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Lithium-Organic Electrolyte Cell Studies

Samuel C. Levy

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LITHIUM-ORGANIC ELECTROLYTE CELL STUDIES

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ABSTRACT

Discharge curves of a commercially-produced lithium-organic electrolyte cell under a wide range of storage and discharge conditions are presented. Certain features of these curves are discussed.

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LITHIUM-ORGANIC ELECTROLYTE CELL STUDIES

Introduction

As part of a continuing study of new electrochemical systems, Sandia Laboratories undertook an evaluation of a commercially produced lithium-organic electrolyte cell. The general effects of storage time and temperature, and discharge rate and temperature on this system are reported under separate cover[1].

This report deals primarily with the raw data obtained in the program. Discharge curves for 200 cells are included and the effects of storage and rate of discharge on them are discussed.

Test Design

The basic test plan is shown in Table I. The test is designed to provide information on capacity, storage capability, and operational performance as a function of discharge rate and temperature as well as storage time and temperature. A detailed description of the plan is given in the companion report.[1]

Discussion

Discharge curves are given in Figures 1-40 for each cell tested. Tables II - X show life, amp-hours delivered, percent of rated capacity, total watt-hours, watt-hours per pound, and watt-hours per cubic inch for each cell.

Active life was taken to a 2.0-volt cutoff. Calculations were based on a cell weight of 0.63 pound, a volume of 6.59 cubic inches, and a capacity of 25 amp-hours. The cells were rated at 25 ma, which corresponds to the 8.6Y rate.[2]

In most cases, performance of the five cells tested at each condition was quite consistent up to a point, then a fairly large variation became evident as the voltage dropped to the cutoff value, resulting in the somewhat large standard deviations shown in Tables II-X. To place this effect in perspective, an attempt was made to identify semi-quantitatively the range of consistent performance for these cells over a wide range of discharge and storage conditions. For tests A through G (those that did not have more than one discharge condition), the point at which consistent performance ceased was arbitrarily selected from the discharge curves, Figures 1-34.

The voltage and the percent of the life to 2.0 volts, at which this point occurred, was noted for each condition. These values were averaged for all cells and indicate a consistent performance to 2.7 ± 0.4 volts, which corresponds to 73 percent, ± 17 percent of the active life to a 2.0-volt cutoff. Thus, although the standard deviations are rather large in some cases, performance is fairly consistent during most of active life, and if a higher cutoff voltage were chosen or a shorter life required, nearly consistent performance could be obtained.

Upon examination of the discharge curves one notes in some instances a sharp drop in voltage at the beginning of the discharge which also recovers rather sharply, followed by a "normal" discharge trace. This phenomenon, known as "saddling," occurs and becomes more severe as the temperature is lowered and the current raised. In previous studies of a different battery system, it was found that saddling was caused by a high resistance at the anode.[3] Therefore, this phenomenon is probably due to a film on the lithium whose resistance increases at lower temperatures and results in a higher iR drop at higher currents. As the discharge proceeds, this film either is removed or breaks up, causing the voltage to return to normal levels. At the very low temperatures, the "saddle" drops below 2.0 volts, resulting in a very short active life. At -54° C, the voltage never recovers from this effect.

In groups H and I, where cells are discharged at different rates and/or temperatures, more than one discharge curve is given for each set of cells. In each instance, the first set of curves, labeled -a, shows the entire discharge for those cells. Subsequent curves, labeled -b, -c, etc., show the discharge at each condition separately on an expanded scale.

Conclusion

The studied cell exhibits consistent performance down to approximately 2.7 volts, corresponding to about 73 percent of its active life over a wide range of discharge and storage conditions.

The lithium anode appears to be coated with a resistive film which results in a phenomenon known as "saddling." This phenomenon becomes more severe as the temperature of discharge is lowered and as the current drain in increased.

References

1. Samuel C. Levy, Storage and Discharge Tests of Lithium-Organic Electrolyte Cells, SAND75-0645, Sandia Laboratories, Albuquerque, New Mexico, 1976.

2. M. Lang, J. R. Backlund, and E. C. Weidner, 26th Annual Proceedings Power Sources Conference, 1974.

3. Samuel C. Levy, Sandia Laboratories, Albuquerque, New Mexico, unpublished data.

TABLE I

Basic Test Plan

A.	1.	71°	*	Y				D.	1.	-32°C	*	Y					
	2.	71°	*	5 Y					2.	-32°C	*	5 Y					
	3.	71°	*	10 Y					3.	-32°C	*	10 Y					
	4.	71°	*	20 Y					4.	-32°C	*	20 Y					
B.	1.	57°	*	Y				E.	1.	-40°	*	Y					
	2.	57°	*	5 Y					2.	-40°	*	5 Y					
	3.	57°	*	10 Y					3.	-40°	*	10 Y					
	4.	57°	*	20 Y					4.	-40°	*	20 Y					
C.	1.	21°	*	Y				F.	1.	-54°	*	Y					
	2.	21°	*	5Y					2.	-54°	*	5 Y					
	3.	21°	*	10 Y					3.	-54°	*	10 Y					
	4.	21°	*	20 Y					4.	-54°	*	20 Y					

Capacity vs. Rate and Capacity vs. Temperature

G.	1.	21°	180	0	→										
	2.	21°	270	0	→										
	3.	21°	360	0	→										
	4.	71°	180	0	→										
	5.	57°	180	0	→										
	6.	-32°	180	0	→										
	7.	-54°	180	0	→										
	8.	21°	60	0		57°	120	0	→						
	9.	21°	60	0		-32°	120	0	→						
	10.	57°	120	0		-32°	120	0	→						
	11.	-32°	120	0		57°	120	0	→						

Storage Capability

H.	1.	57°	120	0	57°	120	Y	→							
	2.	57°	120	0	-32°	120	Y	→							
	3.	-32°	120	0	57°	120	Y	→							
	4.	-32°	120	0	-32°	120	Y	—							
I.	1.	21°	168	Y	71°	14	Y	21°	168	Y	-40°	7	Y	-54°	7 Y →
	2.	21°	168	Y	-40°	7	Y	-54°	7	Y	21°	168	Y	71°	14 Y →

Effects of Combined Storage and Discharge

Operational Performance, 1 Year

Key:

Each set of numbers gives the temperature, time, and discharge rate, e.g., 21° 168 Y means discharge at 21°C for 168 days at a rate of Y.

Y is a yearly discharge rate based on the rated capacity of the cells (2.9 ma).

* means discharge to cut-off voltage (2.0 V) at the given temperature and discharge rate.

→ implies discharge at 21°C to the cell's cut-off voltage (2.0 V) at the 10 Y rate.

TABLE II

Li-Organic Cell Tests A 1-4

Test Condition		Cell Serial Number	Life to 2.0 Volts (hours)	Life to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
A-1	71°C, Y Rate	202	1588.9	66.2	5.9	23.7	19.9	31.6	3.0
		68	1444.5	60.2	5.4	21.7	18.4	29.2	2.8
		18	1361.0	56.7	5.1	20.4	17.2	27.3	2.6
		51	1571.8	65.5	5.9	23.5	19.8	31.4	3.0
		58	1030.3	42.9	3.9	15.5	13.2	21.0	2.0
		Avg	1400±200	58±10	5±1	21±3	18±3	28±4	2.7±0.4
A-2	71°C, 5 Y Rate	70	1091.1	45.5	18.2	72.8	55.9	88.7	8.5
		36	1285.1	53.5	21.6	86.4	66.7	105.9	10.1
		27	1323.1	55.1	21.9	87.6	66.8	106.0	10.1
		60	1083.1	45.1	17.6	70.4	52.8	83.8	8.0
		55	1339.1	55.8	21.7	86.8	64.8	102.9	9.8
		Avg	1220±130	50±5	20±2	81±9	61±7	98±11	9.3±1.0
A-3	71°C, 10 Y Rate	88	510.9	21.3	16.63	66.5	49.64	78.8	7.5
		48	664.9	27.7	21.81	87.3	65.89	104.6	10.0
		73	594.9	24.8	19.71	78.8	59.96	95.2	9.1
		49	539.1	22.5	18.24	72.9	56.25	89.3	8.5
		4	508.5	21.2	17.69	70.8	55.87	88.7	8.5
		Avg	560±70	24±3	19±2	75±8	68±6	91±10	8.7±0.9
A-4	71°C, 20 Y Rate	116	293.8	12.2	18.79	75.2	55.33	87.8	8.4
		196	257.0	10.7	17.30	69.2	52.91	84.0	8.0
		186	213.2	8.9	14.16	56.7	42.67	67.7	6.5
		147	257.2	10.7	16.58	66.3	49.01	77.8	7.4
		39	253.5	10.6	17.38	69.5	53.99	85.7	8.2
		Avg	250±30	11±1	17±2	67±7	51±5	81±8	7.7±0.8

TABLE III

Li-Organic Cell Tests B 1-4

Test Condition		Cell Serial Number	Life to 2.0 Volts (hours)	Life to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
B-1	57°C, Y Rate	141	7267.1	302.8	23.8	95.2	72.0	114.3	10.9
		35	6979.1	290.8	23.3	93.2	71.3	113.2	10.8
		199	6897.6	287.4	22.9	91.6	70.1	111.3	10.6
		15	7171.1	298.8	23.9	95.6	73.3	116.4	11.1
		163	7203.1	300.1	24.0	96.0	73.7	117.0	11.2
		Avg	7100±160	300±7	24±1	94±2	72±2	114±2	10.9±0.2
B-2	57°C, 5 Y Rate	6	1063.1	44.3	18.3	73.2	57.6	91.4	8.7
		11	974.4	40.6	16.8	67.2	52.5	83.3	8.0
		13	1167.1	48.6	20.2	80.8	63.6	101.0	9.7
		38	1127.1	47.0	19.2	76.8	59.9	95.1	9.1
		7	1253.1	52.2	20.5	82.0	61.4	97.5	9.3
		Avg	1120±100	47±4	19±2	76±6	59±4	94±7	9.0±0.7
B-3	57°C, 10 Y Rate	26	528.4	22.0	18.15	72.6	56.62	89.9	8.6
		20	519.5	21.6	17.59	70.4	54.30	86.2	8.2
		155	512.7	21.4	17.42	69.7	53.68	85.2	8.2
		14	475.8	19.8	15.59	62.4	46.66	74.1	7.1
		17	469.2	19.6	16.30	65.2	51.31	81.4	7.8
		Avg	500±30	21±1	17±1	68±4	53±4	83±6	8.0±0.6
B-4	57°C, 20 Y Rate	42	869.4	11.2	18.05	72.2	54.90	87.1	8.3
		191	246.8	10.3	16.40	65.6	49.56	78.7	7.5
		156	273.2	11.4	18.16	72.7	55.02	87.3	8.4
		33	289.9	12.1	18.89	75.6	56.40	89.5	8.6
		5	254.0	10.6	16.88	67.5	51.10	81.1	7.8
		Avg	270±20	11±1	18±1	71±4	53±3	85±5	8.1±0.5

TABLE IV

Li-Organic Cell Tests C 1-4

Test Condition	Cell Serial Number	Life to 2.0 Volts (hours)	Life to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
C-1 21°C, Y Rate	29	7819.1	325.8	25.5	102.0	76.6	121.6	11.6
	52	8107.1	337.8	26.4	105.6	79.0	125.4	12.0
	87	7971.1	332.1	26.3	105.2	80.0	127.0	12.1
	8	7263.1	302.6	23.9	95.6	72.7	115.4	11.0
	189	7747.1	322.8	25.5	102.0	77.6	123.2	11.8
	Avg	7800±300	320±10	26±1	102±4	77±3	123±5	11.7±0.4
C-2 21°C, 5 Y Rate	37	1447.1	60.3	23.0	92.0	67.7	107.5	10.3
	80	1368.8	57.0	22.4	89.6	67.0	106.4	10.2
	74	1339.1	55.8	22.4	89.6	68.2	108.3	10.4
	78	1403.1	58.5	22.7	90.8	67.5	107.1	10.2
	139	1311.1	54.6	21.9	87.6	67.0	106.4	10.2
	Avg	1370±50	57±2	23±1	90±2	68±1	107±1	10.3±0.1
C-3 21°C, 10 Y Rate	91	638.1	26.6	20.0	80.0	57.4	91.1	8.7
	180	674.9	28.1	21.9	87.6	64.7	102.7	9.8
	104	737.9	30.7	23.4	93.6	67.9	107.8	10.3
	148	678.9	28.3	22.1	88.4	65.3	103.7	9.9
	149	619.5	25.8	20.4	81.6	61.3	97.3	9.3
	Avg	670±50	28±2	22±1	86±6	63±4	101±7	9.6±0.6
C-4 21°C, 20 Y Rate	183	283.7	11.8	18.0	72.0	52.0	82.6	7.9
	28	360.1	15.0	21.9	87.6	61.0	96.8	9.3
	23	372.4	15.5	22.3	89.1	61.1	96.9	9.3
	150	324.6	13.5	20.3	81.3	58.2	92.3	8.8
	134	334.2	13.9	20.7	82.6	58.1	92.3	8.8
	Avg	340±30	14±1	21±2	83±7	58±4	92±6	8.8±0.6

TABLE V

Li-Organic Cell Tests D 1-4

Test Condition		Cell Serial Number	Life to 2.0 Volts (hours)	Life to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
D-1	-32°C, Y Rate	130	7139.1	297.5	21.9	87.6	62.6	99.4	9.5
		124	6327.1	263.6	20.0	80.0	58.2	92.4	8.8
		137	7179.1	299.1	22.8	91.2	66.5	105.6	10.1
		182	7051.1	293.8	22.9	91.6	68.0	107.9	10.3
		143	7655.1	319.0	24.4	97.6	71.3	113.2	10.8
		Avg	7000±500	290±20	22±2	90±7	65±5	104±8	9.9±0.8
D-2	-32°C, 5 Y Rate	59	1343.1	56.0	20.2	80.8	56.0	88.9	8.5
		47	1291.1	53.8	19.5	78.0	54.0	85.7	8.2
		54	1363.4	56.8	20.5	82.0	56.7	90.0	8.6
		194	1203.1	50.1	19.1	76.4	56.7	88.4	8.5
		16	1079.1	45.0	16.5	66.0	46.3	73.5	7.0
		Avg	1260±120	52±5	19±2	77±6	54±4	85±7	8.2±0.7
D-3	-32°C, 10 Y Rate	142	682.9	28.5	19.0	76.0	48.4	76.8	7.3
		66	578.9	24.1	17.4	69.6	48.2	76.5	7.3
		61	606.9	25.3	18.2	72.8	49.8	79.1	7.6
		77	666.9	27.8	19.1	76.4	50.3	79.8	7.6
		46	662.9	27.6	19.1	76.4	50.7	80.5	7.7
		Avg	640±40	27±2	19±1	74±3	50±1	79±2	7.5±0.2
D-4	-32°C, 20 Y Rate	152	120.0	5.0	7.1	28.6	19.3	30.6	2.9
		82	157.5	6.6	8.9	35.6	23.0	36.5	3.5
		69	164.8	6.9	9.3	37.1	24.0	38.0	3.6
		50	182.8	7.6	10.0	40.2	25.3	40.2	3.8
		151	174.8	7.3	10.2	40.9	27.2	43.2	4.1
		Avg	160±20	7±1	9±1	37±5	24±3	38±5	3.6±0.4

TABLE VI

Li-Organic Cell Tests E 1-4

Test Condition	Cell Serial Number	Life to 2.0 Volts (hours)	Lift to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
E-1 -40°C, Y Rate	126	8411.0	350.5	24.6	98.4	67.1	106.5	10.2
	157	5407.0	225.3	17.4	69.6	51.4	81.6	7.8
	56	3387.0	141.1	11.8	47.2	37.3	59.2	5.7
	53	8211.0	342.1	23.9	95.6	64.9	103.0	9.9
	62	4075.3	169.8	13.8	55.2	42.4	67.3	6.4
	Avg	6000±2000	250±100	18±6	73±23	53±13	80±20	8.0±2.0
E-2 -40°C, 5 Y Rate	45	1051	43.8	15.9	63.6	43.7	69.4	6.6
	135	775	32.3	11.4	45.6	30.6	48.6	4.6
	172	887	37.0	13.2	52.8	35.7	56.7	5.4
	173	891	37.1	13.9	55.6	39.5	62.7	6.0
	65	1059	44.1	15.8	63.2	42.8	67.9	6.5
	Avg	930±120	39±5	14±2	56±8	39±5	61±9	5.8±0.8
E-3 -40°C, 10 Y Rate	67	487.0	20.3	13.64	54.6	34.70	55.1	5.3
	63	15.0	0.6	0.39	1.5	0.91	1.4	0.1
	95	14.0	0.6	0.37	1.5	0.89	1.4	0.1
	203	2.8	0.1	0.08	0.3	0.20	0.3	0.03
	84	545.8	22.7	14.98	59.9	37.40	59.4	5.7
	Avg	200±300	9±12	6±8	20±30	15±19	24±31	2.3±3.0
E-4 -40°C, 20 Y Rate	132	0.9	0.04	0.04	0.18	0.10	0.2	0.02
	72	1.7	0.07	0.09	0.37	0.23	0.4	0.03
	160	4.6	0.19	0.25	0.98	0.61	1.0	0.15
	76	2.8	0.12	0.16	0.64	0.42	0.7	0.11
	85	6.0	0.25	0.32	1.26	0.77	1.2	0.18
	Avg	3±2	0.1±0.1	0.2±0.1	0.7±0.4	0.4±0.3	0.7±0.4	0.1±0.1

TABLE VII

Li-Organic Cell Tests F 1-4

Test Condition	Cell Serial Number	Life to 2.0 Volts (hours)	Life to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
F-1 -54°C, Y Rate	203	20.1	0.8	0.07	0.26	0.20	0.3	0.03
	65	98.3	4.1	0.34	1.37	1.00	1.6	0.15
	172	54.3	2.3	0.19	0.76	0.60	1.0	0.09
	62	50.1	2.1	0.18	0.70	0.56	0.9	0.08
	132	29.0	1.2	0.10	0.40	0.31	0.5	0.05
	3	18.5	0.8	0.06	0.23	0.17	0.3	0.03
	Avg	45±30	1.9±1.3	0.16±0.11	0.6±0.4	0.5±0.3	0.8±0.5	0.07±0.05
F-2 -54°C, 5 Y Rate	67	2.2	0.1	0.03	0.13	0.09	0.1	0.01
	95	2.0	0.1	0.03	0.12	0.08	0.1	0.01
	56	3.8	0.2	0.06	0.24	0.17	0.3	0.03
	63	10.3	0.4	0.16	0.62	0.43	0.7	0.07
	85	5.8	0.2	0.09	0.37	0.27	0.4	0.04
	Avg	5±3	0.2±0.1	0.07±0.05	0.3±0.2	0.21±0.15	0.3±0.3	0.03±0.02
F-3 -54°C, 10 Y Rate	53	0	0	0	0	0	0	0
	84	0	0	0	0	0	0	0
	45	0	0	0	0	0	0	0
	72	0	0	0	0	0	0	0
	160	0	0	0	0	0	0	0
	Avg	0	0	0	0	0	0	0
F-4 -54°C, 20 Y Rate	76	0	0	0	0	0	0	0
	173	0	0	0	0	0	0	0
	135	0	0	0	0	0	0	0
	126	0	0	0	0	0	0	0
	157	0	0	0	0	0	0	0
	Avg	0	0	0	0	0	0	0

TABLE VIII

Li-Organic Cell Tests G 1-11

	Test Condition	Cell Serial Number	Life to 2.0 Volts (hours)	Life to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
G-1	Storage, 180 days at 21°C	107	705.6	29.4	22.1	88.4	63.8	101.3	9.7
	Discharge, 10 Y Rate, 21°C	83	565.9	23.6	18.6	74.4	56.2	89.2	8.5
		187	443.6	18.5	14.6	58.4	43.6	69.2	6.6
		114	588.0	24.5	19.3	77.2	58.0	92.1	8.8
		127	661.5	27.6	21.0	84.0	61.0	96.8	9.3
		Avg	590±100	25±4	19±3	77±12	57±6	90±12	8.6±1.2
G-2	Storage, 270 days at 21°C	176	588.9	23.7	18.3	73.2	54.3	86.2	8.2
	Discharge, 10 Y Rate, 21°C	94	588.7	24.5	19.3	77.2	57.9	91.9	8.8
		162	427.6	17.8	14.5	58.0	44.7	71.0	6.8
		99	388.6	16.2	13.1	52.4	39.9	63.3	6.1
		161	661.6	27.6	21.5	86.0	64.4	102.2	9.8
		Avg	530±110	22±5	17±4	69±14	52±10	83±16	7.9±1.5
G-3	Storage, 360 days at 21°C	170	656.3	27.4	21.2	84.8	63.2	100.3	9.6
	Discharge, 10 Y Rate, 21°C	165	506.0	21.1	16.5	66.0	49.1	77.9	7.5
		97	709.0	29.5	22.3	89.2	64.7	102.7	9.8
		102	453.5	18.9	14.7	58.8	43.4	68.9	6.6
		92	683.0	28.5	22.0	88.0	65.3	103.7	9.9
		Avg	600±110	25±5	19±4	77±14	57±10	91±16	8.7±1.5
G-5	Storage, 180 days at 57°C	166	360.3	15.0	10.9	43.6	29.9	47.5	4.5
	Discharge, 10 Y Rate, 21°C	175	610.7	25.4	15.5	62.0	35.4	56.2	5.4
		103	1.6	0.1	0.04	0.2	0.08	0.1	0.01
		81	406.4	16.9	10.6	42.4	25.1	39.8	3.8
		115	22.0	0.9	0.5	2.0	1.1	1.7	0.2
		Avg	300±300	12±11	8±7	30±28	18±17	29±26	2.8±2.5
G-6	Storage, 180 days at -32°C	22	709.3	29.6	22.2	88.8	63.6	101.0	9.7
	Discharge, 10 Y Rate, 21°C	25	732.8	30.5	22.6	90.4	64.3	102.1	9.8
		75	670.7	27.9	21.1	84.4	60.9	96.7	9.2
		120	584.6	24.4	19.4	77.6	58.5	93.9	8.9
		21	708.8	29.5	22.8	91.2	67.5	107.1	10.2
		Avg	680±60	28±2	22±1	87±6	63±3	100±5	9.6±0.5
G-7	Storage, 180 days at -54°C	100	589.6	24.6	18.7	74.8	54.7	86.8	8.3
	Discharge, 10 Y Rate, 21°C	101	646.7	26.9	20.7	82.8	60.7	96.3	9.2
		31	662.6	27.6	21.9	87.6	65.8	104.4	10.0
		106	644.0	26.8	21.3	85.2	64.4	102.2	9.8
		24	720.0	30.0	23.1	92.4	67.8	107.6	10.3
		Avg	650±50	27±2	21±2	85±7	63±5	100±8	9.5±0.8
G-8	Storage, 60 days at 21°C,	119	372.0	15.5	12.6	50.4	38.5	61.1	5.8
	120 days at 57°C	12	634.5	26.4	20.4	81.6	60.5	96.0	9.2
	Discharge, 10 Y Rate, 21°C	109	441.6	18.4	14.2	56.8	42.2	67.0	6.4
		41	501.6	20.9	16.9	67.6	51.6	81.9	7.8
		118	420.8	17.5	14.2	56.8	43.8	69.5	6.6
		Avg	470±100	20±4	16±3	63±12	47±9	75±14	7.2±1.4
G-9	Storage, 60 days at 21°C,	19	722.7	30.1	22.6	90.4	65.0	103.2	9.9
	120 days at -32°C	123	670.0	27.9	21.2	84.8	61.3	97.3	9.3
	Discharge, 10 Y Rate, 21°C	96	689.3	28.7	22.1	88.4	64.8	102.9	9.8
		171	696.0	29.0	22.2	88.8	64.7	102.7	9.8
		121	666.0	27.8	21.3	85.2	62.5	99.2	9.5
		Avg	690±20	29±1	22±1	88±2	64±2	100±3	9.7±0.3
G-10	Storage, 120 days at 57°C,	112	565.0	23.5	16.5	66.0	44.4	70.5	6.7
	120 days at -32°C	111	586.3	24.4	15.8	63.2	39.0	61.9	5.9
	Discharge, 10 Y Rate, 21°C	122	329.0	13.7	10.4	41.6	29.7	47.1	7.1
		125	559.0	23.3	15.9	63.6	41.3	65.6	6.3
		9	419.0	17.5	14.2	56.8	43.6	69.2	6.6
		Avg	490±110	21±5	15±3	58±10	40±6	63±9	6.5±0.4
G-11	Storage, 120 days at -32°C,	140	605.8	25.2	17.8	71.2	48.4	76.8	7.3
	120 days at 57°C	184	549.0	22.9	17.3	69.2	50.1	79.5	7.6
	Discharge, 10 Y Rate, 21°C	113	545.0	22.7	16.1	64.4	43.9	69.7	6.7
		174	553.0	23.0	16.0	64.0	42.9	68.1	6.5
		131	617.0	25.7	17.1	68.4	43.1	68.4	6.5
		Avg	570±30	24±1	17±1	67±3	46±3	73±5	6.9±0.5

All 5 cells at condition G-4 (180 days storage at 71°C) vented during storage and could not be discharged.

TABLE IX

Li-Organic Cell Tests H 1-4

Test Condition	Cell Serial Number	Test Condition: Amp-Hrs Out at Y Rate	Test Condition: Watt-Hrs Out at Y Rate	10 Y Rate at 70°F: Life to 2.0 Volts (days)	10 Y Rate at 70°F: Amp-Hrs Out at 10 Y Rate	Total Cell Output: Total Amp-Hrs Out	Total Cell Output: % Rated Capacity	Total Cell Output: Total Watt Hrs	Total Cell Output: Watt Hours per Pound	Total Cell Output: Watt Hours per In^3
H-1 Storage, 120 days at 57°C,	188	9.85	30.7	0	0	9.85	39.4	30.7	48.7	4.7
Y Rate, 120 days at 57°C	105	9.53	28.8	0	0	9.53	38.1	28.8	45.7	4.4
Discharge, 10 Y Rate at 21°C	146	9.56	29.1	0	0	9.56	38.2	29.1	46.2	4.4
	89	10.01	31.8	0	0	10.01	40.0	31.8	50.5	4.8
	159	3.32	10.3	0	0	3.32	13.3	10.3	16.3	1.6
	Avg	9±3	26±9	0	0	9±3	34±12	26±9	42±14	4.0±1.3
H-2 Storage, 120 days at 57°C,	178	9.36	27.7	6.9	3.94	13.30	53.2	36.21	57.5	5.5
Y Rate, 120 days at -32°C	145	9.56	28.9	9.9	6.30	15.86	63.4	44.10	70.0	6.7
Discharge, 10 Y Rate at 21°C	129	8.63	23.6	12.0	7.09	15.72	62.9	39.30	62.4	6.0
	185	9.74	30.0	5.0	3.57	13.31	53.2	39.74	63.1	6.0
	90	8.83	24.8	12.6	8.10	16.93	67.7	44.40	70.5	6.7
	Avg	9±1	27±3	9±3	6±2	15±2	60±7	41±4	65±6	6.2±0.5
H-3 Storage, 120 days at -32°C,	187	10.5	34.8	9.2	6.10	16.60	66.4	50.2	79.7	7.6
Y Rate, 120 days at 57°C	154	10.6	35.4	11.7	7.90	18.50	74.0	55.7	88.4	8.5
Discharge, 10 Y Rate at 21°C	153	10.6	35.5	10.4	7.13	17.73	70.9	54.2	86.0	8.2
	192	10.7	35.9	13.6	9.58	20.28	81.1	61.5	97.6	9.3
	136	10.6	35.4	8.5	5.17	15.77	63.1	47.2	74.9	7.2
	Avg	10.6±0.1	35.4±0.4	11±2	7±2	18±2	71±7	54±6	85±9	8.2±0.8
H-4 Storage, 120 days at -32°C,	117	10.3	33.6	14.5	10.40	20.70	82.8	62.0	98.4	9.4
Y Rate, 120 days at -32°C	169	10.3	33.2	18.2	12.40	22.70	90.8	65.5	104.0	9.9
Discharge, 10 Y Rate at 21°C	200	10.3	33.2	17.7	12.50	22.80	91.2	66.6	105.7	10.1
	179	10.2	32.6	11.4	8.43	18.63	74.5	56.3	89.4	8.5
	138	10.3	33.2	11.2	8.23	18.53	74.1	56.2	89.2	8.5
	Avg	10.3±0.04	33.2±0.4	15±3	10±2	21±2	83±8	61±5	97±8	9.3±0.8

TABLE X

Li-Organic Cell Tests I 1-2

Test Condition	Cell Serial Number	Life to 2.0 Volts (hours)	Life to 2.0 Volts (days)	Total Amp-Hours Out	% Rated Capacity	Total Watt Hours	Watt Hours per Pound	Watt Hours per In^3
I-1 Discharge Y Rate 168 days at 21°C, 14 days at 71°C, 168 days at 21°C, 7 days at -40°C, 7 days at -54°C	34	7955.1	331.5	26.1	104.4	79.3	125.9	12.0
	133	8035.1	334.8	26.5	106.0	80.5	127.8	12.2
	40	7579.1	315.8	25.2	100.8	77.1	122.4	11.7
	181	7072.4	294.7	23.7	94.8	73.2	116.2	11.1
	10	8395.2	349:8	27.4	109.6	82.6	131.1	12.5
		7800±500	330±20	26±1	103±6	79±4	125±6	11.9±0.5
I-2* Discharge Y Rate 168 days at 21°C, 7 days at -40°C, 7 days at -54°C, 168 days at 21°C, 14 days at 71°C	43	8000.5	333.4	26.0	104.0	78.1	124.0	11.9
	30	8040.7	335.0	26.1	104.4	78.6	124.8	11.9
	164	7803.7	325.2	25.4	101.6	76.7	121.8	11.6
	44	6968.4	290.4	23.4	93.6	72.2	114.6	11.0
	201	6914.4	288.1	23.2	92.8	71.5	113.5	10.9
		7500±600	310±20	25±1	99±6	75±3	120±5	11.5±0.5
Avg to initial 2.0 V Cut-Off		4230±24	176±1	15.4±0.1	61.8±0.2	50.8±0.1	80.6±0.2	7.7±0.0

*Volt. went below 2.0 V during -54°C excursion, but recovered when warmed to 21°C.

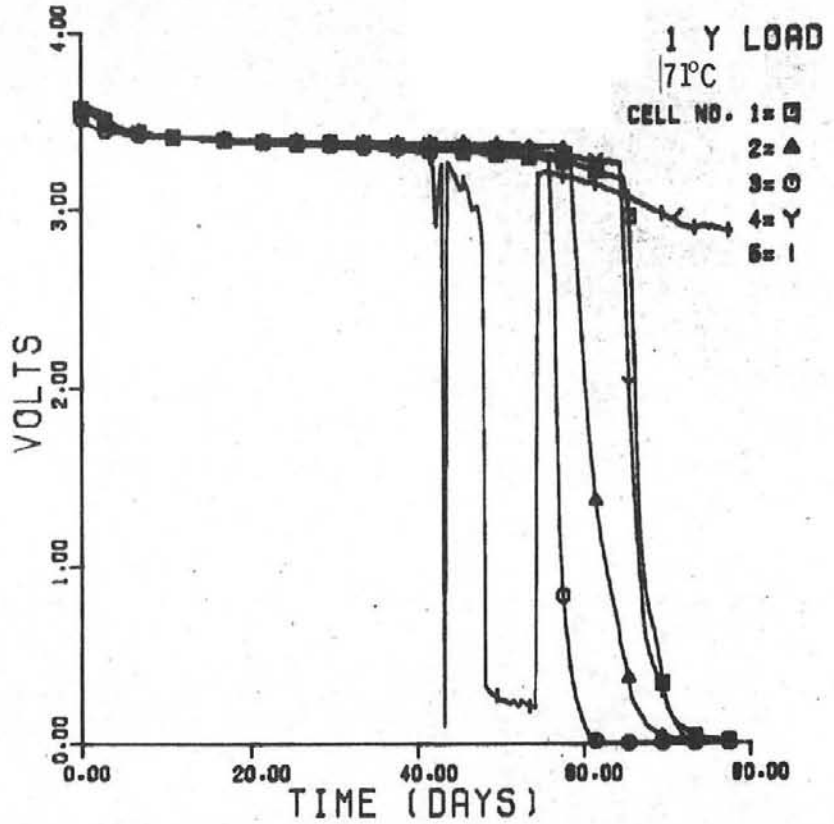


Figure 1. Group A-1

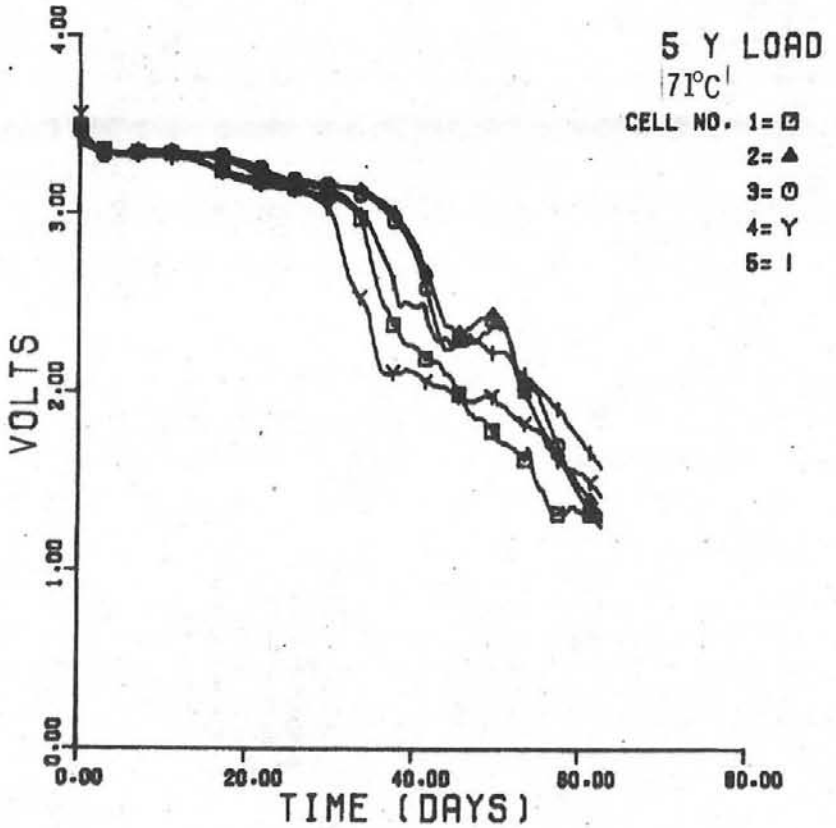


Figure 2. Group A-2

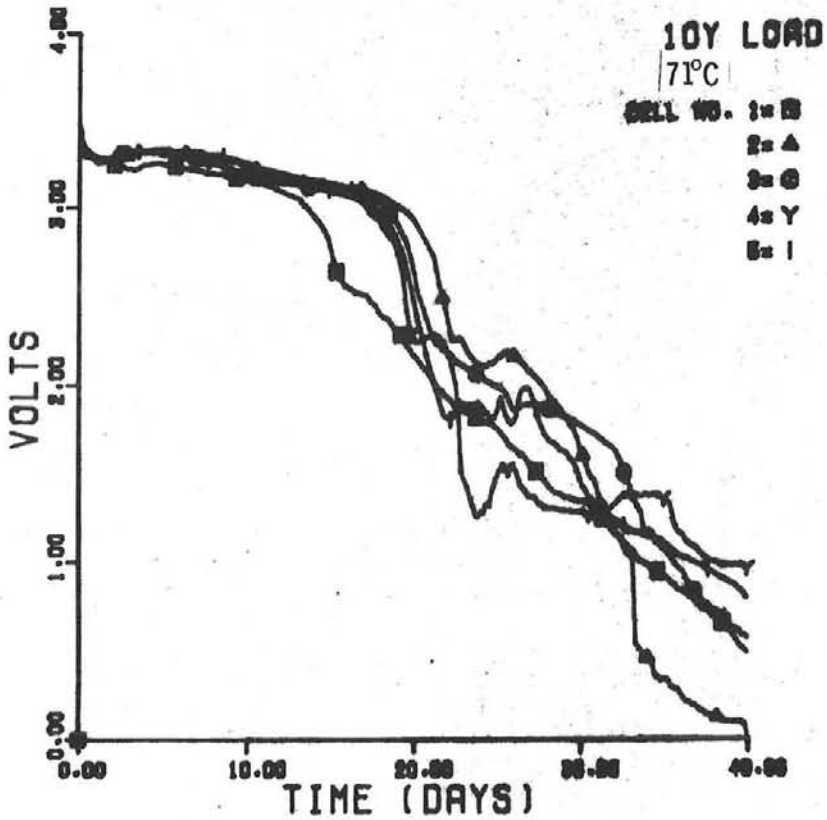


Figure 3. Group A-3

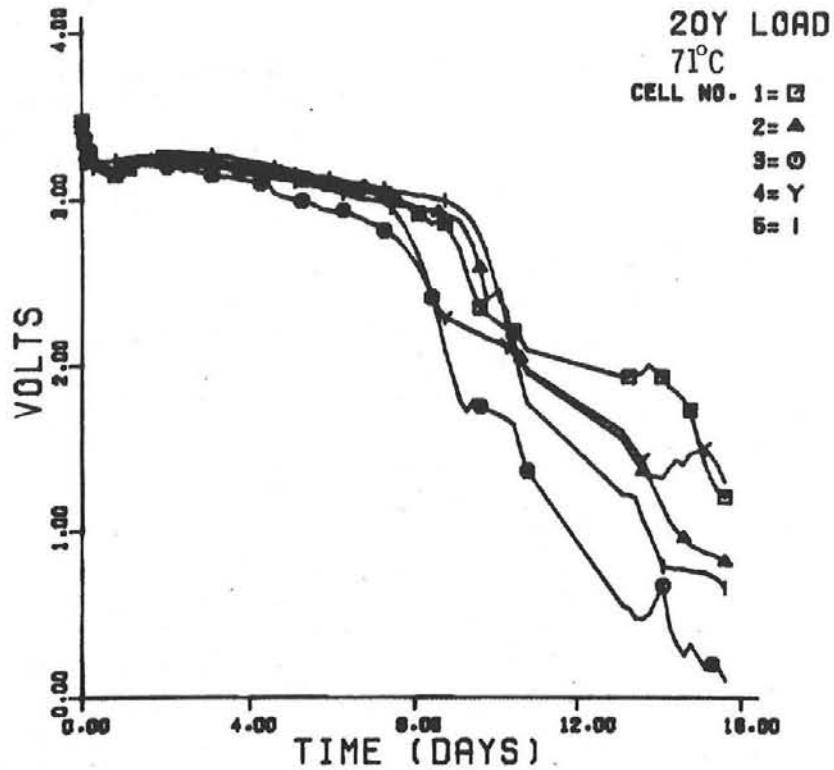


Figure 4. Group A-4

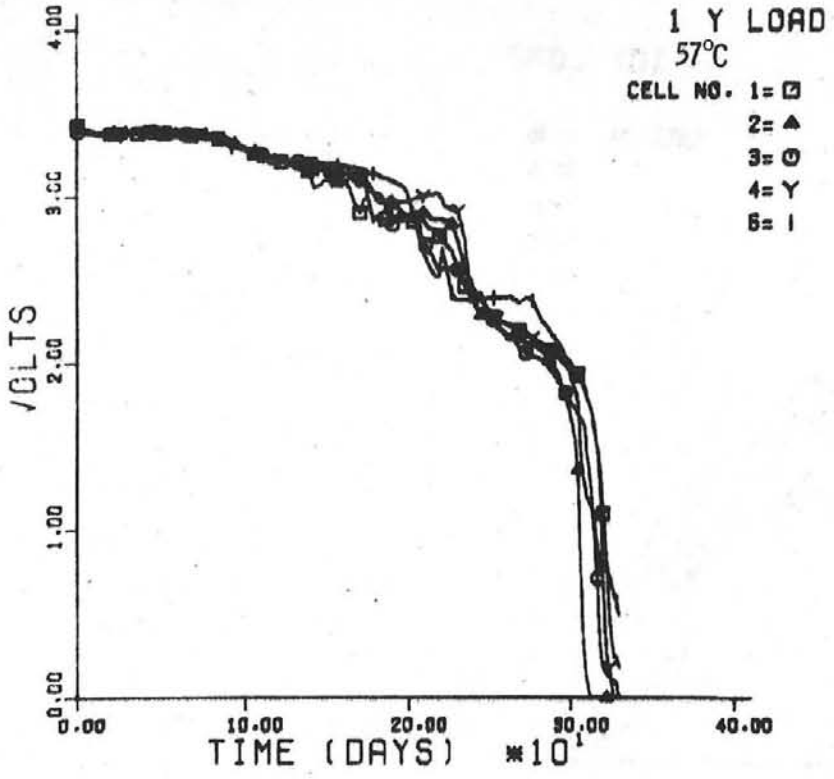


Figure 5. Group B-1

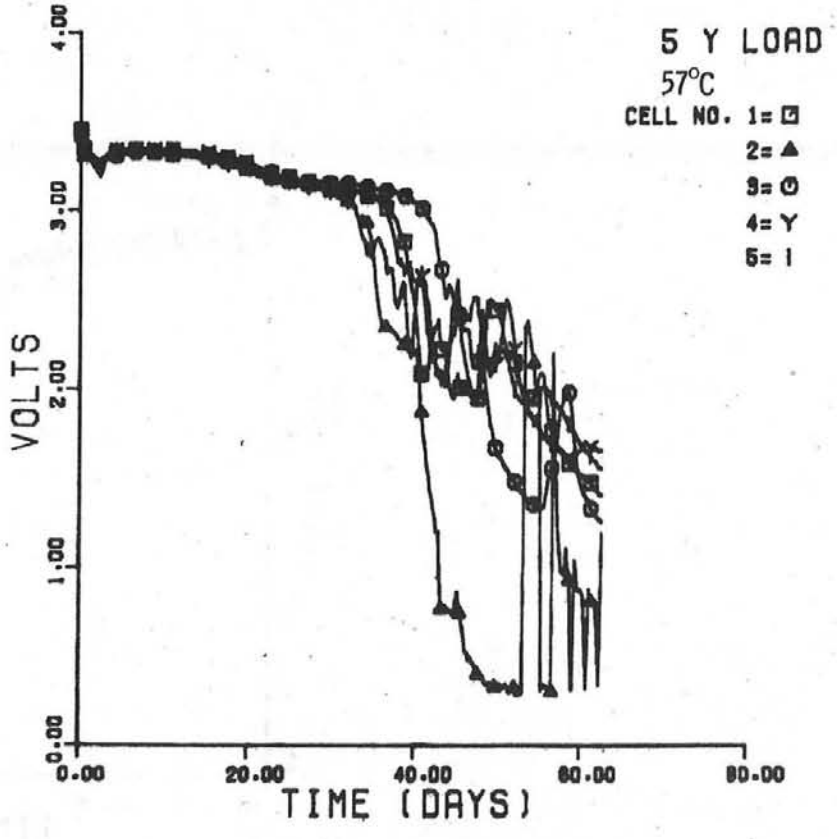


Figure 6. Group B-2

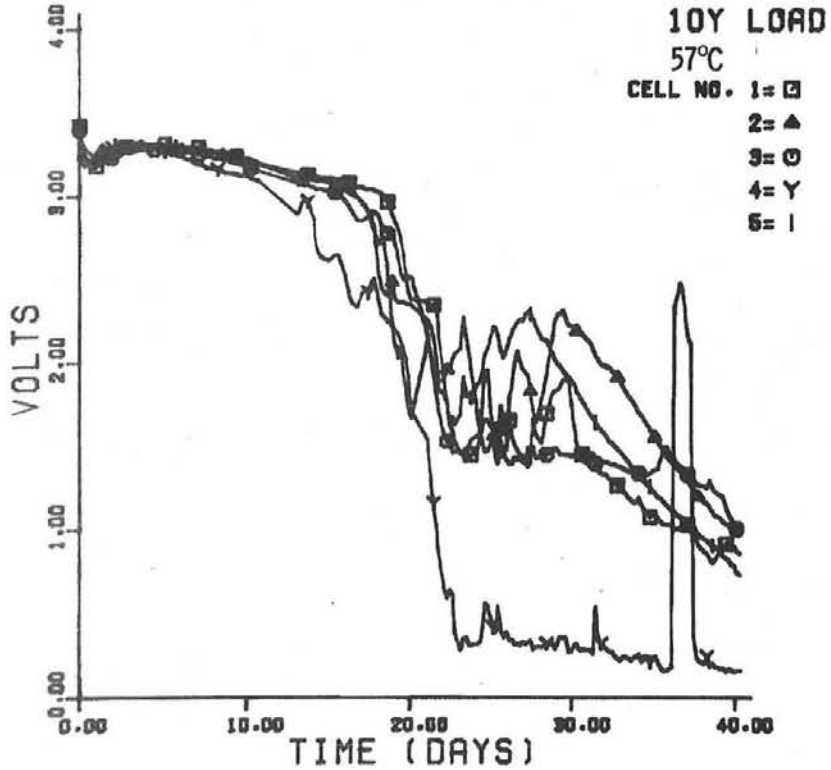


Figure 7. Group B-3

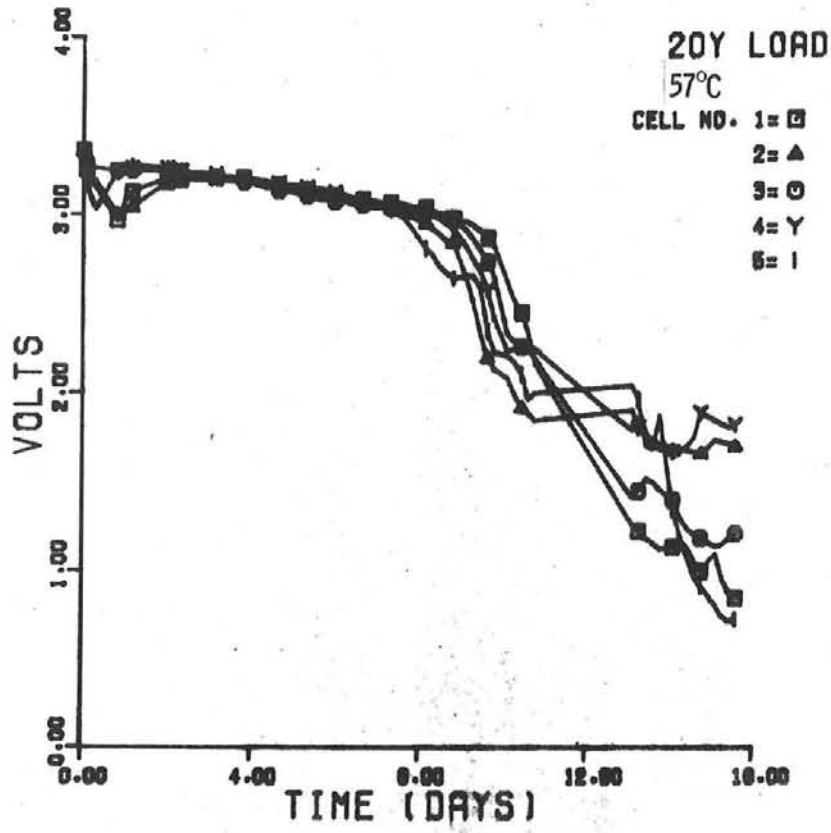


Figure 8. Group B-4

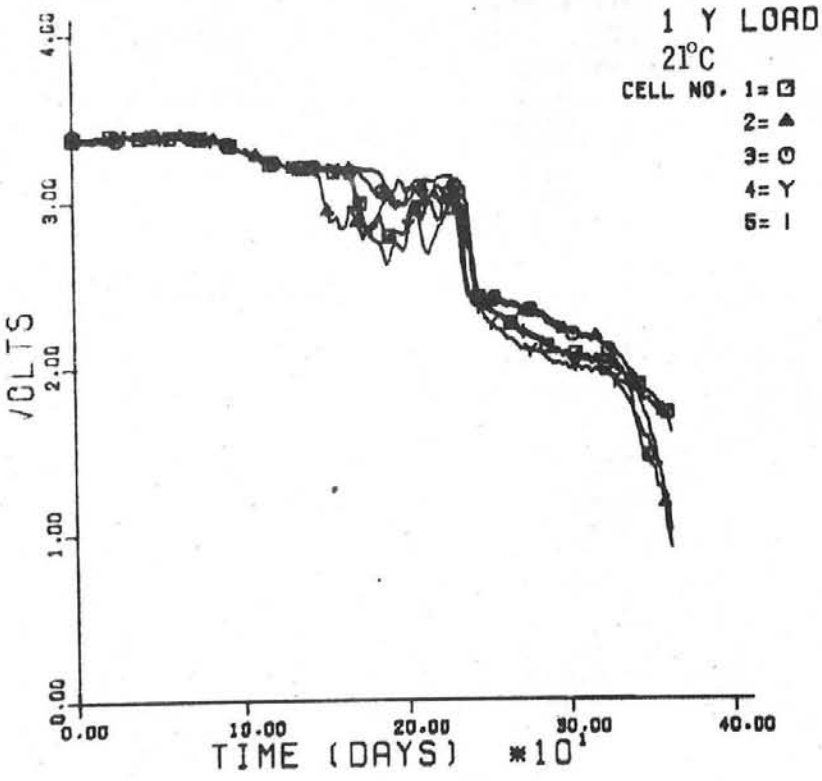


Figure 9. Group C-1

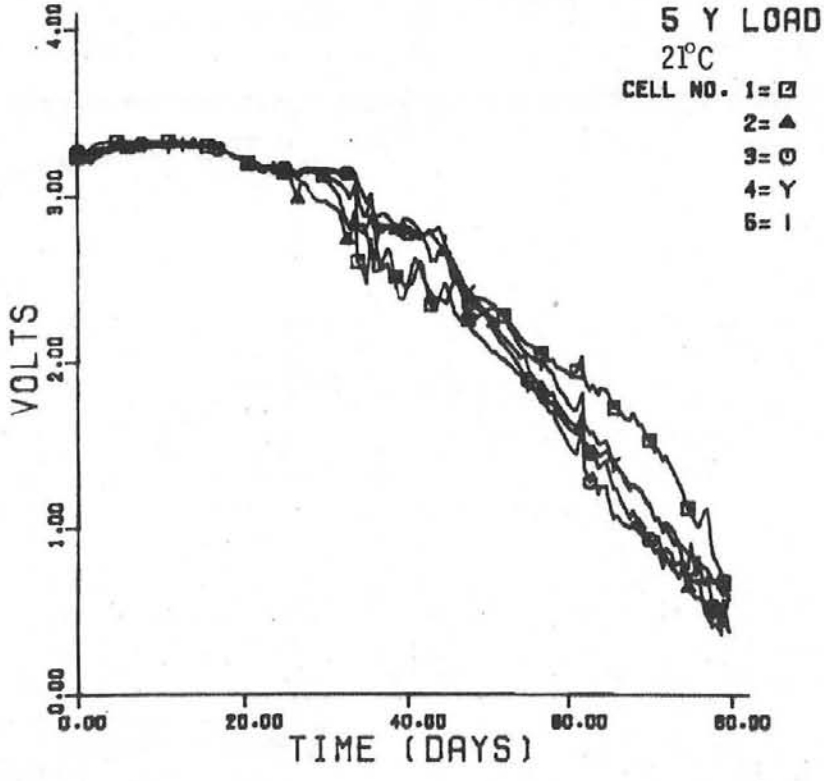


Figure 10. Group C-2

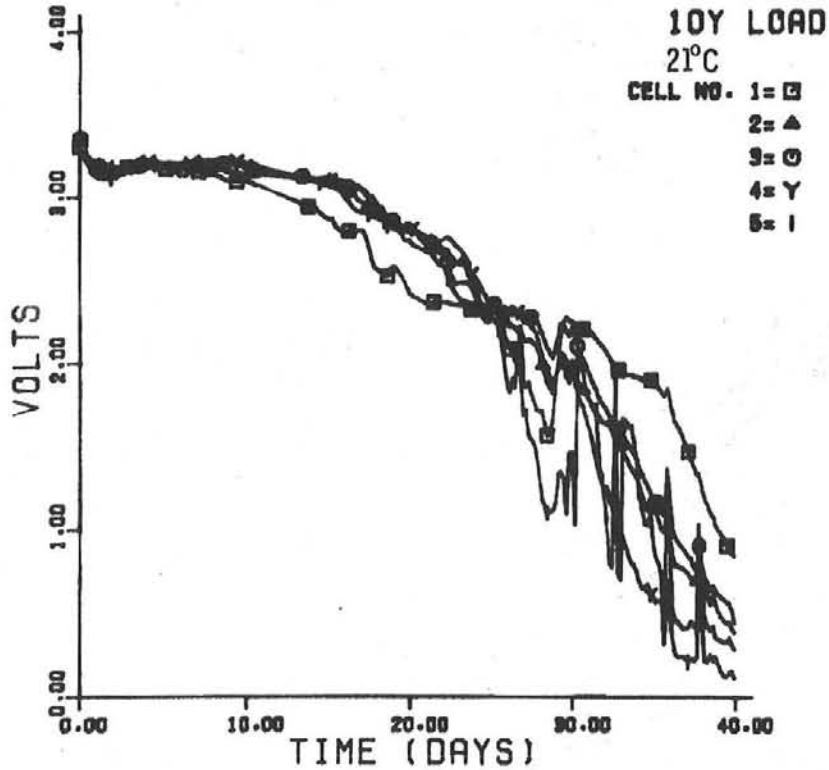


Figure 11. Group C-3

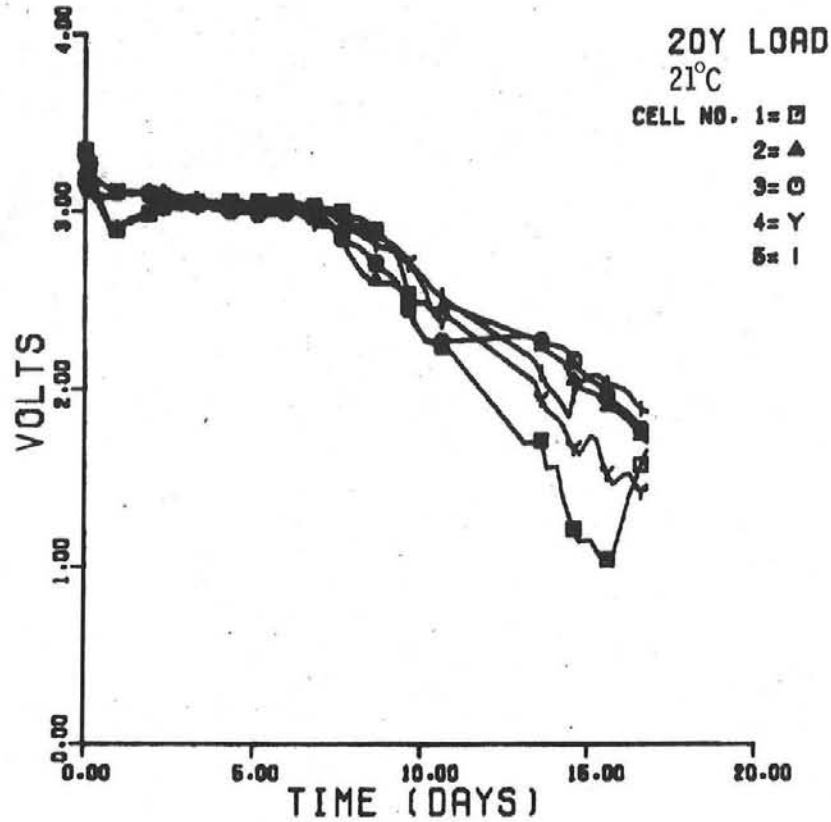


Figure 12. Group C-4

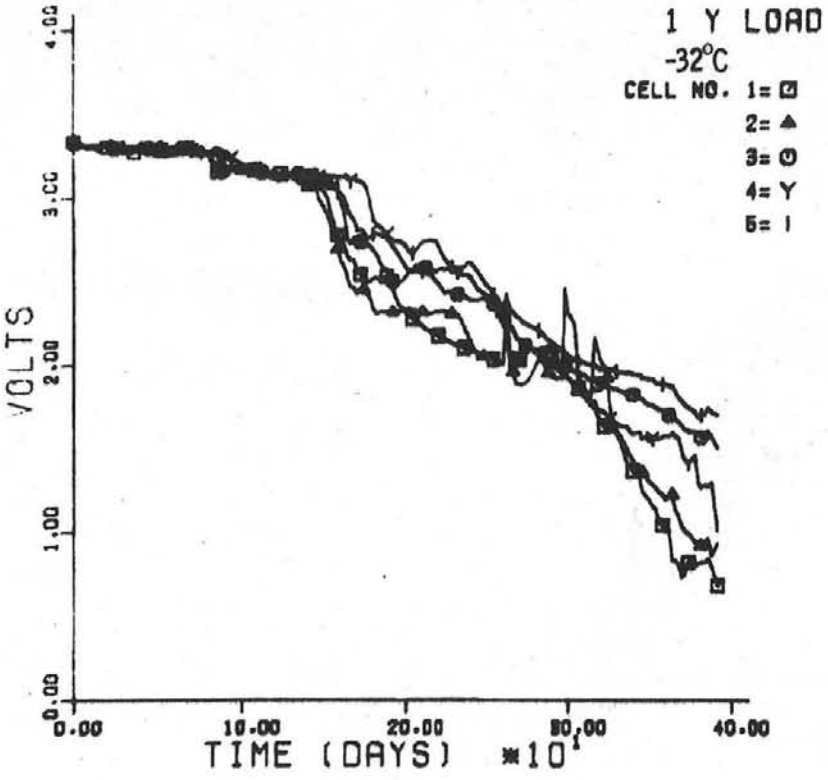


Figure 13. Group D-1

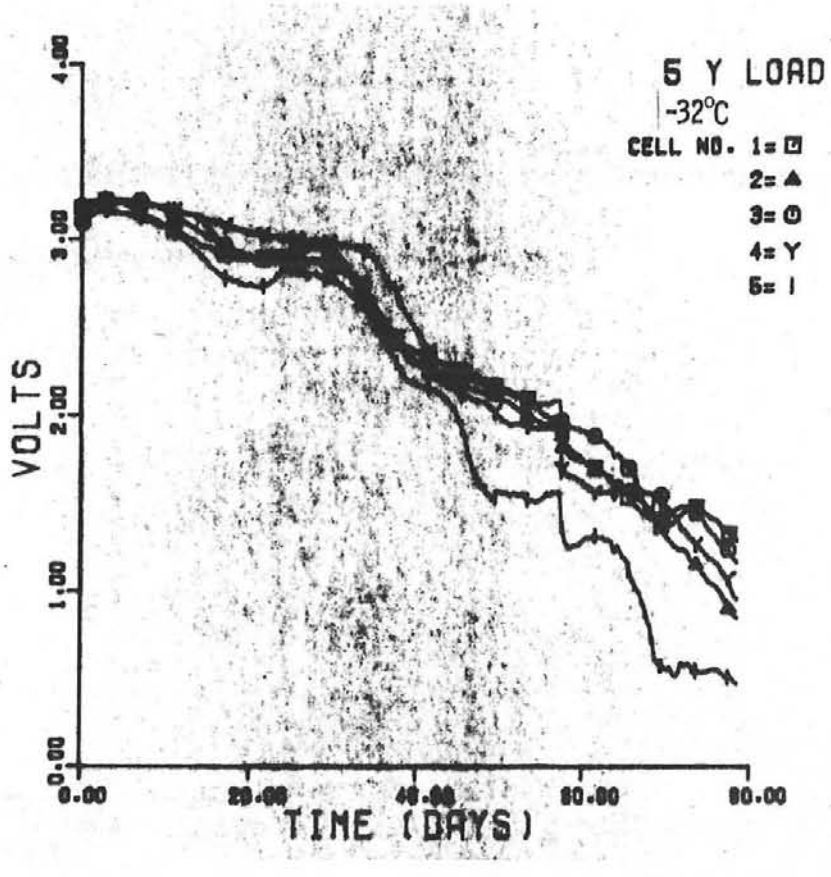


Figure 14. Group D-2

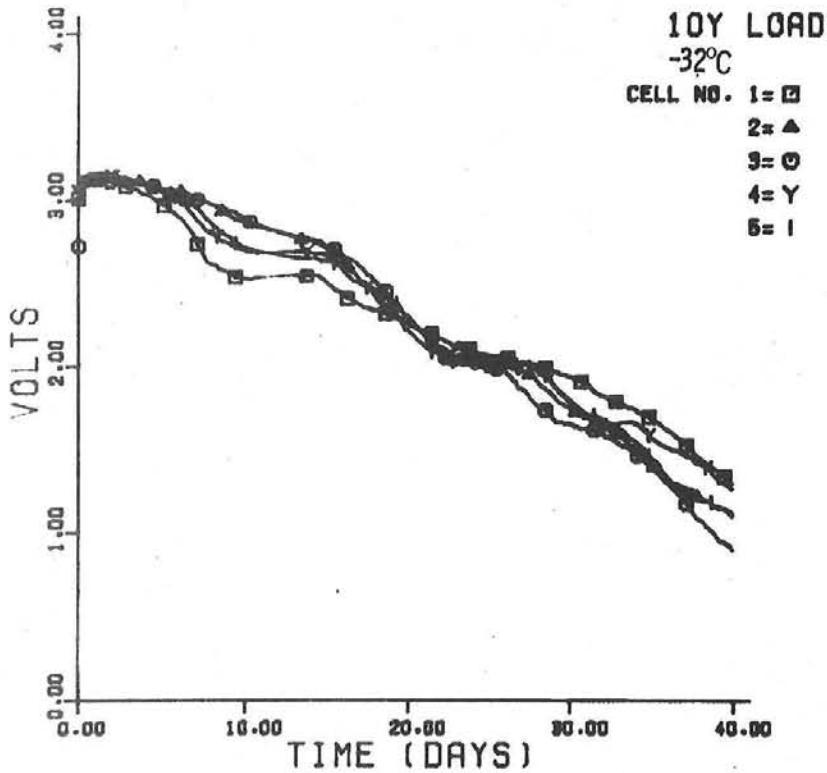


Figure 15. Group D-3

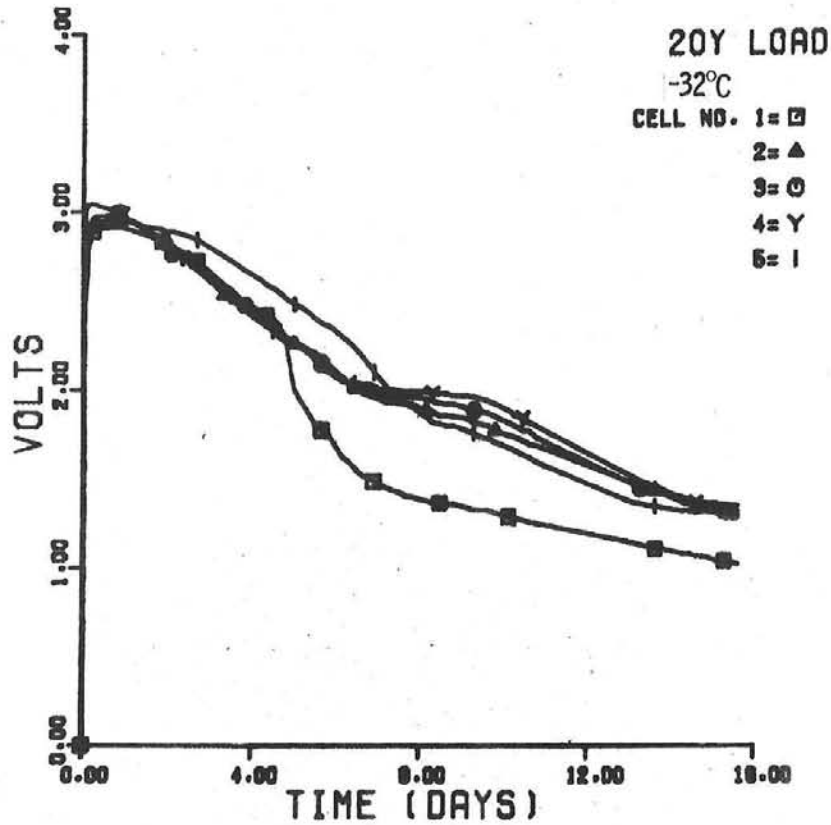


Figure 16. Group D-4

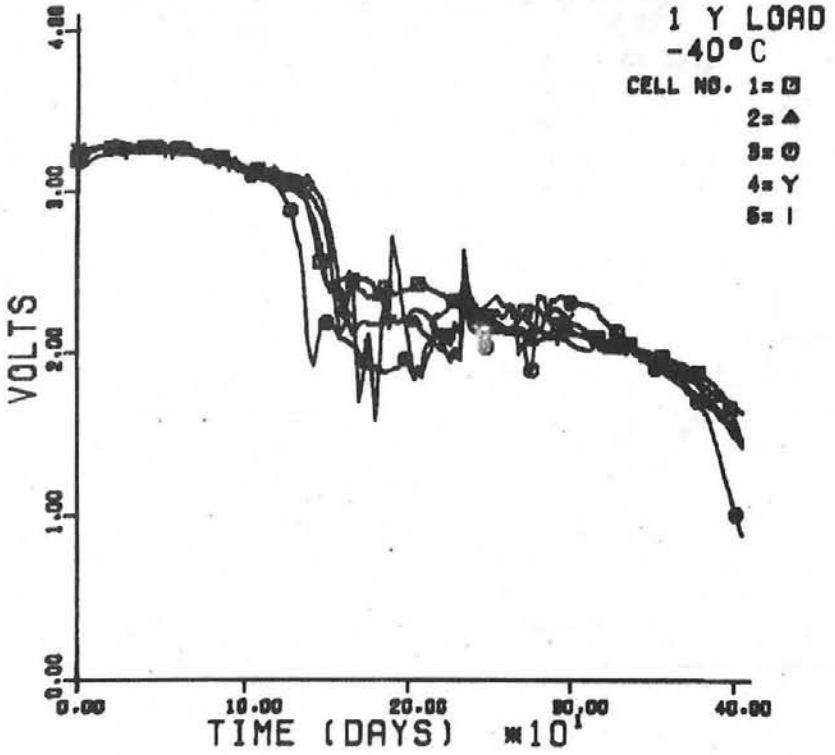


Figure 17. Group E-1

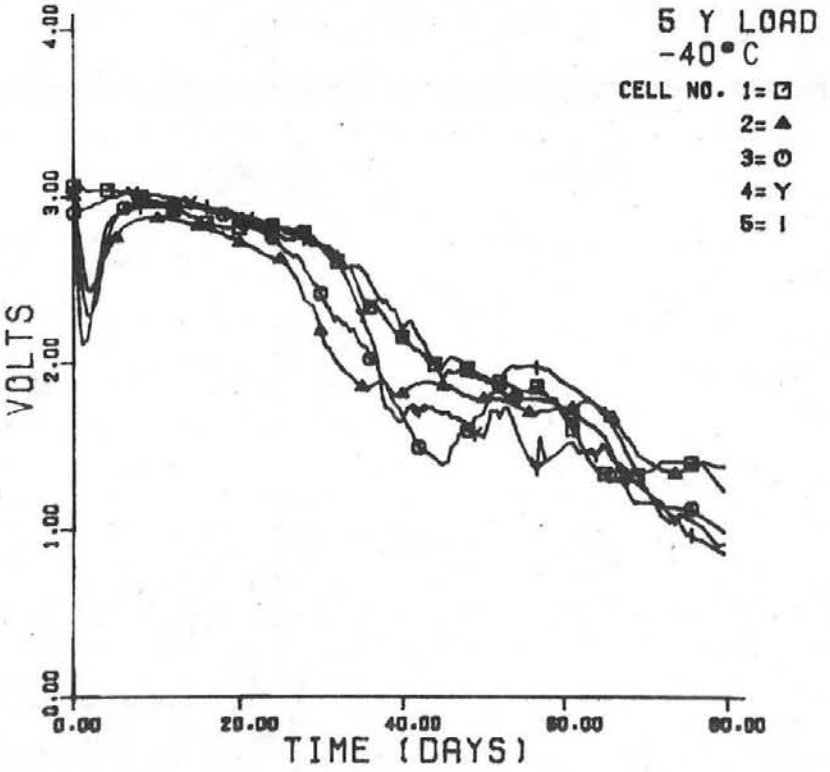


Figure 18. Group E-2

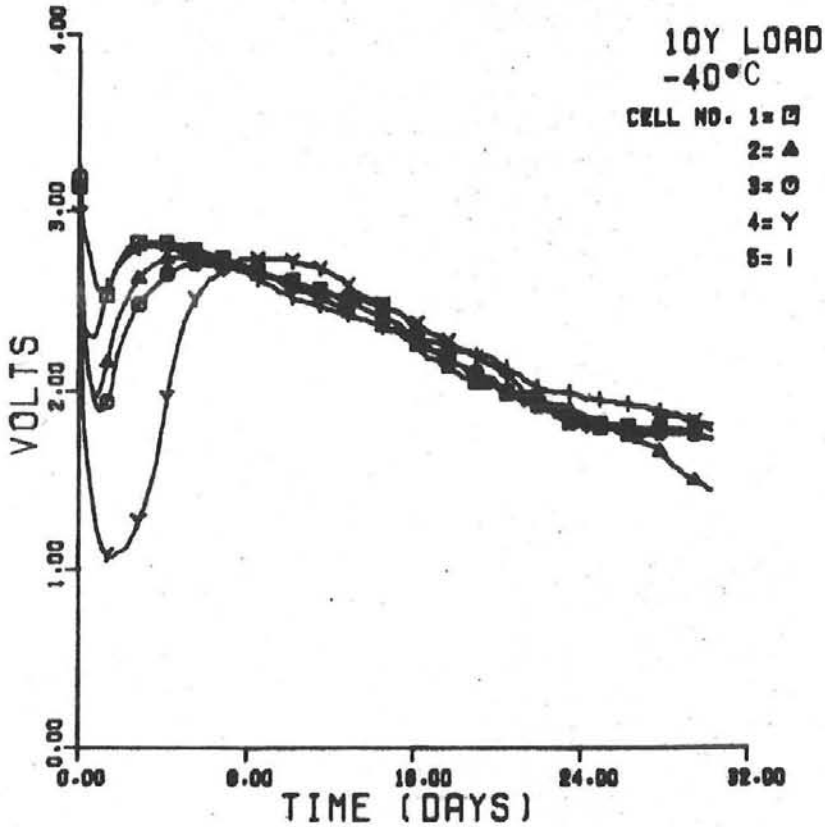


Figure 19. Group E-3

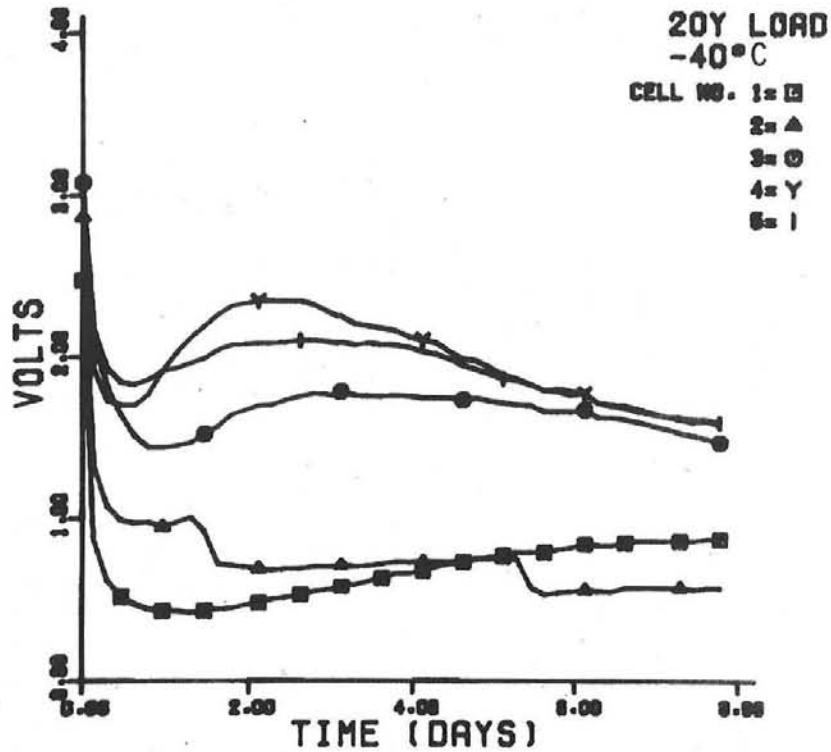


Figure 20. Group E-4

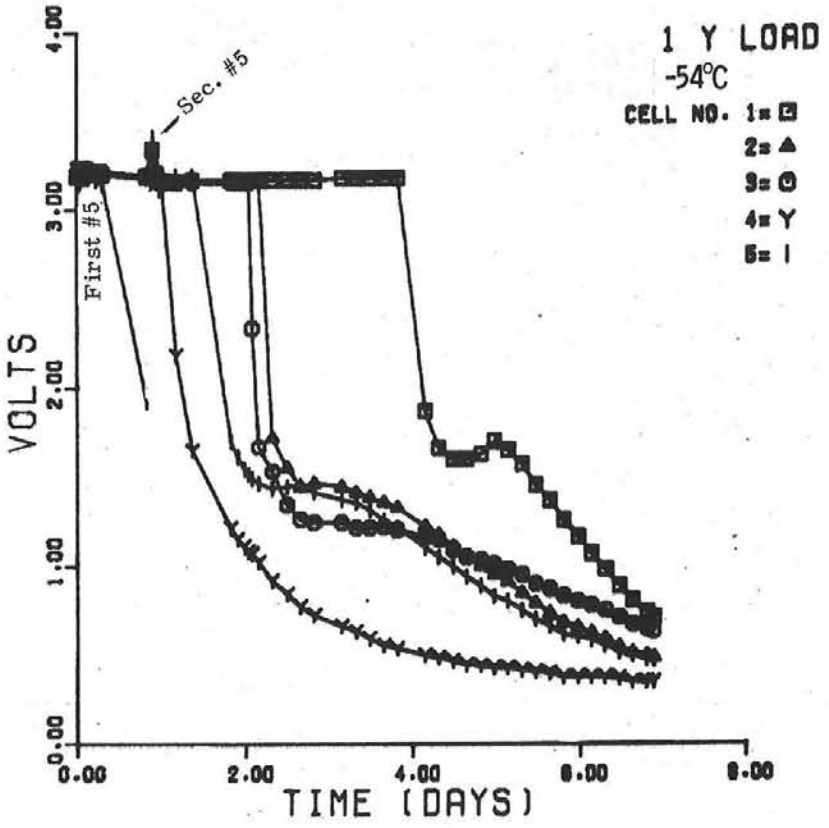


Figure 21. Group F-1

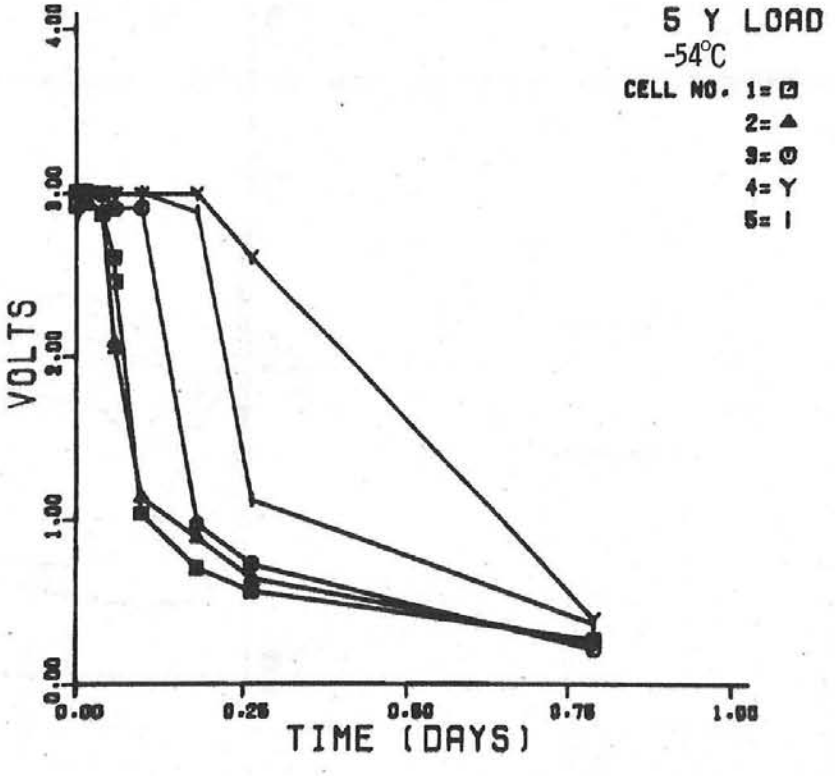


Figure 22. Group F-2

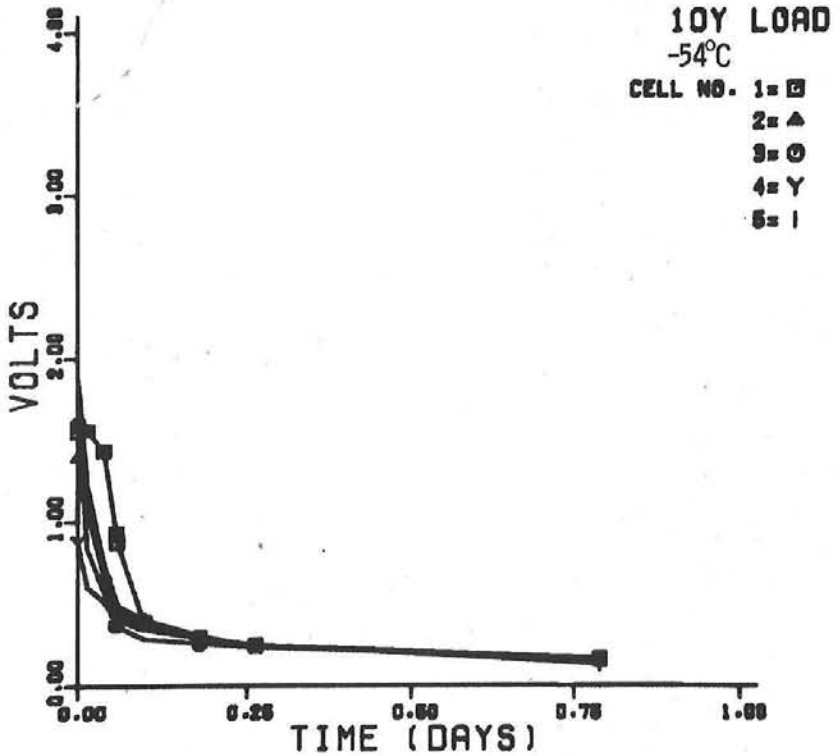


Figure 23. Group F-3

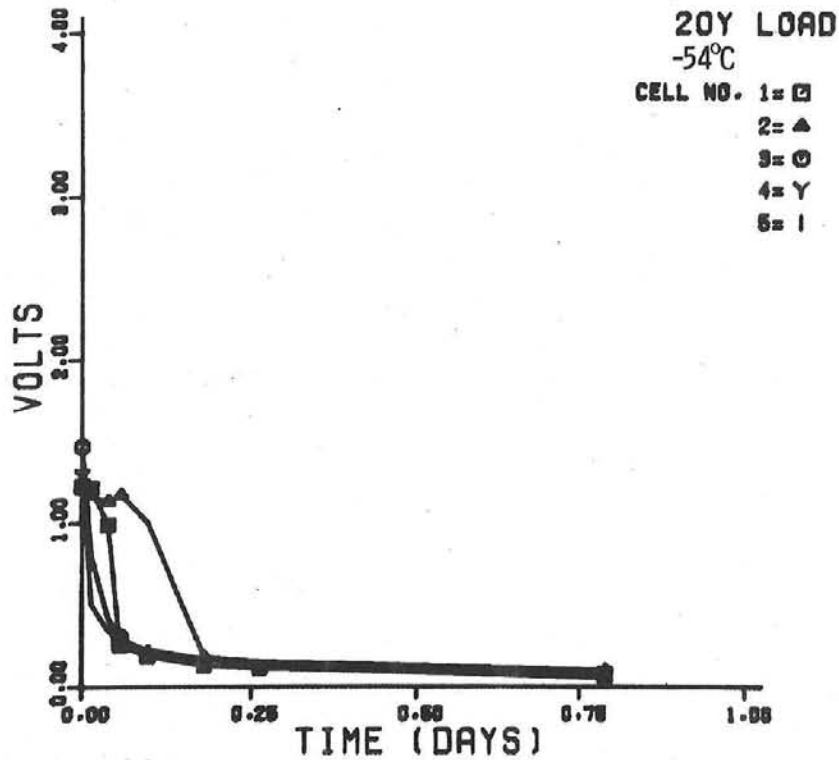


Figure 24. Group F-4

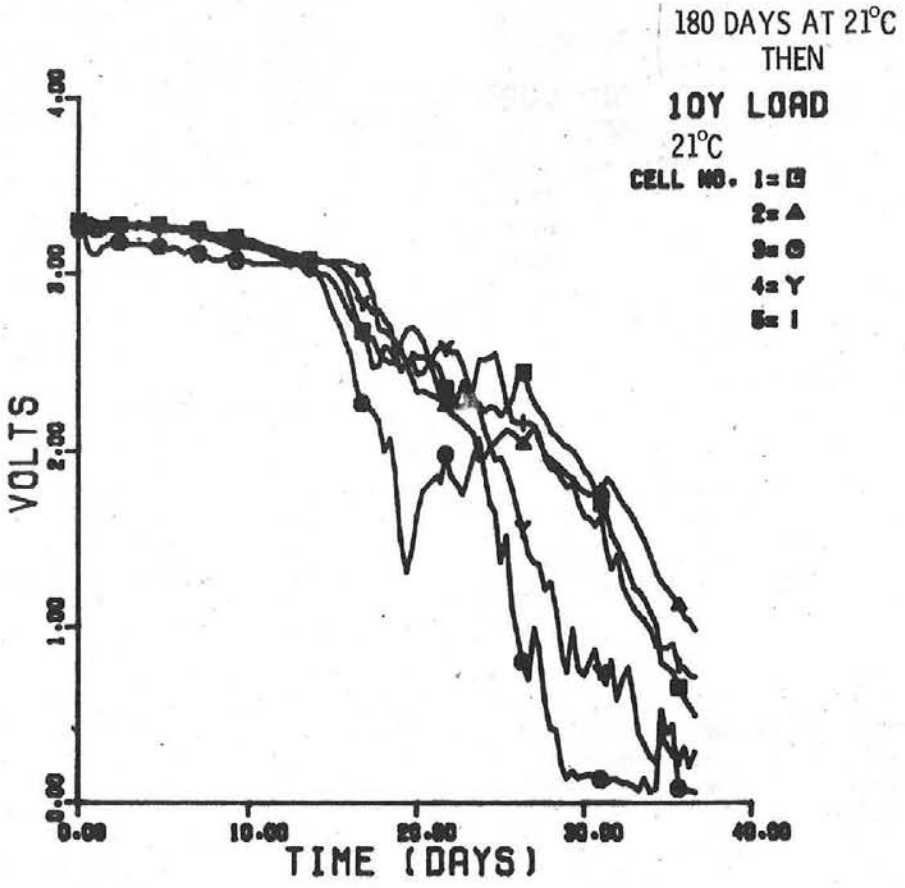
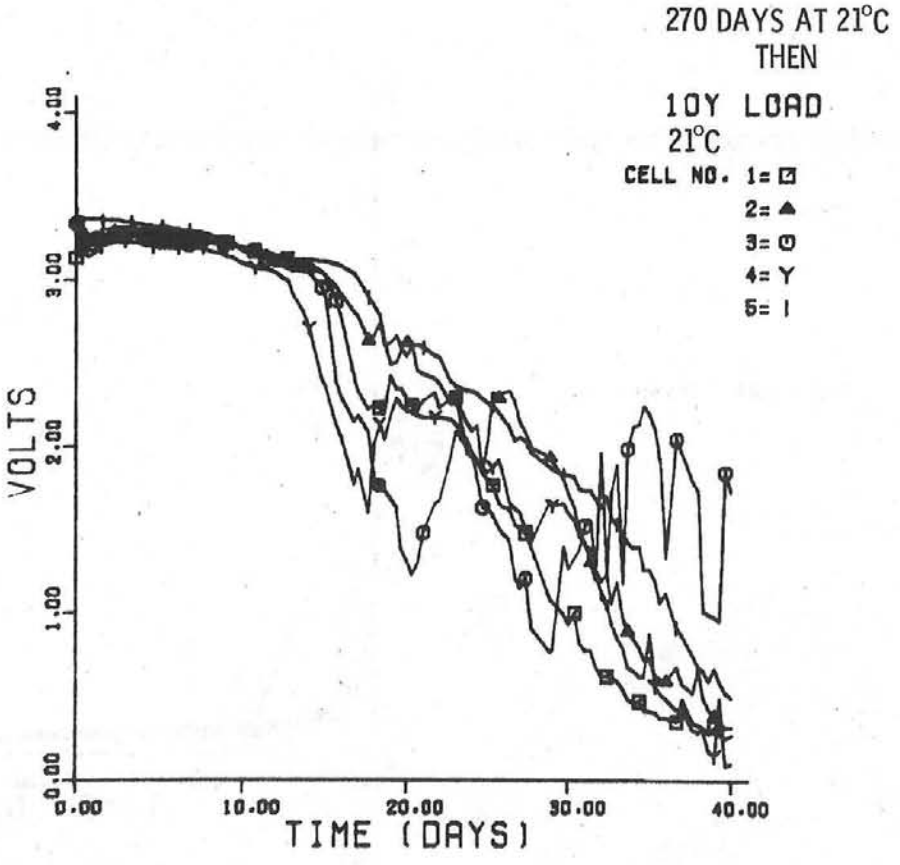


Figure 25. Group G-1



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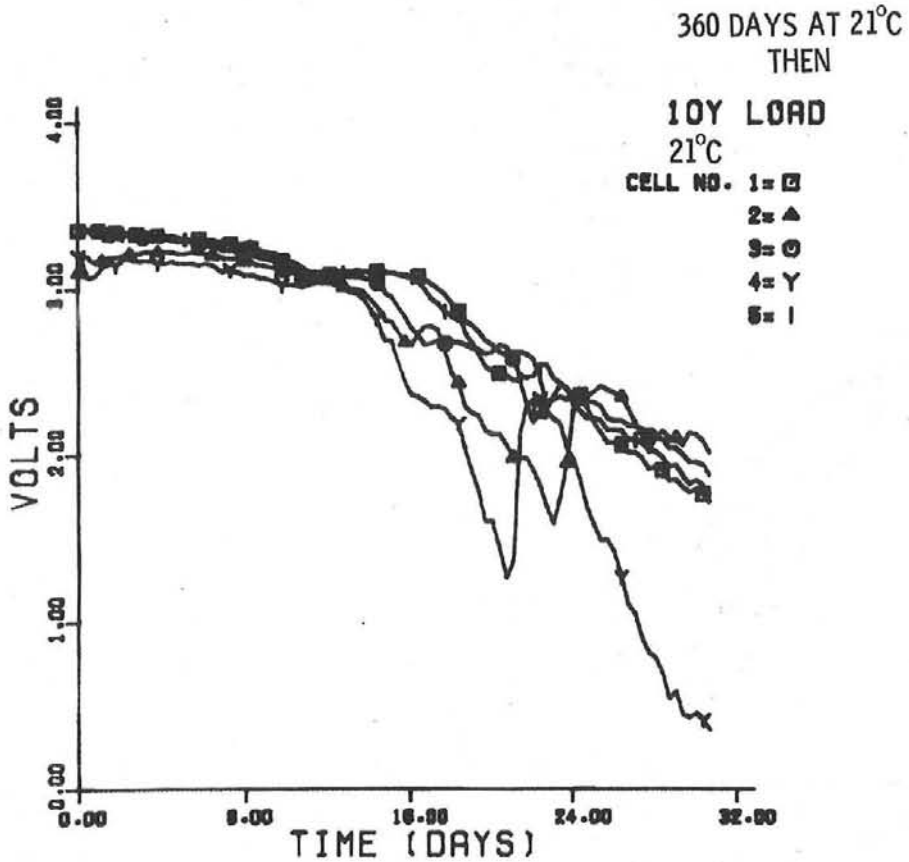

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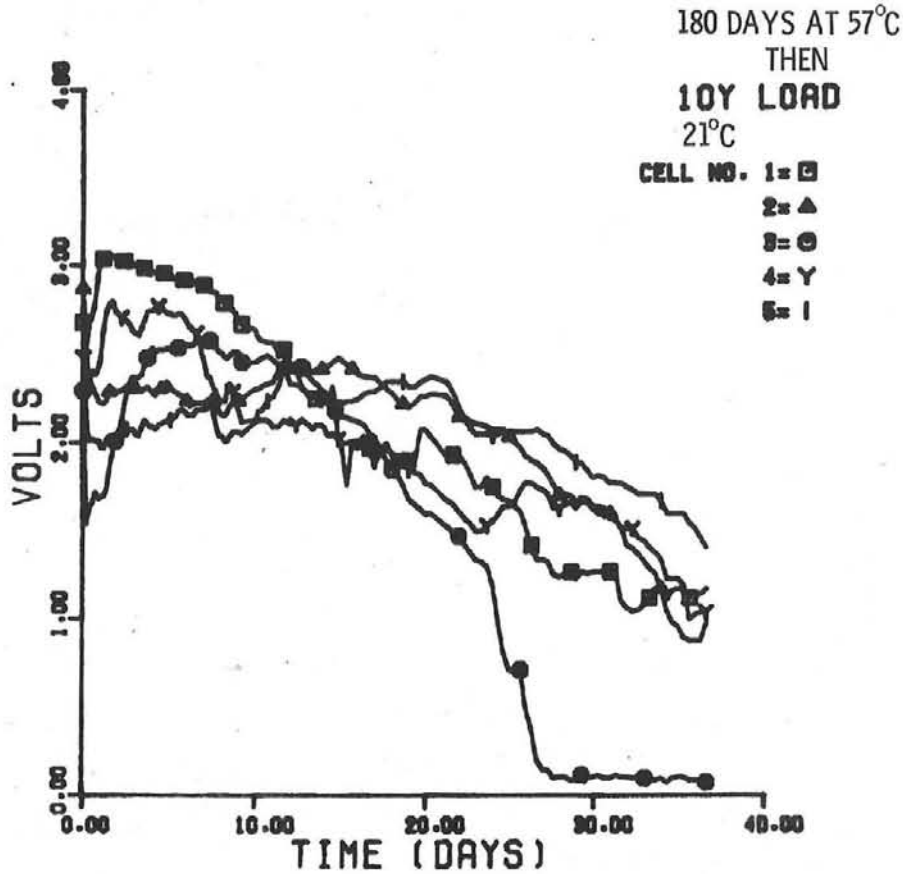

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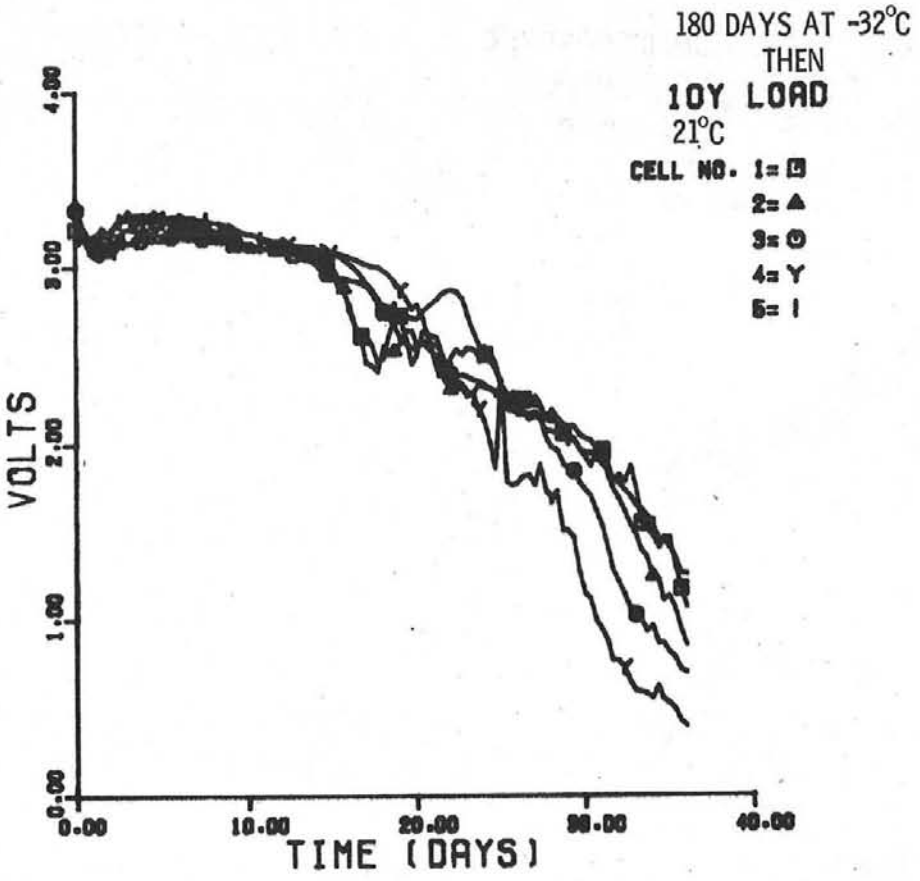

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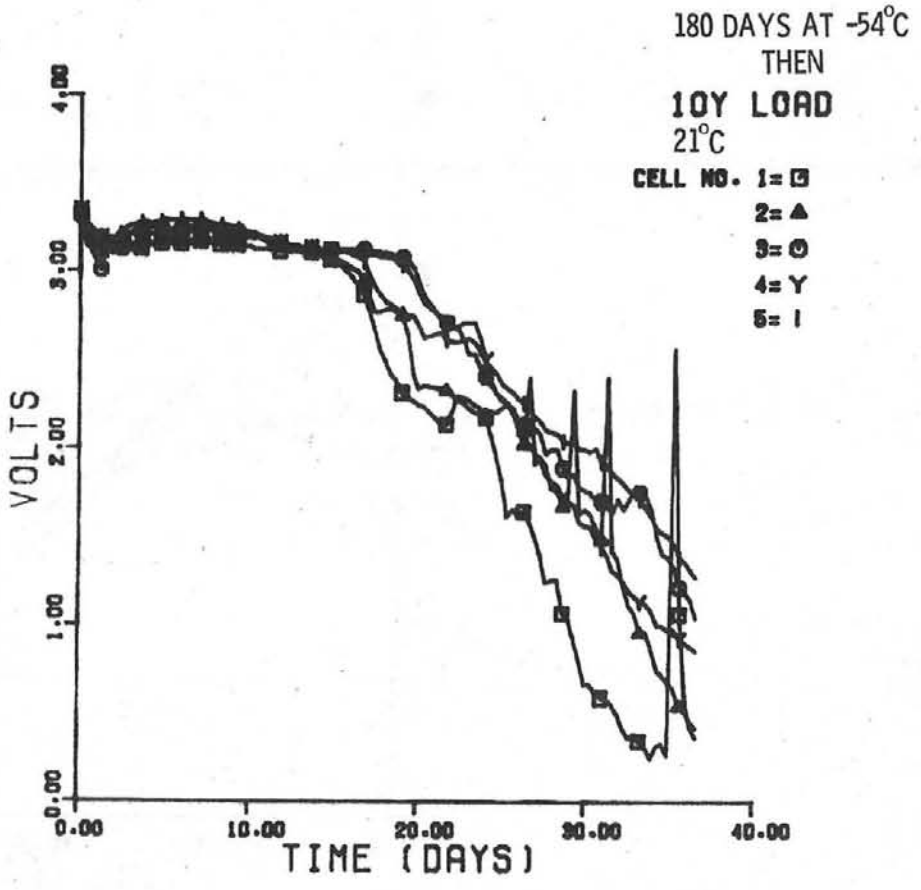

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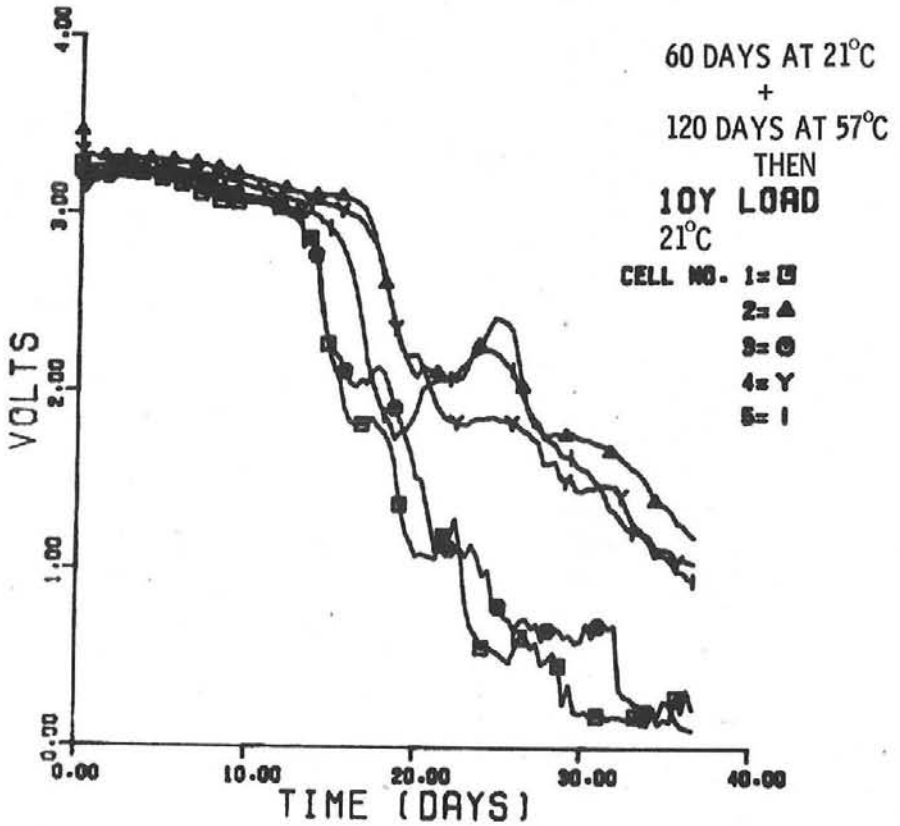

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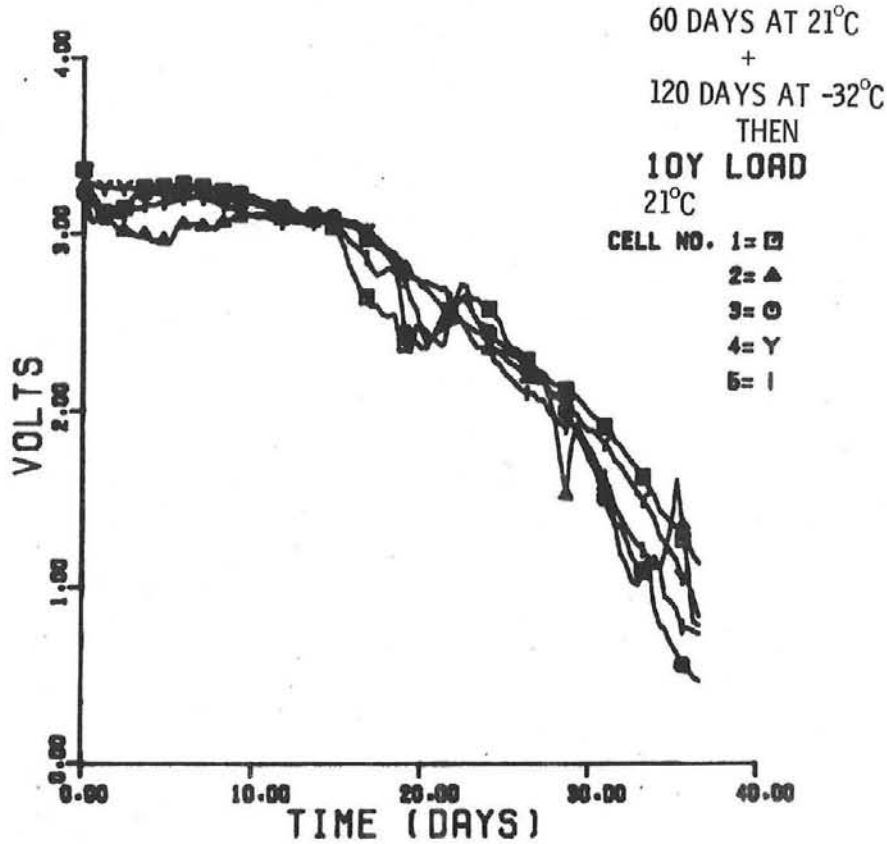

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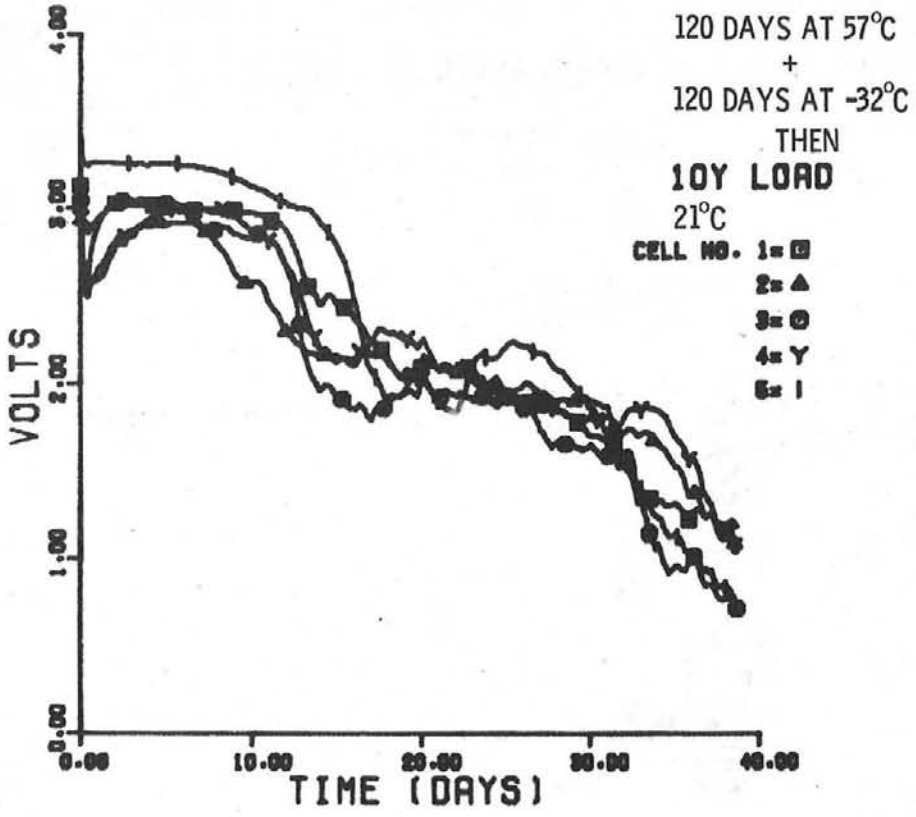

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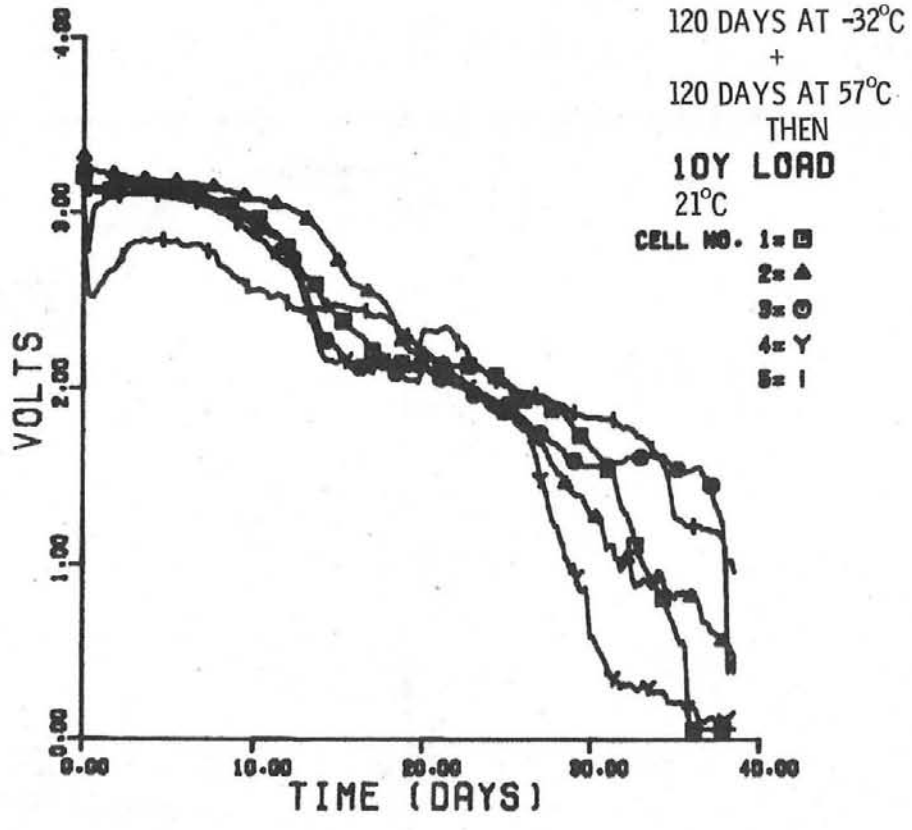

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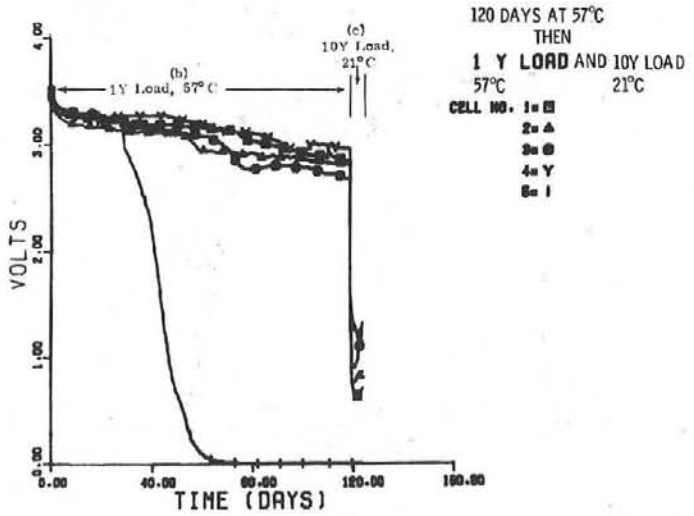
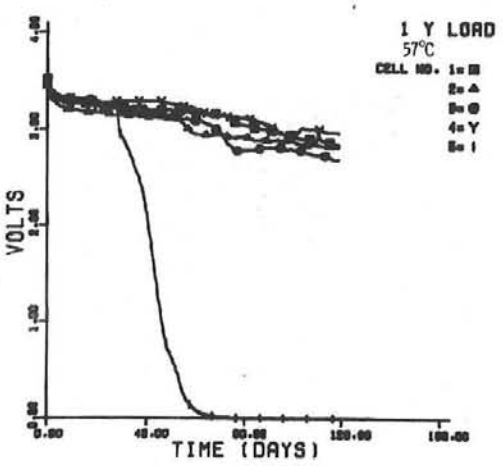




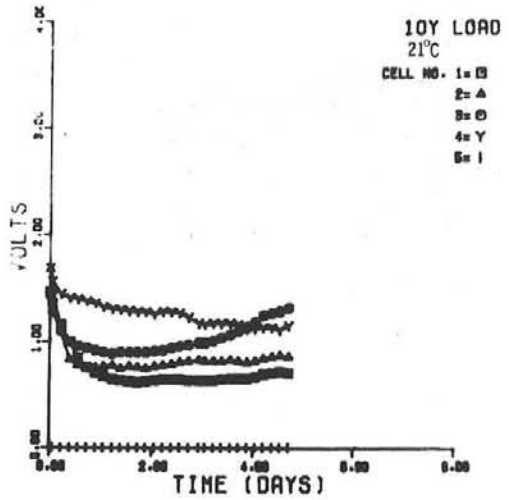
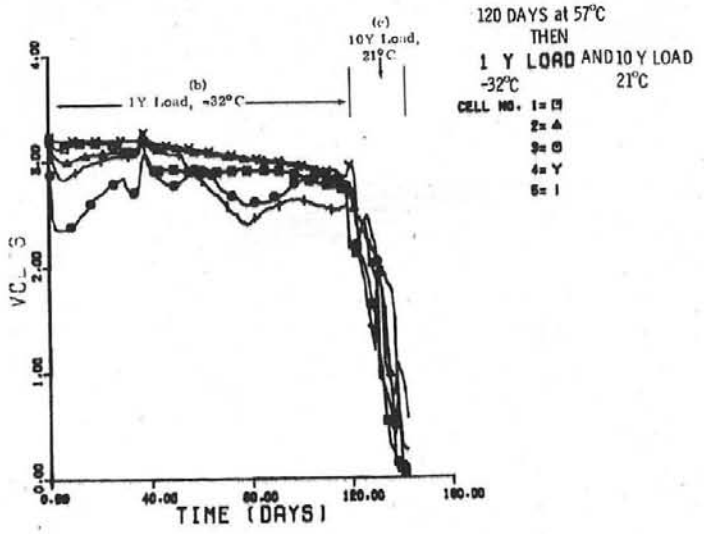


Figure 35. Group H-1



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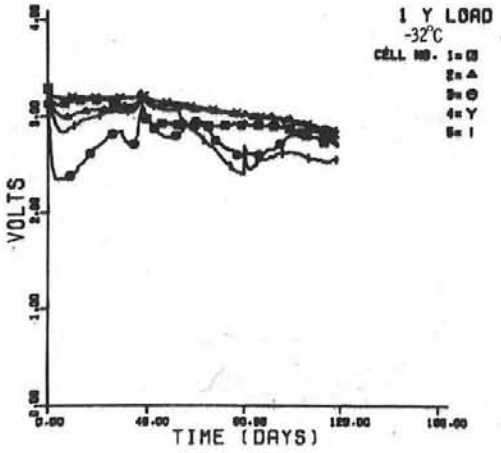

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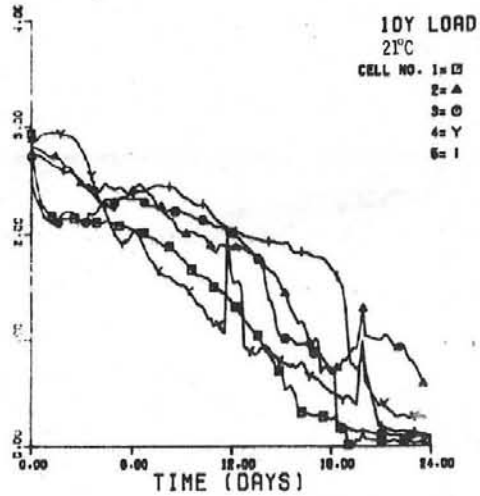
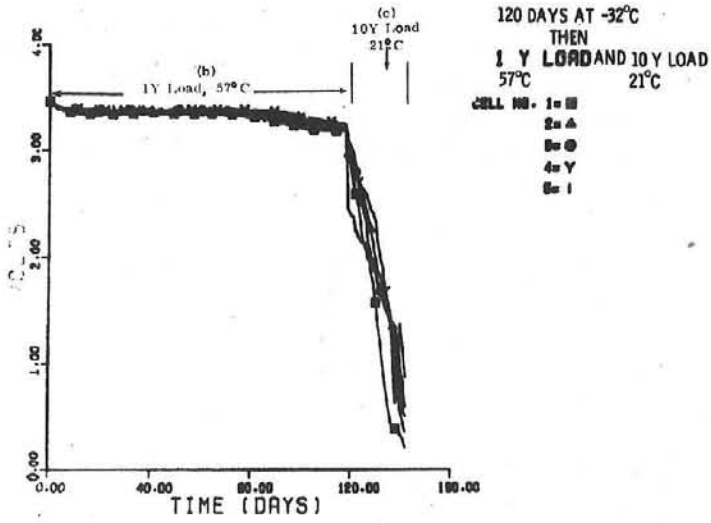


c.

Figure 36. Group H-2



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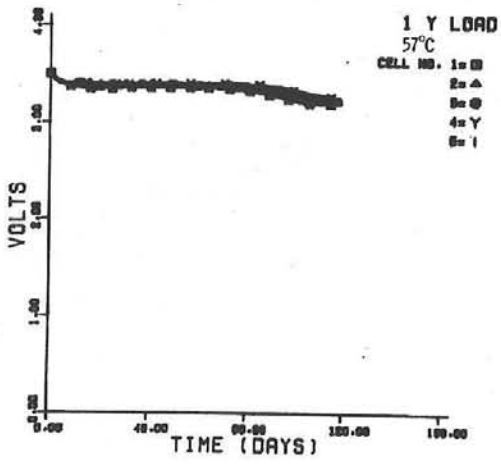

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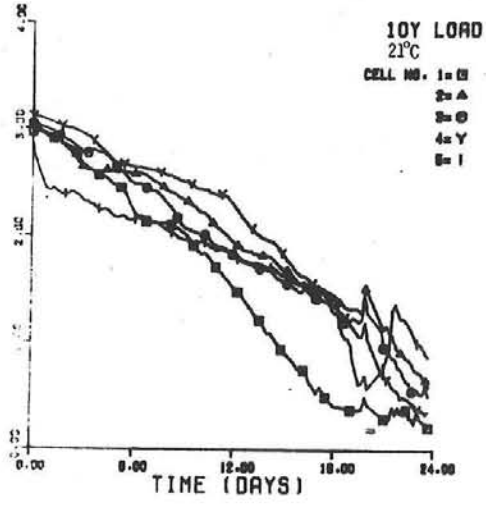

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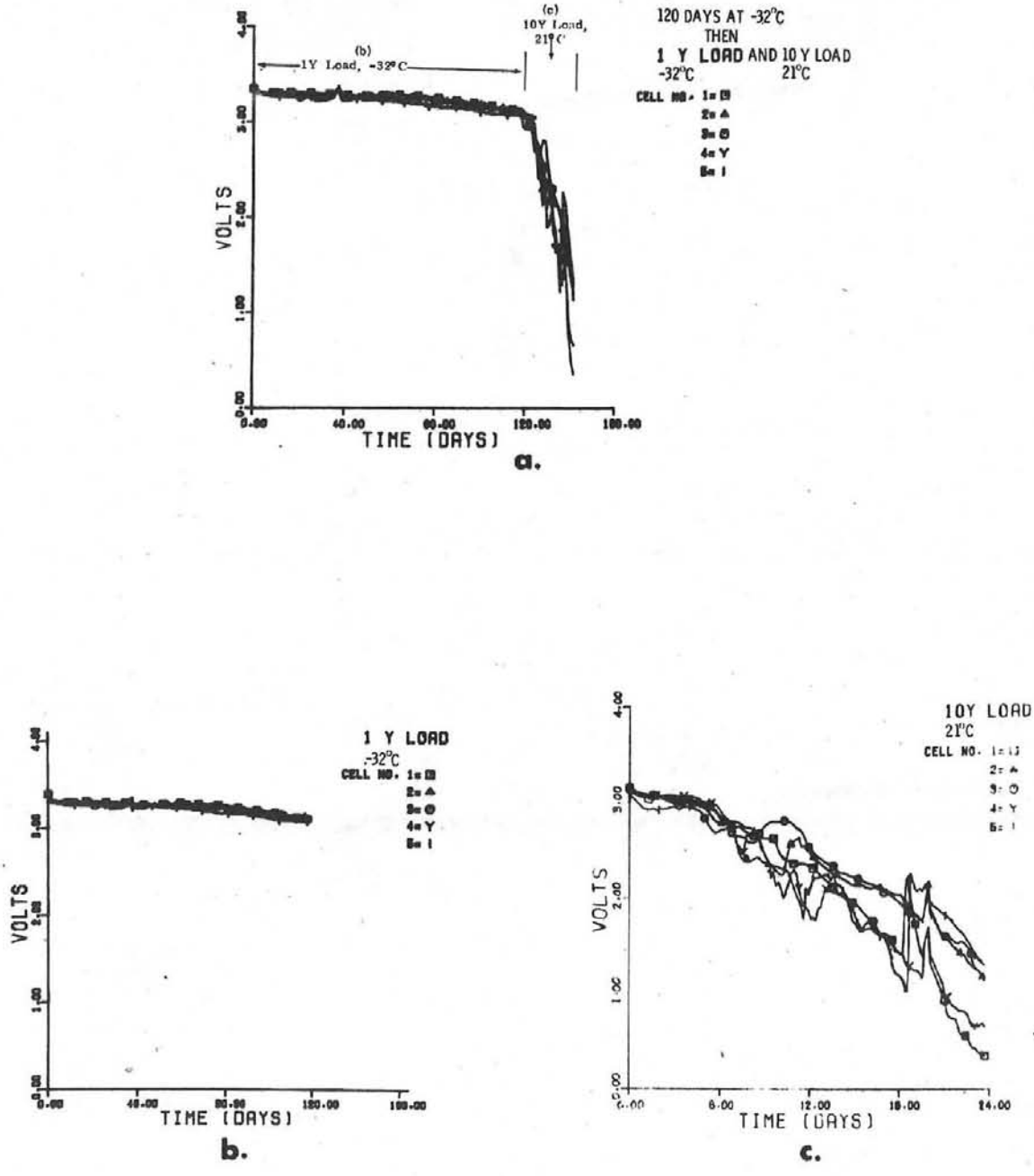
Figure 37. Group H-3



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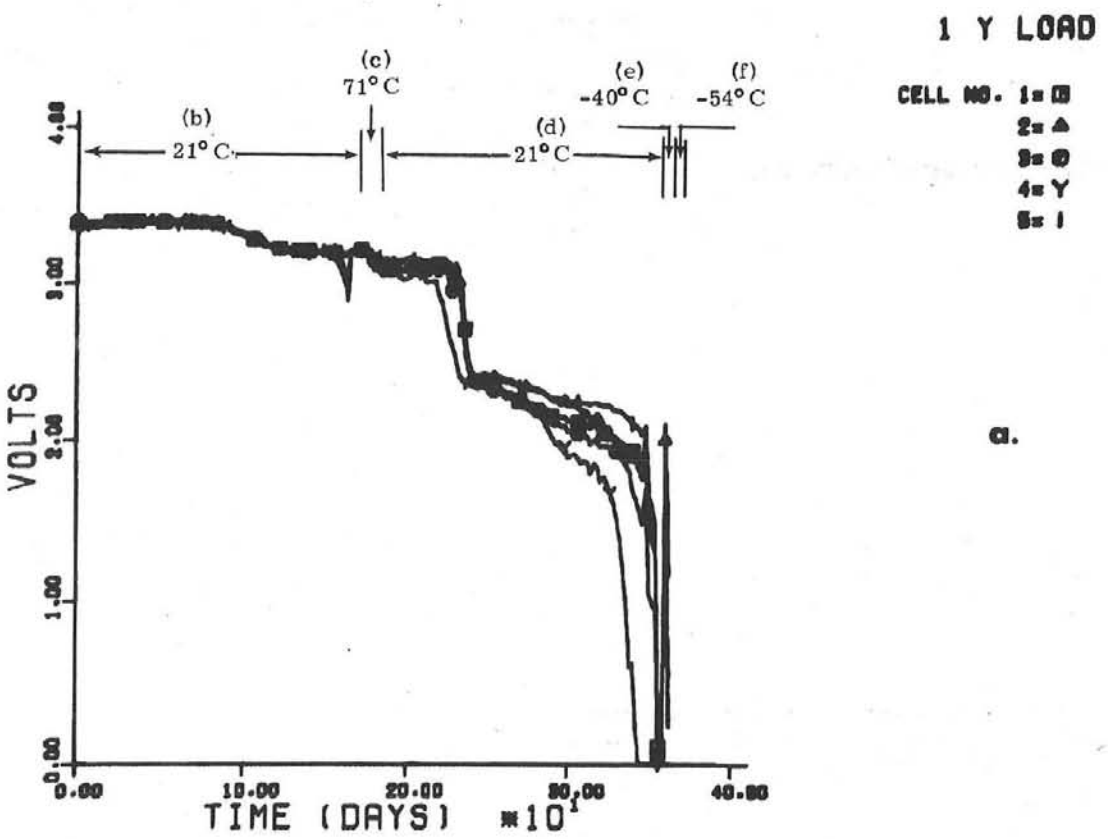


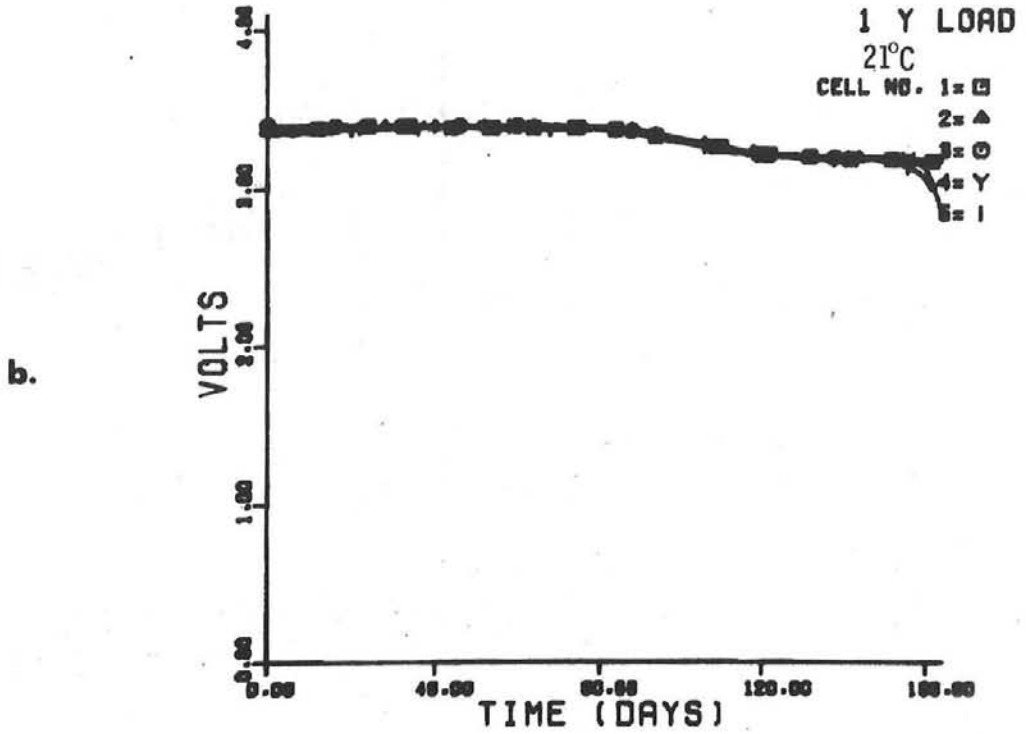
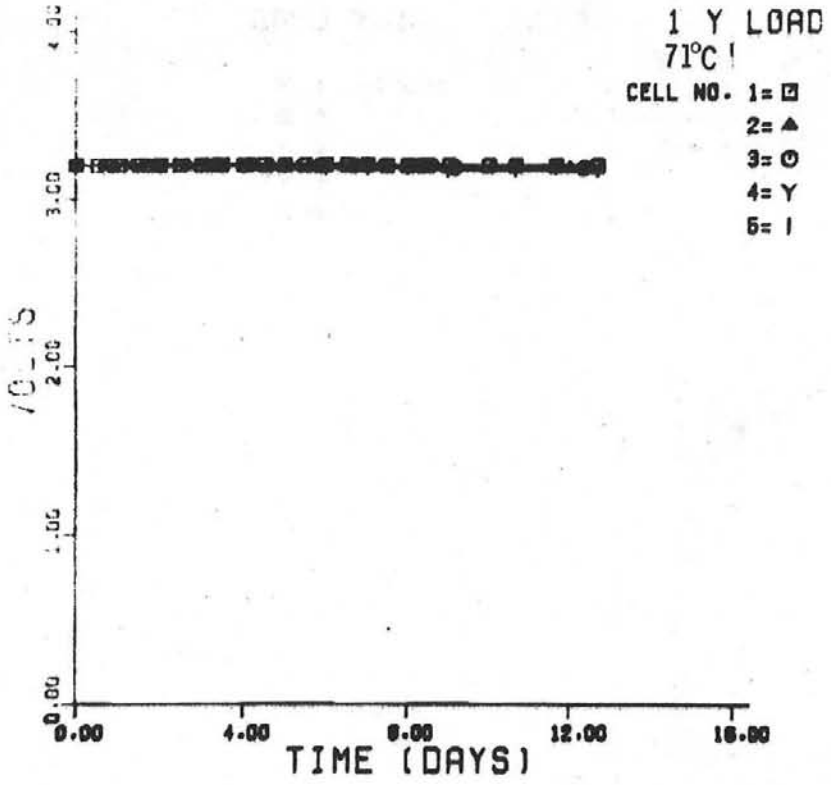


Figure 39. Group I-1



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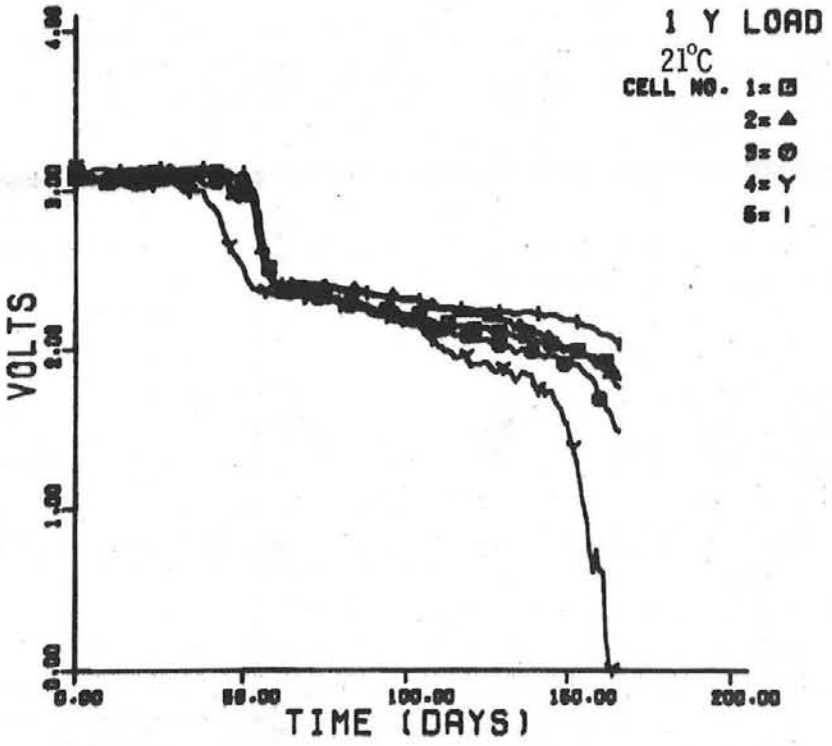

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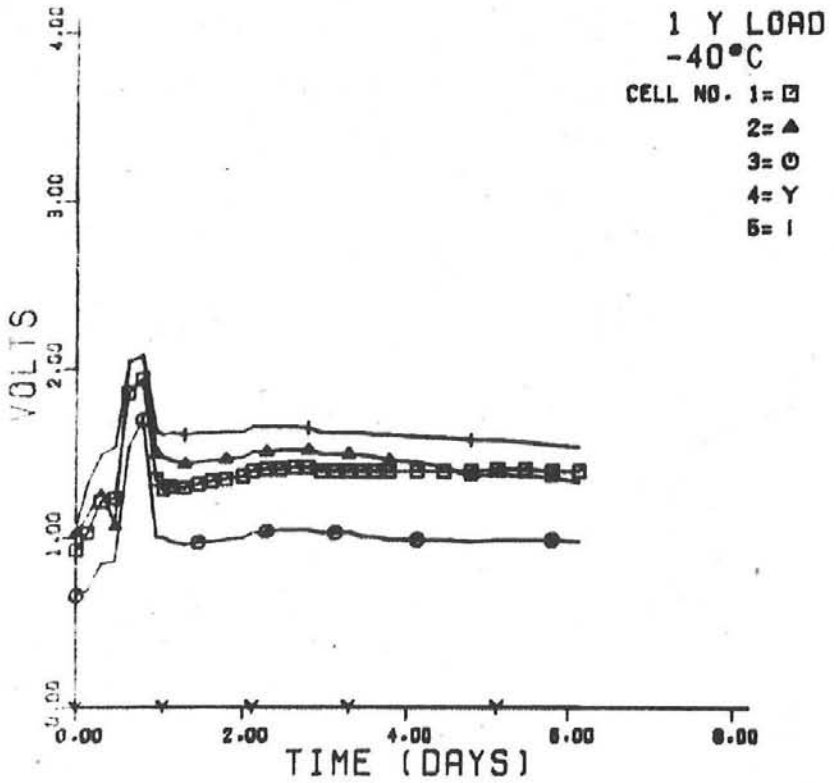

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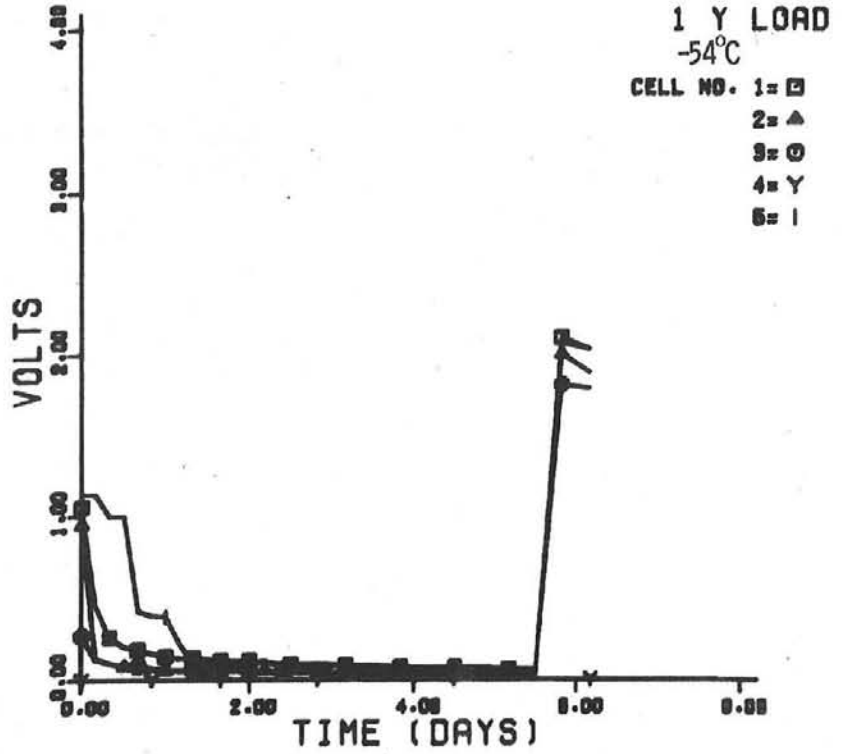

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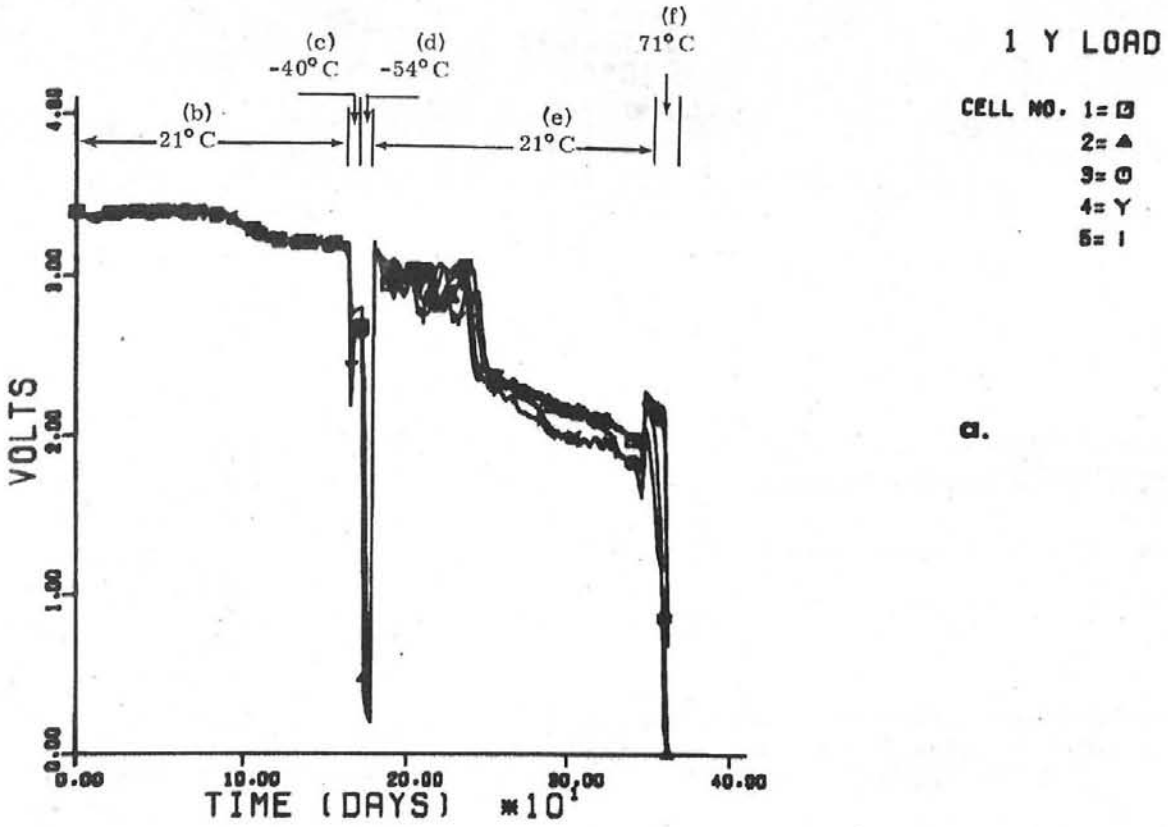

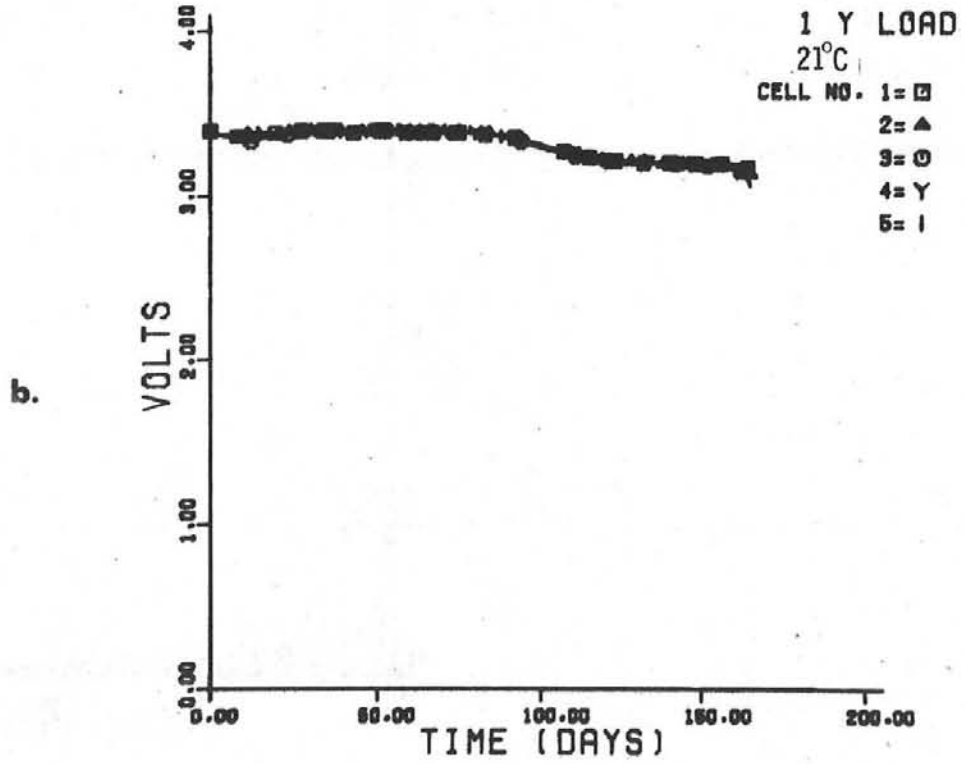

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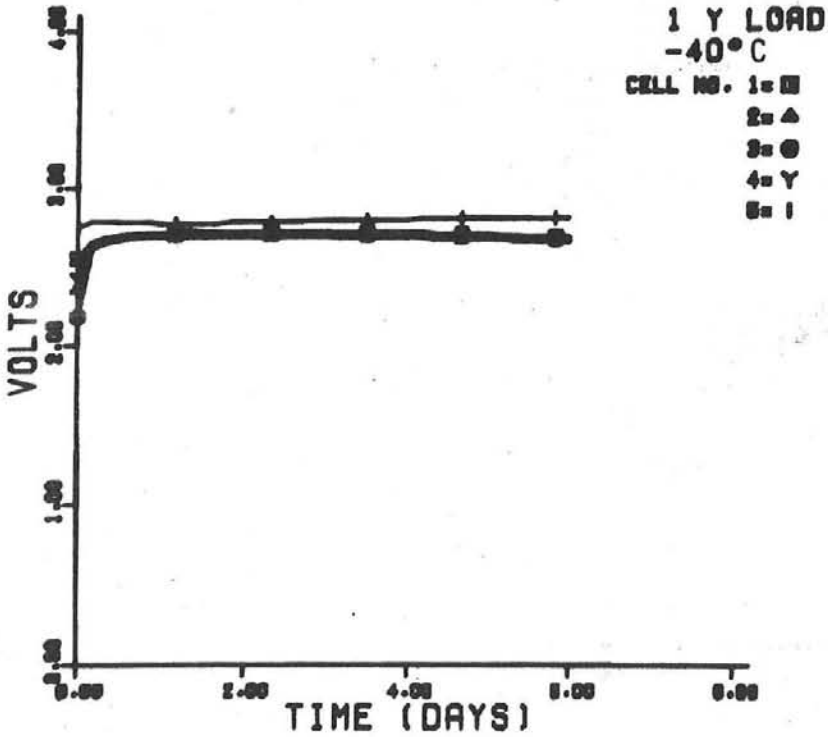

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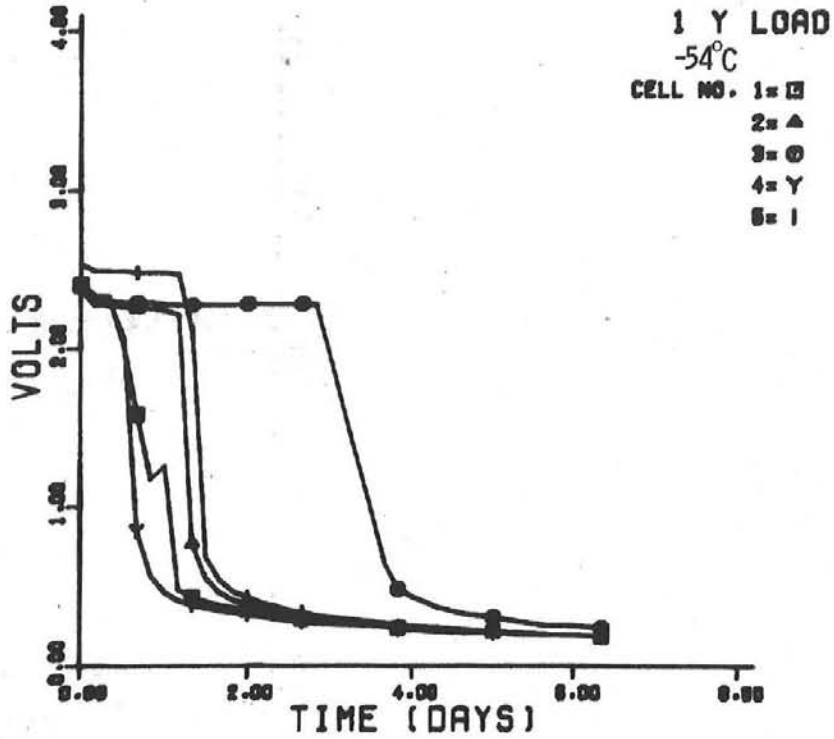

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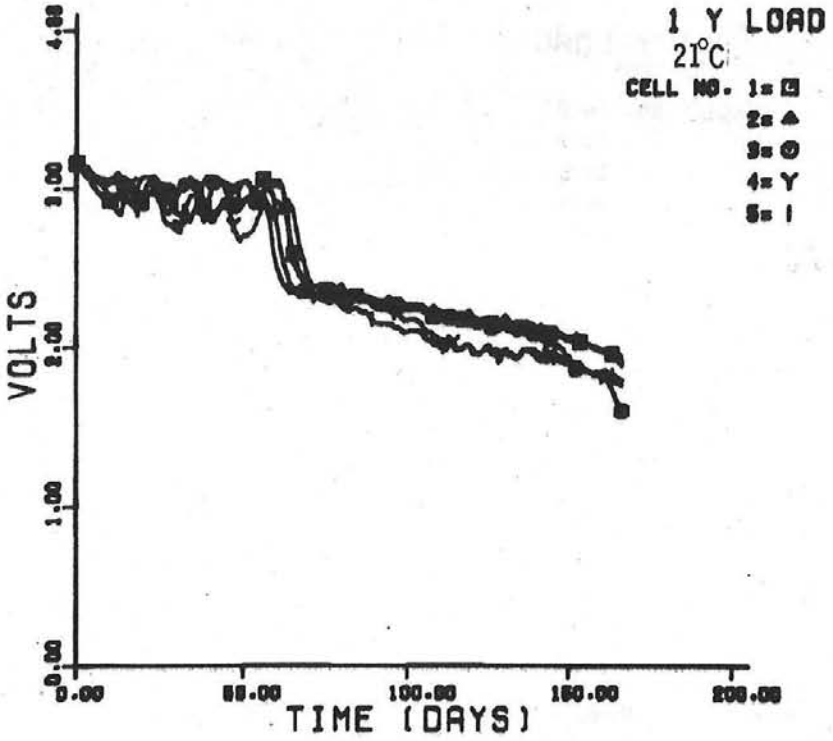

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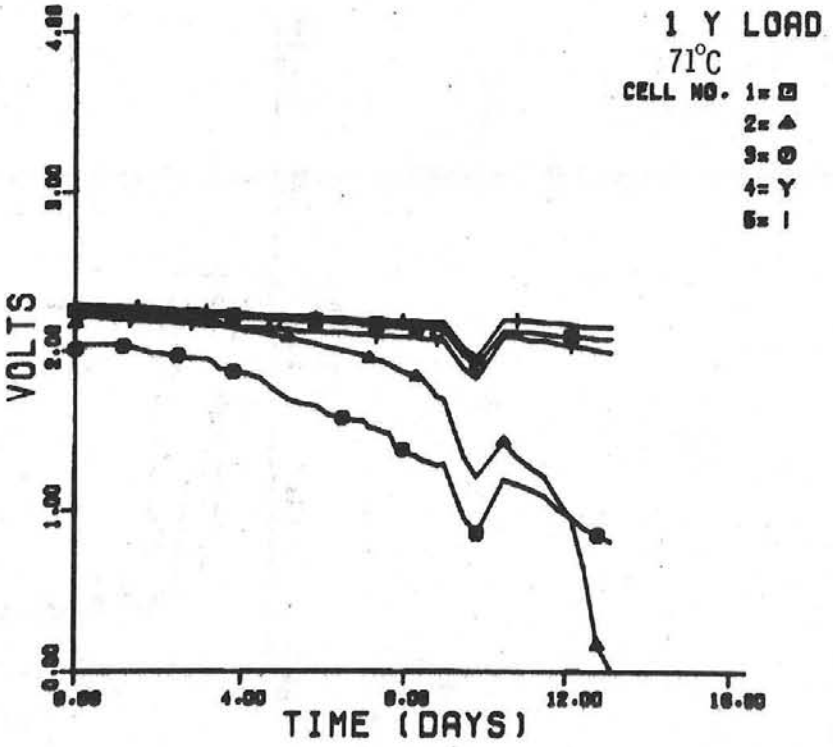

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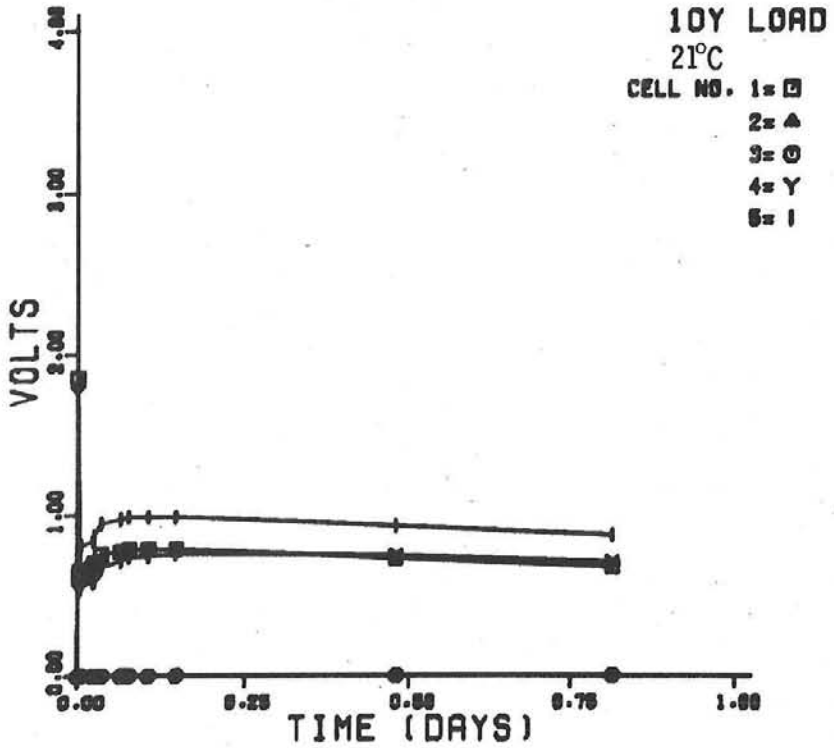

g.

Figure 40. (Continued)

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