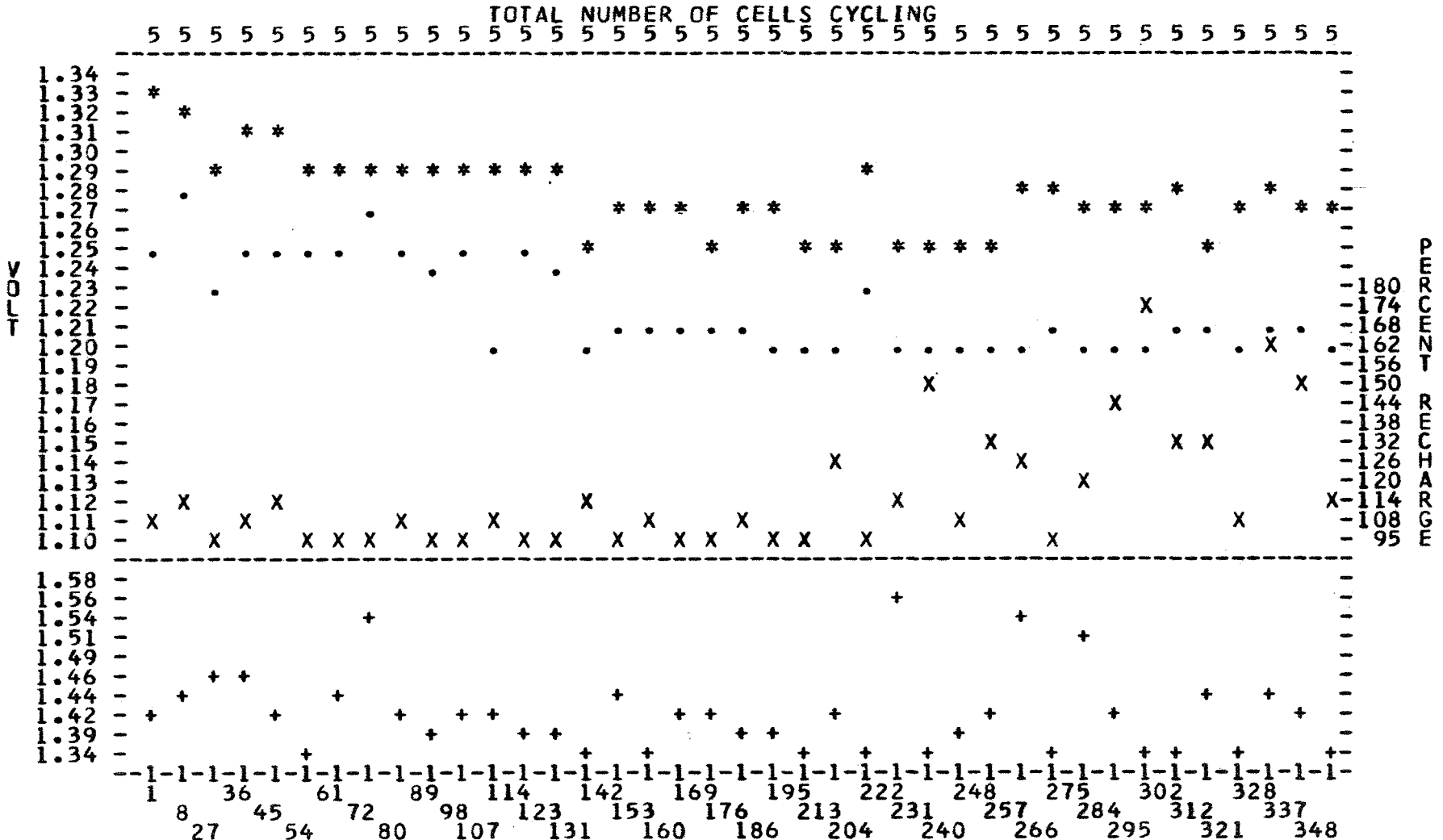


FIGURE 42

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

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors (Ohms)
70A	0° C	25	70	6.2
71B	0° C	40	70	6.2
11B	25° C	40	150	6.2
47B	40° C	25	230	6.2

c. Test Results:

(1) Performance on Cycling: (Figures 43 and 44) 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 16,062 cycles to date with no failures. Packs 71B, 11B and 47B failed on cycles 15,275, 11,933 and 6537, respectively.

(2) Failure Analysis: Analysis of the seven 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.

(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	0°	0°	25°	40°
Depth of Discharge	25%	40%	40%	25%
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
176 Days Disch #2	15.4	14.5	8.1	3.5
264 Days Disch #2	14.7	14.4	6.5	3.2
352 Days Disch #2	9.9	13.0	7.7	5.6
440 Days Disch #2	11.6	11.5	9.0	3.4
528 Days Disch #2	10.6	10.7	7.7	6.3 F
616 Days Disch #2	9.5	9.1	7.4	
704 Days Disch #2	9.2	11.3	7.1 F	
792 Days Disch #2	9.1	10.4		
880 Days Disch #2	8.7	9.5		
968 Days Disch #2		7.8		

F - Failed

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

PACK 070A, MANUFACTURE GULTON 12.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 6.00
DEPTH OF DISCHARGE IN % 25

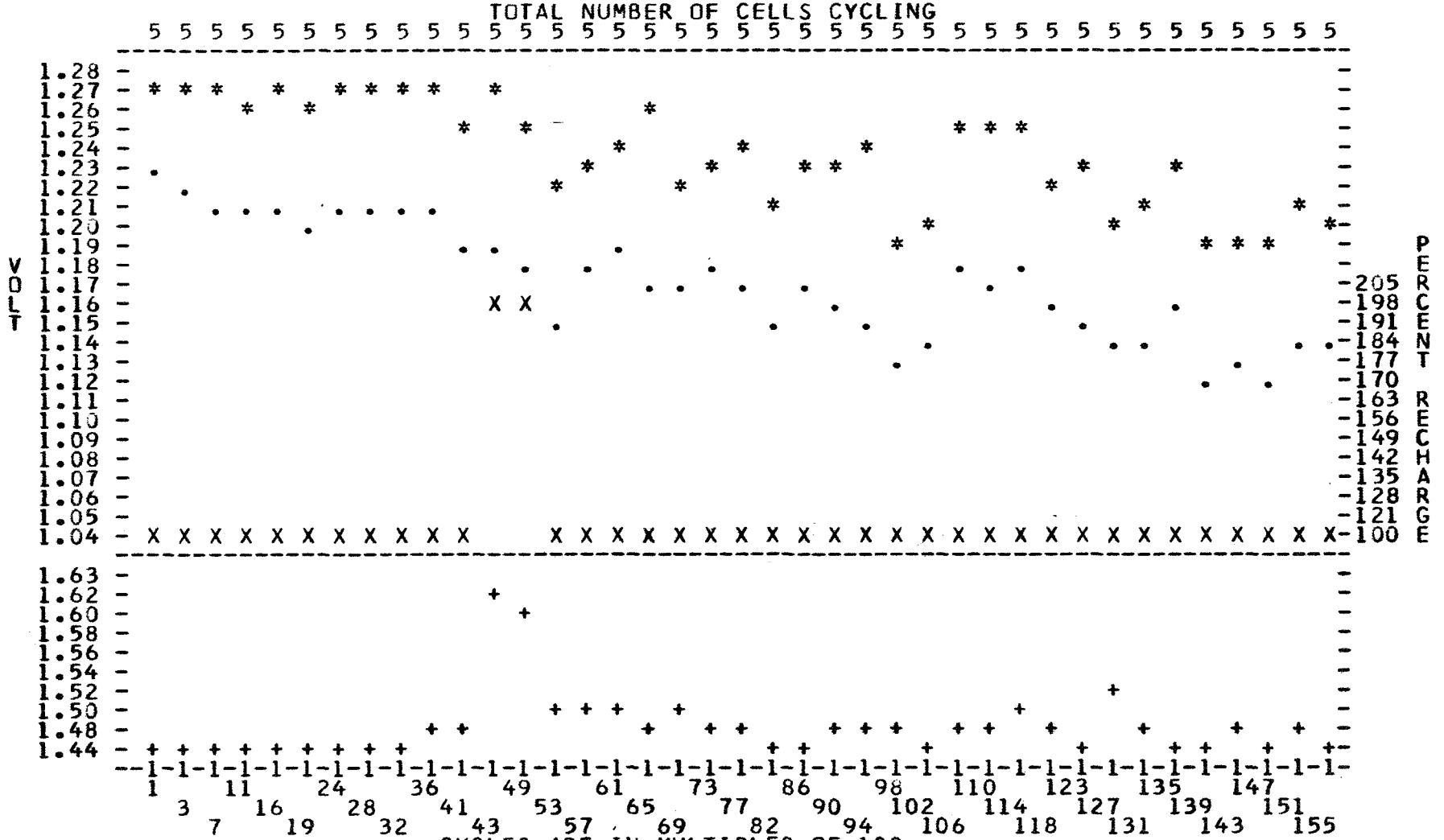


FIGURE 43

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

PACK 071B, MANUFACTURE GULTON 12.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 6.00
DEPTH OF DISCHARGE IN % 40

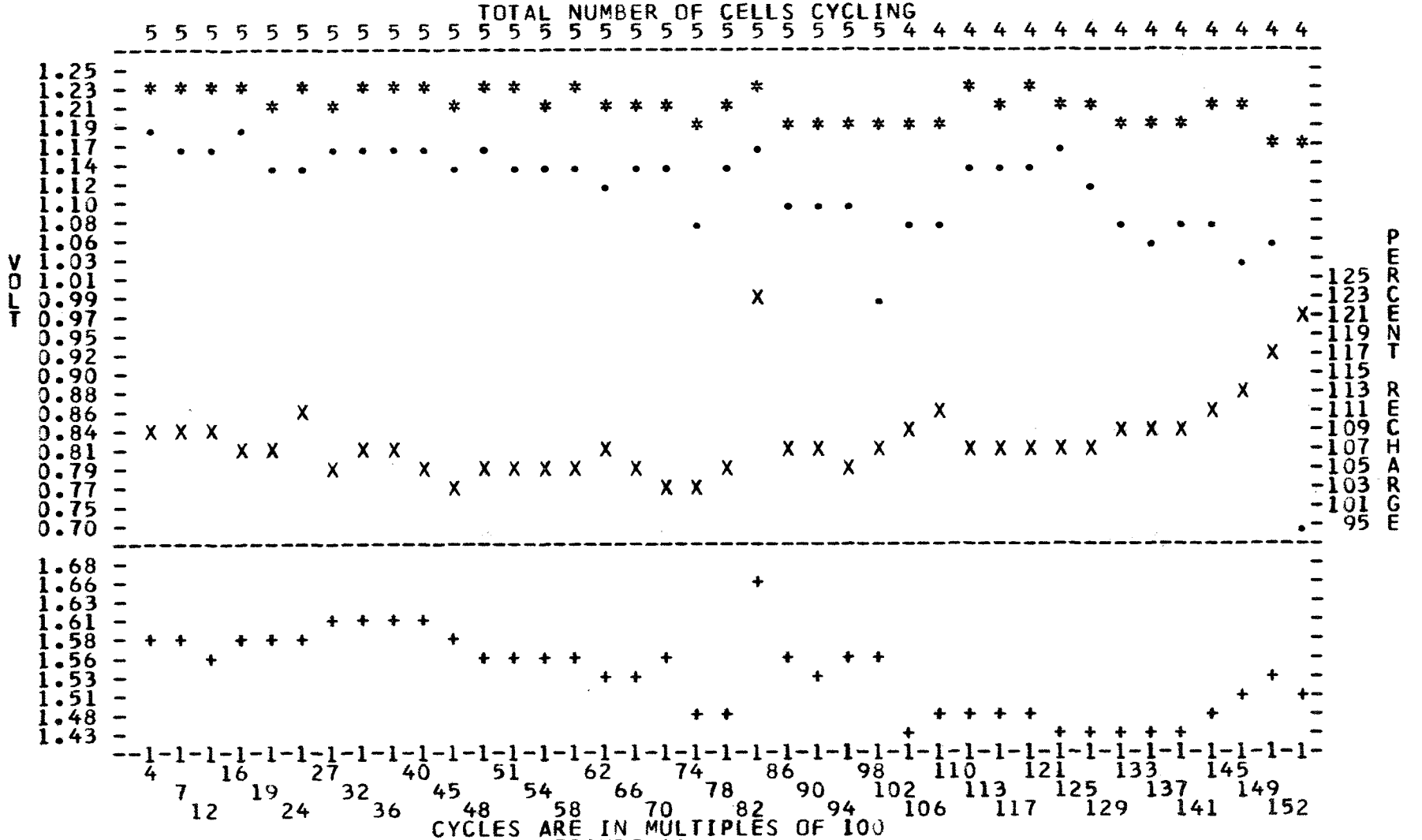


FIGURE 44

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: (Figure 45) Cycling was started in February 1968. Pack 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 F	22.9 F	25.3
88 Days			13.7
176 Days			6.3
264 Days			5.8
352 Days			5.7
440 Days			6.9 D

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

F - Failed

D - Discontinued

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

PACK 012D, MANUFACTURE GULTON 20.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 0/40
CHARGE RATE IN AMPS 10.00
DEPTH OF DISCHARGE IN % 15

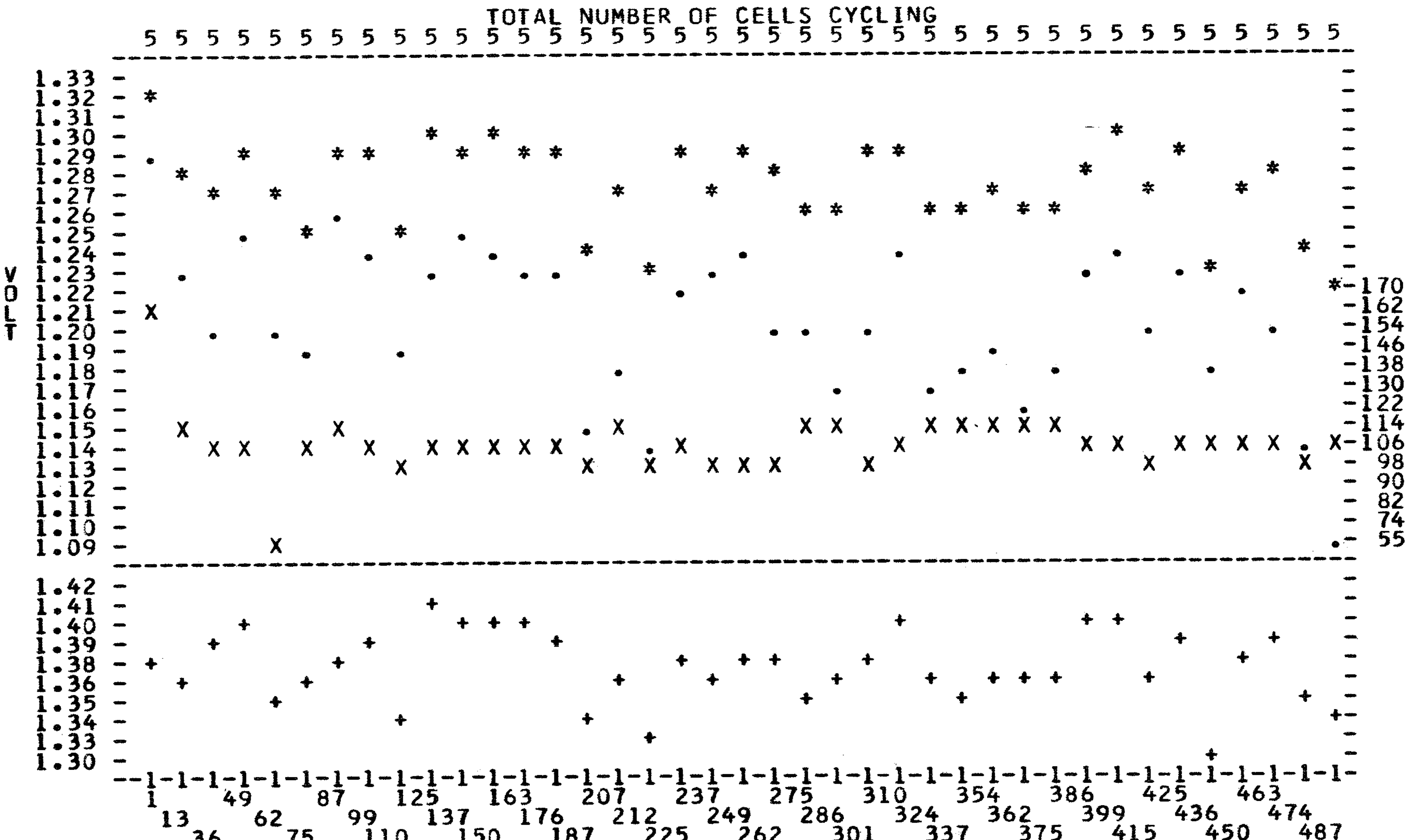


FIGURE 45

5. 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 OAO satellites.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Voltage Limits Per Cell, Average Upper	Lower
54B	0° C	15	250	1.54	1.47
19B	25° C	15	250	1.45	1.38
38E	40° C	15	300	1.40	1.33

Auxiliary Electrode Resistors: 47 Ohms

c. Test Results:

(1) Performance on Cycling: (Figures 46 through 48) Cycling was started in March 1968. Packs 54B and 19B have completed 9993 and 10,004 cycles, respectively, with no cell failures.

(a) Pack 38E: All the cells failed due to loss of capacity at the high temperature on cycle 4943.

(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	0°	25°	40°
Depth of Discharge	15%	15%	15%
Pack Number	54B	19B	38E
Precycling Capacity	22.7	23.3	17.3
88 Days	25.1	19.8	5.6
176 Days	22.7	17.3	3.7
264 Days	24.7	14.9	2.9 F
352 Days	23.6	13.7	
440 Days	24.8	8.7	
528 Days	21.5	8.9	

F - Failed

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

PACK 054B, MANUFACTURE GULTON 20.0 AH
ORBIT PERIOD IN HOURS 1.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 8.00
DEPTH OF DISCHARGE IN % 15

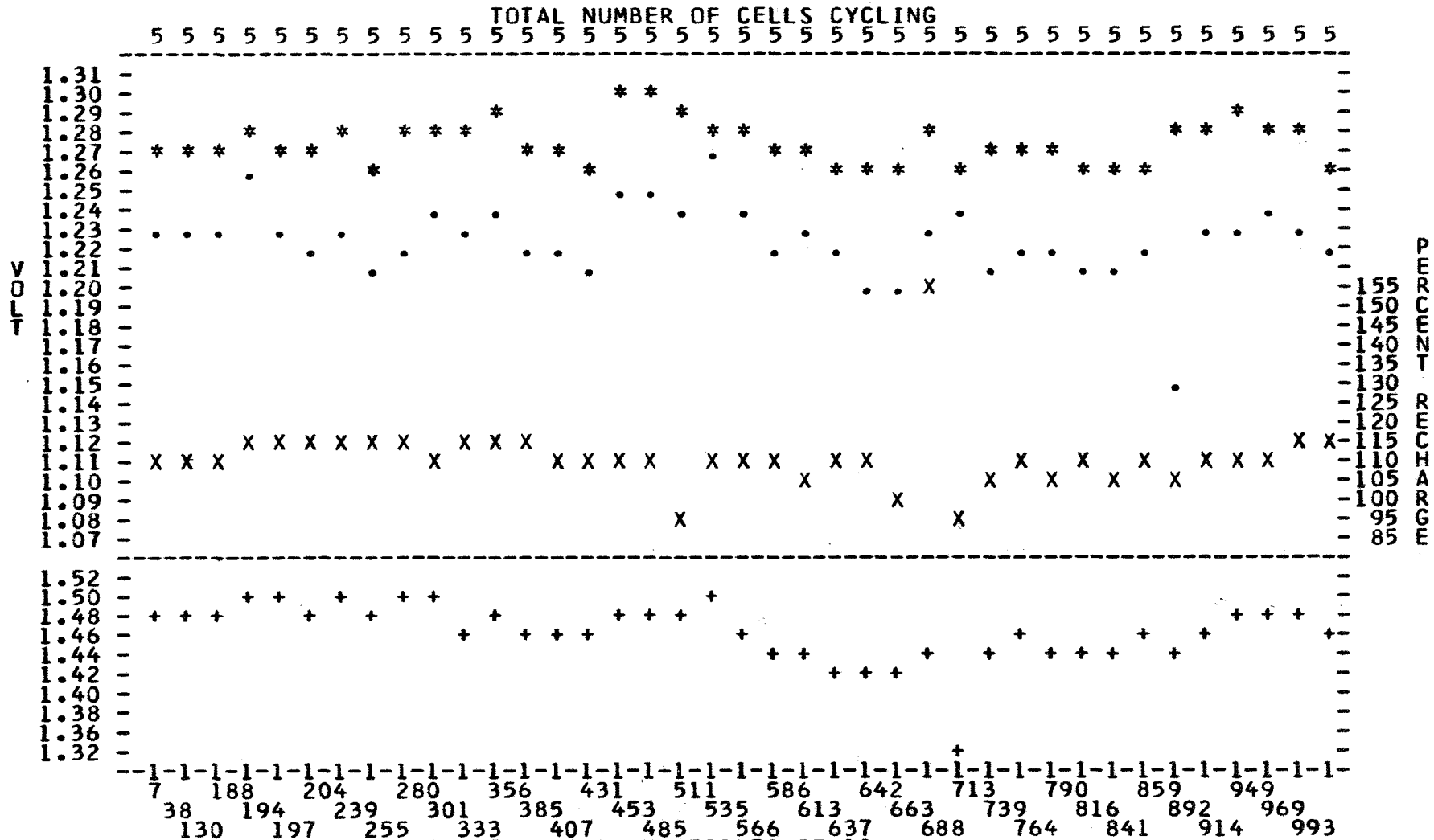


FIGURE 46

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

PACK 019B, MANUFACTURE GULTON 20.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 8.00
DEPTH OF DISCHARGE IN % 15

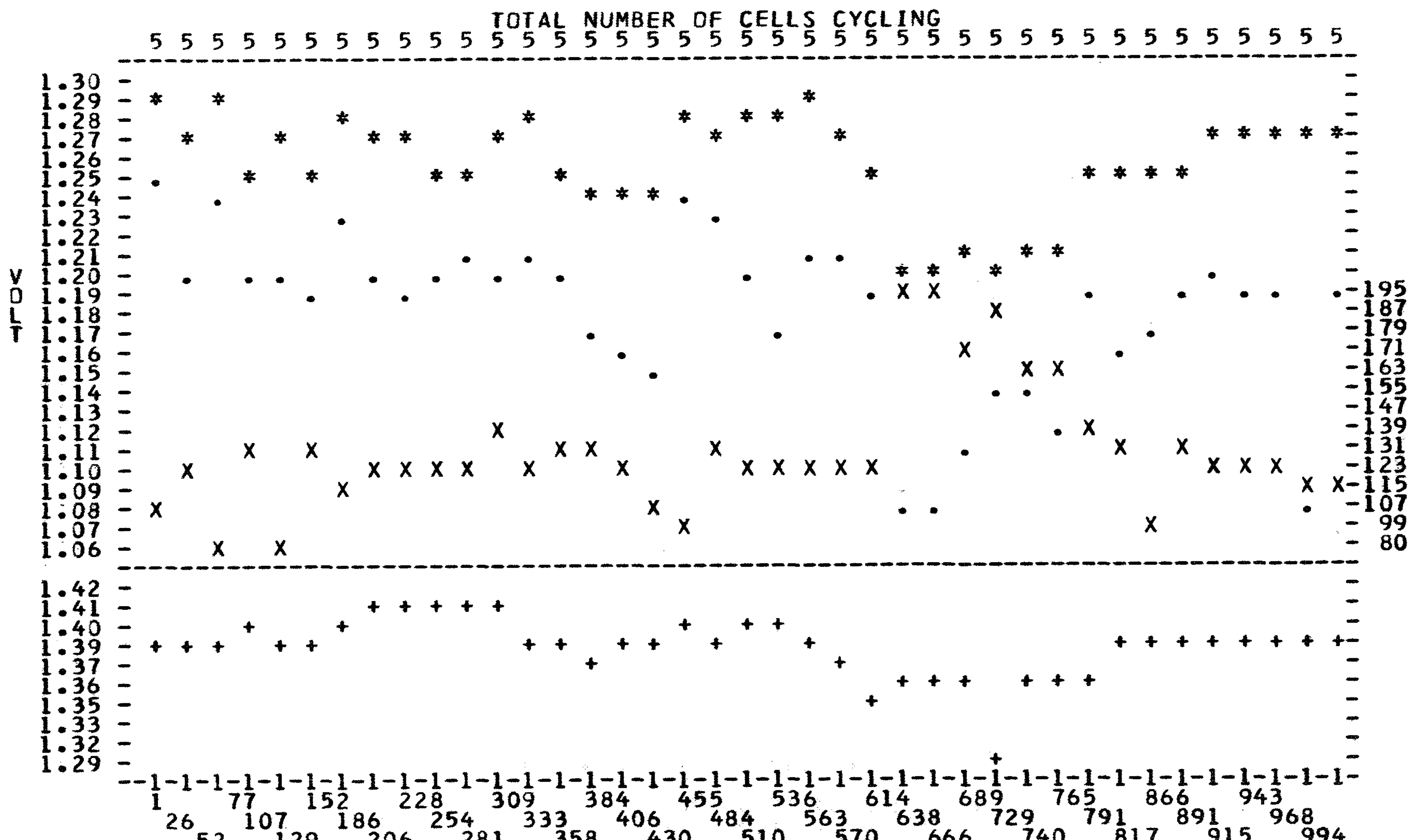


FIGURE 47

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

PACK 038E, MANUFACTURE GULTON 20.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 40
CHARGE RATE IN AMPS 8.00
DEPTH OF DISCHARGE IN % 15

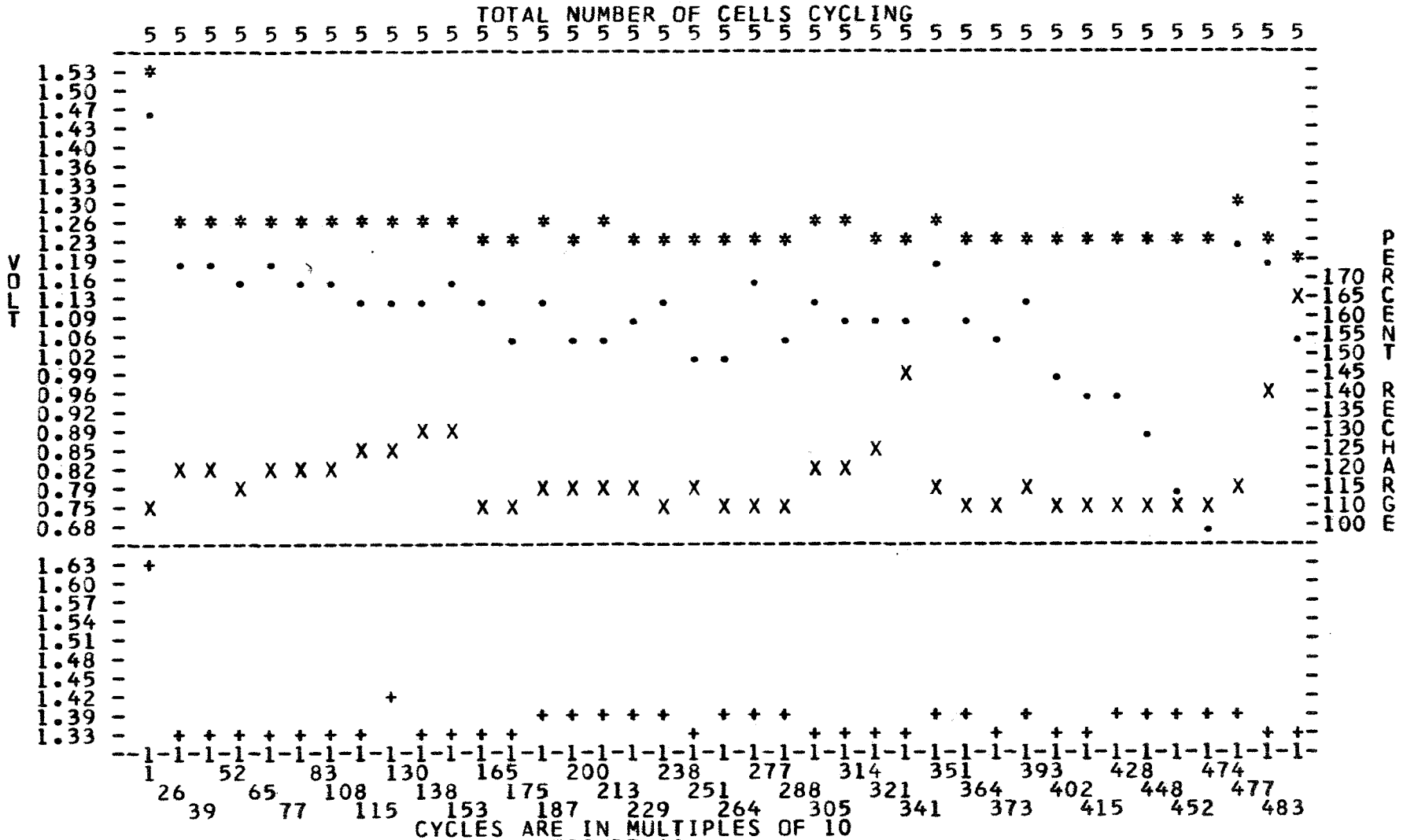


FIGURE 48

6. Gulton 20 ah (OAO), (Nickel-Cadmium), One 5-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 cycling was started, the amount of precharged cadmium material was adjusted so that two cells had 0.0 ah, two had 4.0 ah and two 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 sinuosidally 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: (Figure 49) Cycling started in May 1969. Pack 48C has completed 1360 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. To date there have been no further difficulties.

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

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

PACK 048C, MANUFACTURE GULTON 20.0 AH
ORBIT PERIOD IN HOURS 1.5
TEMPERATURE IN DEGREES C. 0/40
CHARGE RATE IN AMPS 10.00
DEPTH OF DISCHARGE IN % 25

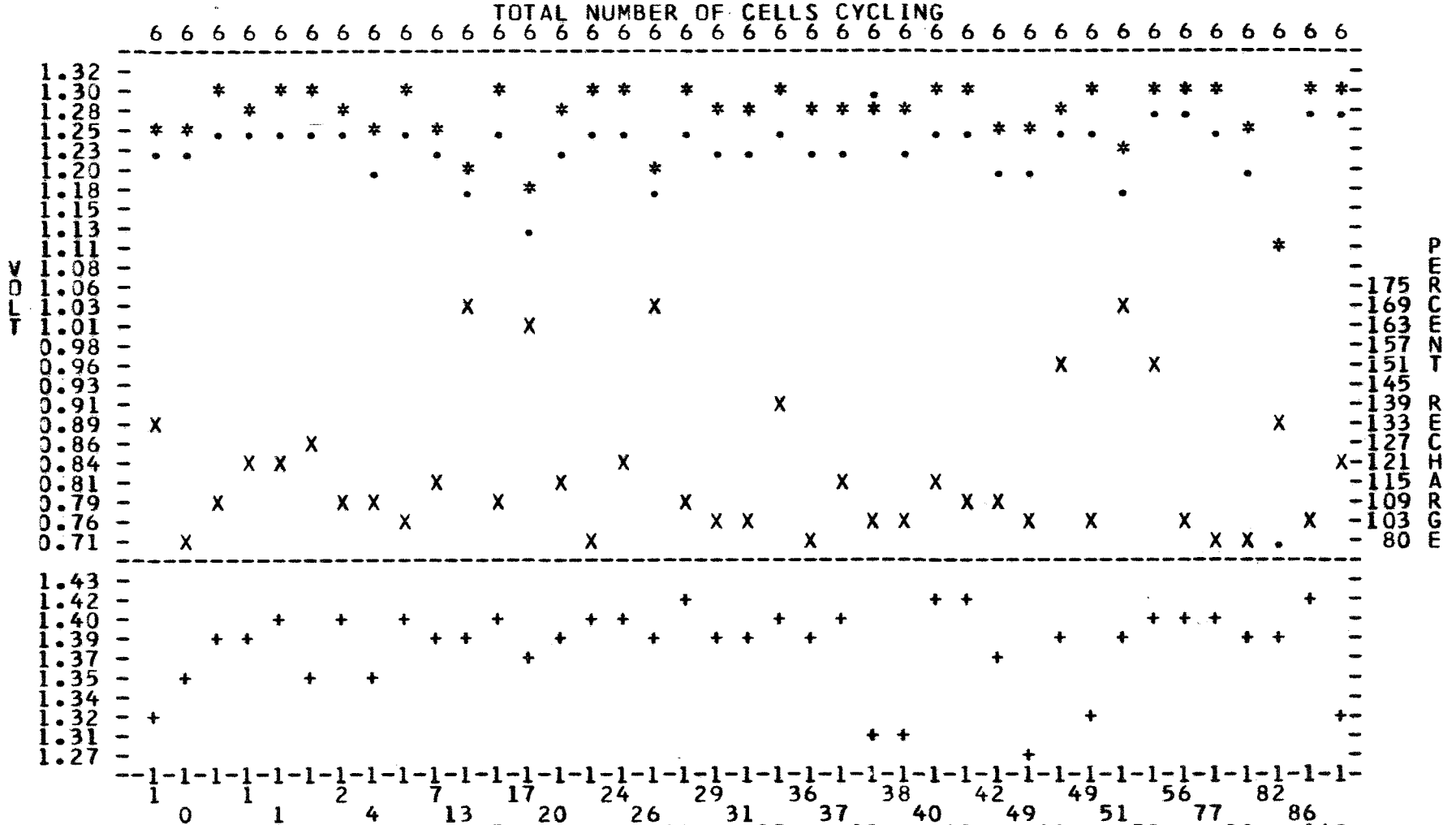


FIGURE 49

7. GE 6.0 ah (Nickel-Cadmium), Eight 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 is welded to the inner surface of the cell container. A resistor is mounted externally between the auxiliary electrode and the negative terminal. 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 platnium loaded sintered nickel plaque with no Teflon coating.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Trip Voltage Level (Millivolts)	Auxiliary Electrode Resistors	Type of Auxiliary Electrode
52C	0° C	25	250	82 Ohms	C
50B	0° C	25	250	82 Ohms	B
5B	25° C	25	250	82 Ohms	C
17B	25° C	25	250	82 Ohms	B
6C	40° C	25	250	82 Ohms	C
42C	40° C	25	250	82 Ohms	B
62B	*	25	250	82 Ohms	C
65B	*	25	250	82 Ohms	B

* 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: (Figures 50 through 56) Cycling started in June 1968. Packs 52C, 50B 5B 17B, 42C, 62B and 65B have completed 8784, 9057, 8198, 9082, 9047, 2316 and

8270 cycles, respectively, with one cell failure in pack 52C. Pack 6C failed on cycle 8072 with three cell failures.

(2) Failure Analysis: Analysis of four failed cells showed that the major causes of failure were due to ceramic shorts, separator deterioration and migration of the negative plate material. All four cells also had bulged cases caused by high internal pressure.

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

Pack Number	52C	50B	5B	17B	6C	42C	62B	65B
Temperature	0°C	0°C	25°C	25°C	40°C	40°C	*	*
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	5.80
176 Days	4.85	7.30	1.85	3.20	1.55	1.75		5.75
264 Days	3.10	7.25	1.50	2.20	2.10	2.20		2.65
352 Days	4.15	7.20	1.65	1.85	2.10	2.15		2.45
440 Days	3.35	7.05	1.75	1.90	2.50 F	2.10		2.00

* 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.

F - Failed

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

PACK 052C, MANUFACTURE GE 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

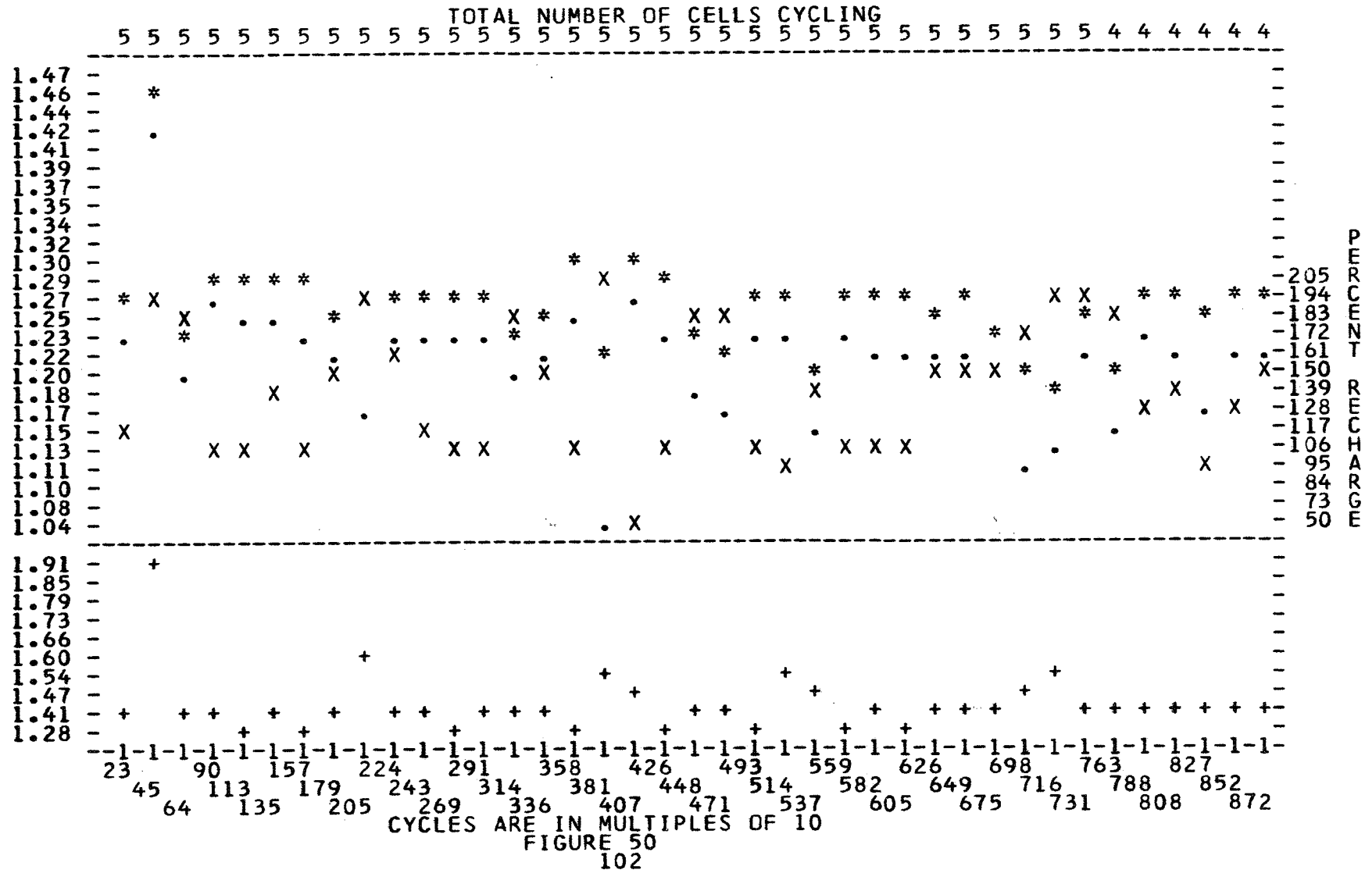


FIGURE 50

QE/C 70-173

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

PACK 050B, MANUFACTURE GE 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

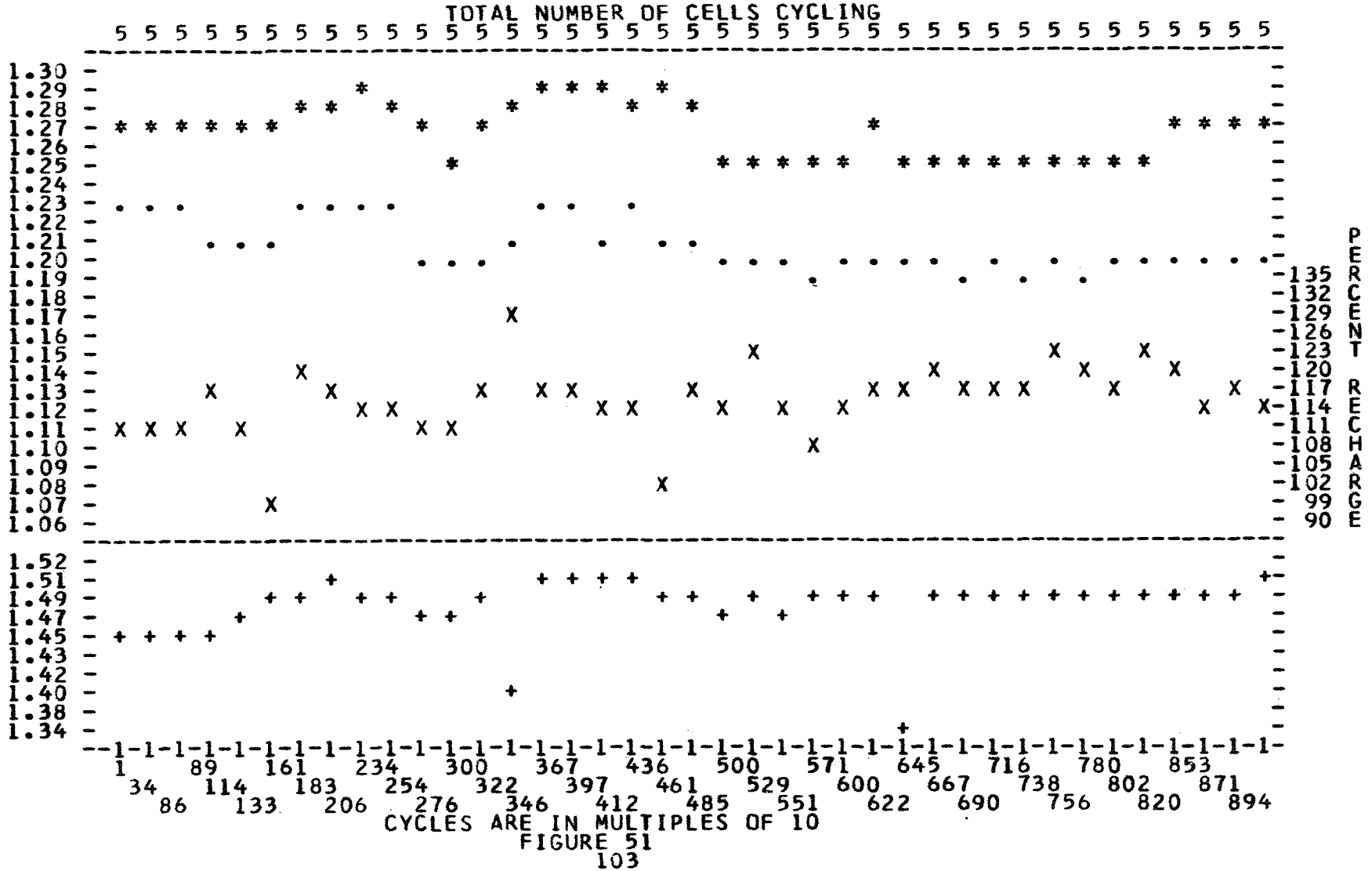
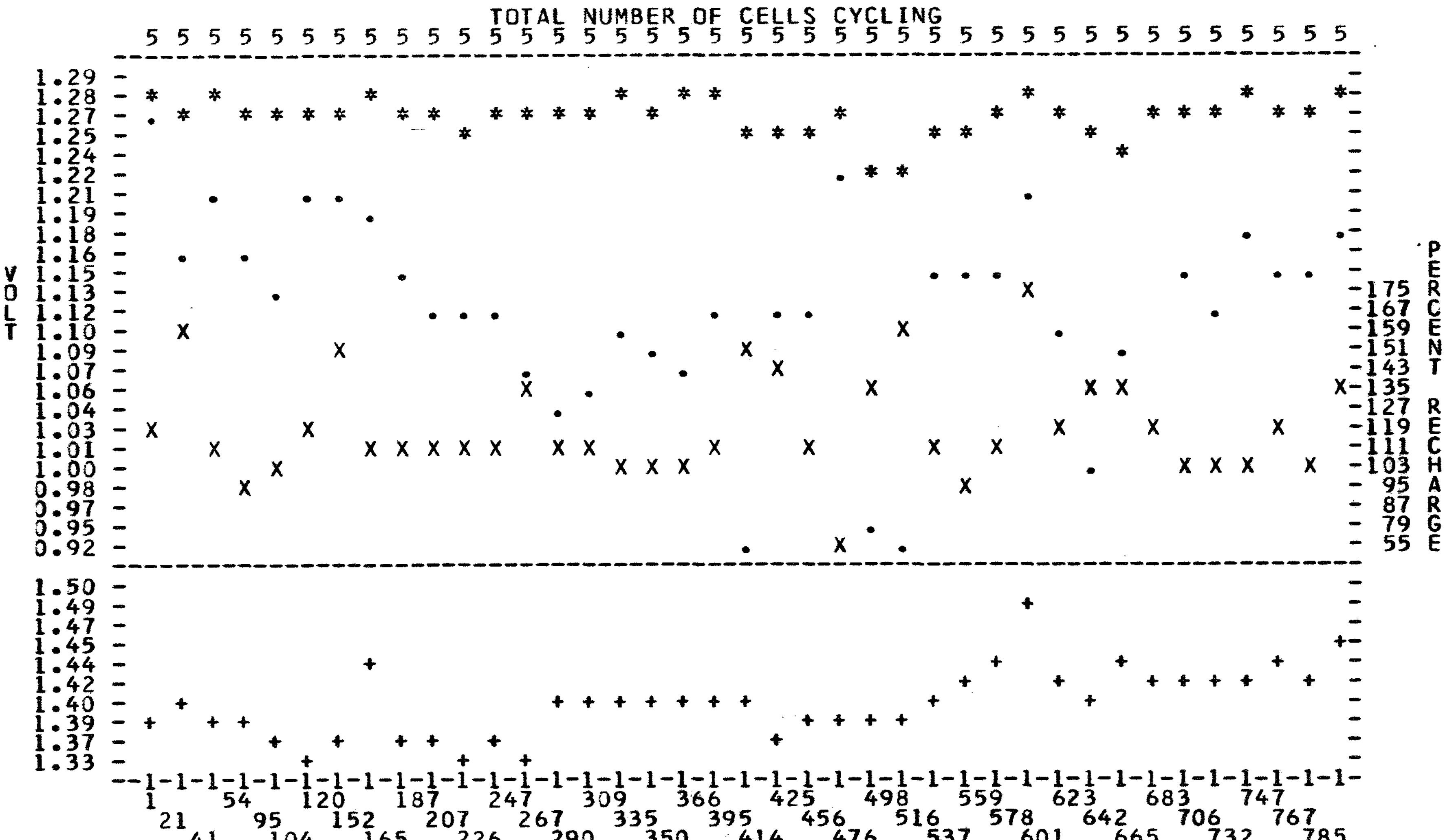


FIGURE 51

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

PACK 005B, MANUFACTURE GE 6.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25



CYCLES ARE IN MULTIPLES OF 10

FIGURE 52

QE/C 70-173

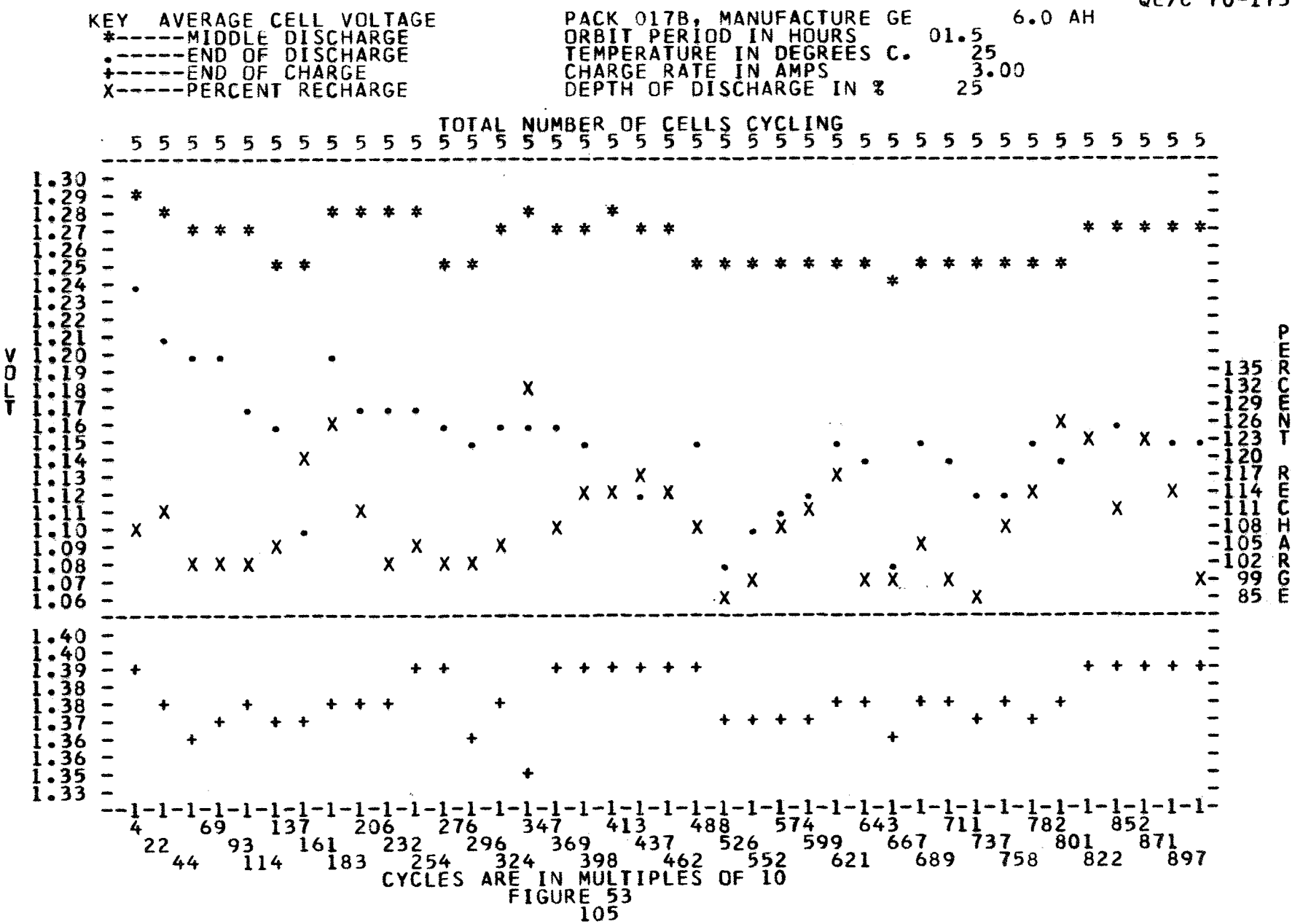
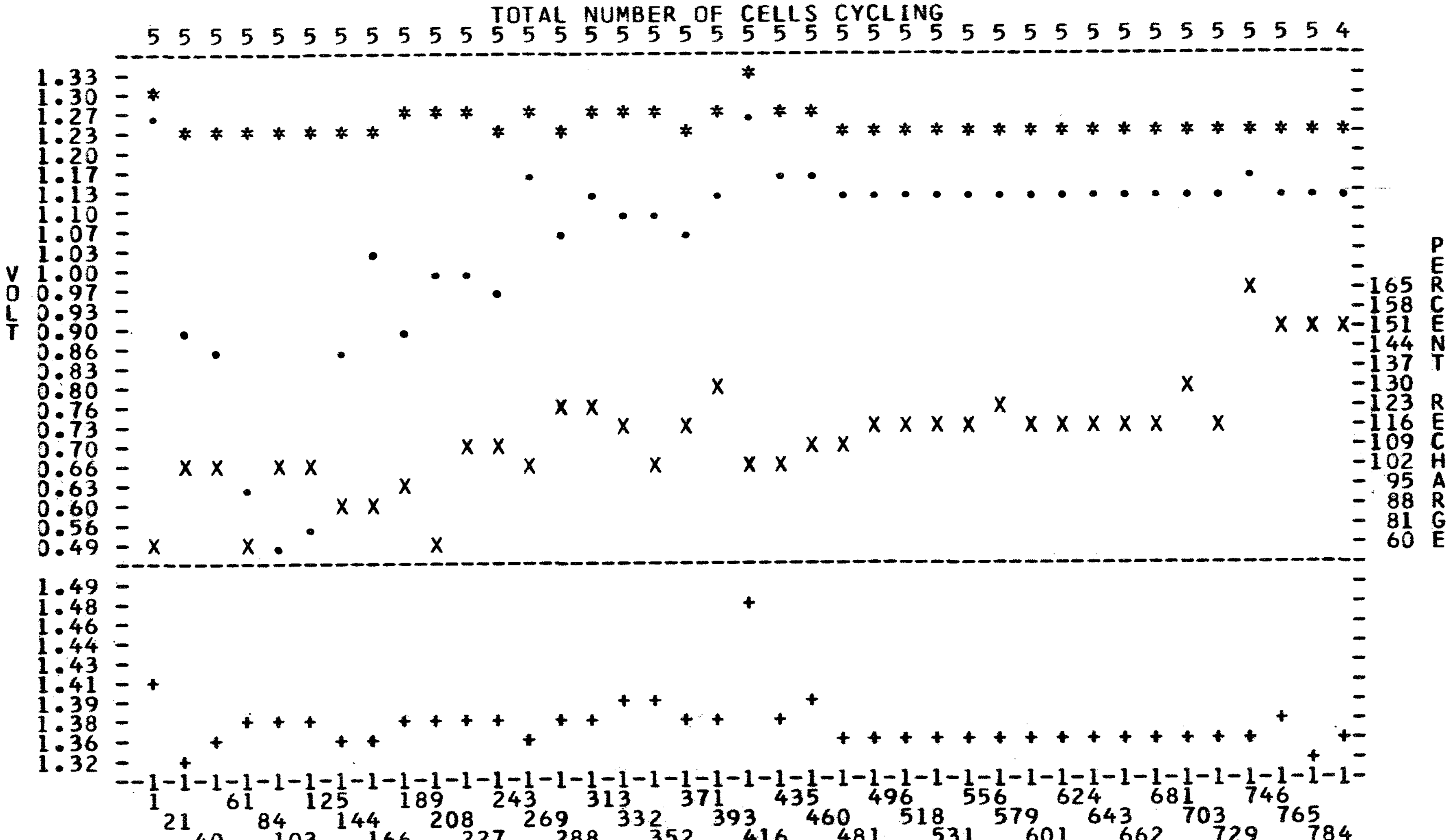


FIGURE 53

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

PACK 006C, MANUFACTURE GE 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 40
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25



CYCLES ARE IN MULTIPLES OF 10

FIGURE 54

QE/C 70-173

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

PACK 042C, MANUFACTURE GE 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 40
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

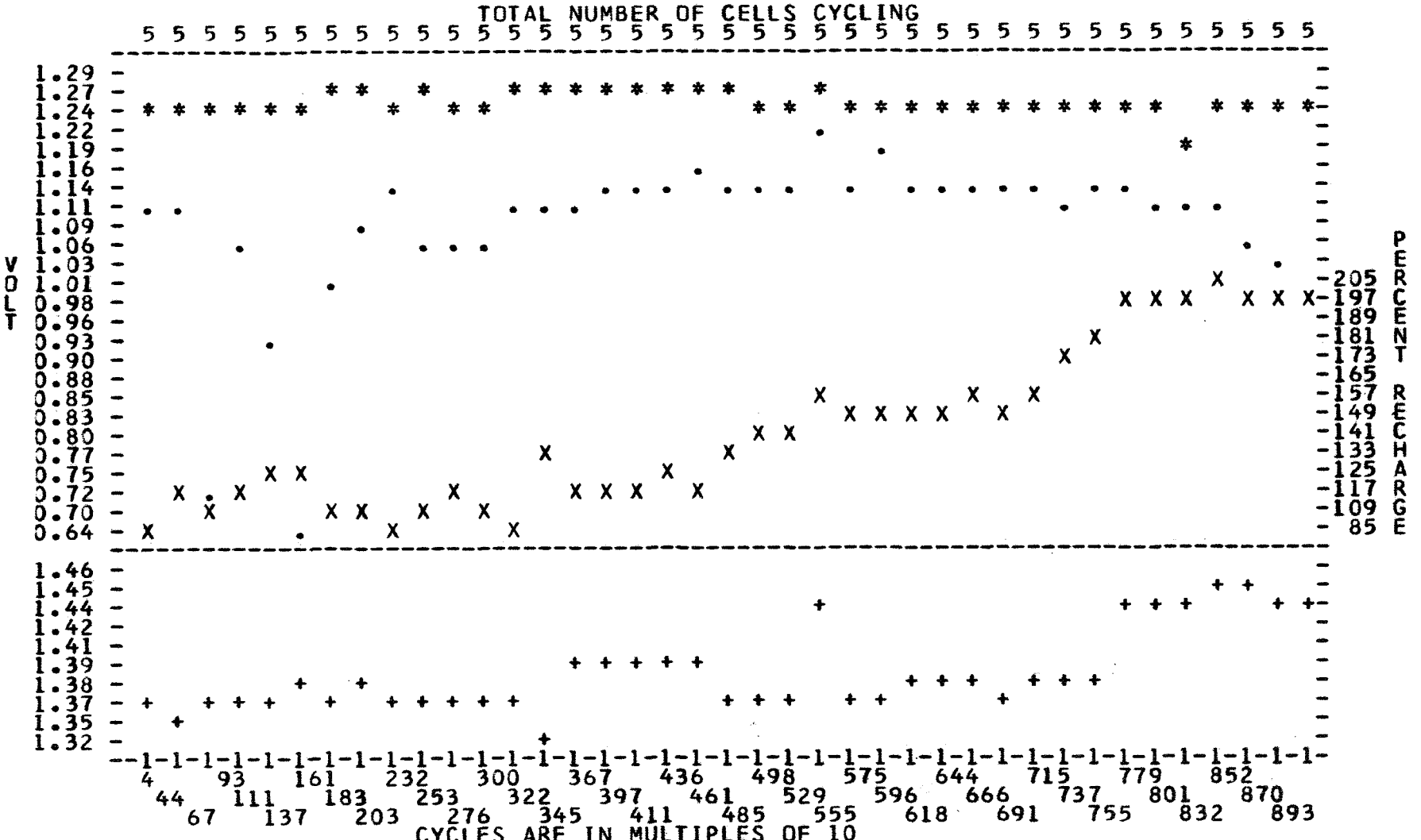


FIGURE 55

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

PACK 065B, MANUFACTURE GE 06.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 0/40
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

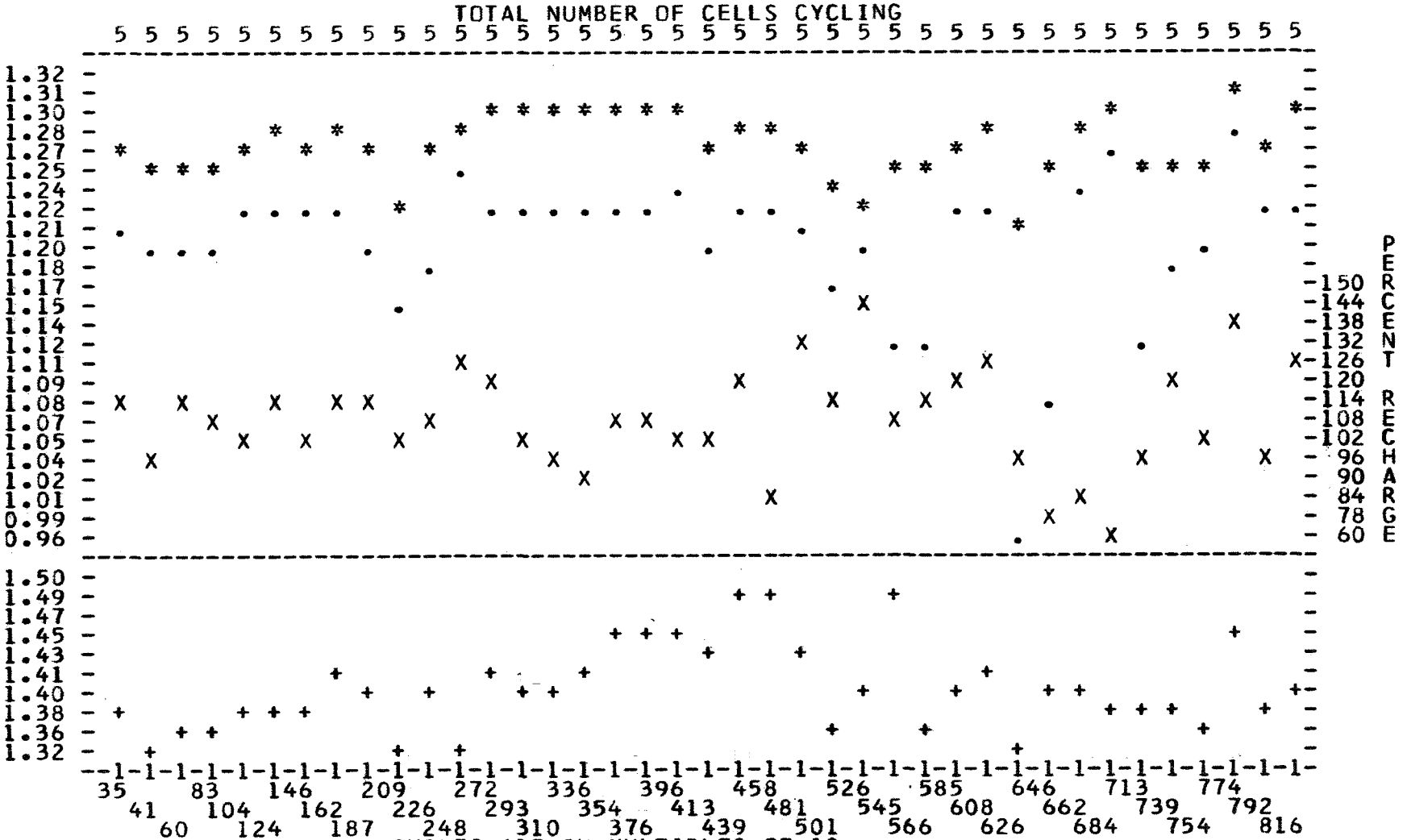


FIGURE 56

8. GE 6.0 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 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 signal electrode, which is used for charge control, is welded to the inside of the container, and its terminal is a stainless steel tab welded to the outside. The gas recombination electrode is welded to a wire that protrudes through a hole in the cell cover which 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: (Figures 57 through 59) Cycling was started in July 1968. Packs 53B and 28C have completed 8080 and 8168 cycles, 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 failed cell from pack 47C showed the major cause of failure to be separator deterioration and migration of negative plate material. The case had also bulged due to high internal pressure.

One cell from 47C which did not fail was analyzed for comparison with the failed cell. The conditions found in this cell were similar to the failed cell except that the separator deterioration and migration were not as severe.

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

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

F - Failed

QE/C 70-173

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

PACK 053B, MANUFACTURE GE 06.0 AH
ORBIT PERIOD IN HOURS 1.5
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 1.80
DEPTH OF DISCHARGE IN % 15

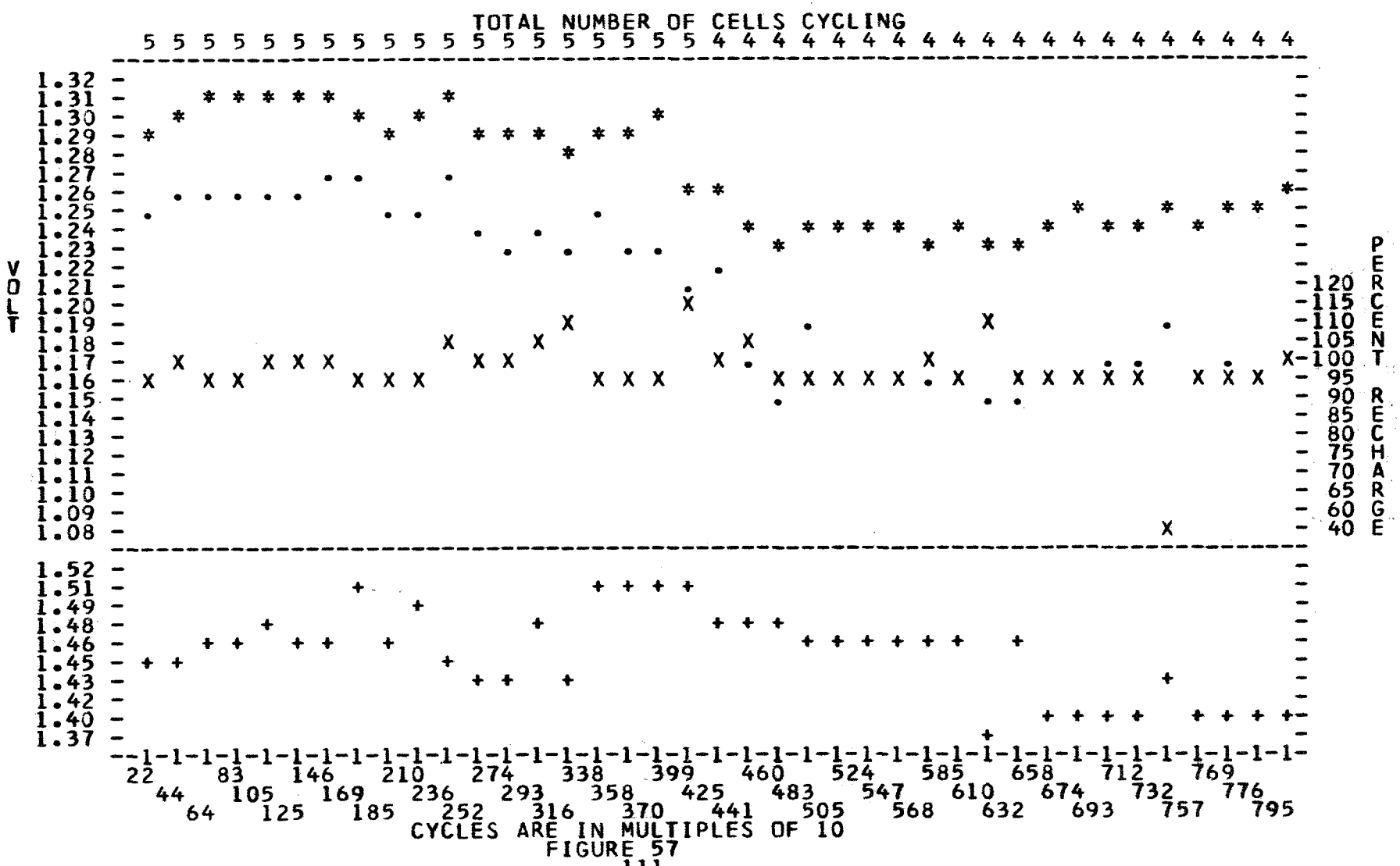


FIGURE 57

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

PACK 028C, MANUFACTURE GE 06.0 AH
ORBIT PERIOD IN HOURS 1.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 1.80
DEPTH OF DISCHARGE IN % 15

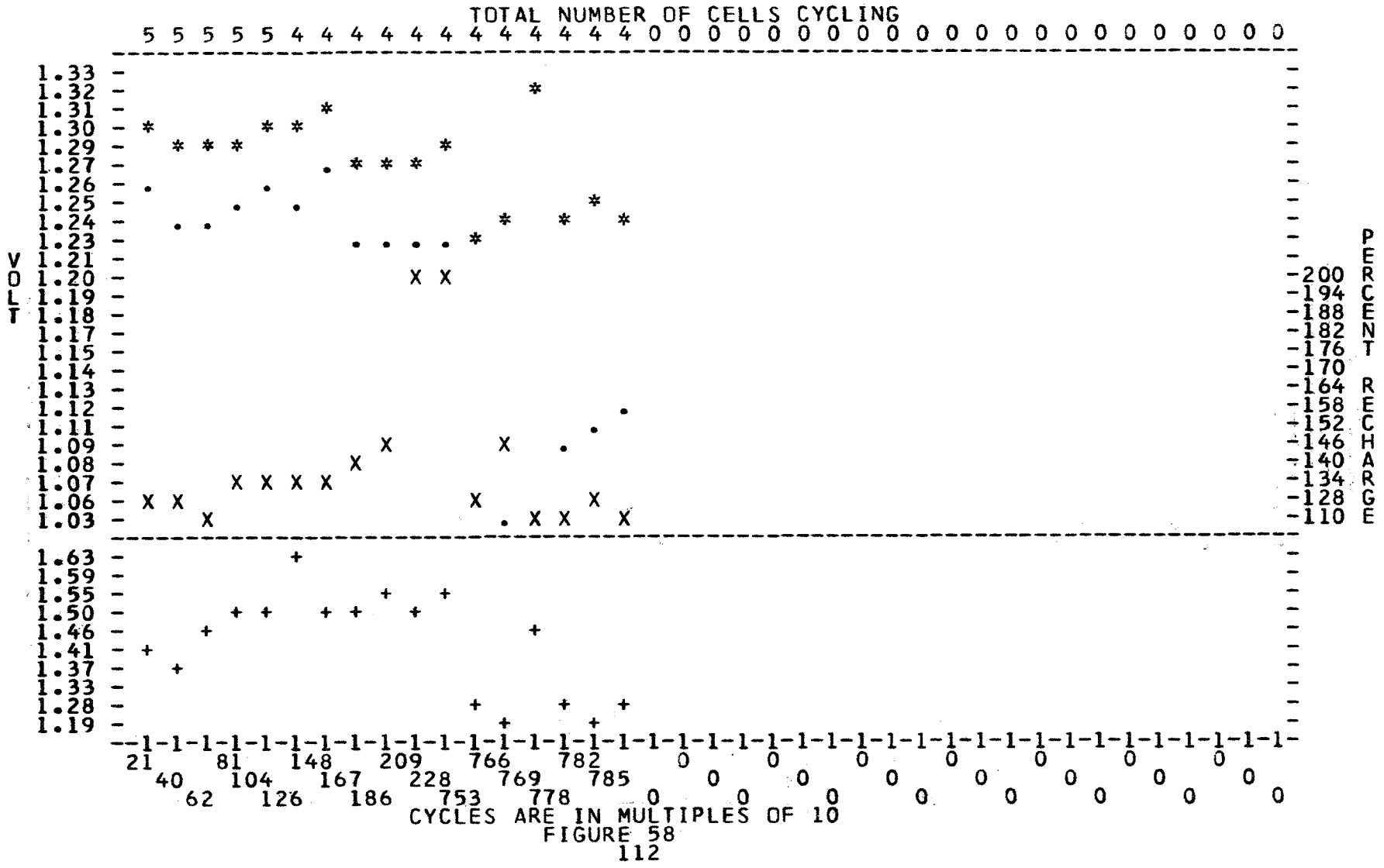


FIGURE 58

QE/C 70-173

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

PACK 047C, MANUFACTURE GE 6.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 40
CHARGE RATE IN AMPS 1.80
DEPTH OF DISCHARGE IN % 15

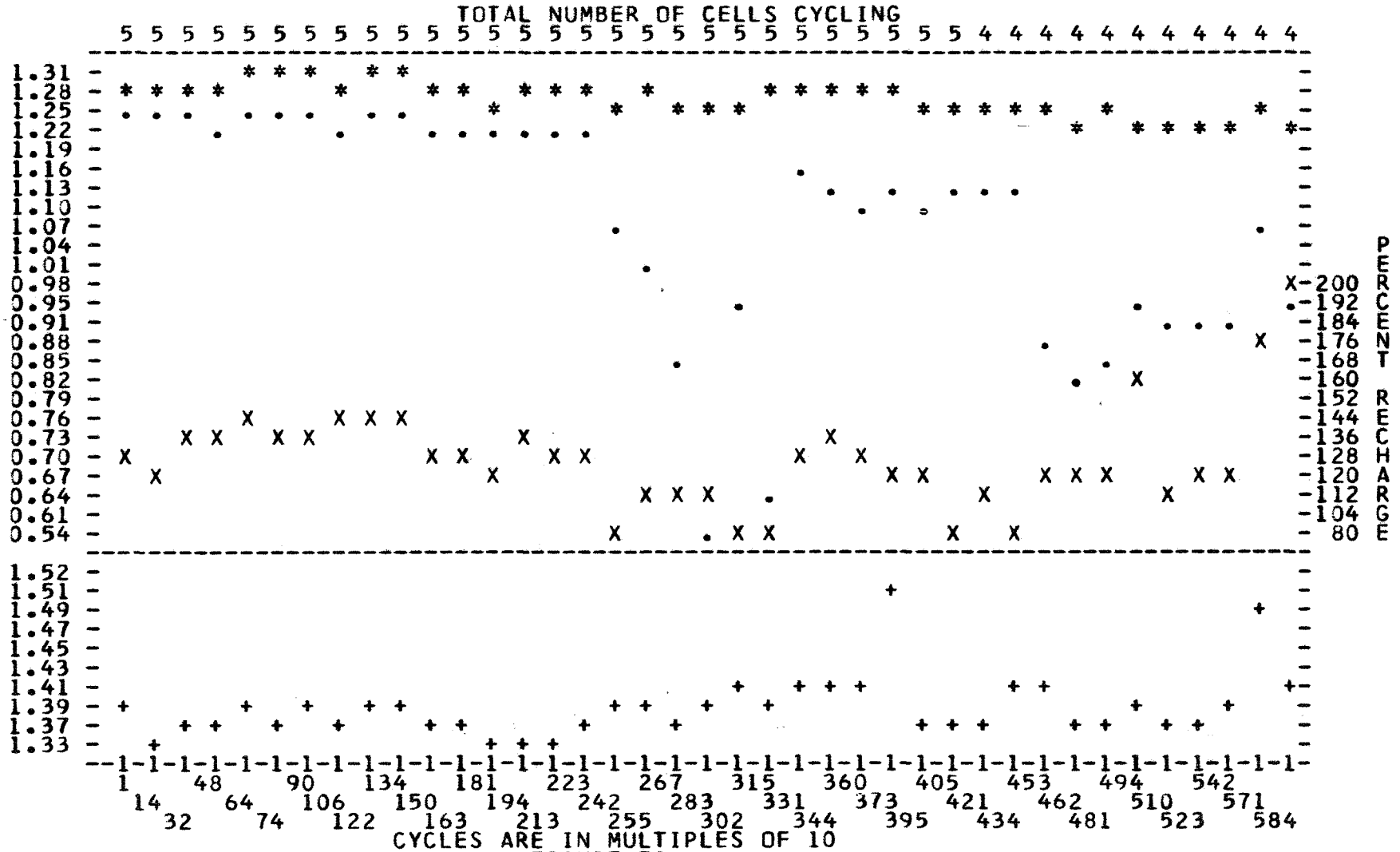


FIGURE 59

9. 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: (Figure 60) Cycling was started in September 1966. This pack has completed 3387 cycles to date with two failures.

(a) One cell failed on cycle 1379 due to an internal short which caused the cell to develop high pressure resulting in the rupture of the plastic case. The other cell failed on cycle 3253. This cell showed excessive migration, loose active (mushy) material, separator deterioration, and carbonate desposits around the outside negative terminal.

(2) 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	3.37
1094	2.67				

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

PACK 001B, MANUFACTURE ESB 08.0 AH
ORBIT PERIOD IN HOURS 08.0
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 0.50
DEPTH OF DISCHARGE IN % 25

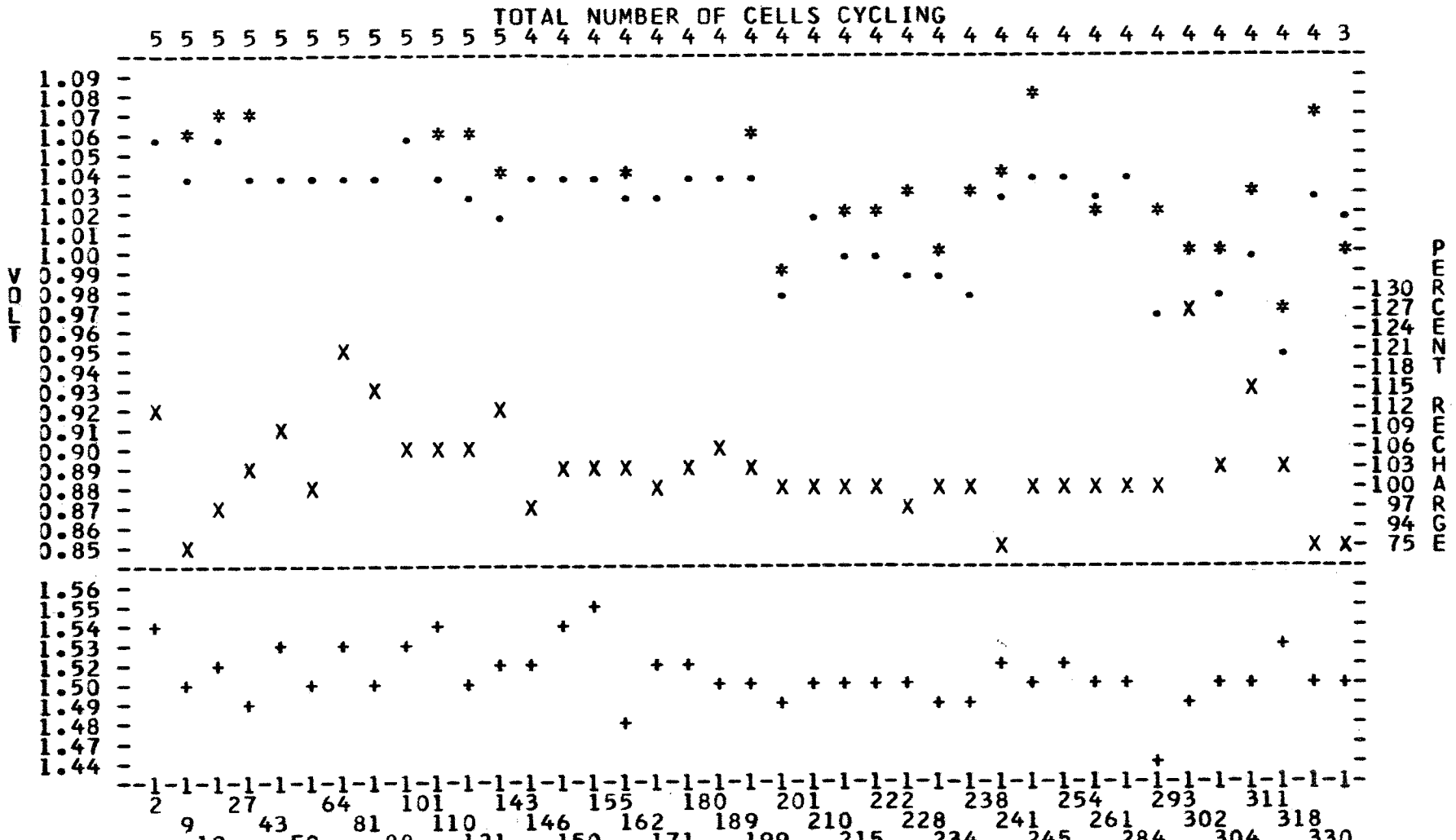


FIGURE 60

10. Yardney 11.0 ah (Silver-Cadmium), Three 5-cell Packs, 24-hour Orbit Period:

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

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge	Charge Voltage Limit, Per Cell	Auxiliary Electrode Resistors (Ohms)
57D	0° C	18	1.51	1
69B	25° C	18	1.51	1
33C	40° C	18	1.51	1

c. Test Results:

(1) Performance on Cycling: (Figures 61 through 63) Cycling was started in February 1968. Packs 57D, 69B and 33C have completed 651, 507 and 447 cycles respectively. Packs 69B and 33C have failed and Pack 57D has one cell failure to date.

(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.

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

PRECYCLING AND CAPACITY CHECKS

Orbit Period		24-hour	
Temperature	0°	25°	40°
Depth of Discharge	18%	18%	18%
Pack Number	57D	69B	33C
100 Days	4.10	7.55	8.70
200 Days	7.20	7.00	6.85
300 Days	4.10	3.50	5.15
400 Days	2.85	2.20	4.85 F
500 Days	8.35	1.85 F	

F - Failed

QE/C 70-173

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

PACK 057D, MANUFACTURE YARDNEY 11.0 AH
ORBIT PERIOD IN HOURS 24.0
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 0.25
DEPTH OF DISCHARGE IN % 18

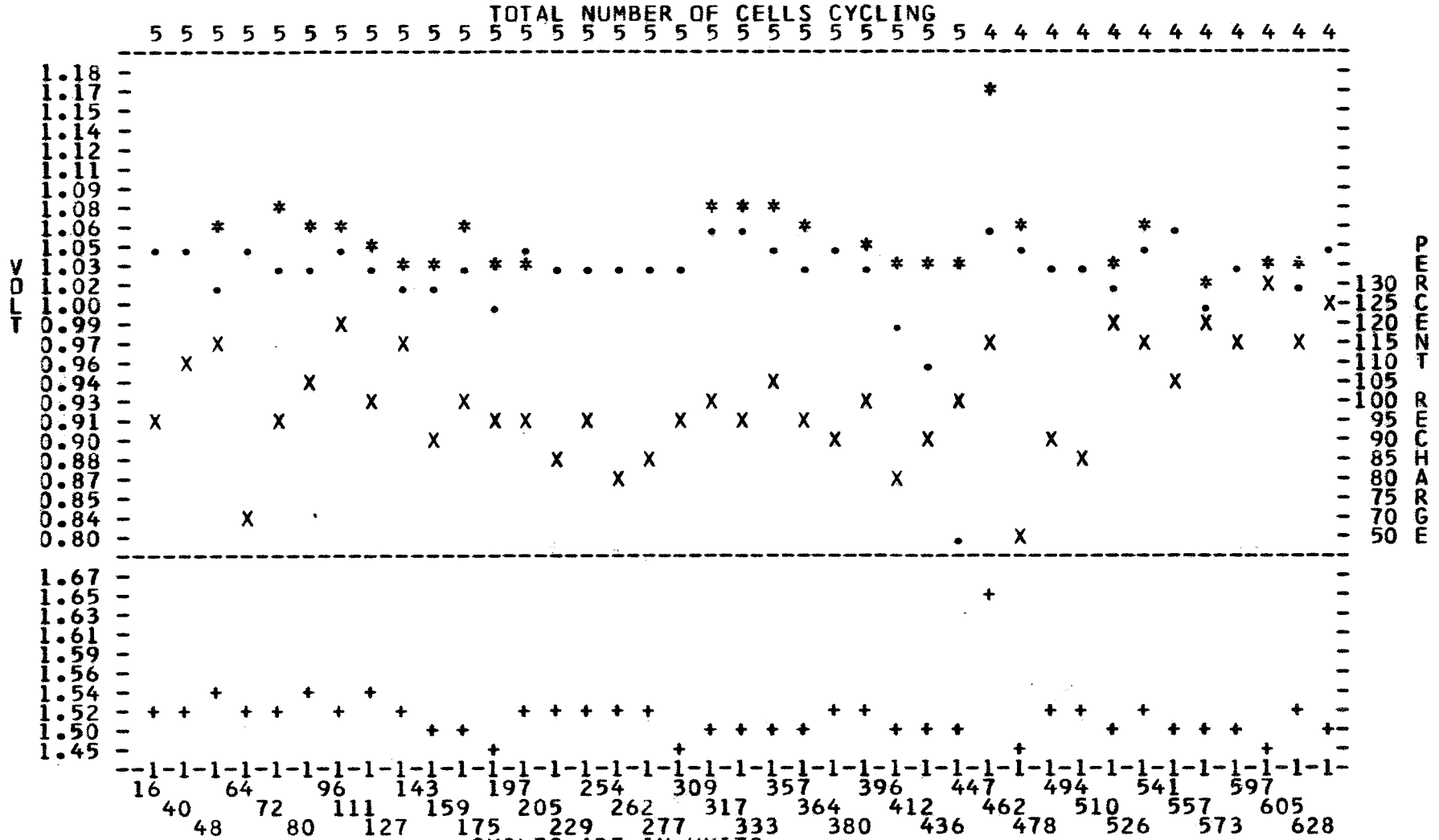


FIGURE 61

QE/C 70-173

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

PACK 069B, MANUFACTURE YARDNEY 11.0 AH
ORBIT PERIOD IN HOURS 24.0
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 0.25
DEPTH OF DISCHARGE IN % 18

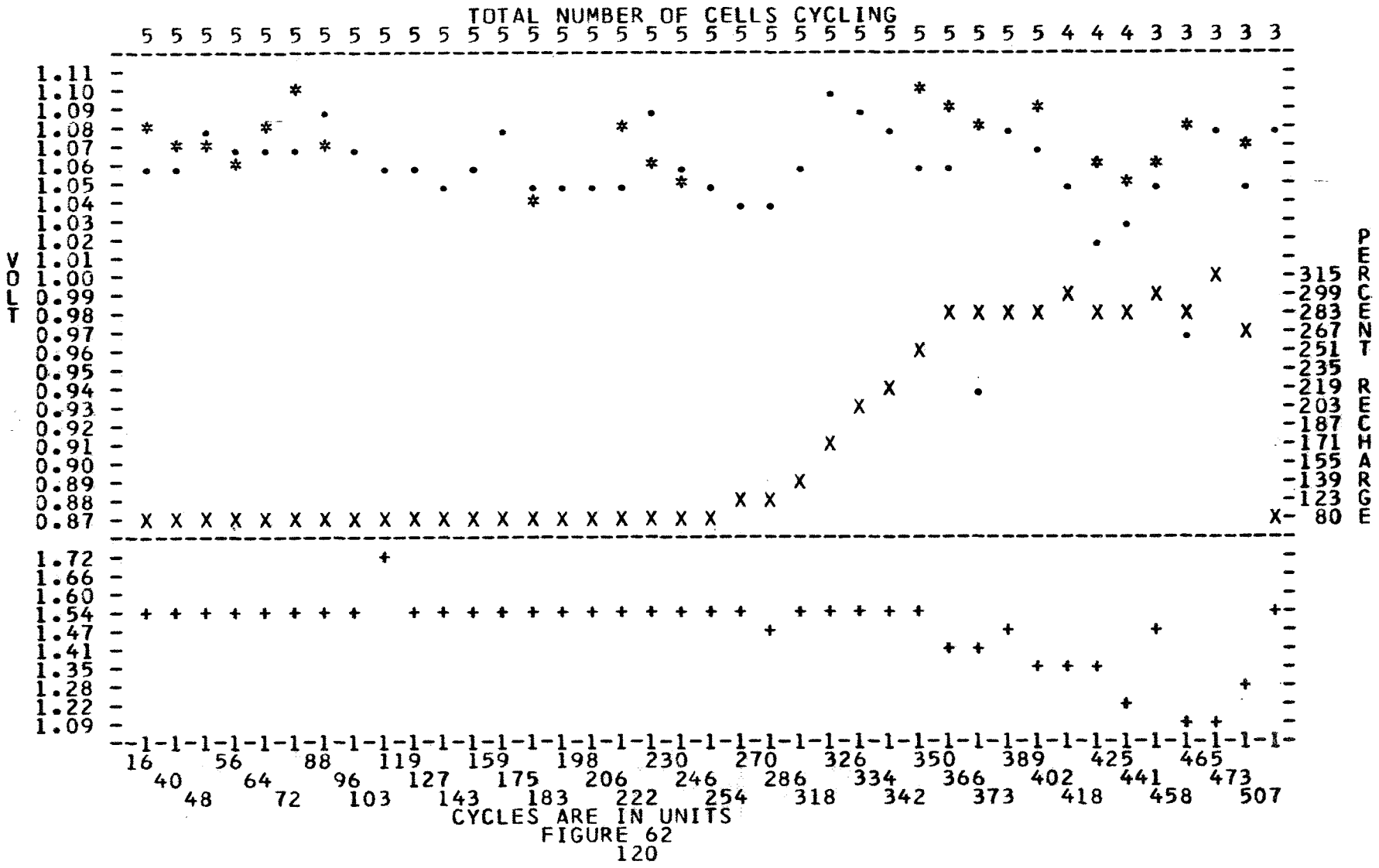


FIGURE 62

QE/C 70-173

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

PACK 033C, MANUFACTURE YARDNEY 11.0 AH
ORBIT PERIOD IN HOURS 24.0
TEMPERATURE IN DEGREES C. 40
CHARGE RATE IN AMPS 0.25
DEPTH OF DISCHARGE IN % 18

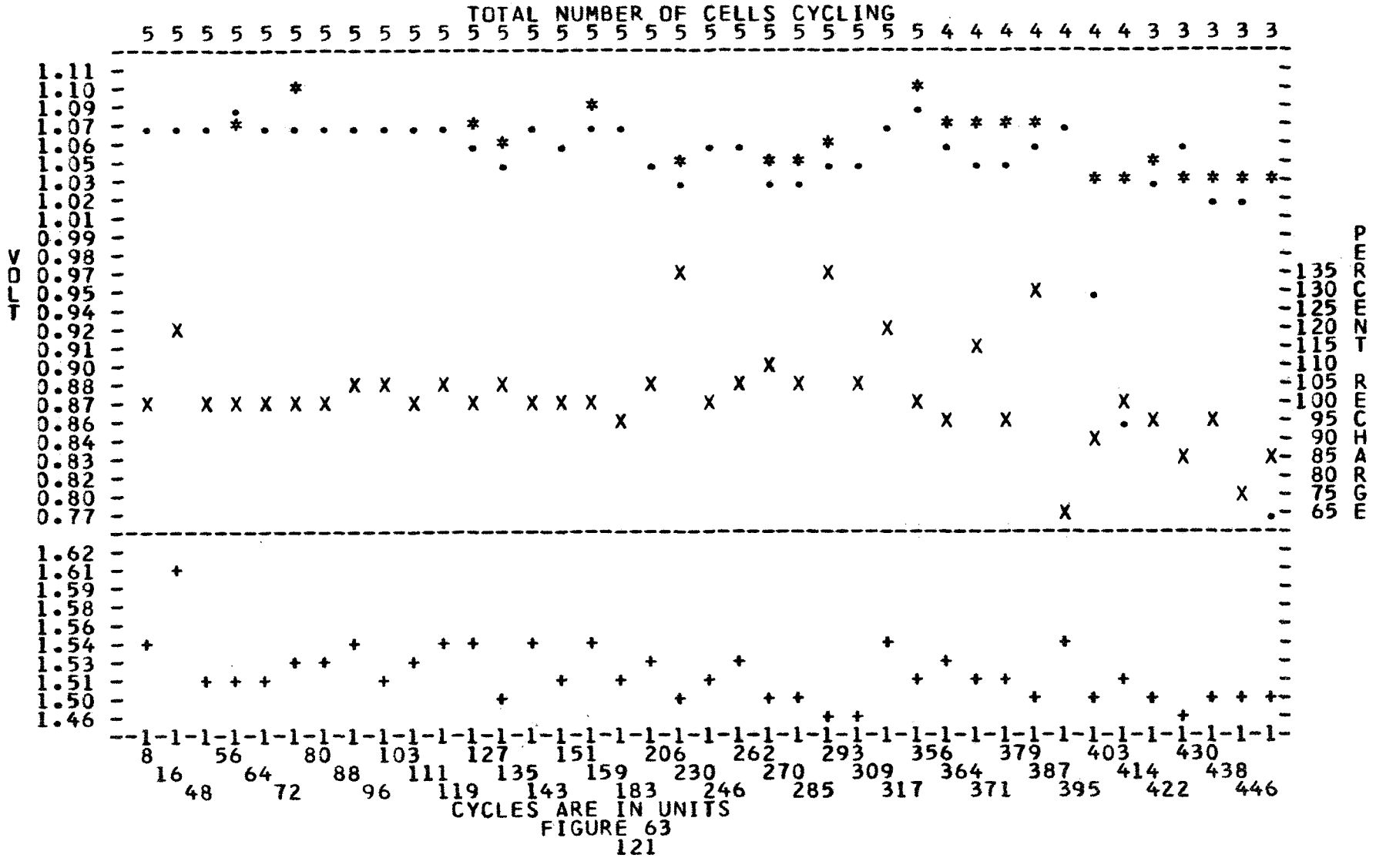


FIGURE 63

C. 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 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: (Figure 64) 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 cell prevented gas recombination to occur which caused the cell 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 F	4.57	3.30
88 Days Disch #2		4.10	3.10	3.50 F		1.87 F	1.13 F
176 Days Disch #2		3.37	2.43				
264 Days Disch #2		2.33	3.37				
352 Days Disch #2		3.80 F	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 F				

* Pack failure occurred during precycling capacity check.

F - Failed

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

PACK 026C, MANUFACTURE GULTON 04.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 1.20
DEPTH OF DISCHARGE IN % 15

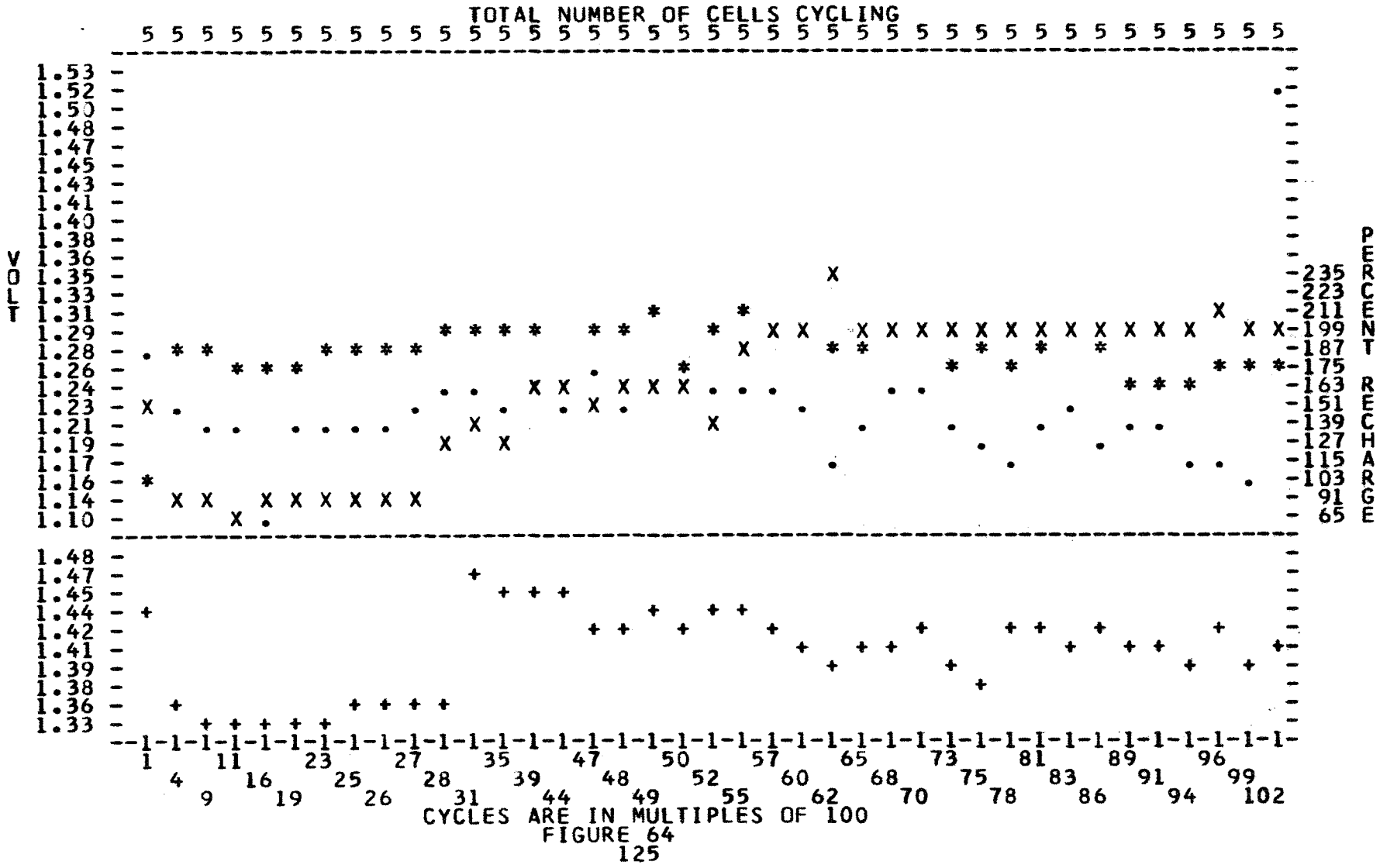


FIGURE 64

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

a. Cell Description: The 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. The cells were designed for use in the Radio Astronomer Explorer satellite.

b. Test Parameters:

Pack Number	Test Temperature	Percent Depth of Discharge
41B	-20° C	25
66B	0° C	25
18C	25° C	25
29B	40° C	25

c. Test Results:

(1) Performance on Cycling: (Figures 65 through 68) Cycling was started in November 1966. Packs 41B, 66B, 18C and 29B have completed 8310, 8717, 8288 and 7941 cycles, respectively, to date. Pack 29B has failed and one cell has failed in each of packs 41B and 18C.

(2) Failure Analysis:

(a) Analysis of four 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 and electrolyte leakage. Due to the swollen condition and danger of damage to the rest of pack 41B, this cell has not been removed and analyzed.

(b) It was necessary to replace the coulometer in pack 41B, operating at -20° C, on six occasions; and on one occasion in pack 66B operating at 0° C because each coulometer had shorted internally. These failures were due to inadequate plate separation having one layer of nonwoven nylon. It has been found

that coulometers require twice the effectiveness of plate separation as that found in its nickel-cadmium counterpart. The failure mode being combated is cadmium migration. These results have lead to the use of two layers of nonwoven nylon in RAE coulometers.

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

PRECYCLING AND CAPACITY CHECKS

Orbit Period		1.5-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
176 Days	Disch #2	4.75	6.40	1.80	1.65
264 Days	Disch #2	4.50	5.70	1.50	1.80
352 Days	Disch #2	3.25	5.25	1.50	1.60
440 Days	Disch #2	3.05	4.75	1.35	1.55
528 Days	Disch #2	0.90	4.55	1.50	1.60
616 Days	Disch #2	2.40	4.00	1.50	1.50
704 Days	Disch #2	2.15	4.25	1.50	1.50
792 Days	Disch #2	1.45	4.25	1.55	1.60
880 Days	Disch #2	1.35	4.00	1.50	2.70 F
968 Days	Disch #2	2.15	6.25		

F - Failed

QE/C 70-173

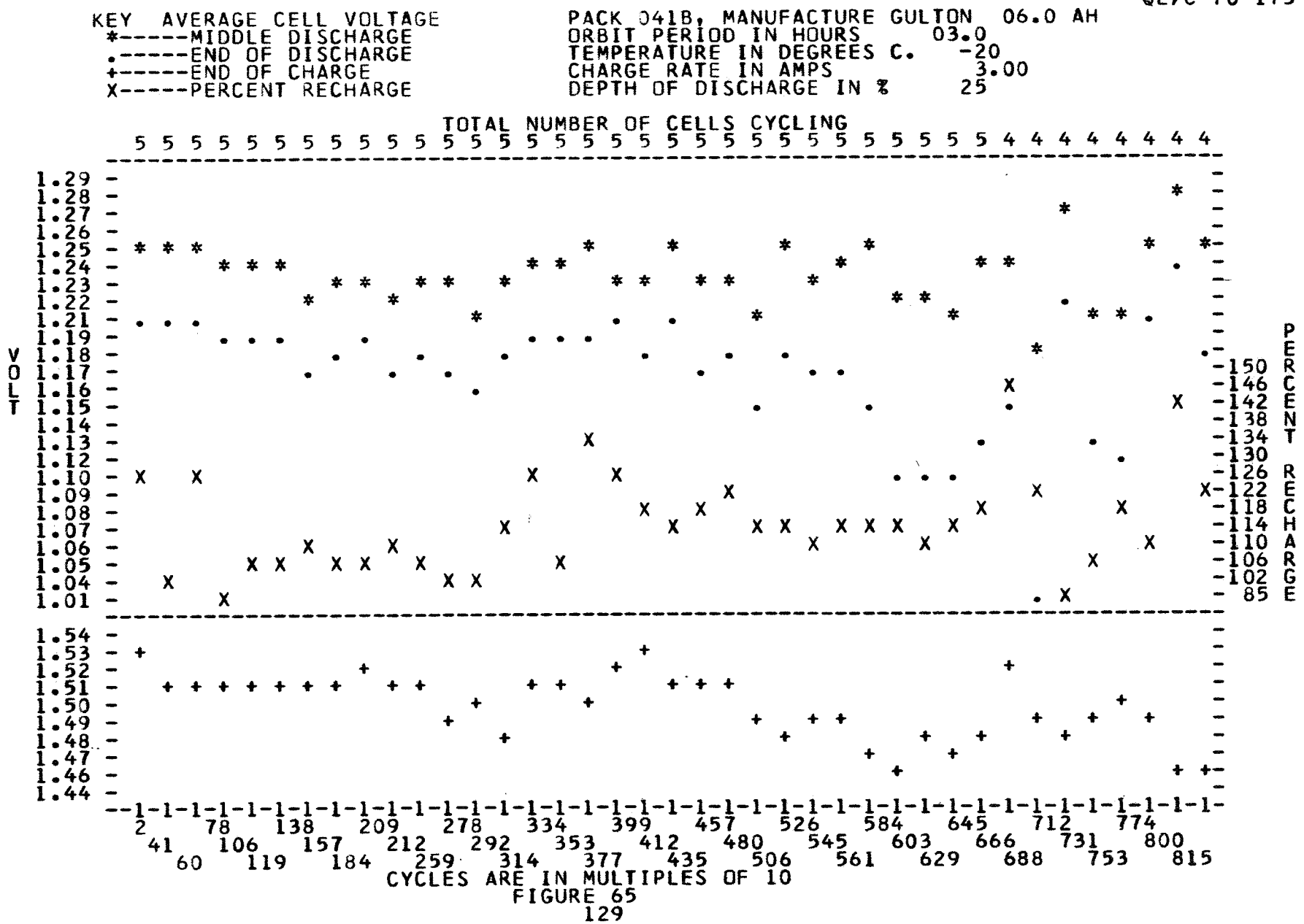


FIGURE 65

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

PACK 066B, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 03.0
TEMPERATURE IN DEGREES C. 00
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

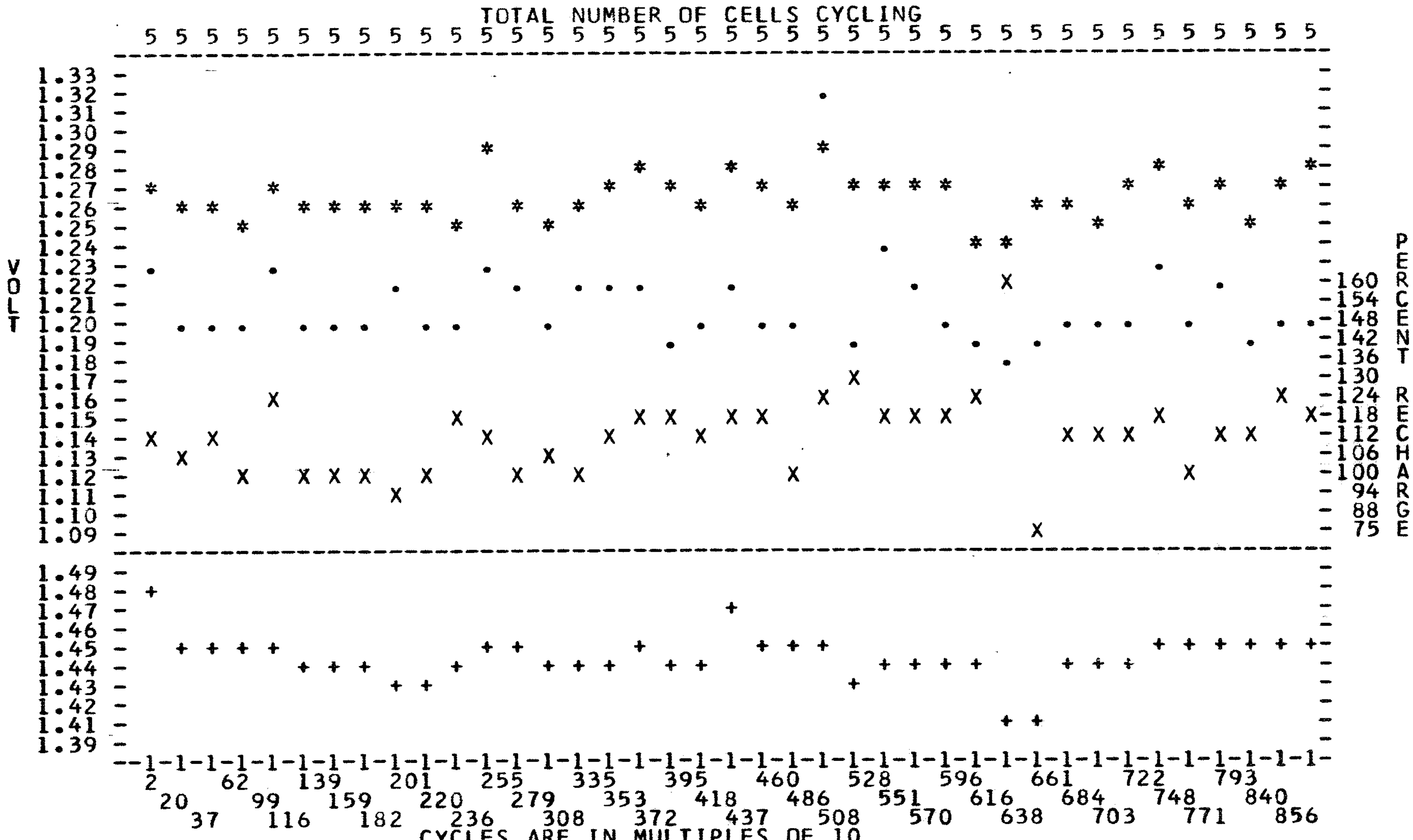


FIGURE 66

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

PACK 018C, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 03.0
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25

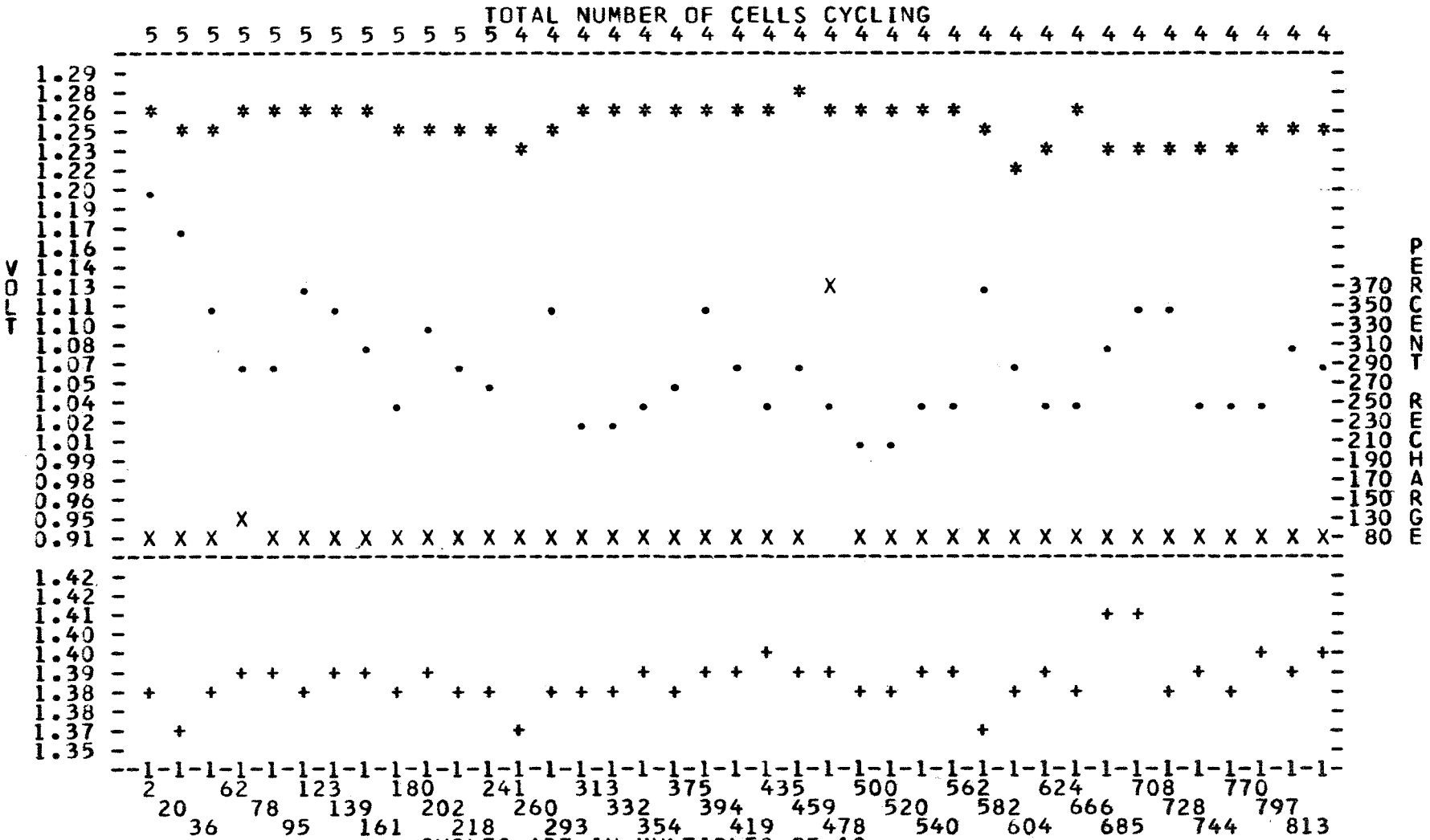
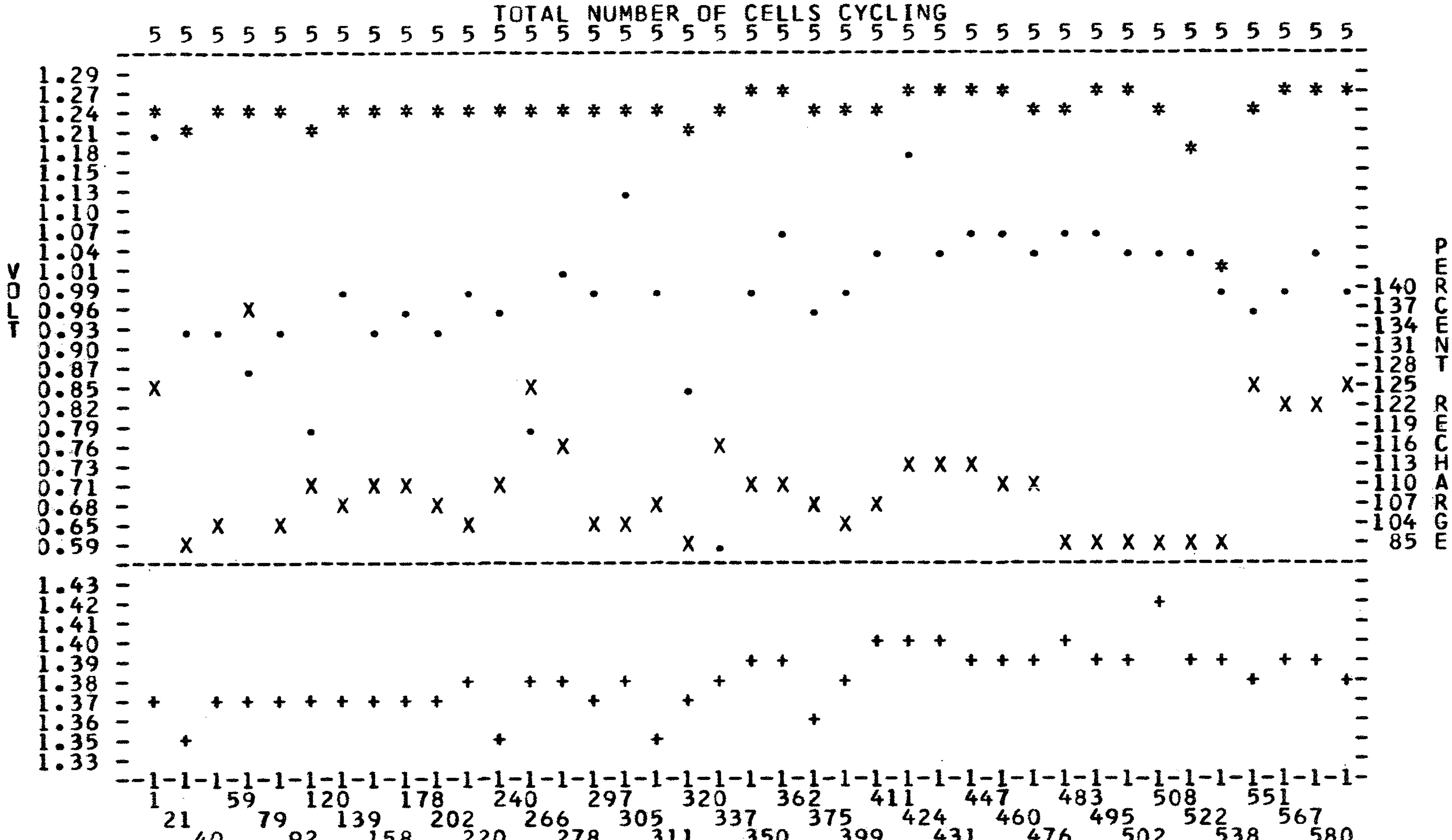


FIGURE 67

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

PACK 029B, MANUFACTURE GULTON 06.0 AH
ORBIT PERIOD IN HOURS 03.0
TEMPERATURE IN DEGREES C. 40
CHARGE RATE IN AMPS 3.00
DEPTH OF DISCHARGE IN % 25



CYCLES ARE IN MULTIPLES OF 10
FIGURE 68

D. 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 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	Recharge Current	Charge Voltage Limit, Per Cell
10A	25° C	25	7.0 Amps	1.50 ± 0.03
22A	25° C	25	20.0 Amps	1.50 ± 0.03
34B	25° C	40	20.0 Amps	1.50 ± 0.03
46A*	25° C	40	20.0 Amps	1.50 ± 0.03
72B	25° C	75	20.0 Amps	1.50 ± 0.03

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

c. Test Results:

(1) Performance on Cycling: (Figures 69 through 73) 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:

PRECYCLING AND CAPACITY CHECKS

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 F
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 D	23.5	
352 Days Disch #2	18.2 D	21.2 D		4.7 D	

D - Discontinued

F - Failed

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

PACK 010A, MANUFACTURE SONOTONE20.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 7.00
DEPTH OF DISCHARGE IN % 25

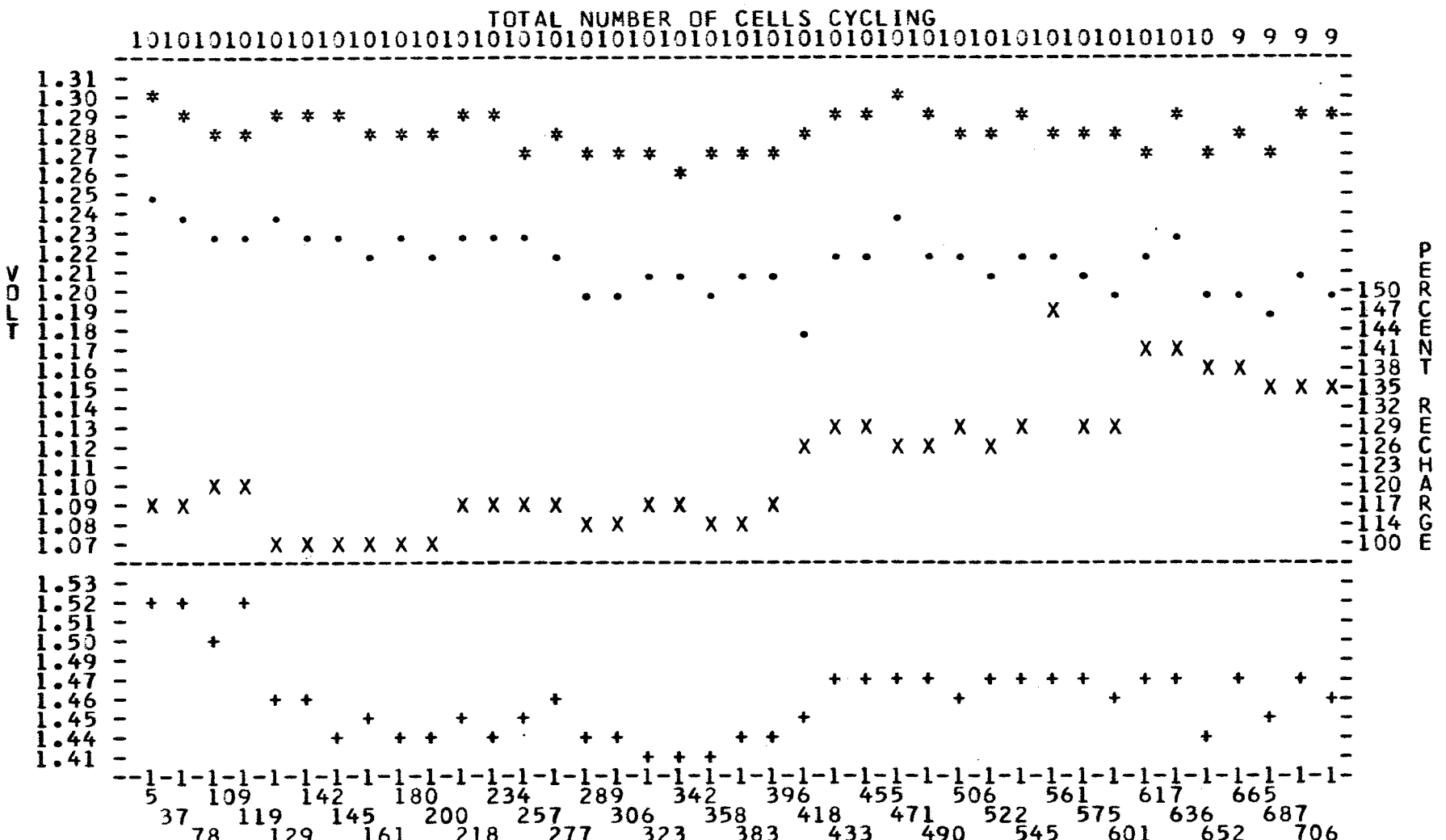


FIGURE 69

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

PACK 022A, MANUFACTURE SONOTONE20.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 20.00
DEPTH OF DISCHARGE IN % 25

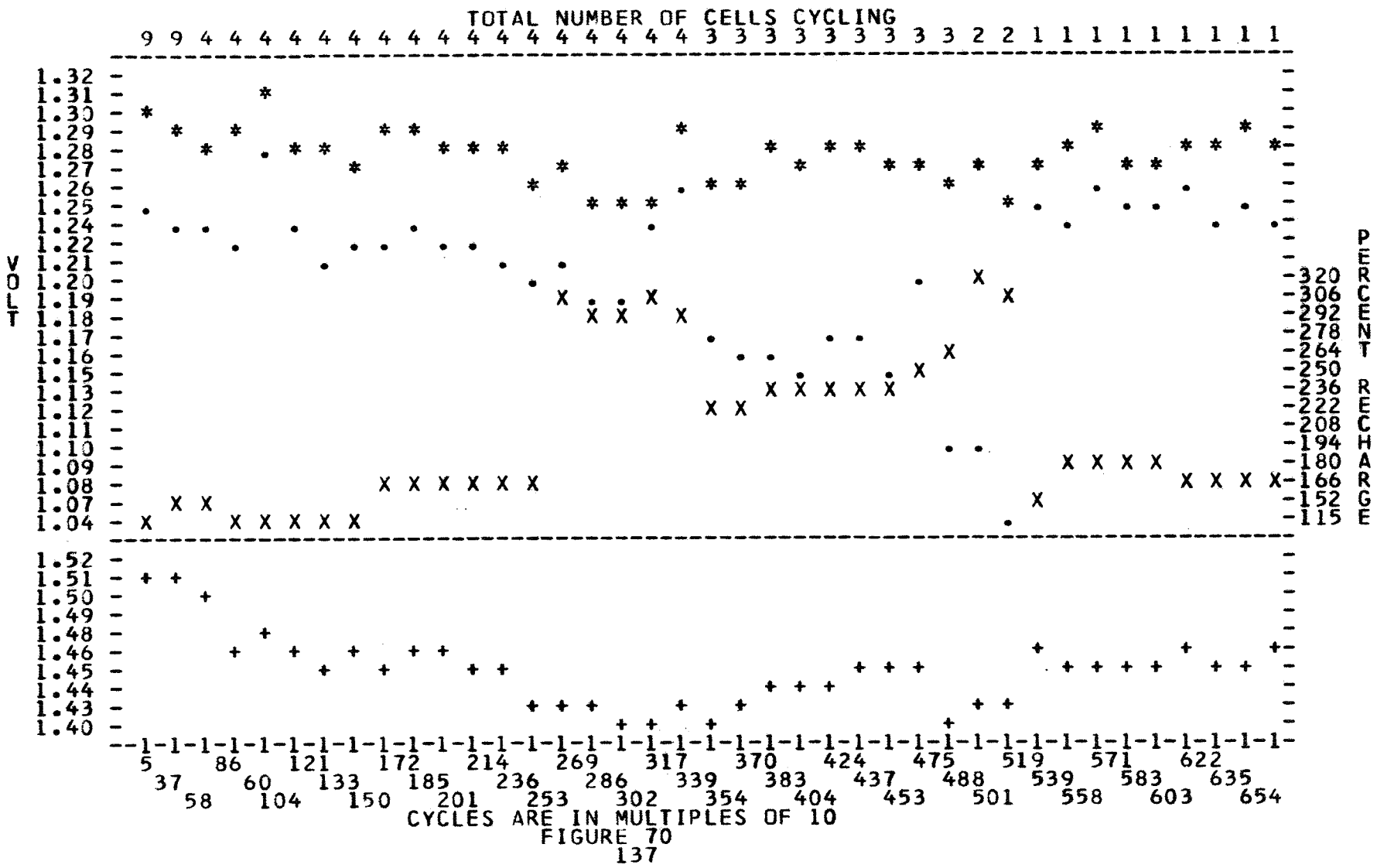


FIGURE 70

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

PACK 034B, MANUFACTURE SONOTONE20.0 AH
ORBIT PERIOD IN HOURS 1.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 20.00
DEPTH OF DISCHARGE IN % 40

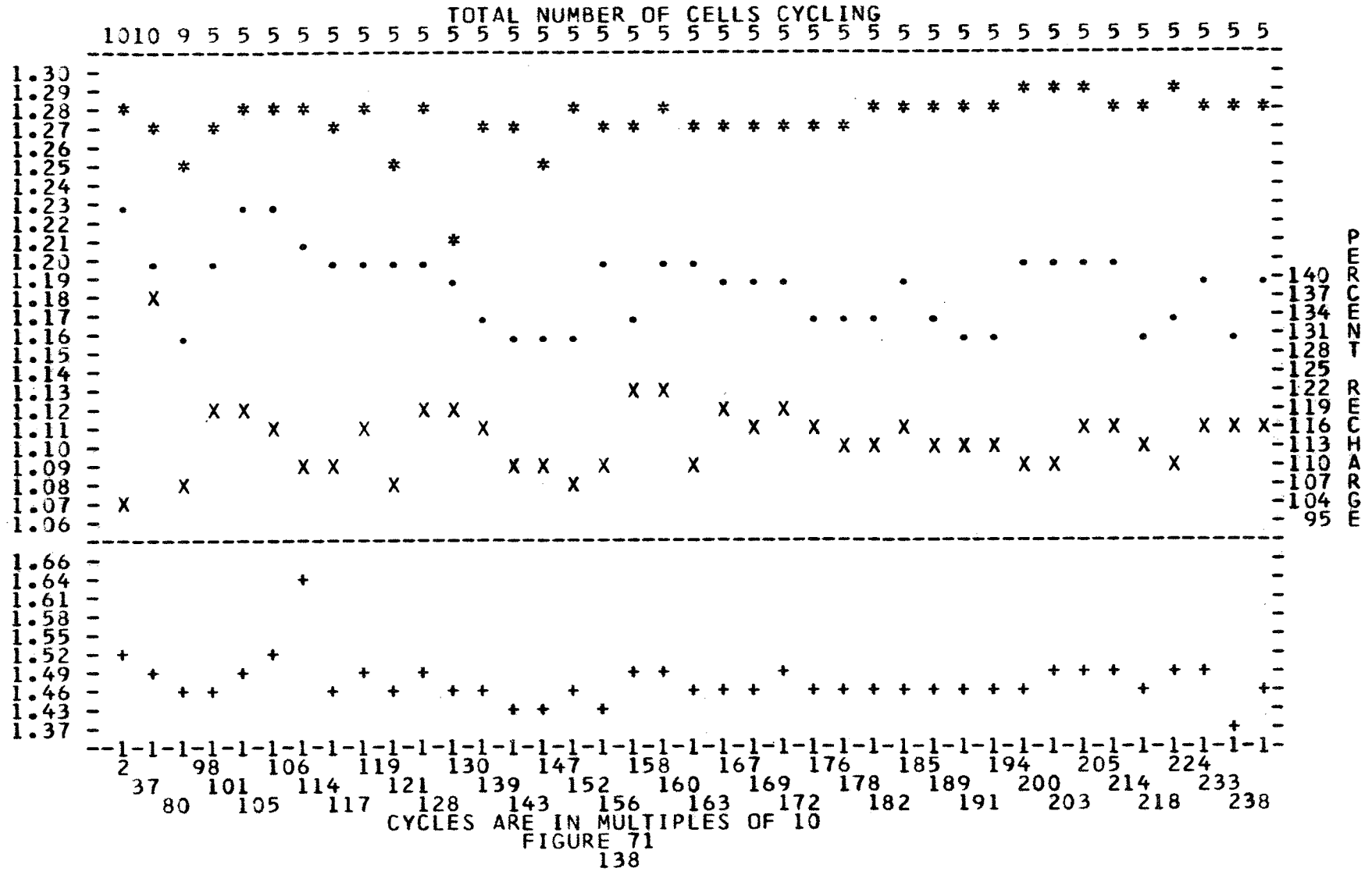
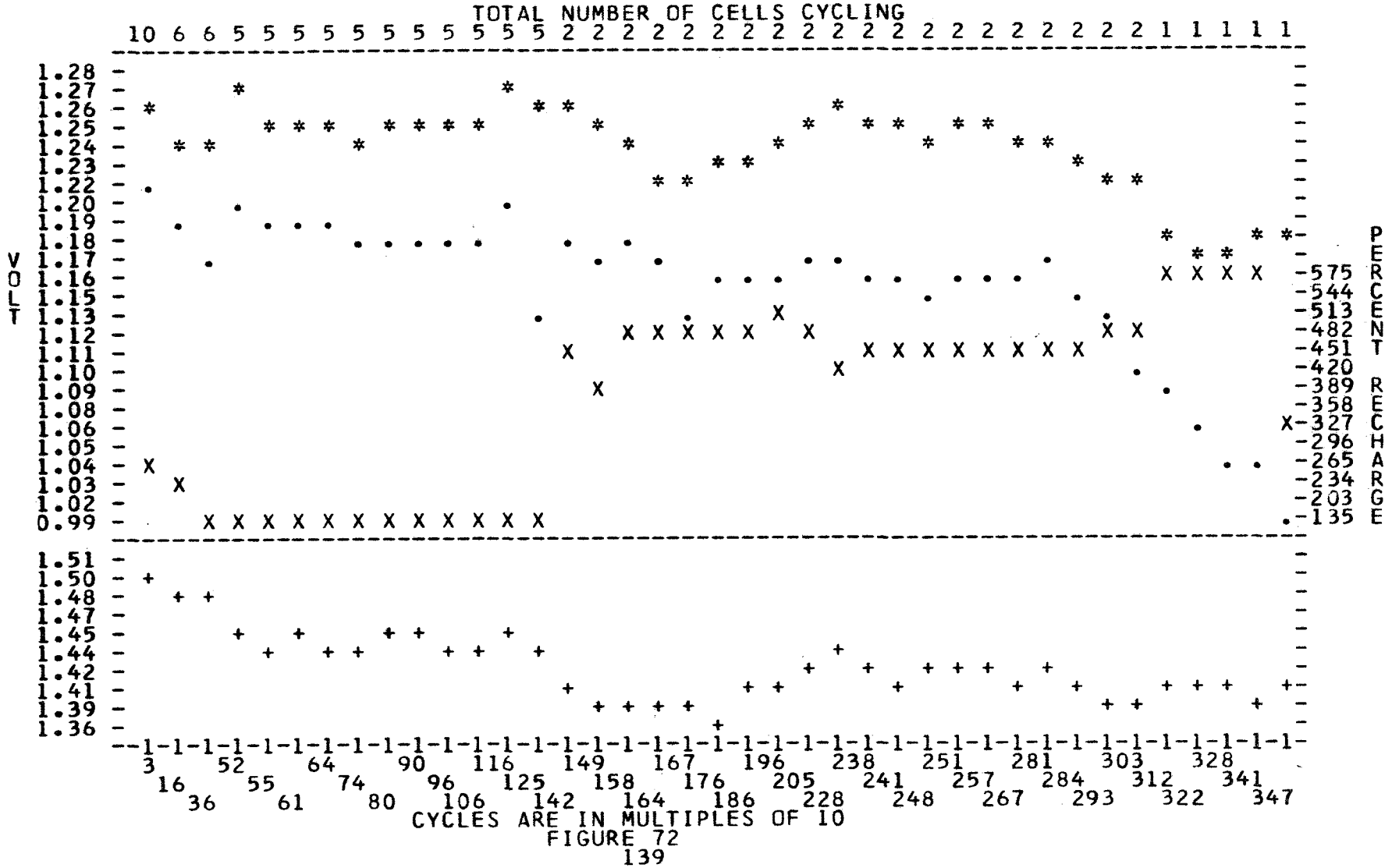


FIGURE 71

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

PACK 046A, MANUFACTURE SONOTONE 20.0 AH
ORBIT PERIOD IN HOURS 03.0
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 20.00
DEPTH OF DISCHARGE IN % 40



CYCLES ARE IN MULTIPLES OF 10

FIGURE 72

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

PACK 072B, MANUFACTURE SONOTONE20.0 AH
ORBIT PERIOD IN HOURS 01.5
TEMPERATURE IN DEGREES C. 25
CHARGE RATE IN AMPS 20.00
DEPTH OF DISCHARGE IN % 75

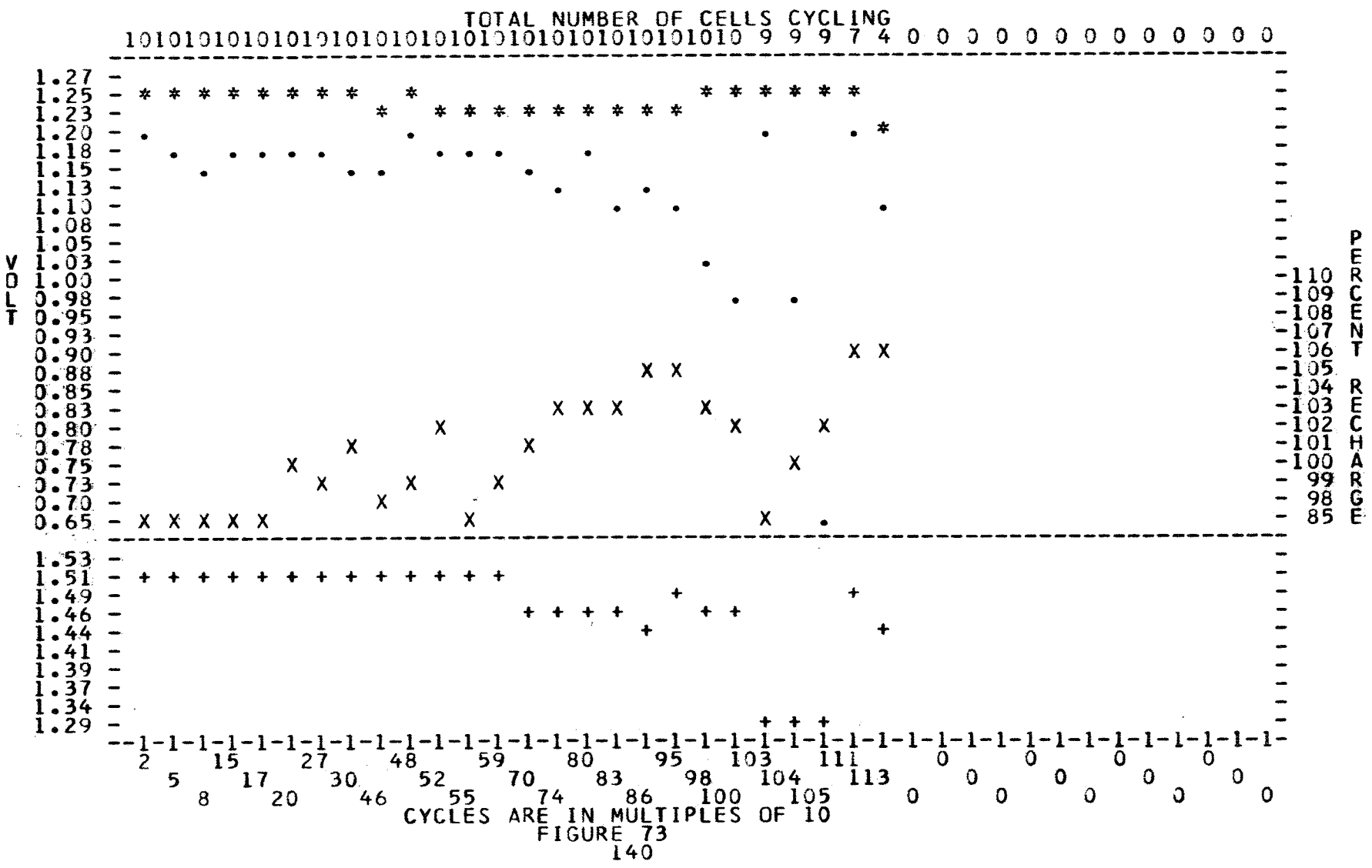


FIGURE 73

SECTION III

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. A new Automatic Data Acquisition and Control System has been proposed to test and record data for life cycle evaluation. The system will control testing by means of operating programmable power supplies, operating switches, and instructing laboratory personnel to perform manual functions. It will also collect data consisting of voltage, current, pressure, and temperature which will then be placed on magnetic tape. The system will have 5000 data collection points and be able to scan and record data every 2 minutes.

B. New Programs:

1. Gulton 6.0 ampere-hour cells with cobalt added to the cells with pellon and polypropolene separators.

2. Gulton 6.0 ampere-hour cells with Gulton manufactured plates.

3. Gulton 20.0 ampere-hour cells with strain gages and pressure transducers.

4. GE 20.0 ampere-hour cells to be evaluated to the OAO performance test.

5. Sonotone 20.0 ampere-hour cells control and internal pressure devices.

6. Texas Instrument 20.0 ampere-hour cells for evaluation.

7. Astropower (McDonnell-Douglas) 5.0 ampere-hour cells with inorganic separators.

SECTION IV

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 more than two-thirds 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.

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 (see Figures 74 through 80). 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) 3.0 ah Cells: There were 48 cell failures, of which four were at 0° C, 19 were at 25° C, and 25 were at the 50°-40° C ambient temperature.

1. 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) 12 ah Cells: There were 27 failures, of which three were at 0° C, 12 were at 25° C and 12 were at 50°-40° C.

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

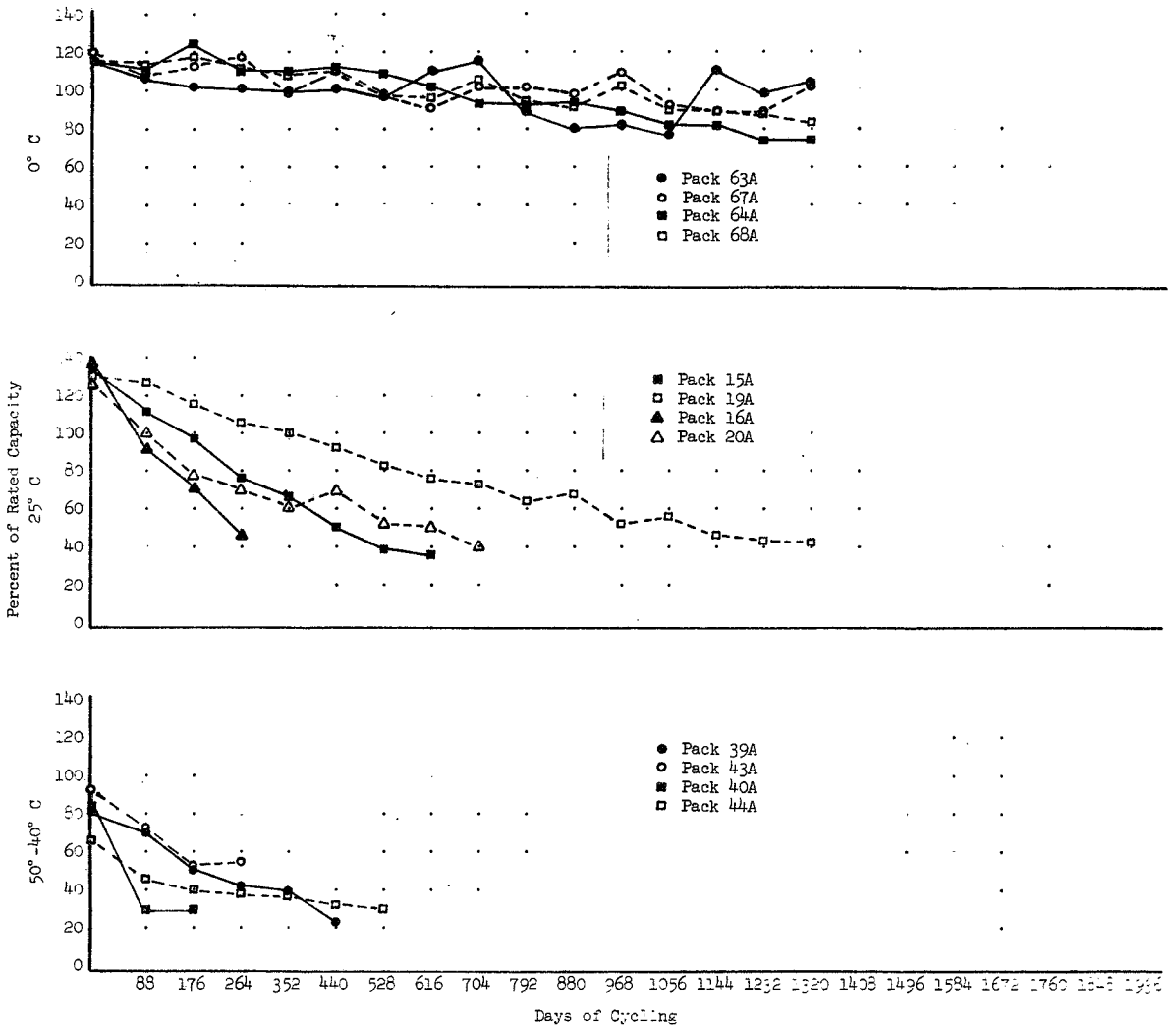
For each orbit period, one pack of each of the seven cell types is cycling at each of the six temperature-depth of discharge combinations.

ORBIT PERIODS: 1.5 Hours and 3 Hours					
Discharge Time	Charge Time	Temperature °C	Percent Recharge ***	Percent Depth of Discharge	On-Charge Voltage Limit Avg./Active Cell
30 Minutes	60 Minutes and 2.5 Hours	(50*)	(160**)	(15) (25)	(1.41)
		40	160	15 25	1.41 (Changed to 1.45)
		25	125	25 40	1.49
		0	115	15 25	1.55

* All packs changed to 40° C ambient.

** One pack of Gulton 6.0 ah cells at 50° C was temporarily raised to 200 percent recharge, but this was not sufficient to maintain normal cycling.

*** May be less due to voltage limits.



G.E. 3.0 ah

PRECYCLING AND CAPACITY CHECK CYCLES

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

1.5-hr. period	3.0-hr. period	Depth of Discharge
—●—	— —o— —	15%
—■—	— —□— —	85%
—▲—	— —△— —	40%

FIGURE 74

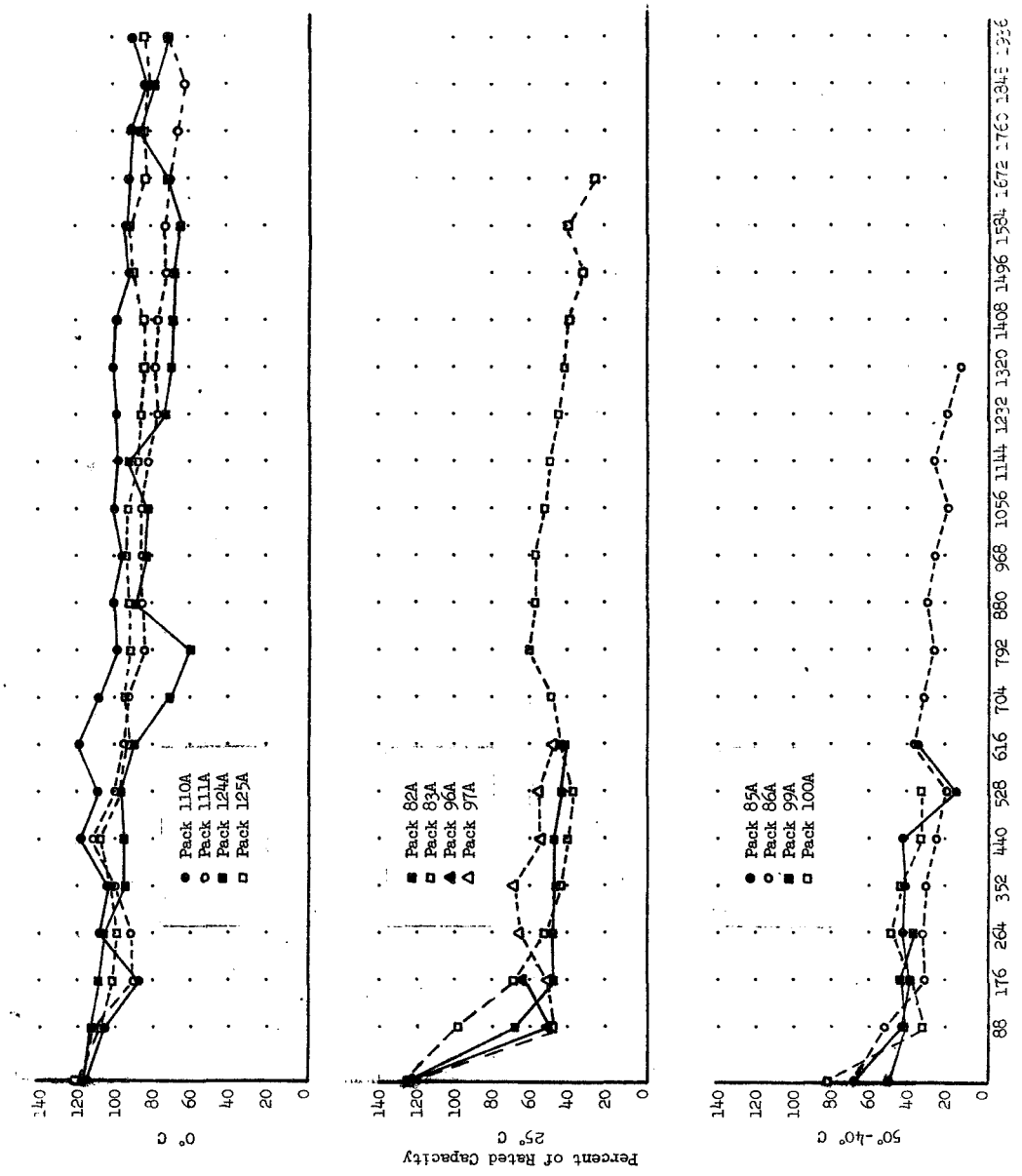

PRECYCLING AND CAPACITY CHECK CYCLES
(Measured ampere-hours expressed as percent of rated capacity)
1.5-hr. period
2.0-hr. period
Depth of Discharge
15%
25%
40%
Pack 110A
Pack 111A
Pack 124A
Pack 125A
Pack 82A
Pack 83A
Pack 96A
Pack 97A
Pack 85A
Pack 86A
Pack 99A
Pack 100A
0° C
25° C
50°-40° C
Percent of Rated Capacity
Days of Cycling
0
20
40
60
80
100
120
140
88
176
264
352
440
528
616
704
792
880
968
1056
1144
1232
1320
1408
1496
1584
1672
1760
1848
1936
G.E. 12 ah

FIGURE 75

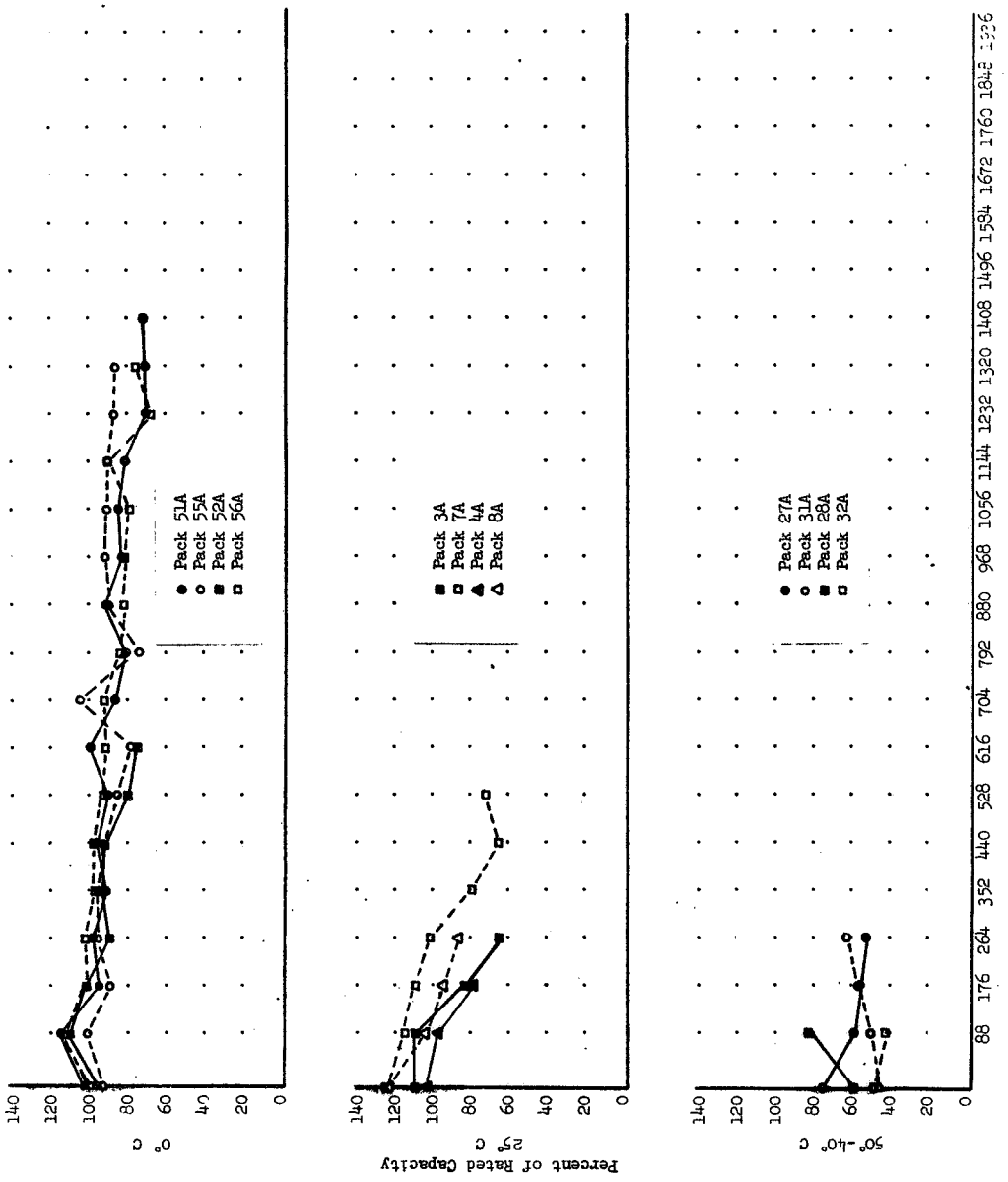
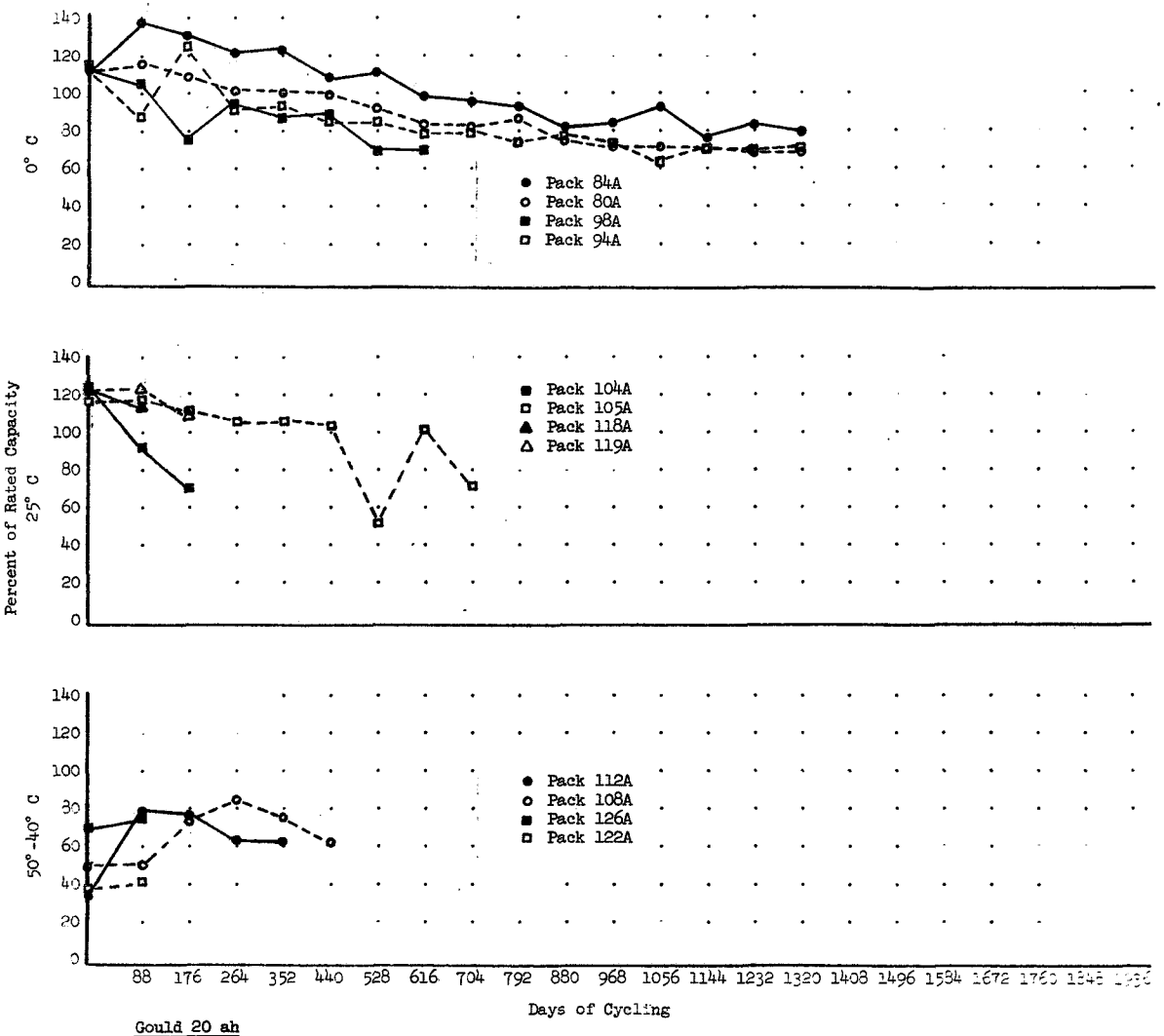

Gould 3.5 ah
PRECYCLING AND CAPACITY CHECK CYCLES
(Measured ampere-hours expressed as percent of rated capacity)
1.5-hr. period
3.0-hr. period
Depth of Discharge
15%
25%
40%
Pack 51A
Pack 55A
Pack 52A
Pack 56A
Pack 3A
Pack 7A
Pack 4A
Pack 8A
Pack 27A
Pack 31A
Pack 28A
Pack 32A
0° C
25° C
50°-40° C
Percent of Rated Capacity
Days of Cycling
0
20
40
60
80
100
120
140
88
176
264
352
440
528
616
704
792
880
968
1056
1144
1232
1320
1408
1496
1584
1672
1760
1848
1936

FIGURE 76



Gould 20 ah

PRECYCLING AND CAPACITY CHECK CYCLES

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

1.5-hr. period	3.0-hr. period	Depth of Discharge
—●—	— —o— —	15%
—■—	— —□— —	25%
—▲—	— —△— —	40%

FIGURE 77

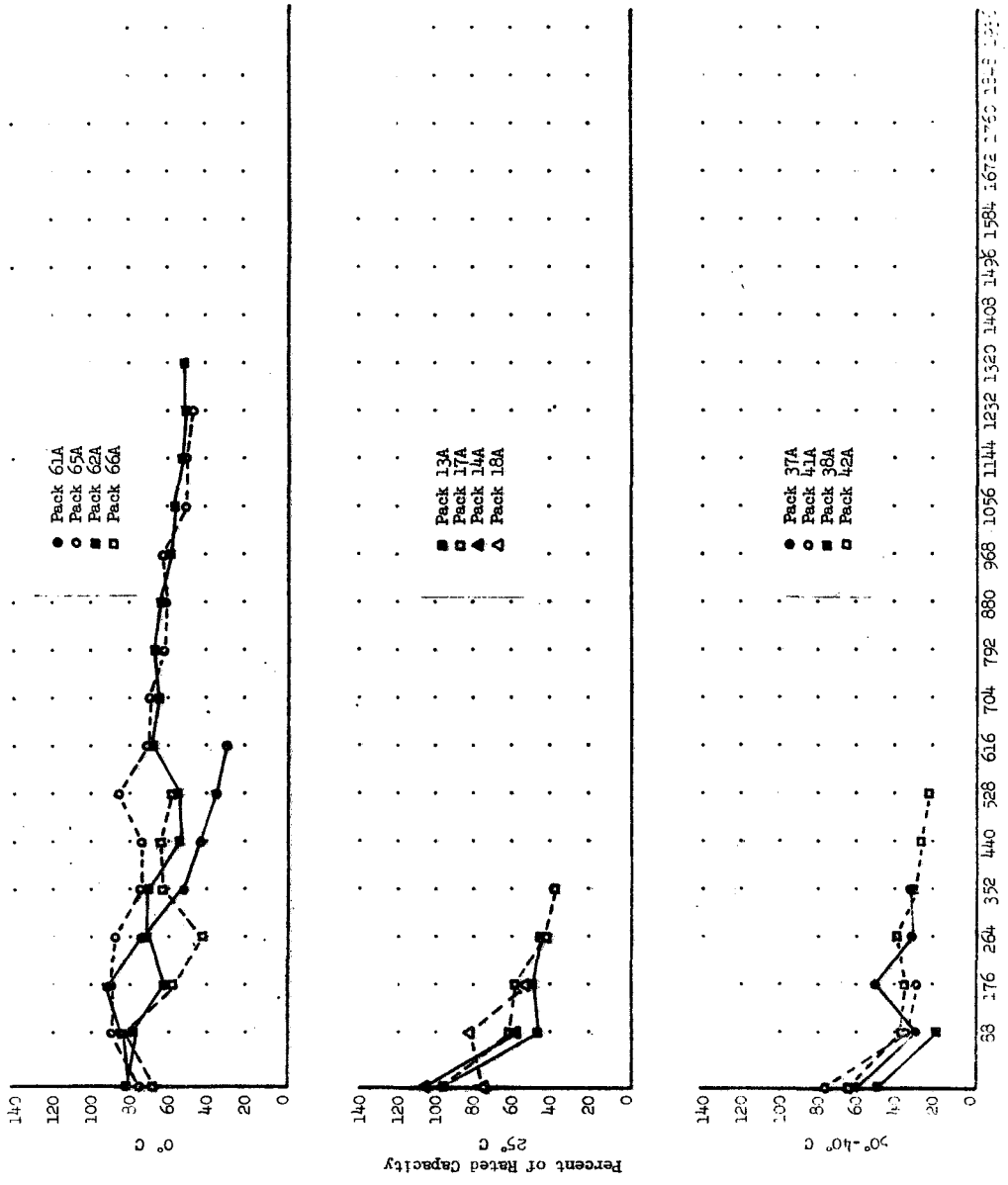
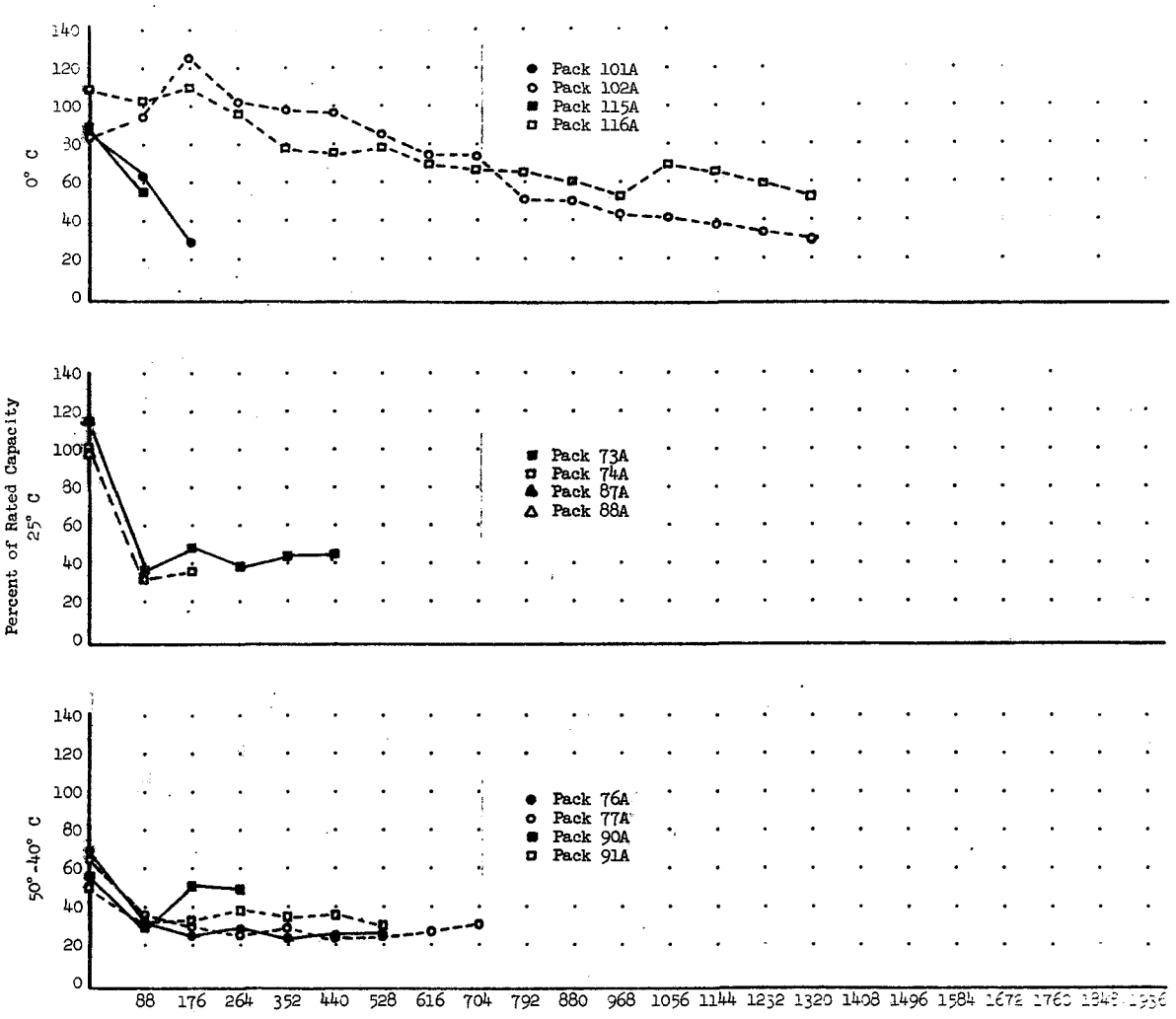

PRECYCLING AND CAPACITY CHECK CYCLES
(Measured ampere-hours expressed as percent of rated capacity)
Gulton 6.0 ah
Percent of Rated Capacity
Days of Cycling
0° C
25° C
50°-40° C
Pack 61A
Pack 65A
Pack 62A
Pack 66A
Pack 13A
Pack 17A
Pack 14A
Pack 18A
Pack 37A
Pack 41A
Pack 38A
Pack 42A
1.5-hr. period
3.0-hr. period
Depth of Discharge
0
20
40
60
80
100
120
140
88
176
264
352
440
528
616
704
792
880
968
1056
1144
1232
1320
1408
1496
1584
1672

FIGURE 78



Gulton 20 ah

PRECYCLING AND CAPACITY CHECK CYCLES

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

1.5-hr. period	3.0-hr. period	Depth of Discharge
—●—	— —o— —	15%
—■—	— —□— —	25%
—▲—	— —△— —	40%

FIGURE 79

154

GE/C 70-173

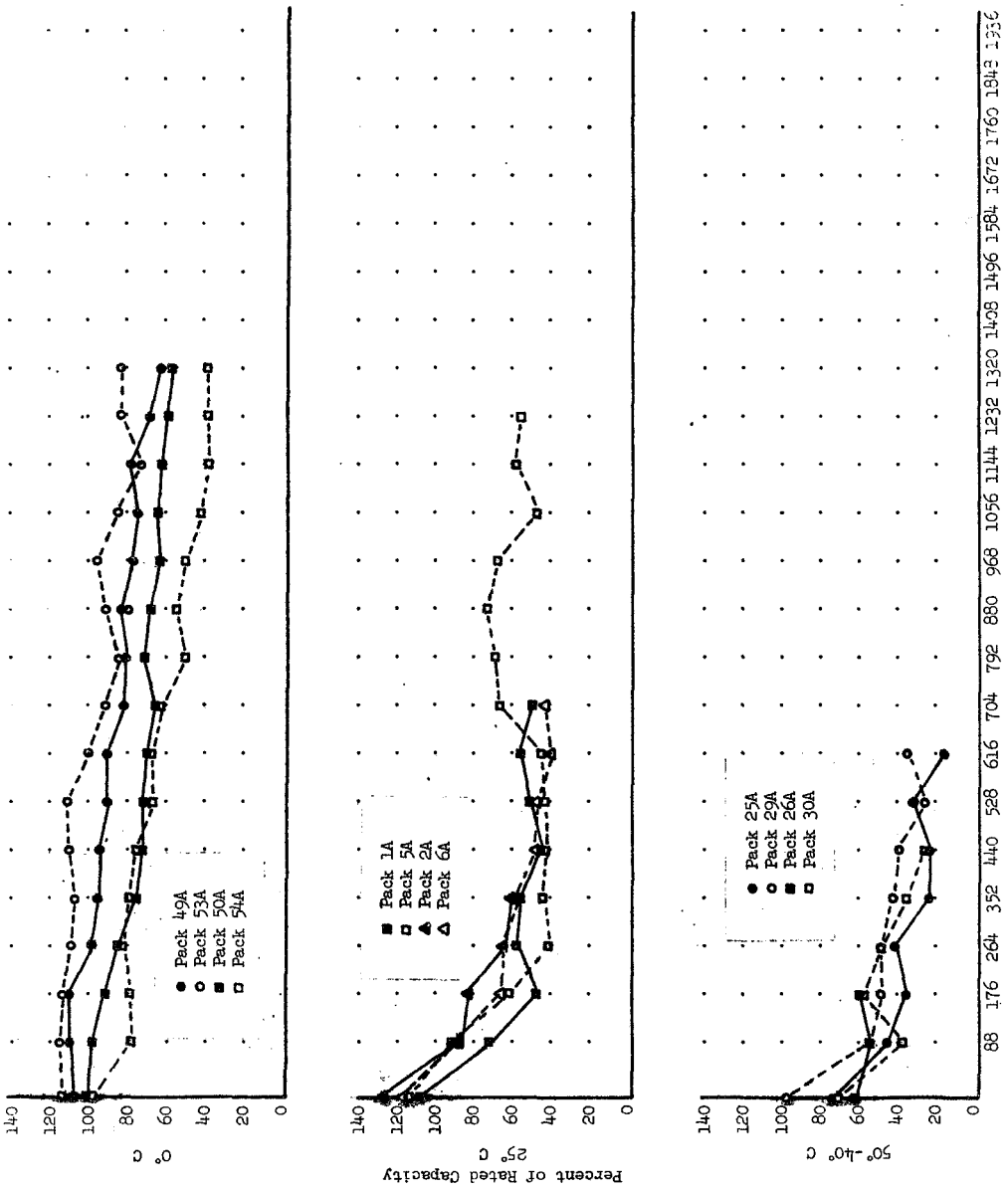

Sonotone 5.0 ah
PRECYCLING AND CAPACITY CHECK CYCLES
(Measured ampere-hours expressed as percent of rated capacity)
1.5-hr. period
3.0-hr. period
Depth of Discharge
15%
25%
40%
Pack 49A
Pack 53A
Pack 50A
Pack 54A
Pack 1A
Pack 5A
Pack 2A
Pack 6A
Pack 25A
Pack 29A
Pack 26A
Pack 30A
0° C
25° C
50°-40° C
Percent of Rated Capacity
Days of Cycling
0
20
40
60
80
100
120
140
88
176
264
352
440
528
616
704
792
880
968
1056
1144
1232
1320
1408
1496
1584
1672
1760
1848
1936

FIGURE 80

SECTION V

CELLS ON NEW PROGRAMS
WHICH HAVE COMPLETED TEST

I. CELLS ON NEW PROGRAM WHICH HAVE COMPLETED TEST

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 two-thirds 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. 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%.

(3) Percent of Recharge: 150%.

(4) Charge Voltage Limit: 1.49 $\pm$ 0.03 volts per cell, average.

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 volt per cell. The end-of-charge voltages remainded 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

2. 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	Percent of Recharge	Charge Voltage Limit, Per Cell
95A	0° C	25	115	1.55 ± 0.03
123A	40° C	25	160	1.45 ± 0.03

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.

3. 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%.

(3) Percent of Recharge: 150%.

(4) Charge Voltage Limit: 1.49 $\pm$ 0.03 volts per cell, average.

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. 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) Charge Voltage Limit: 1.97 $\pm$ 0.03 volts per cell, average.

(4) 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.

2. 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) Charge Voltage Limit: 1.97 $\pm$ 0.03 volts per cell, average.

(4) 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.

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

(4) 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.

4. 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) Charge Voltage Limit: 1.97 $\pm$ 0.03 volts per cell, average.

(4) 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. 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%.

(3) Charge Voltage Limit: 1.52 $\pm$ 0.03 volts per cell, average.

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.

2. 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	Charge Voltage Limit, Per Cell
57B	0° C	20	1.50 ± 0.03
21A	25° C	20	1.50 ± 0.03
45A	40° C	20	1.50 ± 0.03

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		

3. 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 (2×10^7 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	Charge Voltage Limit, Per Cell
9C	25° C	20	1.50 ± 0.03
33B*	25° C	20	1.50 ± 0.03

* 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		

4. 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%.

(3) Charge Voltage Limit: 1.50 $\pm$ 0.03 volts per cell, average.

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

5. 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	Charge Voltage Limit, Per Cell
114B	0° C	20	1.50 ± 0.03
118C	25° C	20	1.50 ± 0.03

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

6. 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%.

(3) Charge Voltage Limit: 1.51 $\pm$ 0.03 volts per cell, average.

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

7. 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	Charge Voltage Limit, Per Cell
45B	0° C	40	1.51 ± 0.03
21B	25° C	40	1.51 ± 0.03

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	

8. 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	Charge, Voltage Limit, Per Cell	Type of Separator
21C	25° C	27	1.51 ± 0.03	Pellon
45C	25° C	27	1.51 ± 0.03	Woven Nylon

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.

9. 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	Charge Voltage Limit, Per Cell
57A	0° C	50	1.50 ± 0.03
33A	40° C	50	1.50 ± 0.03

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

10. 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	Charge Voltage Limit, Per Cell
85B	-20° C	25	1.60 ± 0.03
97B	0° C	25	1.58 ± 0.03
82B	25° C	25	1.55 ± 0.03

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 III.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:

PRECYCLING AND CAPACITY CHECKS

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 III.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 III.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. 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 III.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.

5. 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 III.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:

CAPACITY CHECKS

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.

6. 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 III.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

(1) Upper Voltage Limit: 1.47 $\pm$ 0.03 volts per cell, average.

(2) Lower Voltage Limit: 1.40 $\pm$ 0.03 volts per cell, average.

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.

7. 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) Charge Voltage Limit: 1.50 $\pm$ 0.03 volts per cell, average.

(4) 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.

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

a. Cell Discription: 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	Charge Voltage Limit, Per Cell	Auxiliary Electrode Resistors (Ohms)
21D	0° C	43	1.51 ± 0.03	1
9F	40° C	43	1.51 ± 0.03	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 tne "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 4388, 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 III.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 II.A.4.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. 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 terminals. 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 $\pm$ 0.03 volts per cell, average.

(4) Low Current Level: 0.35 amps.

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

c. Test Results:

(1) Performance on Cycling:

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

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

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

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

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

b. Test Parameters:

(1) Depth of Discharge: 31%.

(2) Upper Voltage Limit: 1.98 $\pm$ 0.03 volts per cell, average.

(3) Low Current Level: 0.10 amperes.

(4) Lower Voltage Limit: 1.86 $\pm$ 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.

SECTION VI

TEST FACILITIES

I. TEST FACILITIES

A. Environmental Chambers: Ambient test temperature conditions were obtained with the following equipment:

1. -20° C: A 12 cubic foot chamber manufactured by General Thermodynamics, Inc., Model UCH 322 C-B, temperature controls accurate to within ± 1.5° C.

2. 0° C: A 27 cubic foot chamber manufactured by the A. Webber Engineering Corporation, Model WF-27-40, temperature controls accurate to within ± 1.5° C.

3. 25° C: Packs cycling at 25° C are located in an air conditioned room with other temperature critical equipment. The temperature is maintained at 25° ± 2° C.

4. 40° C: A 27 cubic foot chamber manufactured by Tenney Engineering, Inc., Model UF-40240, temperature controls accurate to within ± 1.5° C.

5. Several small chambers are used as required for additional packs and for any special temperature requirements. They range in size from 1.5 to 2.5 cubic feet and have a temperature range of -75° C to 175° C.

B. Charge and Discharge Control Units:

1. Each cell pack is connected to its own, independent, solid state current limiting charging unit. These units control the charge rates and voltage limits by regulating the current supplied by a 28 VDC generator which is common to all units. They also discharge the packs by a relay switching system which changes the current lead connections within the units. Each has two ammeters rated at ± 1 percent accuracy for visual monitoring of the charge and discharge currents, and three separate controls for setting the currents and voltage limit at the desired values. A 3-position switch selects between continuous charge, continuous discharge, and automatic cycling operation. Automatic cycling is controlled by a stepping relay which receives a pulse for each minute from a digital clock. The stepping relay is wired for both the 1.5-hour and 3-hour orbits. Each unit is connected to the corresponding output for its cycle period. The reference voltage for the voltage limiting circuit in each unit is supplied by using a voltage divider in series with a constant current circuit.

2. Photograph 1 shows a front view of several charge-discharge units.

C. Upper and Lower Voltage Limit Monitoring System:

1. Each pack is connected to its own lower limit voltmeter which sets off an alarm common to the system and turns on an identifying light for the particular pack when the terminal voltage of the pack falls below a preset limit. Photograph 2 is a picture of the lower voltage limit monitoring system.

2. An additional system is used to scan each individual cell voltage. When the voltage of any cell is found to be outside the preset upper or lower limits, the system automatically sets off the alarm and the identifying light in the lower voltage limit monitoring system and also disconnects the current leads of that pack by de-energizing a relay. The system includes a 900-point modified crossbar scanner which scans continuously at a rate of 330 points per minute, so that each cell is scanned every 2 minutes. Voltages are measured by a DC to frequency converter and a frequency counter. The scanning system is shown in Photograph 3.

D. Data Logging System:

1. Brief Summary:

a. Recordings are made by means of a data logging system (Photograph 4) obtained from Gulf Aerospace Corporation. All monitoring leads from a given pack of cells are scanned, converted to digital form and fed to the Tally Mark 45P paper tape punch and programmed reader. The system permits the current, pack terminal voltage, all cell voltages and the thermocouple voltages for a given pack to be read and punched out within less that 4 seconds. An additional switching arrangement permits recording up to six 10-cell packs and 12 5-cell packs at one time.

2. Technical Description:

a. This system is designed to record data from 30 data channels by sampling and scanning the input voltages. The data is converted to binary code by a precision amplifier and a high speed analog to digital converter and is presented serially by character to the paper tape punch for storage of the data. Figure 81 is a block diagram of the data logging system.

b. The system measurements are either timed and controlled by the system's digital clock, or manually controlled

by the operator. Additional features of the system provide for a typed report of the stored data.

c. The system has 30 input channels. Of these, channels 1 to 10 have a full scale input of 10 volts and measure cell voltages. Channels 11 and 13 have a full scale range of 20 volts and measure the total pack voltages. Channels 12 and 14 have a full scale range of 100 millivolts and measure the voltage across 100 millivolt current shunts.

d. All of these inputs, 1 to 14, are sample and hold type inputs. They are sampled simultaneously for 400 milliseconds. The attenuated input signal voltages, all of which are normalized to 100 millivolts full scale, are stored on high quality capacitors. The scanner then sequentially scans these capacitors for data readout. This technique is used to eliminate any difference in time between the first 14 input readings. The accuracy of these channels is $\pm$ 0.25 percent of full scale reading.

e. Channel 15 is used for battery pack identification. Another instrument, which provides selection for monitoring a given pack from a group of packs, provides an output from which the particular pack selected can be identified. This output voltage is read on channel 15 as the position identifying the pack. The operator or project leader correlates these readings with specific packs being tested.

f. Channels 16 through 30 are low level input channels ($\pm$ 10 millivolts full scale) designed to monitor thermocouple inputs with an accuracy of $\pm$ 1 percent of full scale. These channels have a maximum common mode voltage than can exist between the signal and the system ground of $\pm$ 10 volts. If the common mode voltage exceeds this value, accurate readings can no longer be taken. (Common mode voltages of over $\pm$ 20 volts may damage the differential amplifier.)

g. Cycle time for this system is less than 4 seconds for all 30 channels. The readout system, a Tally Mark 45P, is capable of receiving data from the analog to digital converter, from a prepunched paper tape, or from the Selectric typewriter by manual input and may be programmed to print out the data, off line, in any desired format.

3. System Operation:

a. During the scanning process each channel in turn is routed to the input of a high impedance differential amplifier, the gain of which is automatically switched between 100 (the amount

used for the high level channels) and 1000 (the amount required for the low level channels). The sensing for the gain change is supplied by the relay drivers. Provisions are made to eliminate amplifier drift while sampling voltage across the storage capacitiors. The output of the amplifier is applied through a low pass filter at the input of the analog to digital converter. The analog to digital converter is then given a command to read.

b. The analog to digital converter converts the analog signal to a binary coded decimal signal. A serializer sequentially sends one digit at a time from the output of the clock or from the analog to digital converter to the perforator driver. The zero generator and the parity generator maintain the proper digital format for punching paper tape and operating the Selectric typewriter in the Tally Mark 45P system. The punched-paper-tape code is compatible with IBM binary coded decimal code (Hollerith).

4. System Controls:

a. The 30-position data scanner has several modes of operation. Mode switch may be set to continuous cycling, preset cylce, single cycle, single step, and manual select. In the continuous cycling position the scanner continues to sample the data at a rate determined by the digital clock. In the present cycle position the scanner takes a sample of the data at a time determined by the preset time selector. In the single cycle position the scanner samples the data once each time the step/cycle push button is depressed. In the single step position the scanner is advanced one channel at a time by depressing the step/cycle push button switch. In the manual select position the scanner remains at the channel selected by the manual select switches. When in either of the two manual modes a reading is taken by pushing the print button. The scanner has two front panel displays, one for channel number and one for voltage. All system functions are timed by a unijunction oscillator and are controlled by logic circuits in the scanner assembly.

E. Central Wiring Panel:

1. All electrical connections are made through a centrally located wiring panel which houses the current shunts and a plug-in panel. Photograph 5 shows the front view of the central wiring panel.

F. Pack Selector Switch:

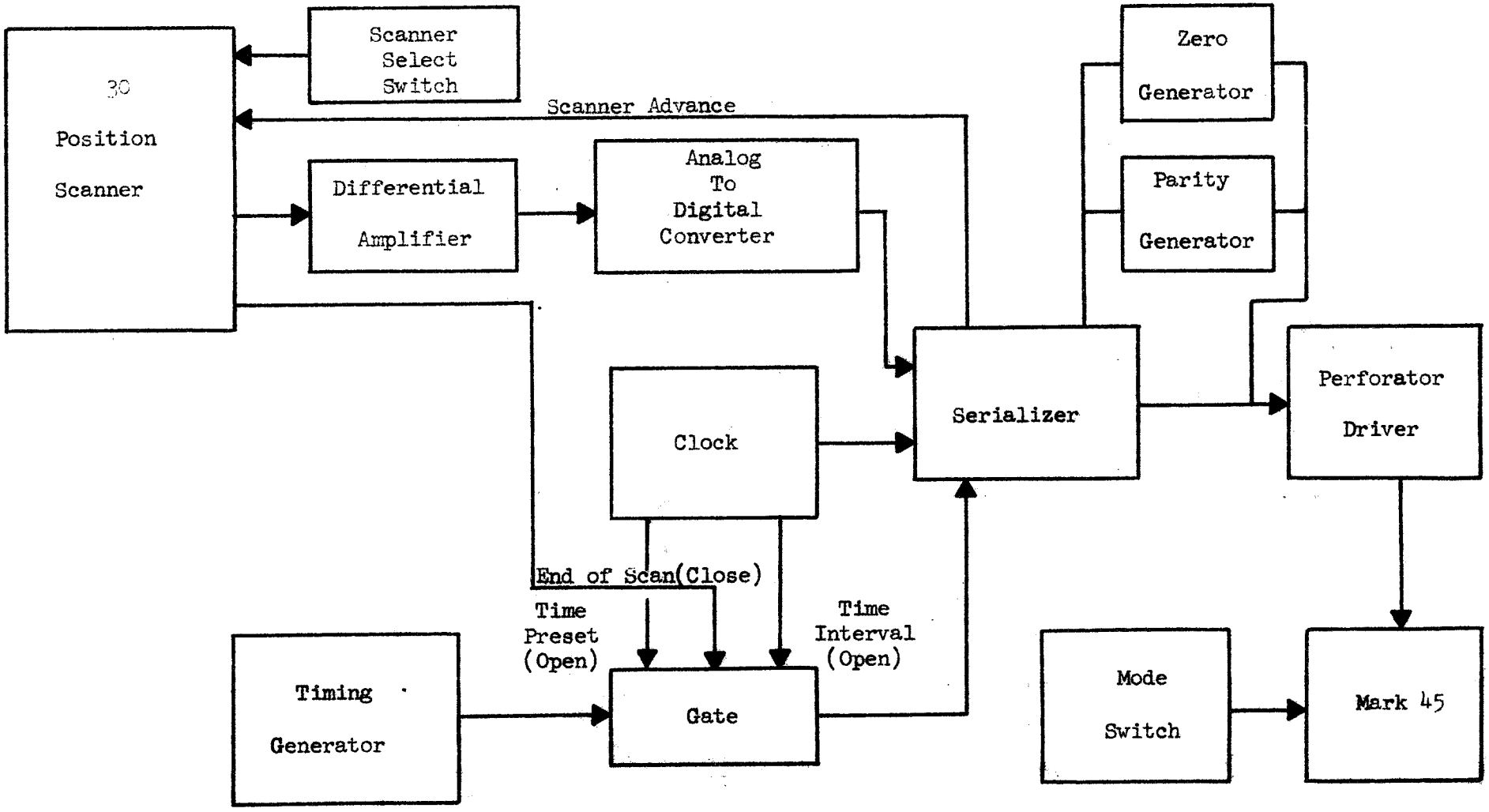
1. Up to six 10-cell packs and 12 5-cell packs may be plugged into a selector system from the central wiring panel. Through reed relays operated by a selector switch, any of these packs can then be connected to the input of the data logging system. This arrangement allows all currents and cell and thermocouple voltages for all 18 packs to be recorded by the data logging system within 48 seconds.

2. The switching system also provides a voltage which identifies the selected position and which is automatically recorded as part of the data for the pack selected.

3. Photograph 3 shows the pack selector switch located on top of the data logging system.

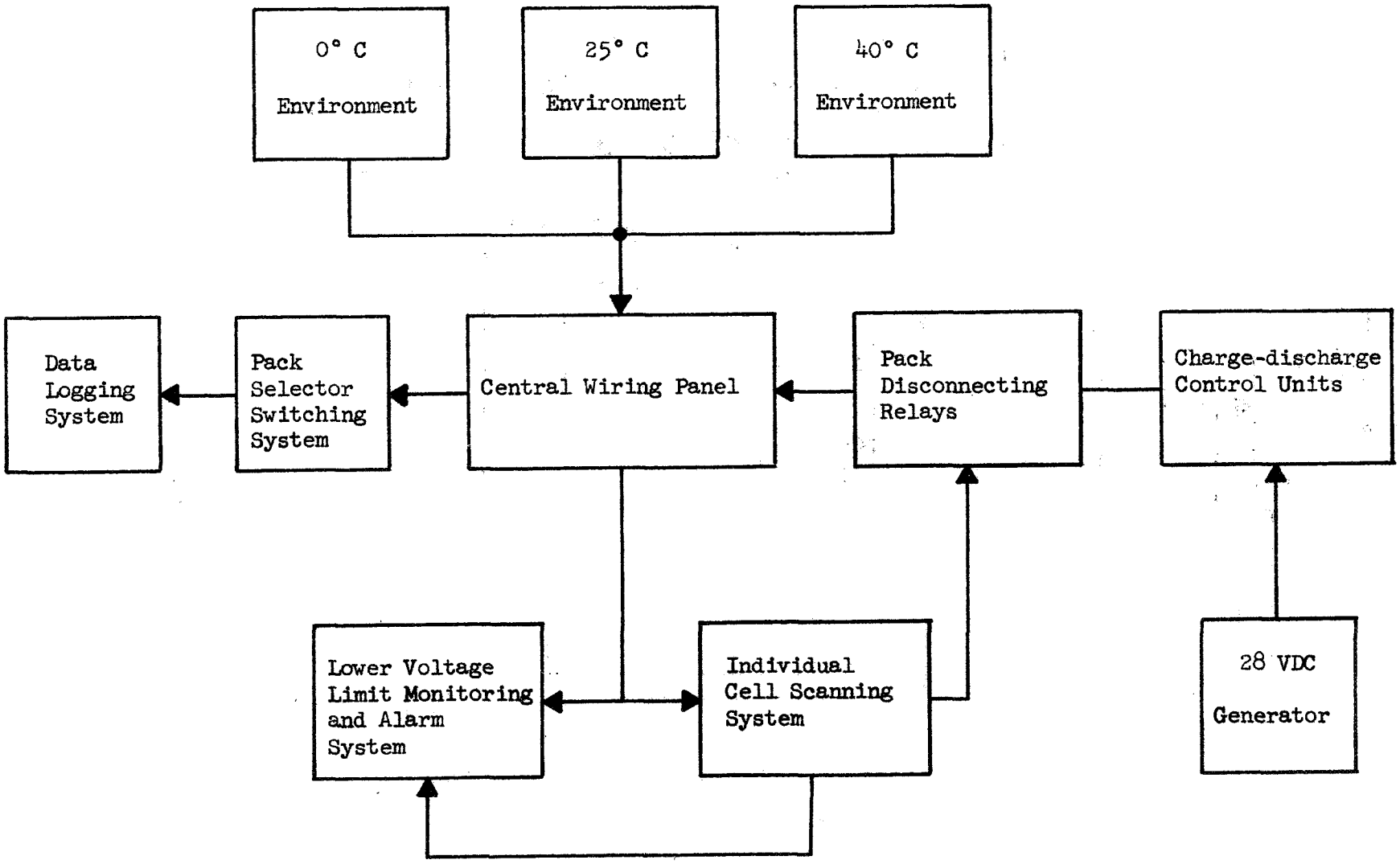
G. Block Diagram of Entire Test Setup: Figure 82 shows the arrangement from the packs at each of the three ambient temperatures to the central wiring panel. Leads from the central wiring panel connect all packs and/or cells to the charge-discharge units and the 28 volt DC source, the circuit relay switching system, the voltage limiting monitoring system and the data logging system.

H. Photograph of Test Area: Photograph 6 shows the overall arrangement of the test equipment described above.



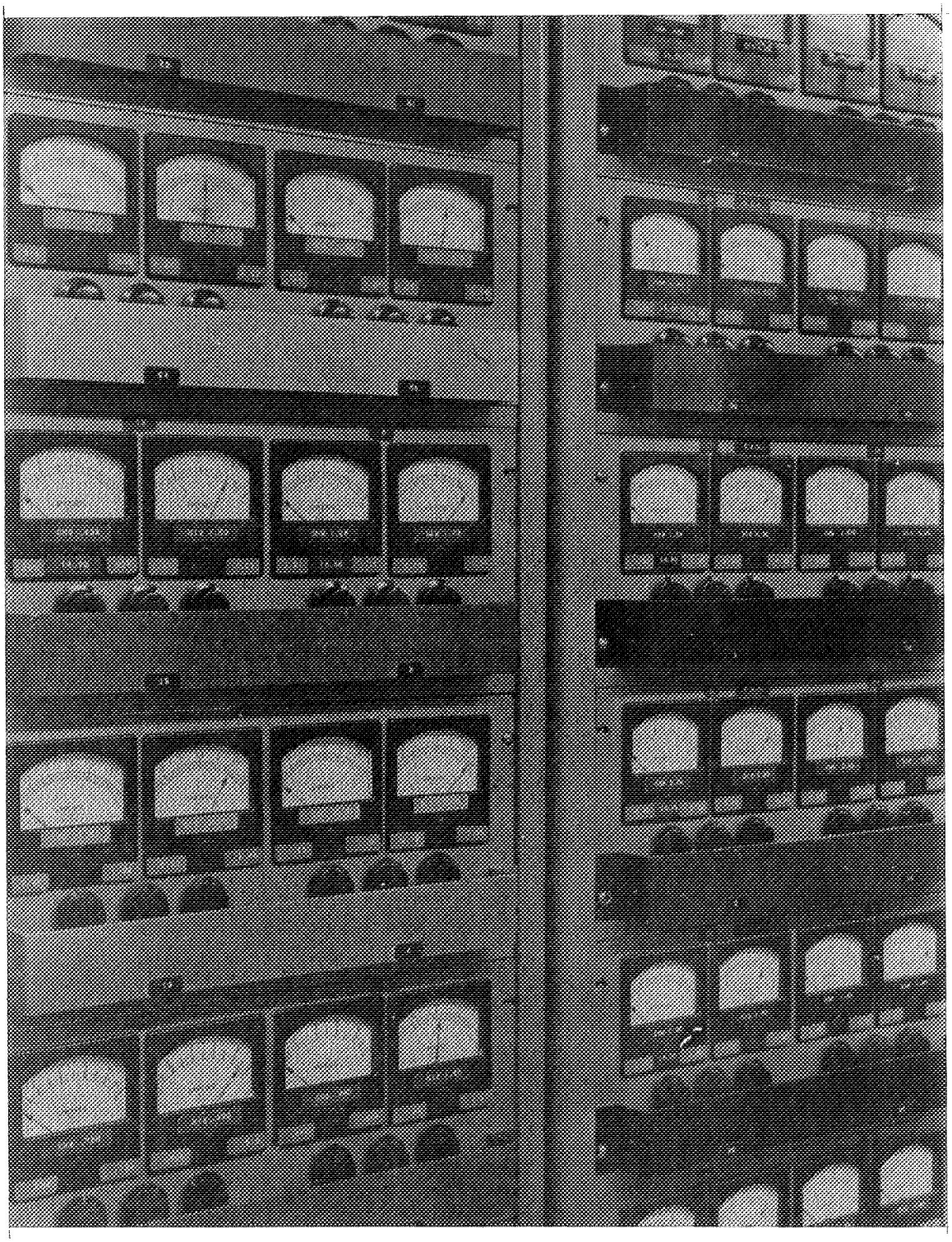
Block Diagram of Data Logging System

FIGURE 81



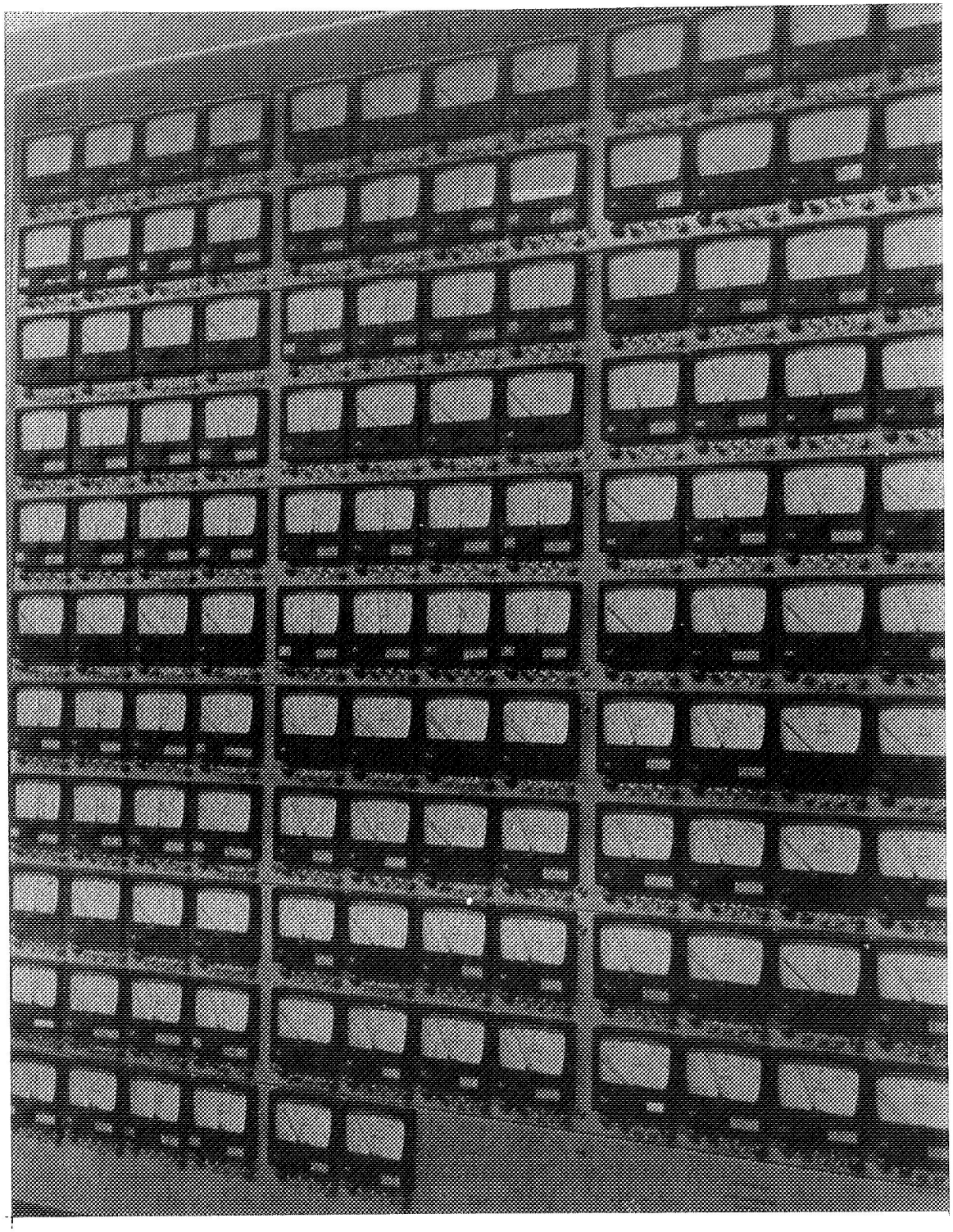
Block Diagram of Test Setup

FIGURE 82



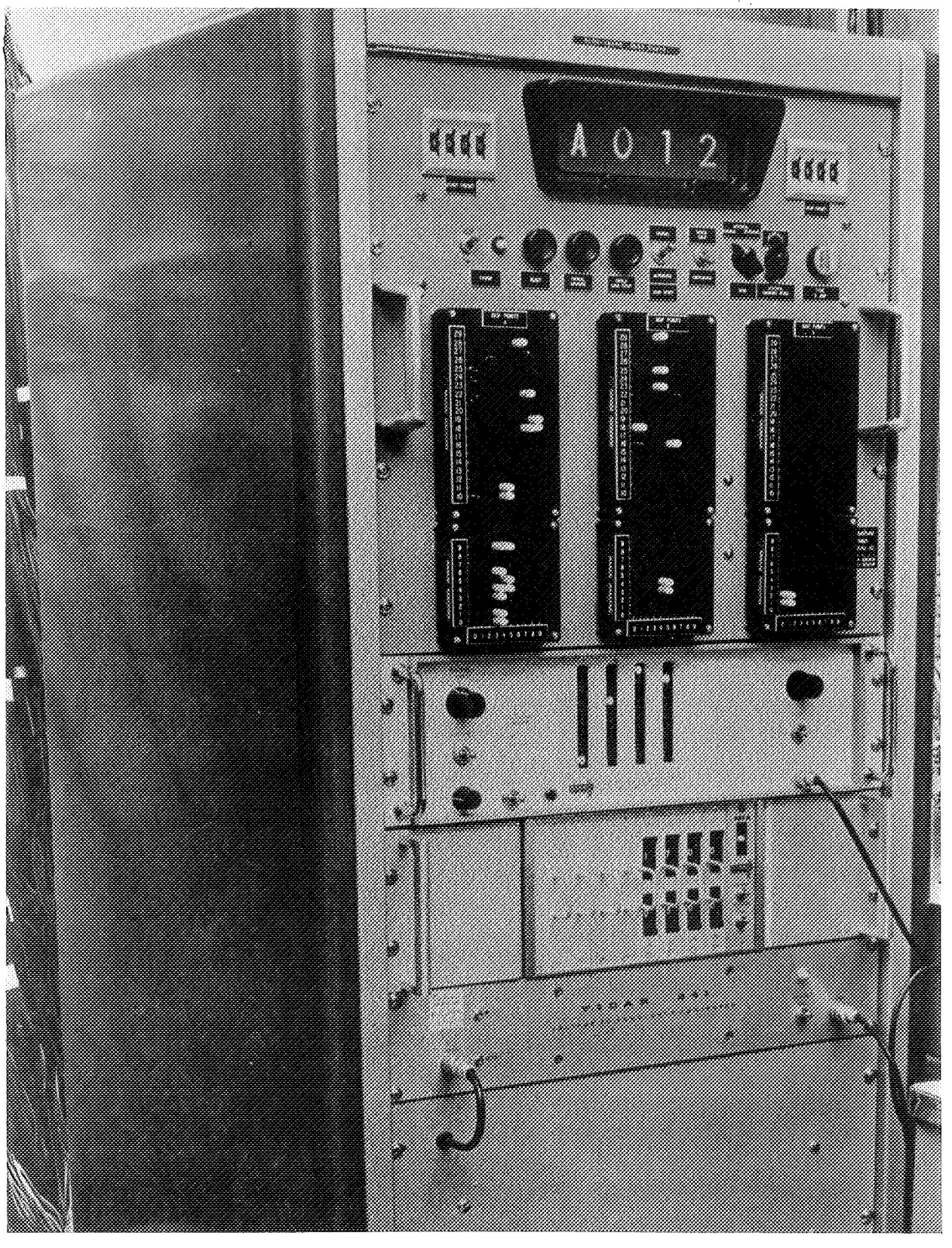
Several Charge and Discharge Control Units

PHOTOGRAPH 1



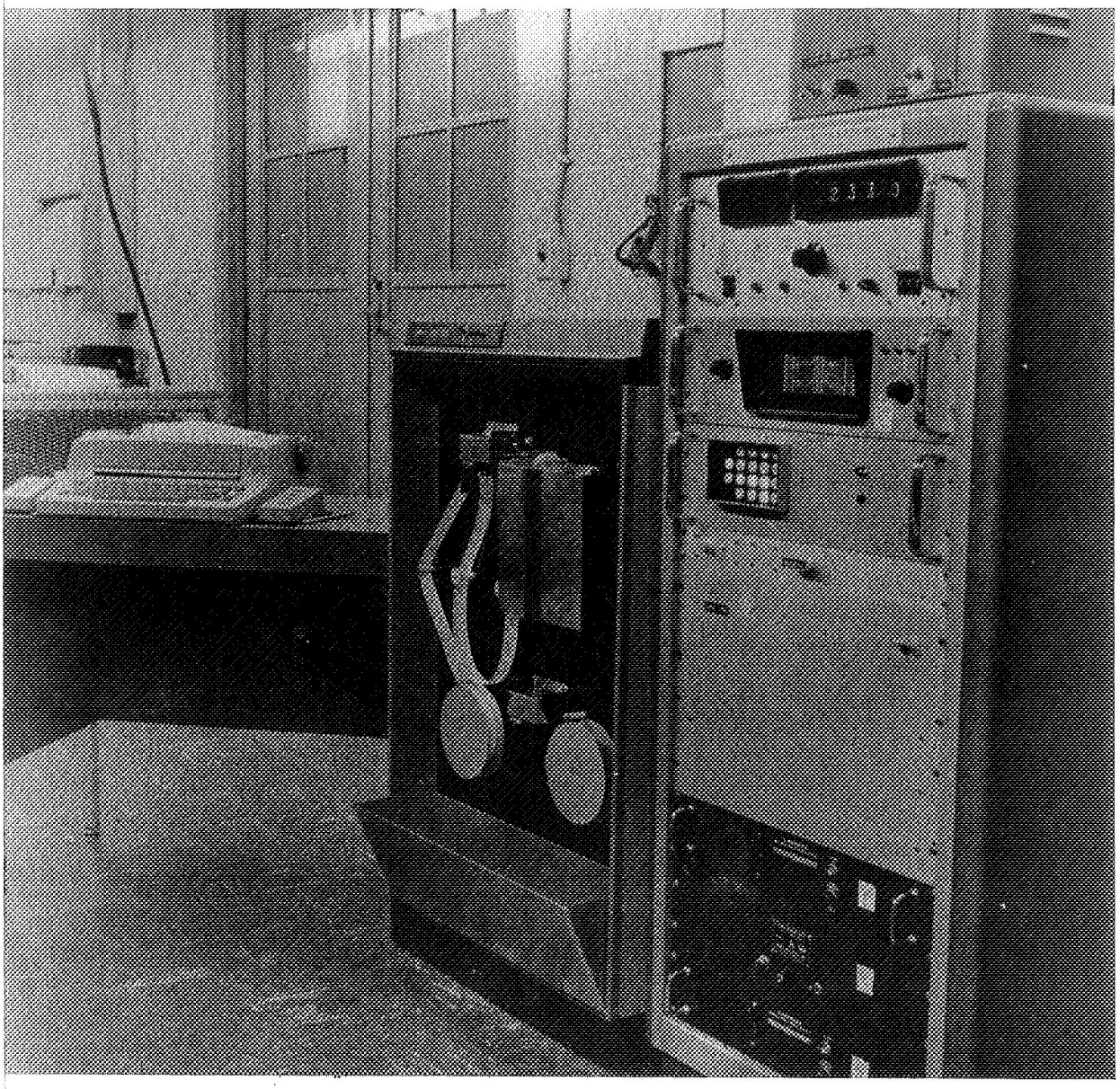
Pack Voltage Monitoring Panel

PHOTOGRAPH 2



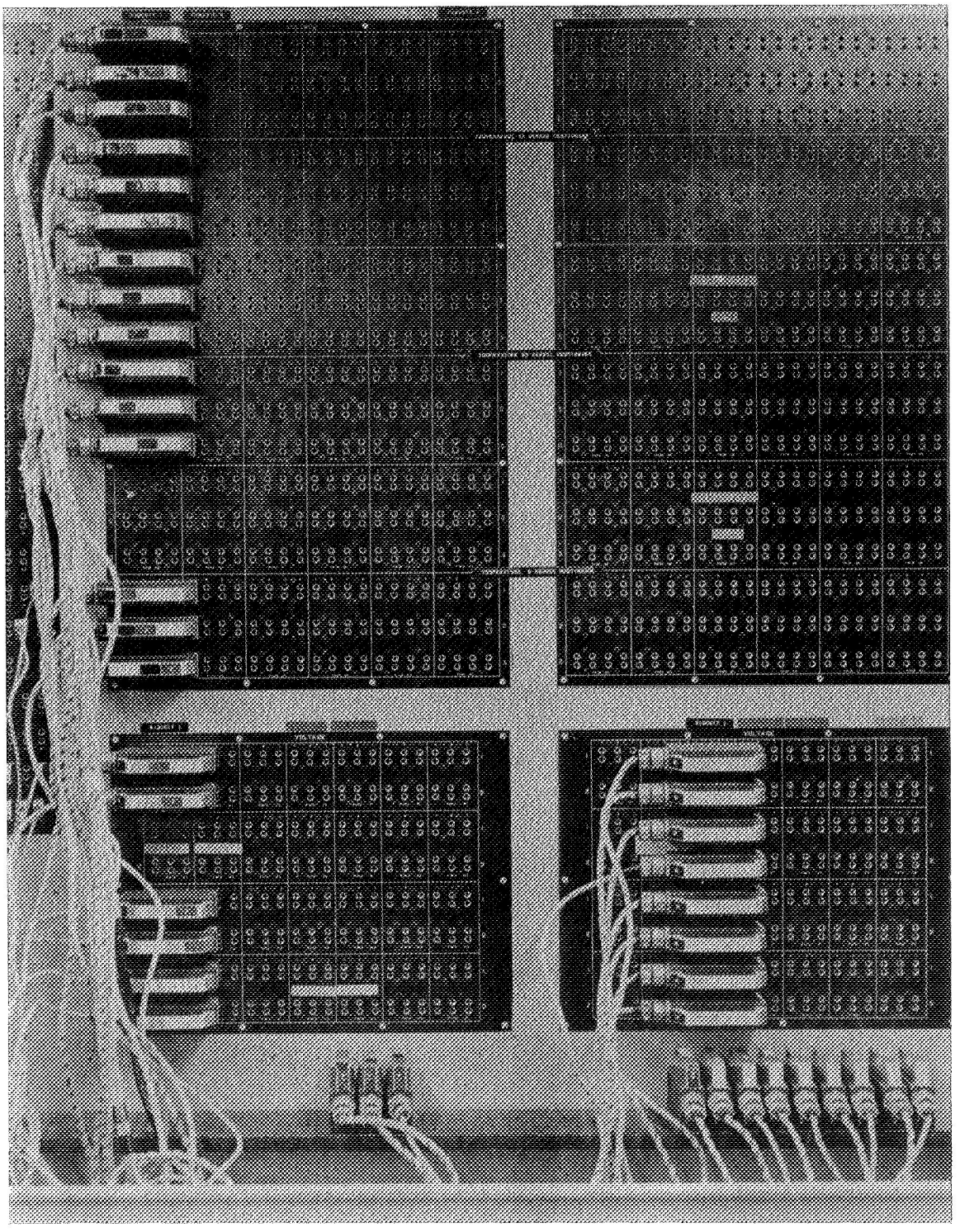
Individual Cell Voltage Scanning System

PHOTOGRAPH 3



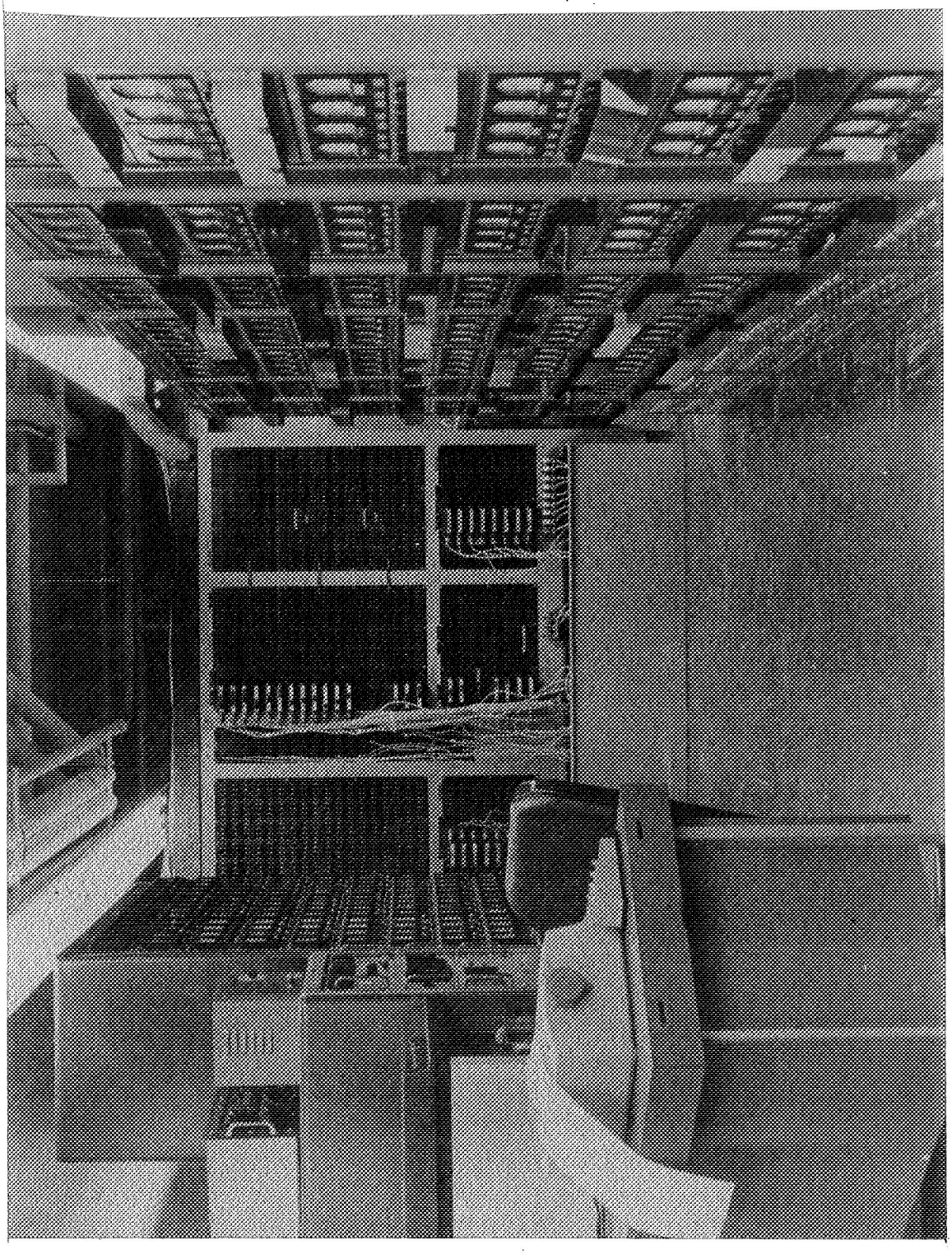
Data Logging System

PHOTOGRAPH 4



Portion of Central Wiring Panel

PHOTOGRAPH 5



Test Area

PHOTOGRAPH 6

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137 Union Carbide Corporation, Development Laboratory Library, P. O. Box 5056, Cleveland, Ohio 44101

138 Union Carbide Corporation, Consumer Products Division (Dr. Robert Powers), P. O. Box 6166, Cleveland, Ohio 44101

139 University of Pennsylvania, Electrochemistry Laboratory (Prof. John O'M. Bockris), Philadelphia, Pennsylvania 19104

140 Westinghouse Electric Corporation, Research and Development Center (Dr. C. C. Hein, Contract Admin.), Churchill Borough, Pittsburg, Pennsylvania 15235

141 Whittaker Corporation, Power Sources Division (Mr. J. W. Reiter), 3850 Olive Street, Denver, Colorado 80237