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FABRICATION AND TESTING OF SILVER-HYDROGEN CELLS

by M. G. Klein

ENERGY RESEARCH CORPORATION

prepared for

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FABRICATION AND TESTING OF SILVER-HYDROGEN CELLS

M. G. Klein

1. SUMMARY

This report covers the results and progress achieved on Contract NAS3-19780 for the development of Silver Hydrogen Secondary Batteries. This program, which covered an eighteen month period,was a continuation of Contract NAS3-18543, reported in final report #NAS-CR-134878.

The silver hydrogen battery system has potential capabilities of high energy density and long cycle life which make it an attractive secondary battery for aerospace and other applications. This program was directed at developing and life testing sin'e electrode and multi electrode stacks to optimize the indi.idual components and characterize the performance characteristics of the system. At the conclusion of the program, four 20 ampere-hour boilerplate assemblies were delivered to NASA-Lewis for life testing.

A major share of the experimental efforts was directed at variations of the electrolyte rese-voir and hydrogen electrode arrangement. ERC standard silver electrodes of one nominal design were used throughout the program and no emphasis was made to optimize the silver electrode within the program. Emphasis was placed on the use of a NASA developed inorganic separator material as the main separator within the cells. This material is prepared by coating one face of fuel cell grade asbestos with a thin ceramic plastic composite layer. Single electrode test cells were cycled at 75% of nominal capacity out through approximately 1,000 cycles in a number of cases where deterioration in performance was observed. This deterioration in performance appeared to be a decay in usable capacity of the silver electrode; but the exact mechanism has not yet been identified. Twenty ampere-hour boilerplate test cells consisting of a stack of ten silver electrodes and twenty hydrogen electrodes were cycled also at 75% depth of discharge. The oldest stack achieved 522 stable cycles to the end of the program.

Weight analysis of light-weight cells showed that 50 ampere-hour cells with improved components could be capable of as much as 40 watt hours per pound.

2. INTRODUCTION

Many space probes and satellite systems employ rechargeable secondary batteries for peak power, eclipse portion of the orbits, and other auxiliary functions. Most systems employ nickel-cadmium or silver-zinc batteries for such applications. To achieve improvements, investigations are underway on nickel-hydrogen batteries. The silver-zinc system is limited in life due to the instability of the zinc electrodes, and the nickel systems are relatively heavy. This program is directed at the development of the silver-hydrogen battery systems which represents the marriage of the type of silver electrode used on silver-zinc cells and the hydrogen electrode used in nickel-hydrogen cells. This combination of electrodes offers a promising set of characteristics in terms of energy density and cycle life.

The development program was divided into tasks as follows:

TASK I - SINGLE ELECTRODE STUDIES

A. Test Cells

The construction of ten boilerplate test housings for cycle testing of various single electrode combinations.

B. Life Tests

The performance of life tests on six specified electrode separator sequences. The life testing was conducted on an 8-hour cycle, 6.8-hour charge, 1.2-hour discharge at 75% of nominal depth up to cell failure.

C. Cell Electrolyte Reservoir Studies

The test and evaluation of a number of different electrolyte reservoir configurations in single electrode test cells.

D. Electrolyte Entrainment Barrier System

The test and evaluation of a number of electrolyte barrier concepts in the single electrode test cells.

E. Second Life Test Series

Based on the results of the above subtask, new configurations were selected and life tests conducted.

TASK II - MULTI ELECTRODE CELL TESTS

A. Test Cell Construction

The design and fabrication of four boilerplate test housings sized for 20 Ahr cell size.

B. Feasibility Test

The construction of configurations of 20 Ahr cell stacks for initial testing and characterization in the above boilerplate housing.

C. Life Test

The selection of optimum configurations for 20 Ahr cell stacks and the life testing of these cells.

TASK III - DESIGN ANALYSIS

The preparation of a final design of a 20 Ahr lightweight cell based on the above test results.

TASK IV - CELL FABRICATION

The construction and delivery of four 20 Ahr electrode stacks in heavy-walled test housings to NASA.

TASK V - RELIABILITY AND QUALITY ASSURANCE

Maintenance of a quality program in conformance with NASA, DOD requirements for all aspects of the program.

TASK VI - REPORTING REQUIREMENTS

The preparation of an initial work plan, monthly summary reports, and a final report.

3. RESULTS AND DISCUSSION

3.1 TASK I - SINGLE ELECTRODE STUDIES

In order to optimize the electrode matrix reservoir configuration,a number of single electrode tests were conducted. These tests were conducted in heavy walled test cells that contained one silver electrode and two hydrogen electrodes with appropriate separators. Ten boilerplate test housings were

constructed for the screening and life test experiments on the single electrodes. The boilerplate cell housings(as pictured in Figure 1)contain 2 insulated feed-throughs of the connex type with neoprene sealing glands. These glands have ceramic insulators which readily crack during handling and assembly. The feed-throughs were modified by using machined ABS plastic insulators for the test cells. These seals worked successfully throughout the program with minimal leakage. Each of the test housings had a 0 to 1,000 psi pressure gauge and one Bellows type manual valve for filling and venting. The boilerplate housings were bolted together by a ring of six 1/4" bolts and had an "O" ring seal between the lid and the base of the housing. All the fittings were heli-arc welded where possible. The electrode stack within the test housing was contained between two flat polysulfone endplates and was held in compression by means of tie rods on the parameter of the stack which also served as the terminals for the insulated feed-throughs.

Nineteen such single electrode test cells were built during the course of the program for life and feasibility testing of various configurations. The construction variables of these cells are listed in Table I, along with the life test results. All the cells contained silver electrodes that were nominally 30 mils thick, were 1-3/4 inches across the flat and 2-3/8 inch diameter with an active area of 3.8 square inches. The nominal active material in each silver electrode was to be 7 to 7-1/2 grams. The actual theoretical capacities to the individual cells is shown in Table I. Initially, silver wires were considered for the current collective for the silver electrodes, but silver tabs were found to be more stable and all the test electrodes contained a silver tab 1/4" wide .005" thick. The tabs for the hydrogen electrode were 1/4" wide .005" thick nickel in all cases except where silver collectors were used for the hydrogen electrode.

All cells were assembled dry into a stack with the endplates, then placed into a container which was evacuated and electrolyte was dropped in over the stack assembly to completely fill the pores of the electrodes in a vacuum environment. The electrode stack which was totally emersed in excess electrolyte,was heated to 160^{O}F and maintained at that temperature for 16 hours. This heat treatment was suggested by NASA-Lewis Technical Representatives to improve wettability of the separator and possibly react some of the constituents in the inorganic separator to reduce its internal resistance. The first six test cells were built in accordance with a construction matrix that was established at the contract outset. Some of the cells contained hydrogen electrodes supplied by NASA which were of the PPF type manufactured by United Technologies. This electrode consisted of a Teflon bonded platinum black catalyst on a silver plated woven nickel screen with a catalyst loading of 8 to 10 milligrams per square centimeter. Other cells employed hydrogen electrodes manufactured by ERC. The standard ERC hydrogen

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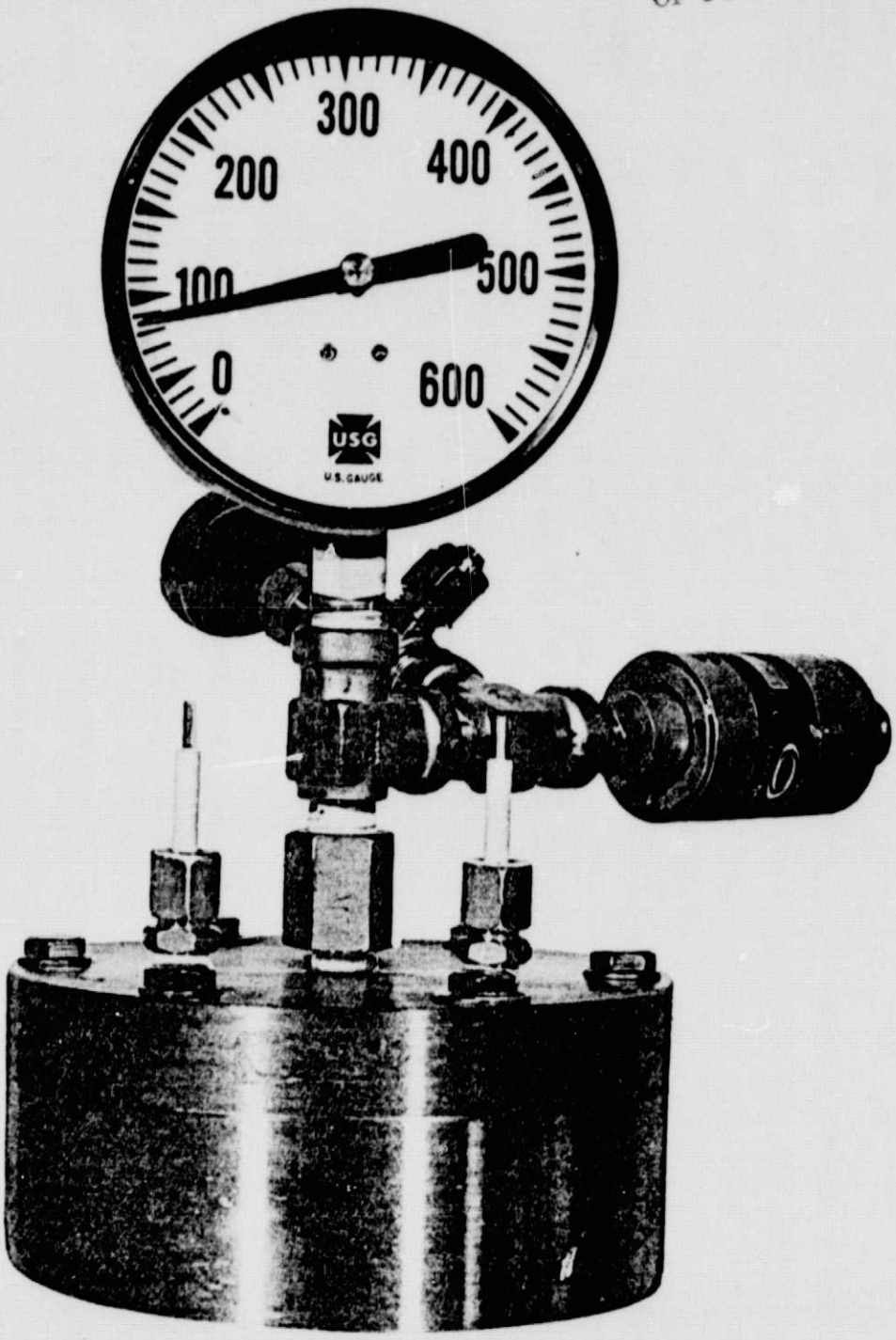


FIGURE 1 SINGLE ELECTRODE TEST CELL

CELL CONSTRUCTION VARIABLES AND TEST RESULTS

TABLE I

CELL No.	SILVER ELECTRODE	HYDROGEN ELECTRODE	SEPARATOR	IER	ENTRAINMENT BARRIER	THEORETICAL CAPACITY	ELECTROLYTE QUANTITY INITIAL	ELECTROLYTE QUANTITY FINAL	CYCLES TO DATE 8/25/77	COMMENTS & RESULTS
1	STD .030"	PPF	NASA I/O	STD.	—	3.93 AMP-HOUR	30% KOH 7.15 gr.		925	5.8 HR. CHARGE-.28A 1.2 HR DISCHARGE-1.43A (TERMINATED)
2	STD .030"	PPF	NASA I/O	STD.	—	4.00 AMP-HOUR	30% KOH 6.34 gr.		865	CELL NOS.1-6
3	STD .030"	PPF	NASA I/O	NONE	—	3.98 AMP-HOUR	30% KOH 4.34 gr.		865	REFILLED WITH ELECTROLYTE AT CYCLE 400 SHORTED
4	STD .030"	TEFLON-BACKED	NASA I/O	NONE	—	3.96 AMP-HOUR	30% KOH 4.11 gr.		925	
5	STD .030"	TEFLON-BACKED	NASA I/O ASBESTOS	NONE	—	4.21 AMP-HOUR	30% KOH 5.70 gr.		1090	
6	STD .030"	PPF	NASA I/O ASBESTOS	NONE	—	3.99 AMP-HOUR	30% KOH 5.93 gr.		1125	REBUILT AFTER 1000 CYCLES
7	STD .030"	PPF	NASA I/O	NICKEL SPONGE	—	4.02 AMP-HOUR	30% KOH 11.19 gr.		1048	
8	STD .030"	PPF	NASA I/O	SINTERED NICKEL	—	4.03 AMP-HOUR	30% KOH 6.94 gr.			NOT CYCLED
9	STD .030"	PPF	NASA I/O	POROUS POLYSULFONE	—	4.20 AMP-HOUR	30% KOH 5.42 gr.			"
9R	STD .030"	PPF	NASA I/O	PLASTIC PLAQUE NI-PLATE	—	4.54 AMP-HOUR	30% KOH 6.12 gr.			"
10	STD .030"	ERC	NASA I/O	—	ZITEX	3.99 AMP-HOUR	30% KOH 4.17 gr.			"
11	STD .030"	ERC	NASA I/O	NICKEL FOAM	ZITEX	4.41 AMP-HOUR	30% KOH 17.56 gr.			"
14	STD .030"	ERC	ERC 2,002/ ASBESTOS	NONE	—	4.1 AMP-HOUR	30% KOH 5.4 gr.		470	"
15	STD .030"	ERC	NASA I/O NASA K-17	NONE	—	4.05 AMP-HOUR	30% KOH 6.66 gr.		472	"
16	STD .030"	Pt CARBON FOAM AG XMET	NASA I/O ASBESTOS	NONE	—	4.1 AMP-HOUR	—		POOR VOLTAGE	"
17	STD .030"	Pt CARBON FOAM AG FOIL	NASA I/O	NONE	—	4.12 AMP-HOUR	—		"	"
18	STD .030"	ERC AG XMET	NASA I/O ASBESTOS	NONE	—	4.1 AMP-HOUR	—		357	STABLE AT PROGRAM END
19	STD .030"	ERC	ASBESTOS ASBESTOS	NONE	—	4.1 AMP-HOUR	—		352	"

electrode used in many of the cells consisted of a nickel expanded metal current collector and a Teflon bonded platinum black catalyst layer loading at 3 milligrams per centimeter. On the back face of the electrode, a two mil micro-porous Teflon layer is bonded to reduce electrolyte entrainment when hydrogen evolves off the back side of the electrode. Most of the cells contained NASA I.O. type separator material which was government furnished to ERC. The I.O. material consists of an inorganic pigment plastic bonded coating on one face of fuel cell grade asbestos that has been lightly impregnated with polyphenyleneoxide plastic binder. In all cases where the NASA I.O. separator was utilized, the ceramic face of the separator faced the hydrogen electrode. The sequence of the electrodes in the cell construction is shown in Figure 2. In some of the experimental cells, electrolyte reservoirs were used on the back face of the hydrogen electrode. In cells #1 and #2, this reservoir consisted of a porous sintered carbonyl nickel plaque that was 30 mils thick and approximately 80% porous. Into the face of the reservoir that contacted the hydrogen electrode, a grid pattern was coined utilizing a 20 x 20 x .007 screen as the coining pattern to allow for hydrogen access into and out the back of the hydrogen electrode. In cells #5 and #6, an additional layer of fuel cell asbestos was used to increase the electrolyte inventory within the cell. This asbestos was placed between the hydrogen electrode and the I.O. separator. Cells #1 through #6 were classed the first life test series and, after initial formation testing, the cells were placed on a life test consisting of an 8 hour cycle, 6.8 hours charge at 0.28 amps and 1.2 hours discharge at 1.43 amps. The test condition was selected to simulate an accelerated synchronous mode of operation in which approximately 75% of the electrodes nominal capacity was removed on each discharge. The recharge ratio was set to recharge the cell with a 10% overcharge. Figures 3 through 8 show the voltage performance of the cells at various accumulated cycles. At about the 400-cycle point, cell #3 started to exhibit deterioration in capacity. The cell was taken out of the test housing and disassembled. No visual defects were found. The assembly was weighed and it was found that the electrode stack had lost .85 grams in electrolyte as compared to the original amount. The stack was then revacuum-filled with electrolyte, towel dried and weighed again. The cell lid picked up an additional 2.43 grams of electrolyte. The stack was then reinstalled in the test housing and placed on cycle test. The performance recovered and continued to be stable on through 900 cycles. It may have been that the cell was not properly filled with electrolyte initially.

Cell #4 developed an internal short at 350 cycles. When the cell was disassembled, it was found that the separator material was substantially discolored from silver migration, yet it was difficult to locate exactly where the short had occurred.

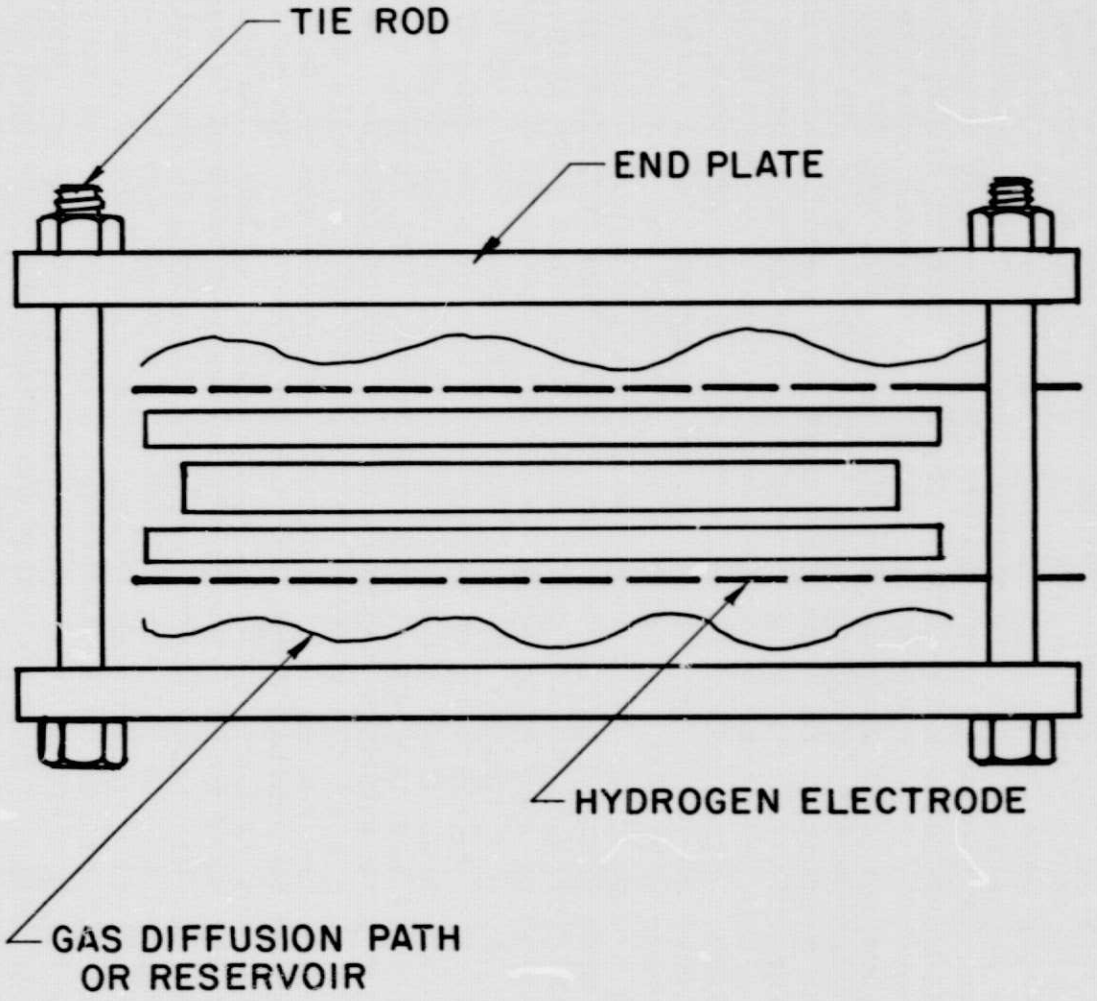


FIGURE 2. STACK ASSEMBLY

FIGURE 3. RESULTS OF CELL NO. 1. $Ag-H_2$

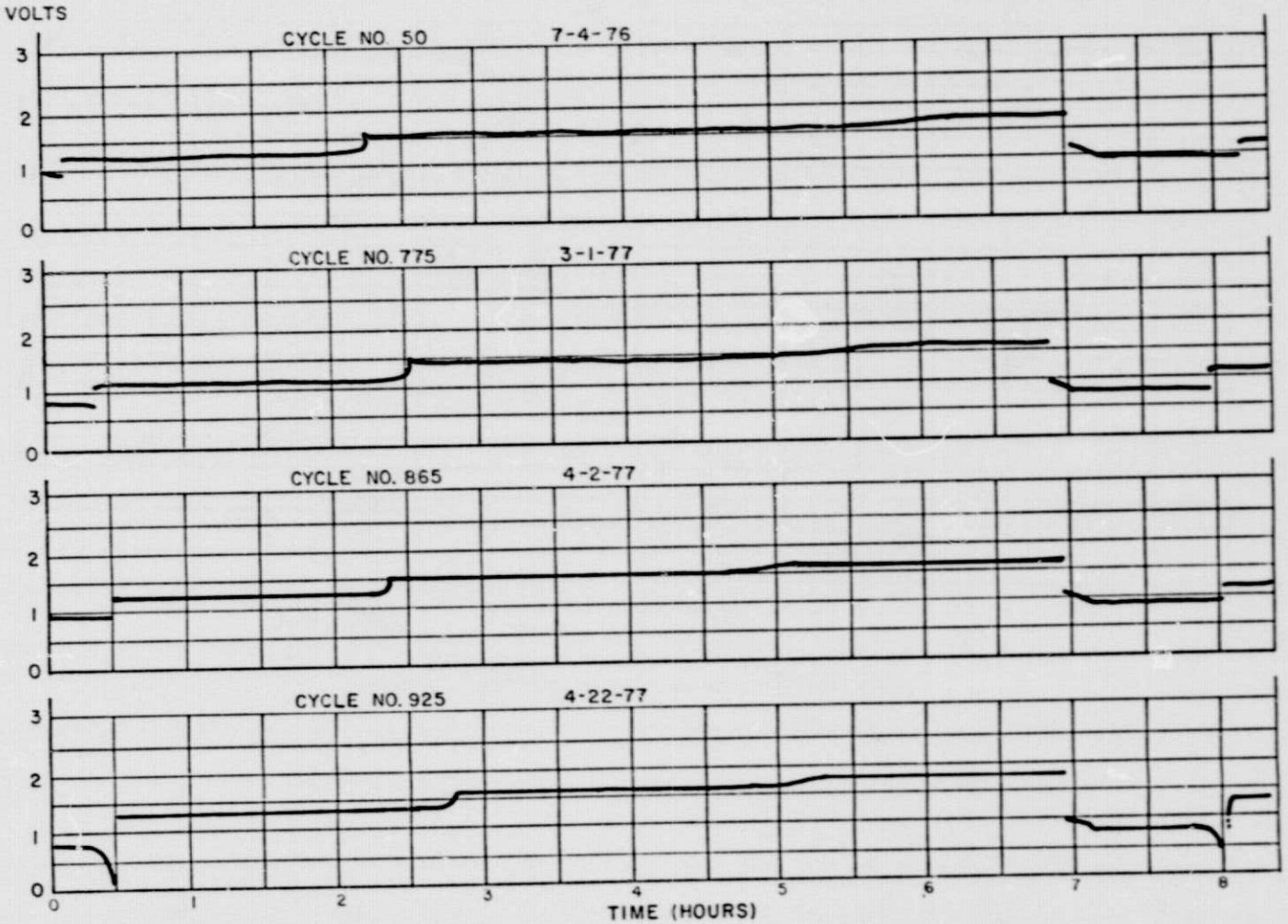


FIGURE 4. RESULTS OF CELL NO. 2 $Ag-H_2$

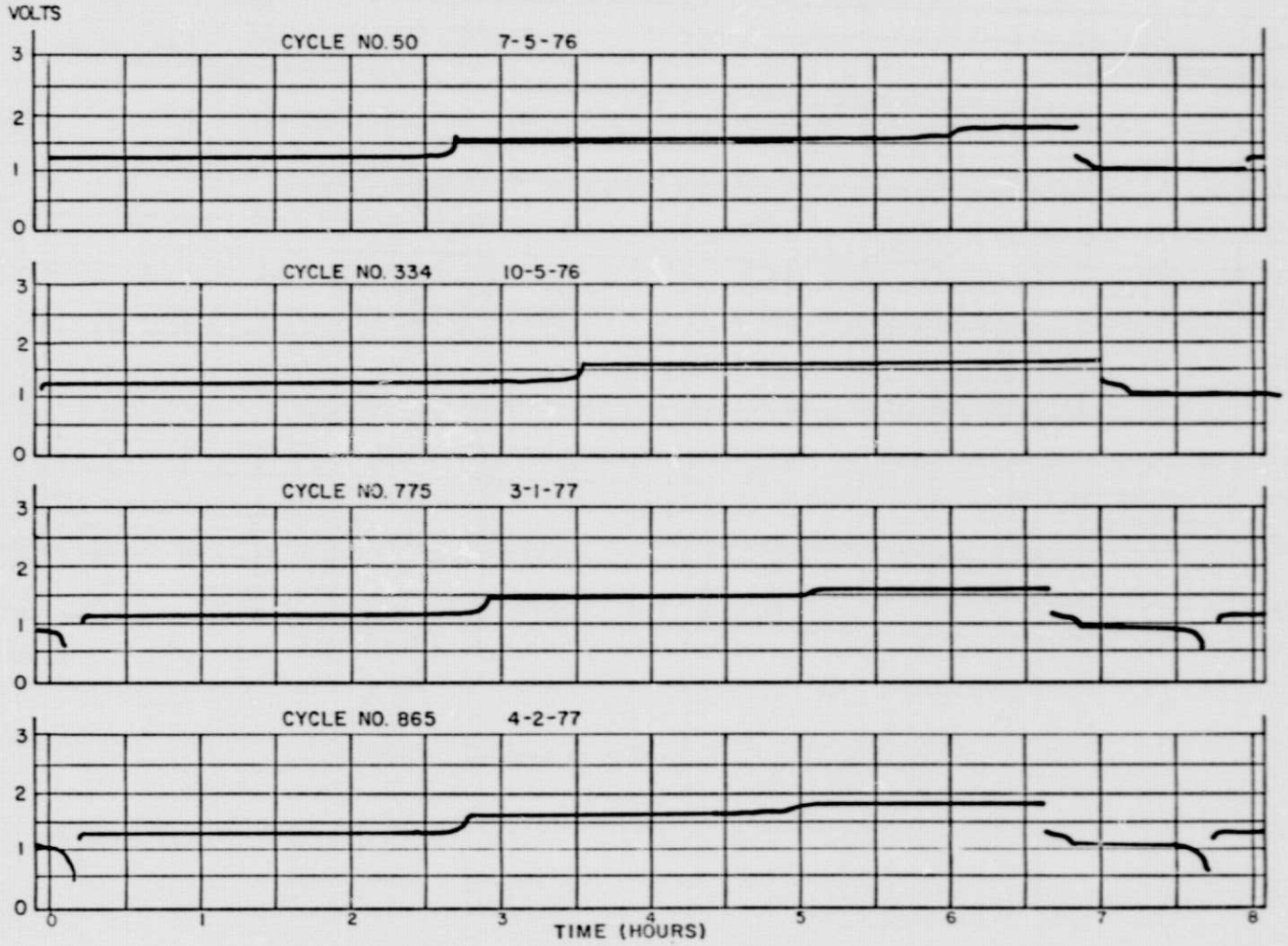


FIGURE 5. RESULTS OF CELL NO. 3. $Ag-H_2$

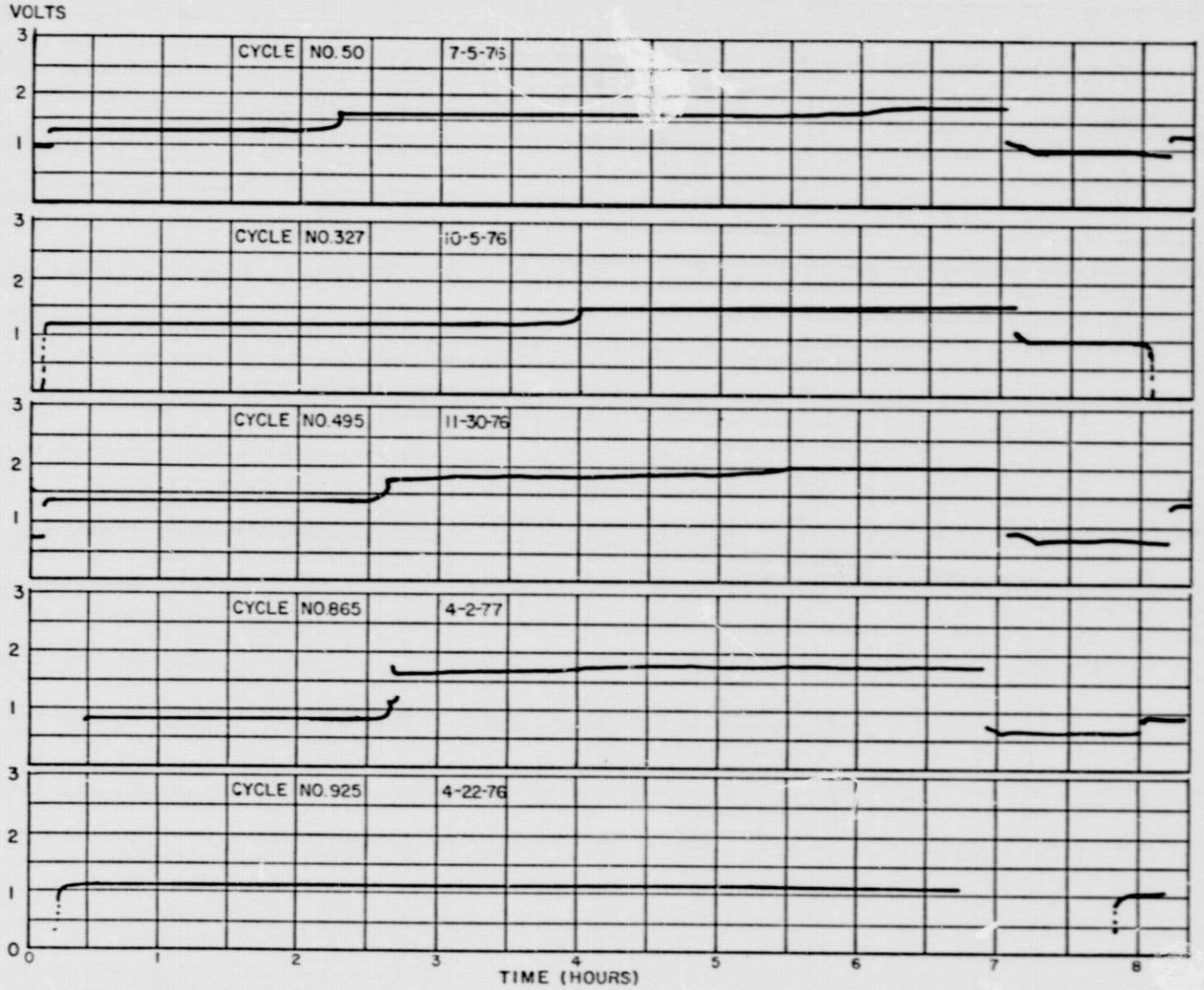
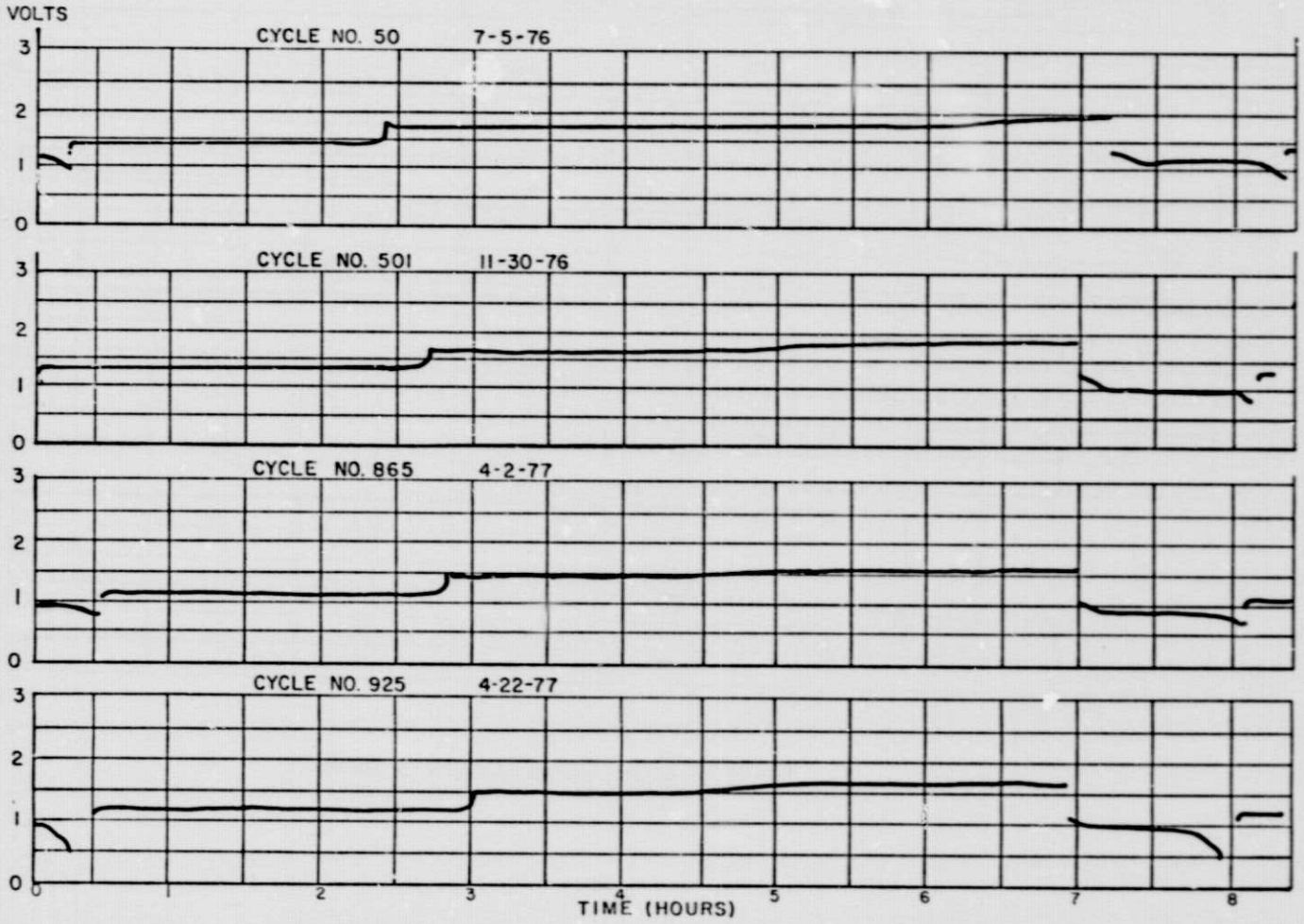


FIGURE 6. RESULTS OF CELL NO. 4. Ag-$^{1}/_{2}$



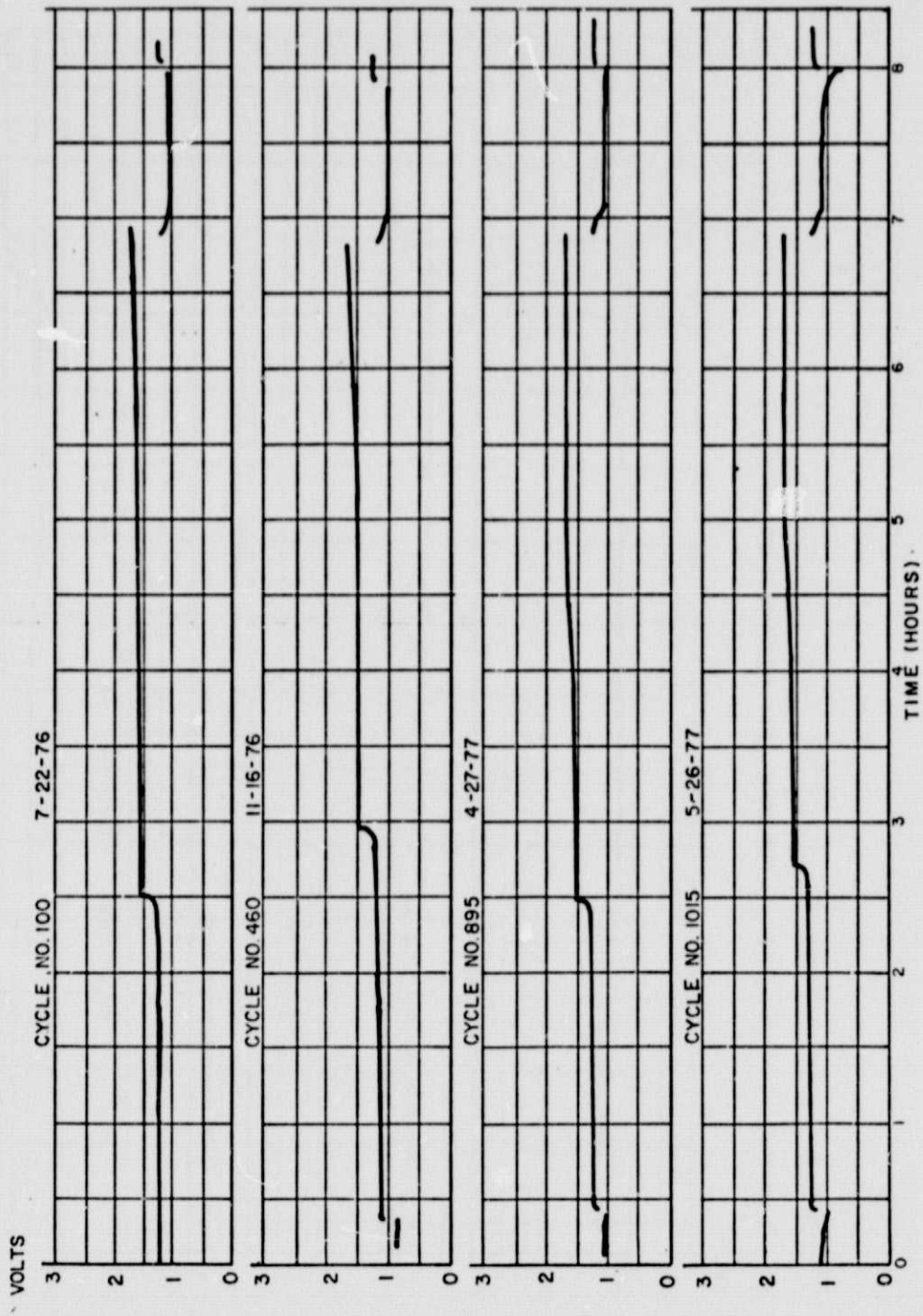
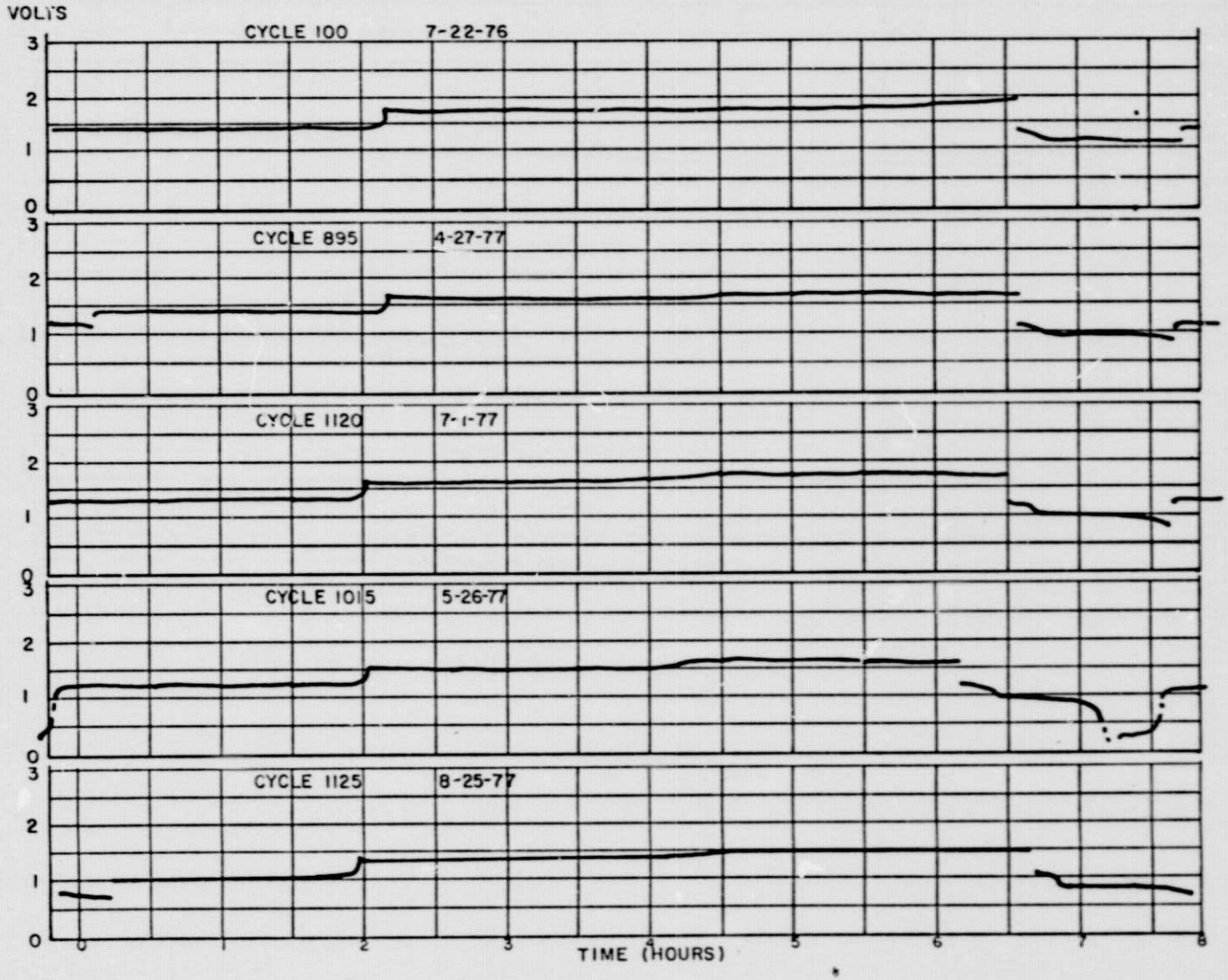


FIGURE 7. RESULTS OF CELL NO.5 Ag-H_2

FIGURE 8. RESULTS OF CELL NO. 6. $Ag-H_2$



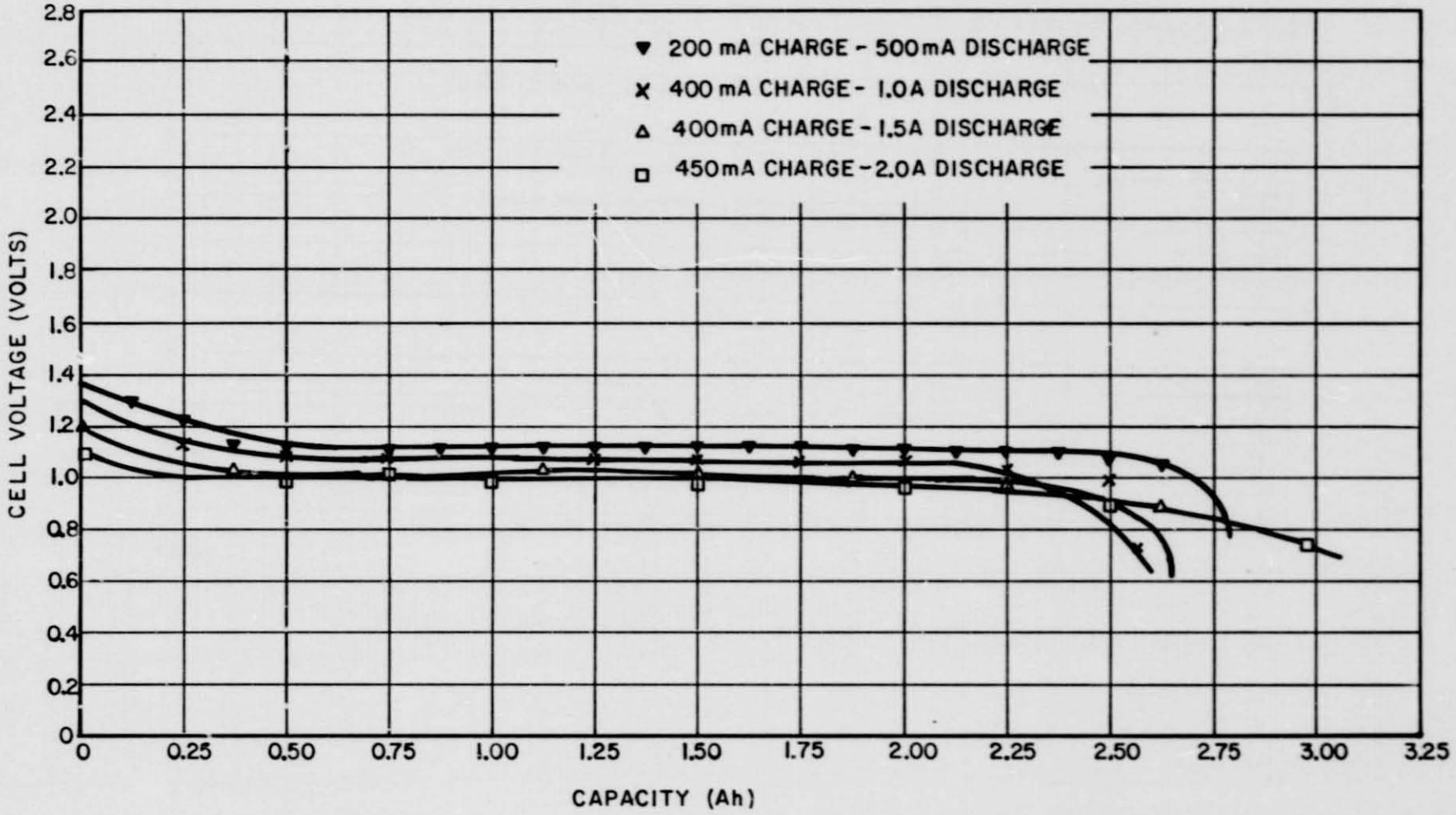


FIGURE 9. NICKEL FOAM CELL NO. 7

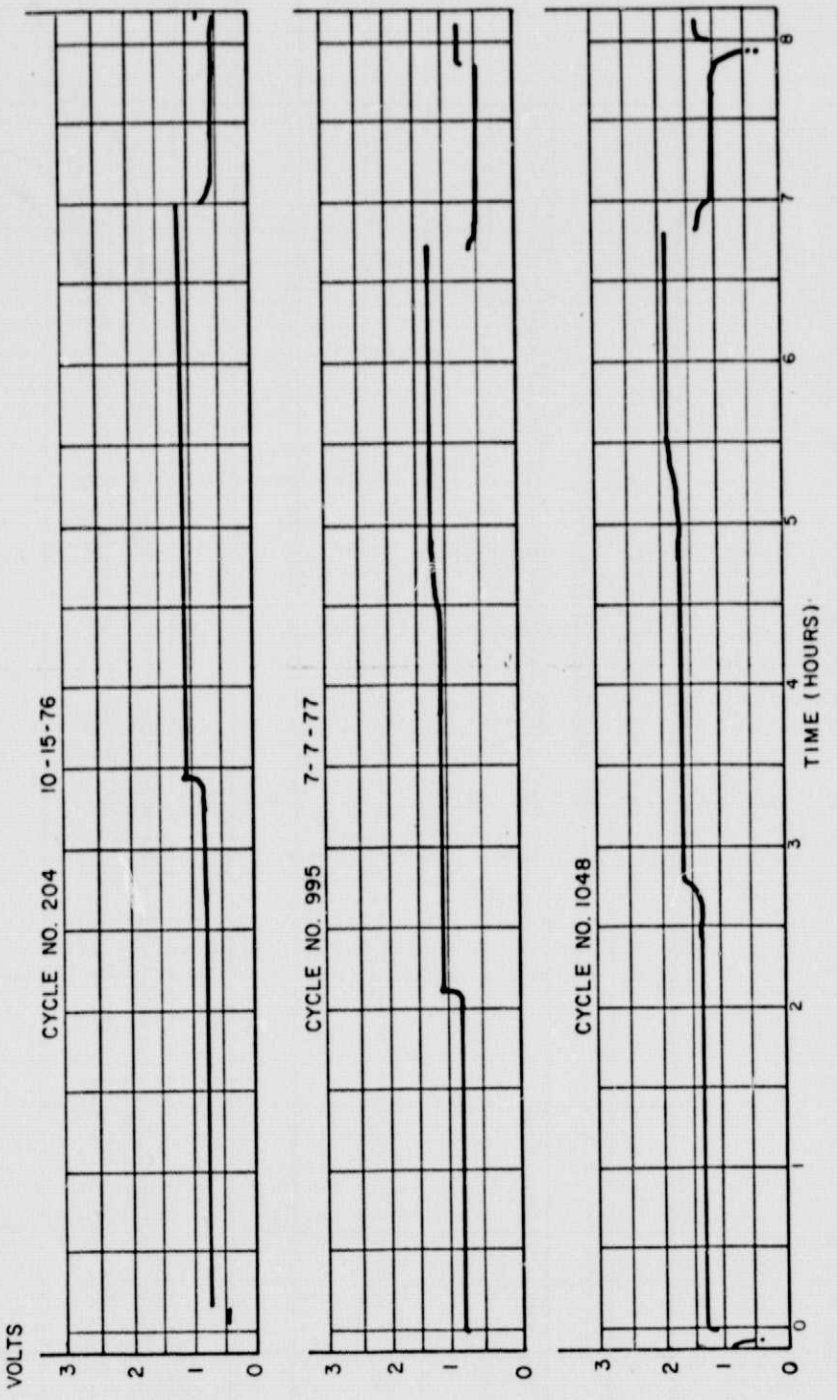


FIGURE 10. RESULTS OF CELL NO.7 $Ag-H_2$

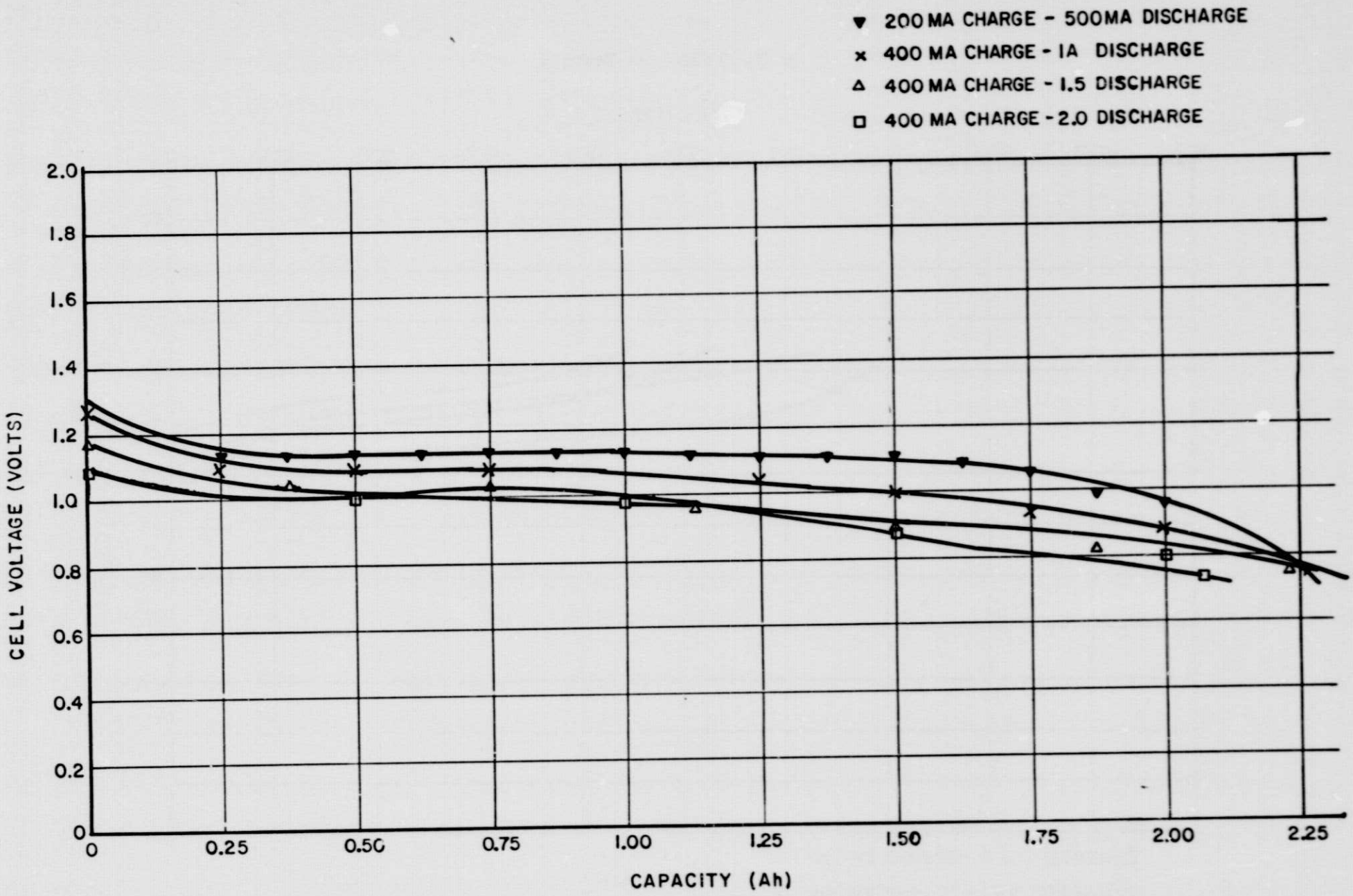


FIGURE 11. CELL NO. 8

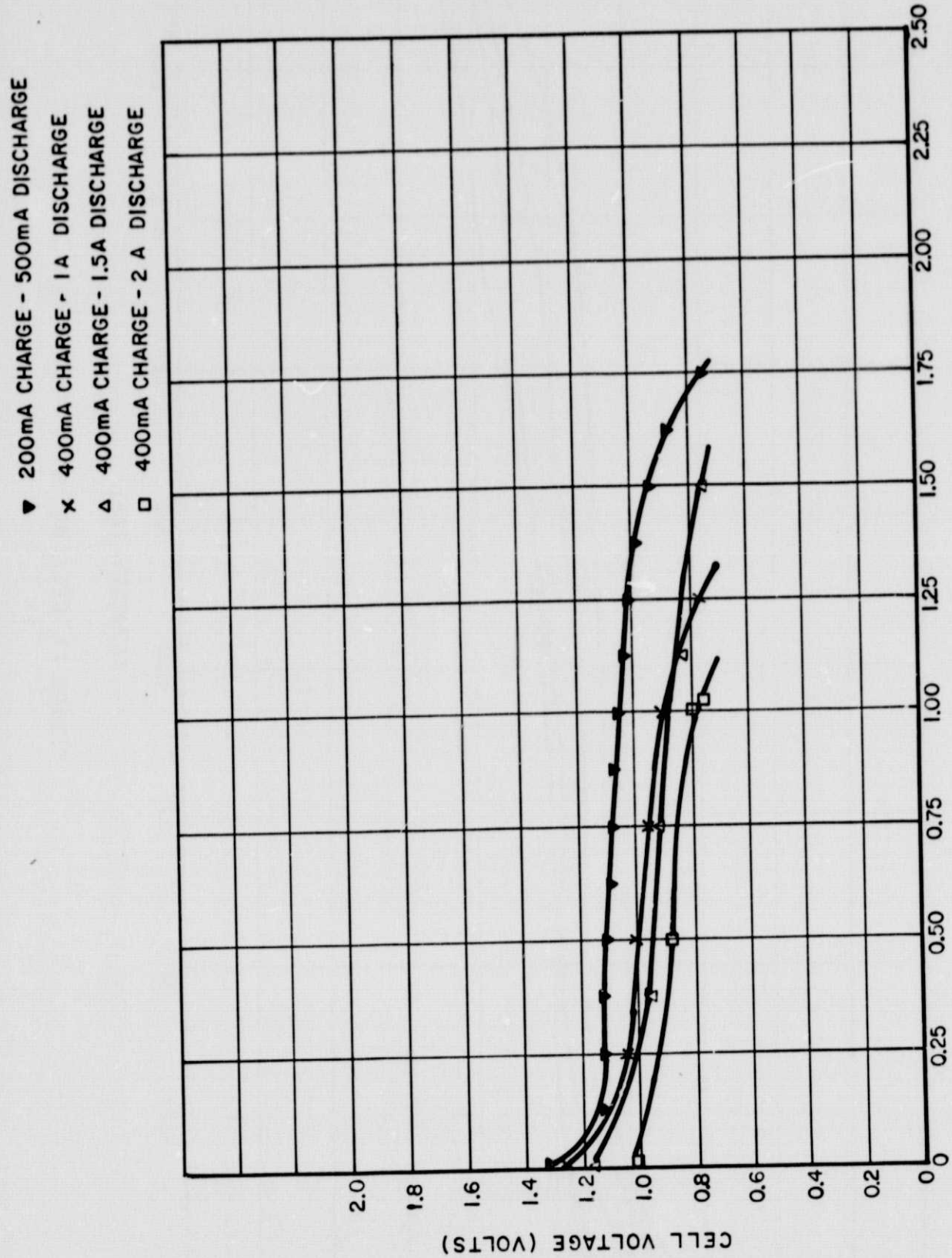


FIGURE 12. CELL NO. 9

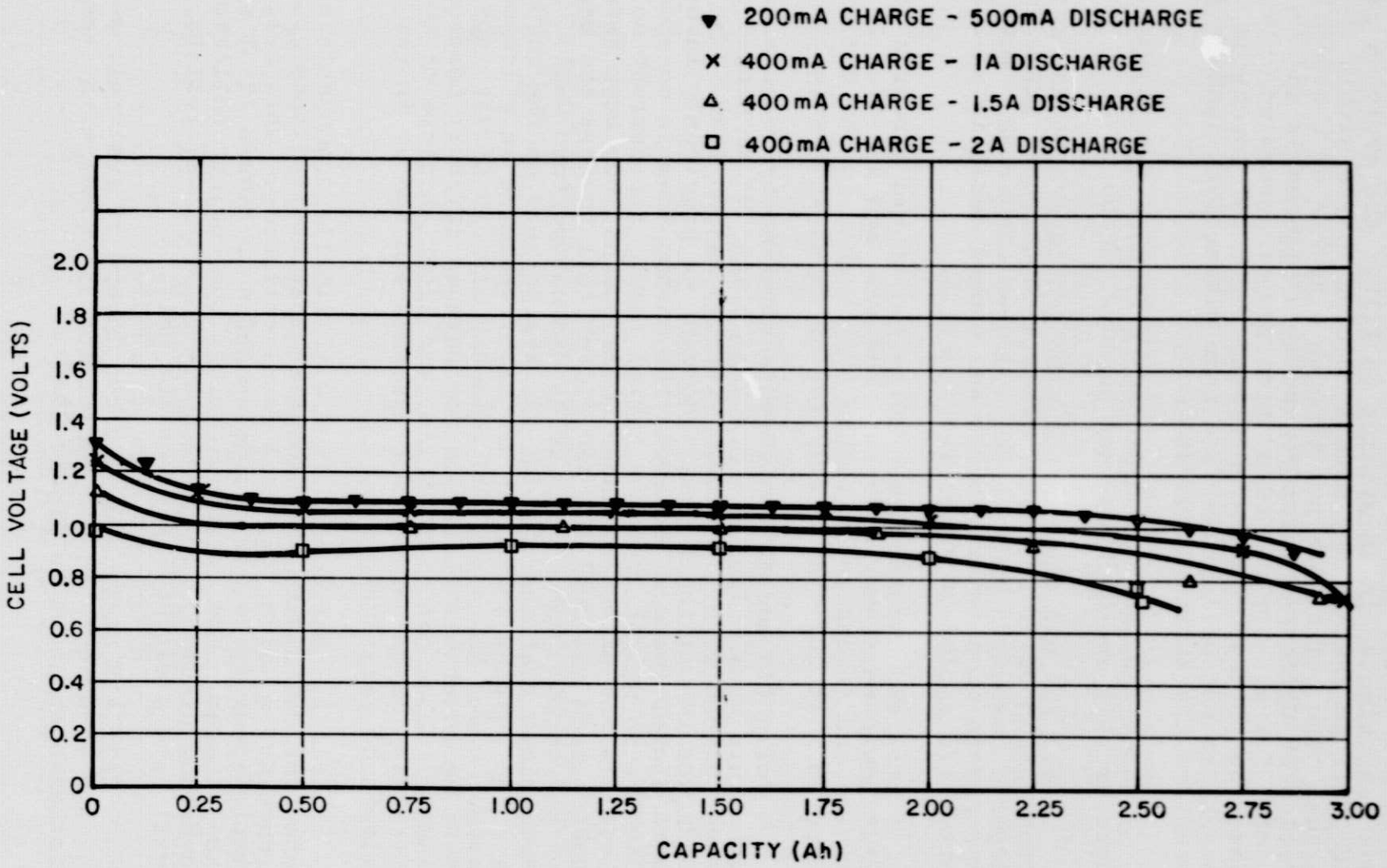


FIGURE 13. CELL NO. 9R

stack and bonded to the top and bottom endplates. This concept was investigated in an attempt to filter the evolving gas from the cell to contain any entrained electrolyte within the electrode stack. The cells were put through a number of charge-discharge cycles at different rates(as shown in Figures 14 and 15) cycled for a short period of time and disassembled. It was found that the porous Teflon wrap around the outer parameter of the stack was not well sealed and some electrolyte leakage from the stack to the surroundings did occur.

Since results were encouraging without an entrainment barrier this approach was not pursued further.

Cell #14 was constructed with two layers of ERC's inorganic composite separator material 2002,.004" thick and a layer of asbestos against the hydrogen electrode. This cell was placed on automatic cycle and showed decay in capacity after 470 cycles,as shown in Figure 16.

Cell #15 contained a combination of two asbestos coated NASA-Lewis separator materials,the I.O. and a K-17. It was also cycled and demonstrated stable performance to the end of the program. It achieved 472 cycles,as shown in Figure 17.

Cells #16 and #17 employed a combined hydrogen electrode structure consisting of a platinum black Teflon bonded catalyst layer placed on a 1/8"-thick vitreous carbon foam. The object here was to utilize the same concept as previously investigated with nickel sponge. However, the carbon foam is considerably lighter in weight than the nickel foam. For current collection, Cell #16 had silver expanded metal against the back face of the carbon foam and Cell #17 had silver foil against the back face of the carbon foam. Both cells did not perform well. It was determined that the contact resistance between the carbon foam and the current collector was high,resulting in a low voltage output under discharge and somewhat erratic performance. This approach was therefore not pursued further; however, the same vitreous carbon foam was used later in place of the gas diffusion screen as a stack extender and spacer in the multi electrode cell tests.

Cell #18 was constructed with similar components as previous cells with the exception that the hydrogen electrode contained a silver expanded metal collector. This cell performed satisfactorily to 357 cycles(as shown in Figure 18)at the end of the program. The use of silver as the current collector for the hydrogen electrode is favored due to its lower resistance and will have a weight impact on the cell.

Cell #19 contained just two layers of fuel cell asbestos as the separator and was cycled for 352 times with stable performance as shown in Figure 19.

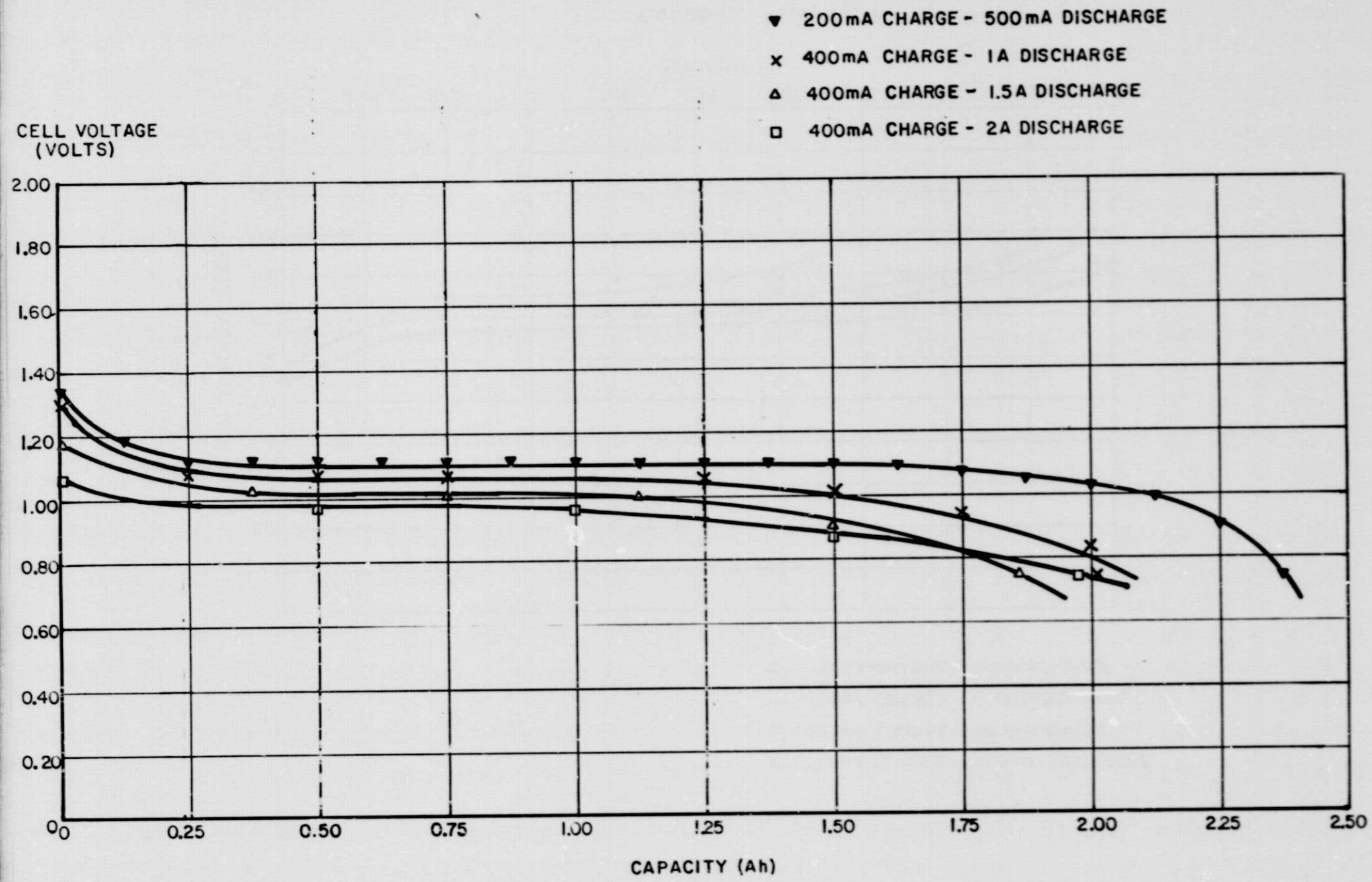


FIGURE 14. CELL NO. 10

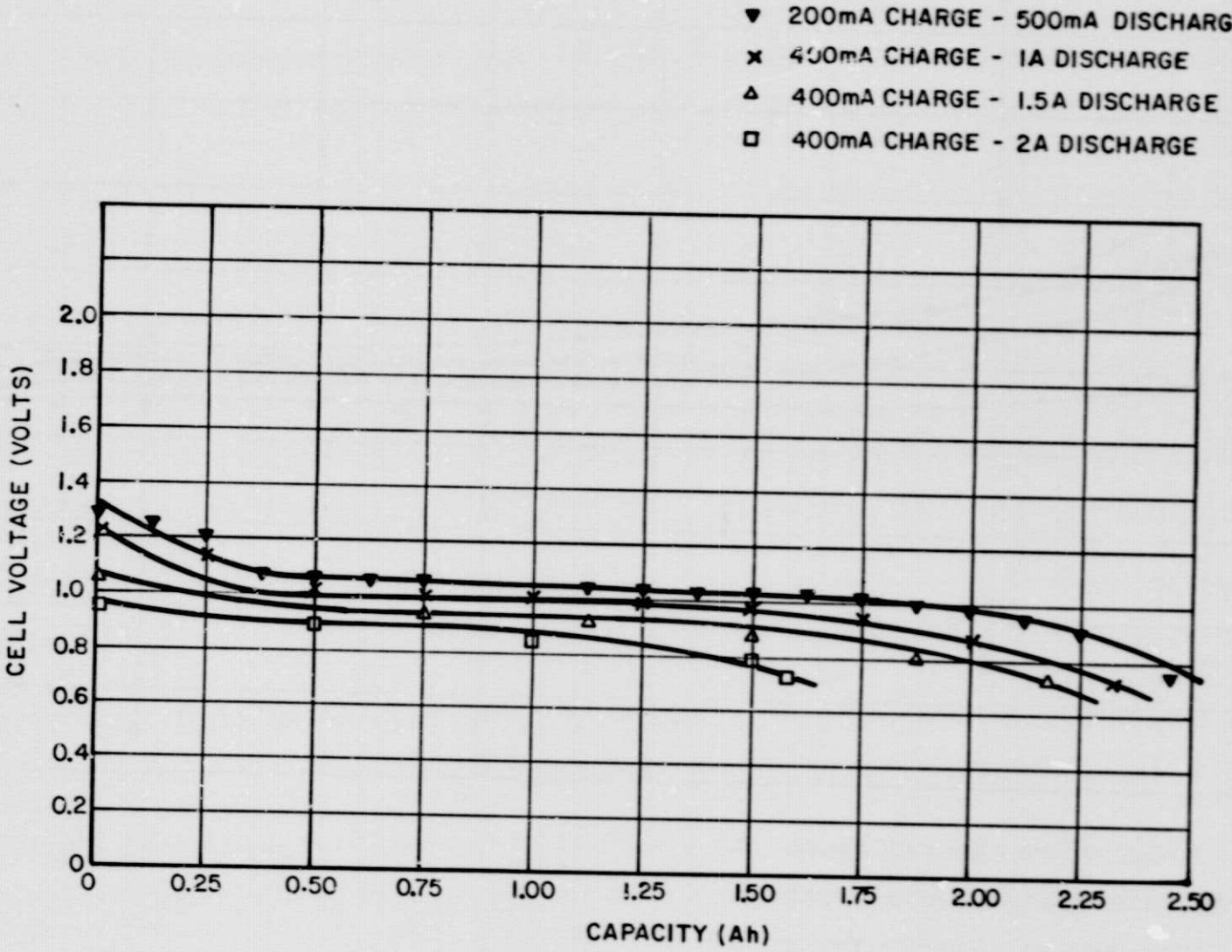


FIGURE 15. CELL NO. 11

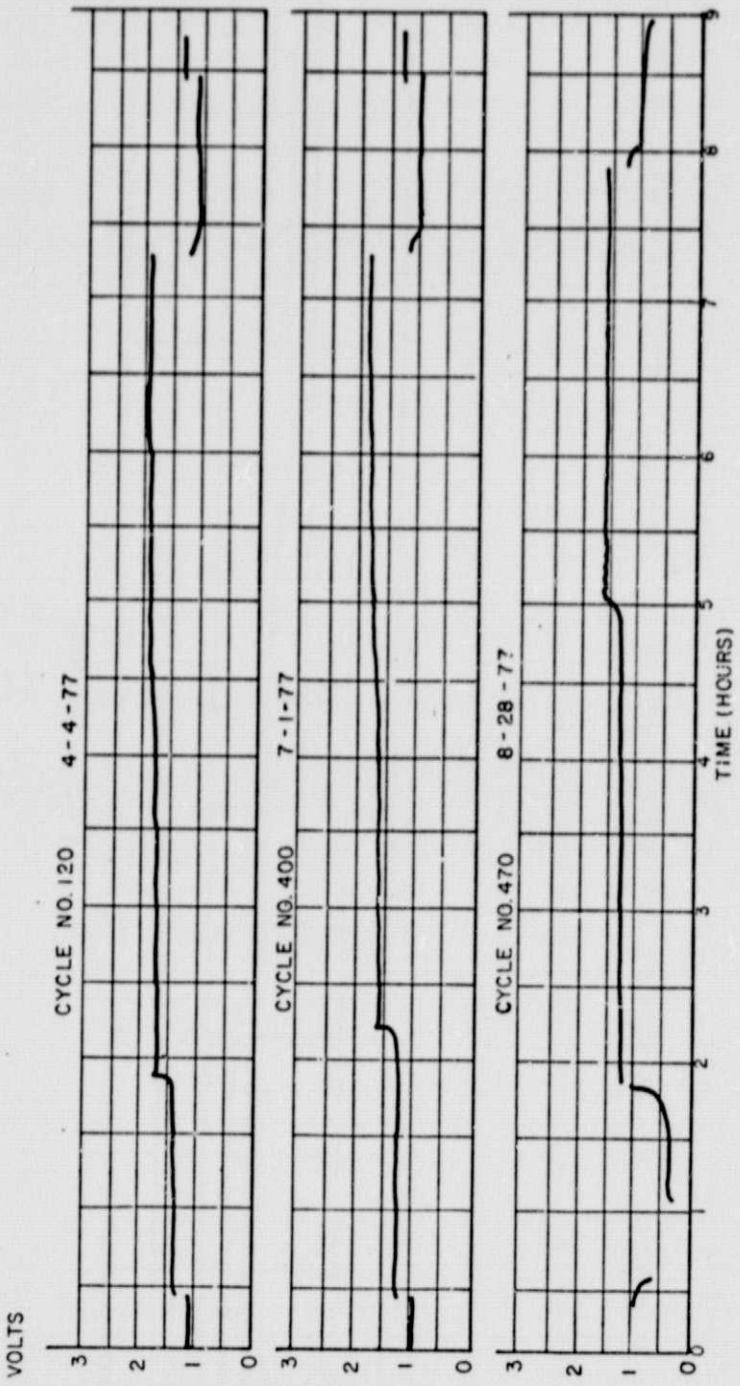


FIGURE 16. RESULTS OF CELL NO. 14 $Ag-H_2$

FIGURE 17. RESULTS OF CELL NO.15 – $Ag-H_2$ 8-24-77 CYCLE NO. 472

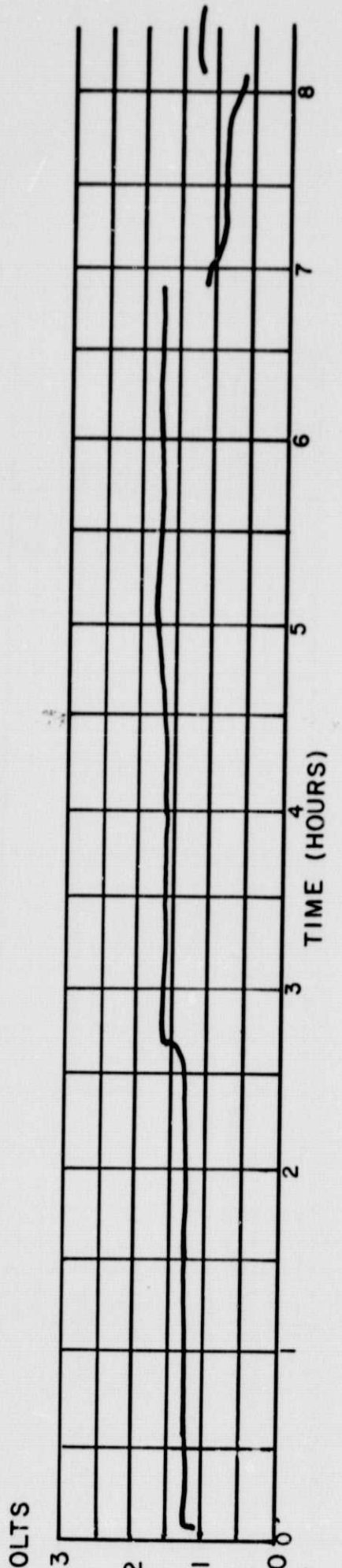


FIGURE 18. RESULTS OF CELL NO. 18. $Ag-H_2$ 8-24-77 CYCLE NO.357

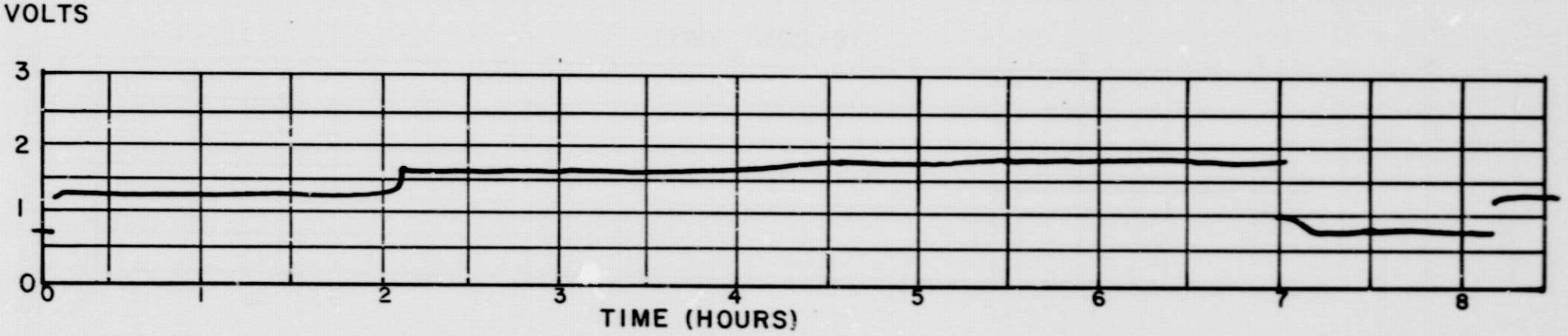
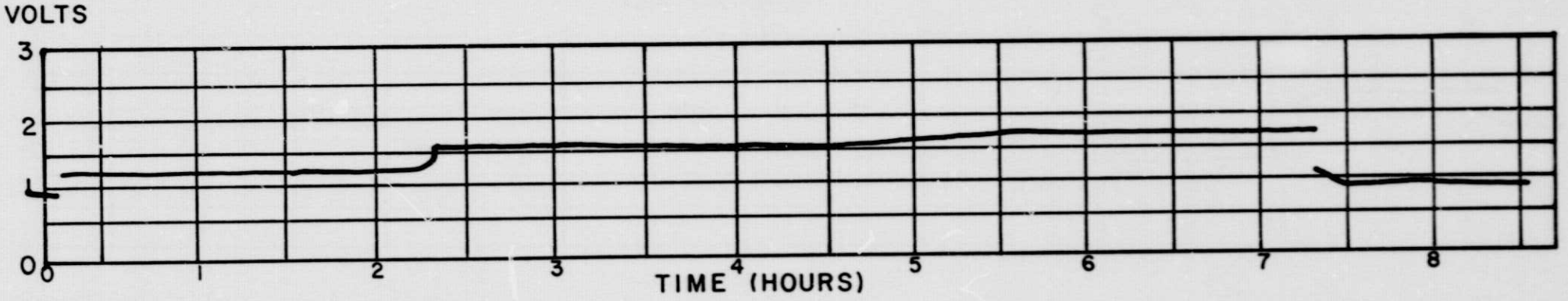


FIGURE 19. RESULTS OF CELL 19. $Ag-H_2$ 8-24-77 CYCLE NO. 352



This was the last cell in the single electrode series. The results of these cells were utilized in the selection of the construction approach for the multi-electrode test cells and for the design analysis.

3.2 TASK II - MULTI ELECTRODE CELL TESTS

An independent task was undertaken to scale up the single electrode test cells into multi electrode configurations. For these experiments, a 20 ampere-hour module was selected as the working size. The 20 ampere-hour cells were tested in heavy walled housings. The housings were similar in construction to the single electrode test housings with the exception of a deeper compartment to contain the electrode stack. The same electrode arrangement as the single electrode test cells was utilized; however, 10 silver electrodes were stacked electrically in parallel to achieve the 20 ampere-hour capacity. Table II shows a summary of the construction features and cycle results achieved for the stacks built during the course of the program.

Cells #1 and #2 were subjected to different rates of discharge initially,as shown in Figures 20 and 21. The operating voltage on discharge was found to be lower than expected and this was traced to a high voltage drop in the connex feed-through that contained stainless steel posts as the terminals. All subsequent boilerplate cells were built with gold plated copper terminal rods to overcome the voltage drop in the test housings. After assembly and check-out, the boilerplate housings were all cycled on a test condition consisting of a 1.2 hour discharge at 12.5 amps and a 6.8 hour charge at 2.42 amps. This cycle removed what is nominally 75% of the cell's capacity and re-charged the cell including a 10% overcharge.

Cell #4 developed an internal short after 30 cycles. Disassembly of this cell revealed that the electrode had been misaligned in assembly such that one of the silver electrodes was touching the hydrogen electrode on the stack edge. To overcome the assembly alignment problem, it was decided to investigate stack tie rods to provide better assemblies. From a thermal analysis of the stack design, it was felt that increased stack height would be preferred to give a larger stack perimeter area for better heat dissipation to the cell housing. Therefore, Stacks 5,6 and 7 contained reticulated carbon foam as the gas diffusion spacer to increase the stack height.

Stack 7 contained a single central tie rod and Stack 8 contained two tie rods up through the electrode for better alignment. Figures 22 through 27 show the last cycle of the various stacks at the end of the testing. These cells with the exception of Cell #6 exhibited stable performance throughout the

TABLE II

20 AH BOILER PLATE TEST CELLS

CELL #	SILVER ELECTRODE	HYDROGEN ELECTRODE	SEPARATOR	GAS DIFFUSION IER	CYCLES TO END OF PROGRAM	COMMENTS
1 (5-20)	STD 10 x .030	ERC	NASA I.O. Asbestos	VEXAR	437	
2 (7-20)	STD 10 x .030	NICKEL FOAM	NASA I.O.	———	522	
3 (R8-20)	STD	ERC	NASA I.O. Asbestos	VEXAR	435	Gold Plated Copper Terminal Rods
4 (9-20)	STD 10 x .030	NICKEL FOAM	NASA I.O.	———	30	" Shorted Due To Plate Misalignment
5 (10-20)	STD 10 x .030	ERC	NASA I.O. Asbestos	CARBON FOAM	377	
6 (11-20)	STD 10 x .030	ERC	NASA I.O. Asbestos	CARBON FOAM	302	Central Tie Rod Refilled with Electrolyte at cycles 231
7 (12-20)	STD 10 x .030	ERC	NASA I.O. Asbestos	CARBON FOAM	227	Double Tie Rods

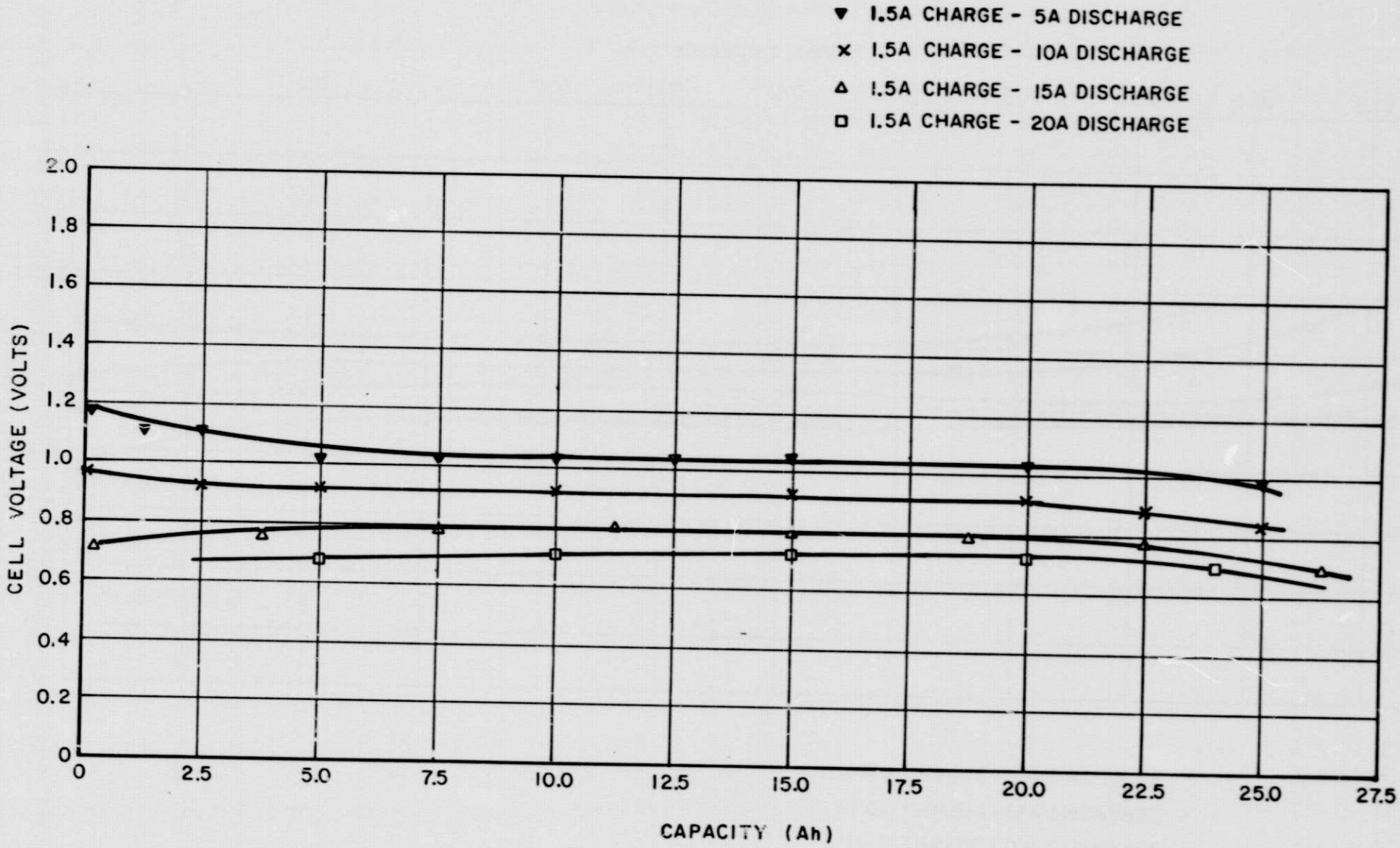


FIGURE 20. CELL NO. 20-1

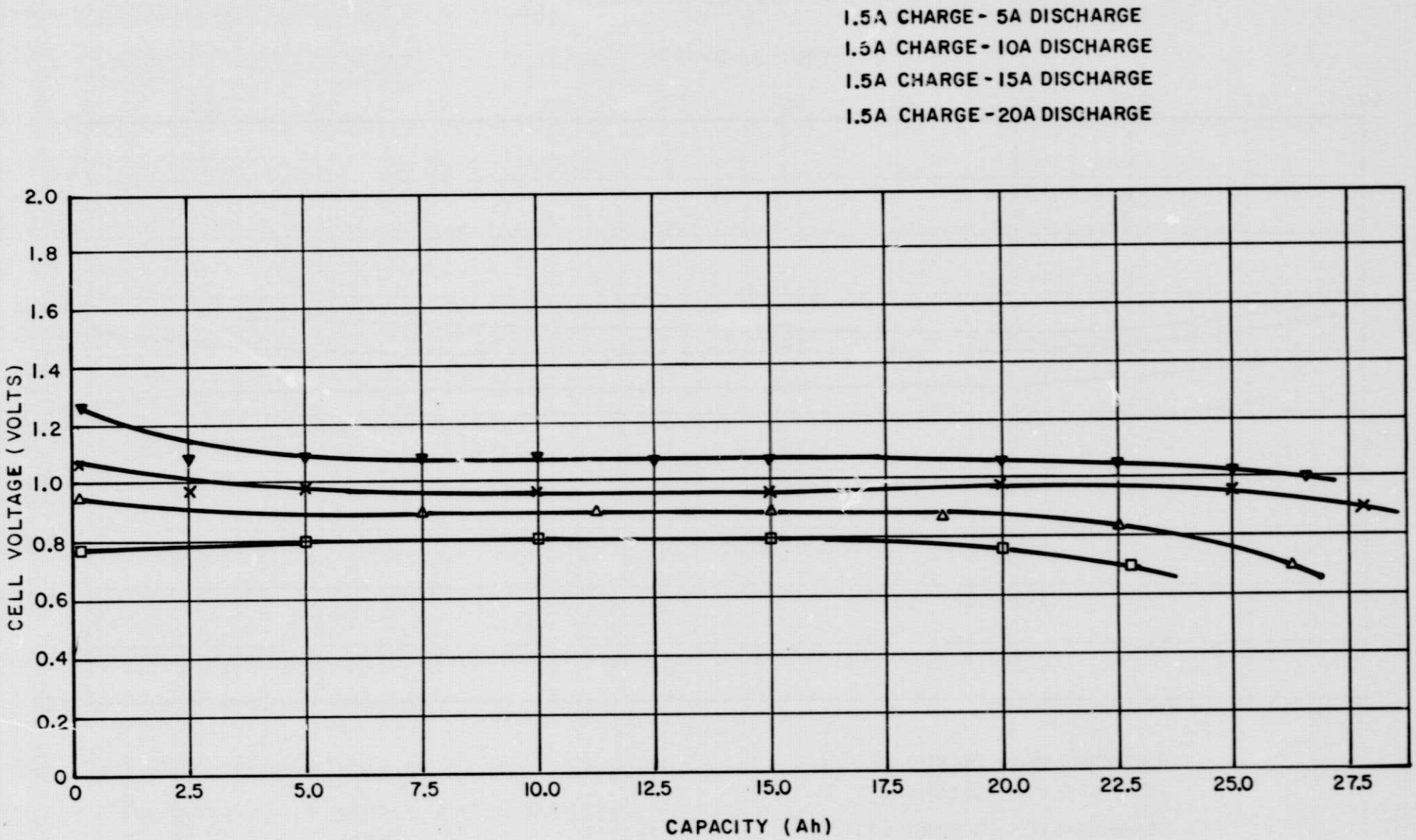
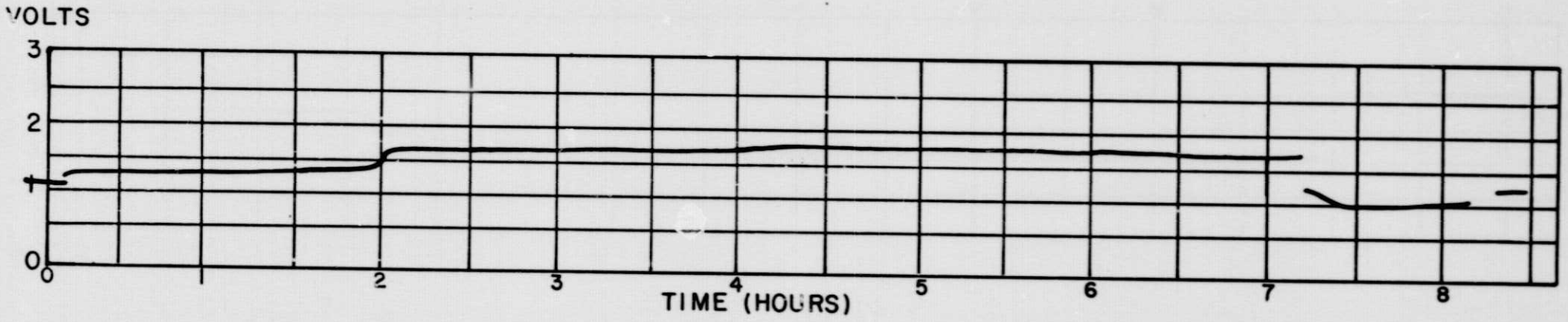


FIGURE 21. CELL NO. 20-2

FIGURE 22. CELL NO. 520 8-24-77 Ag - H_2 CYCLE 437



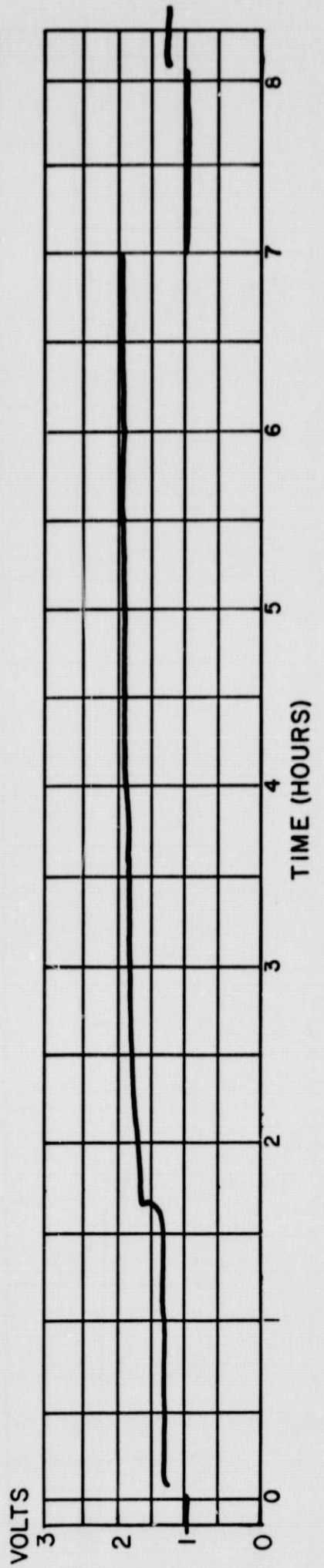
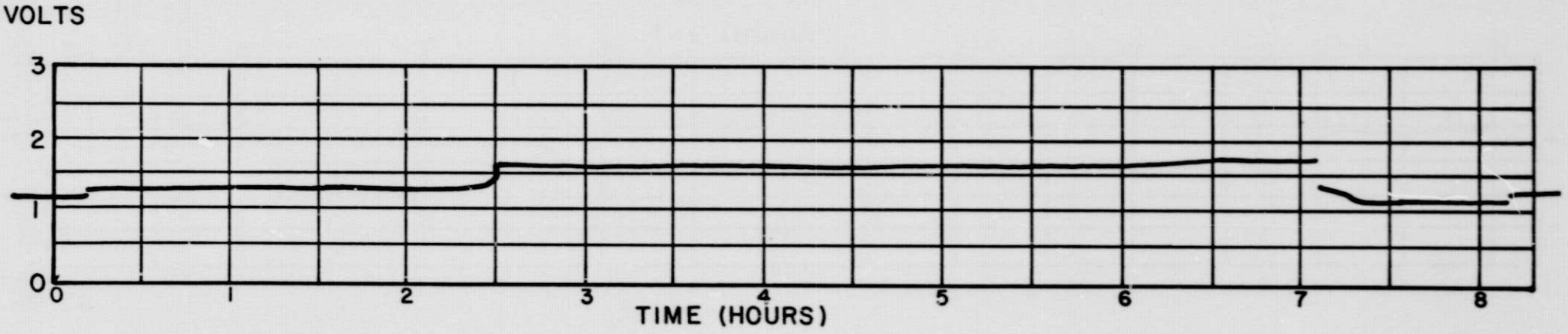


FIGURE 23. CELL NO. 7-20 8-24-77 Ag-H_2 CYCLE 522

FIGURE 24. CELL NO. R-820 8-9-77 Ag-H_2 CYCLE 435



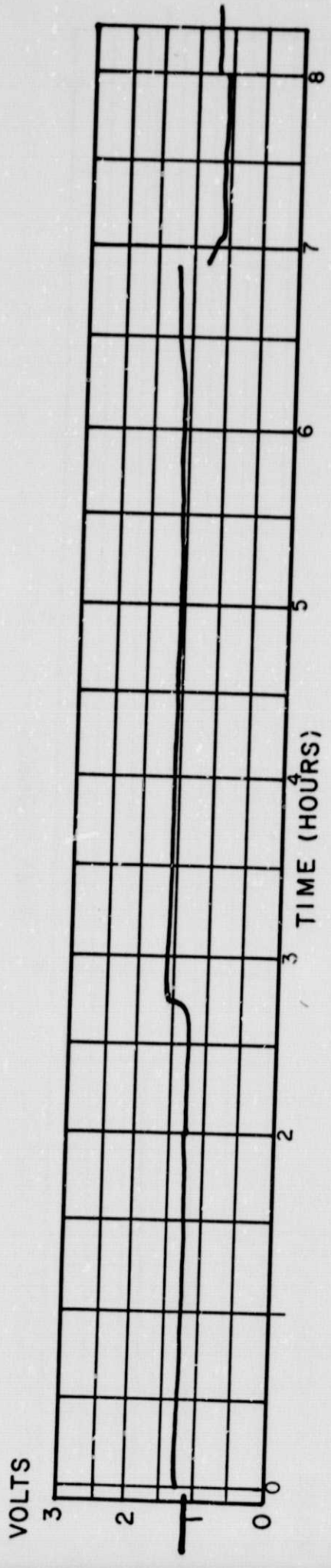
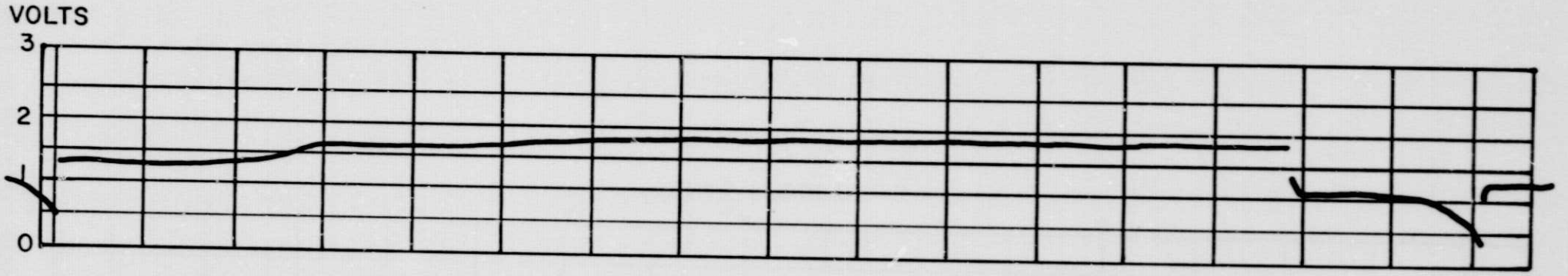


FIGURE 25. CELL 10-20 8-9-77 Ag-H_2 CYCLE NO. 377

FIGURE 26A & B

CELL NO. 11-20 7-1-77 $Ag-H_2$ CYCLE NO. 230



CELL NO. 11-20 8-24-77 $Ag-H_2$ CYCLE NO. 302

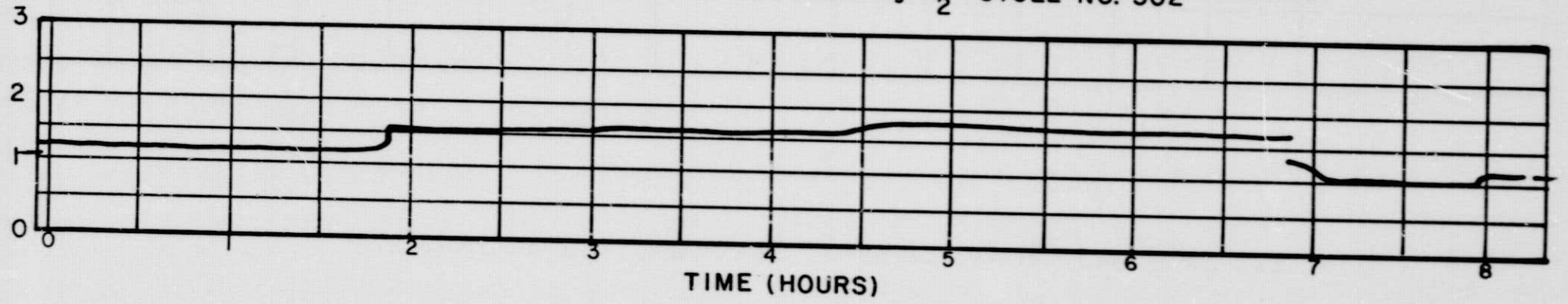
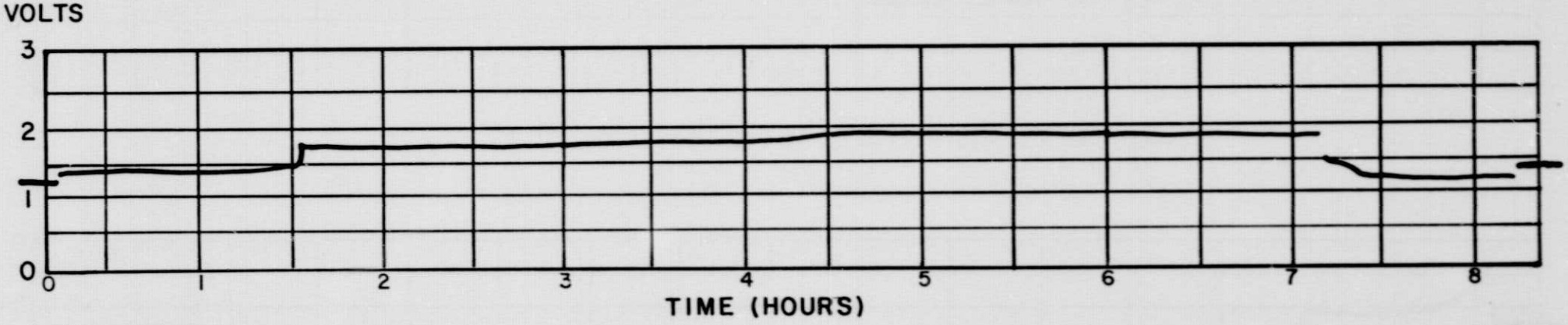


FIGURE 27. CELL NO. 12-20 8-24-77 Ag-H_2 CYCLE NO. 227



program. Cell #6 showed decay and was refilled with electrolyte after 230 cycles. The performance then recovered, indicating possibly poor filling originally. At the conclusion of the program, new stacks were constructed into the boilerplate housings and delivered to NASA-Lewis.

3.3 TASK III - DESIGN ANALYSIS

To evaluate final design options a design analysis and weight breakdown was prepared for lightweight 20-Ahr cells with various stack arrangements and are presented in Table III. The analysis is based on the same design concept presented in Report NAS-CR-134878 which covered the previous $AgO-H_2$ Program.

Table IV shows weight breakdown for 50 Ah cells with improved components. This scaling with components shows energy density potential to 40 watt hours per pound for the silver hydrogen system.

3.4 TASK IV - CELL FABRICATION

Based on the test results of the single and multi electrode stacks and design analysis, a design selection was made for the deliverable cells at the end of the contract. All of the cells contained a separator configuration of one layer of I.O. separator, and one layer of fuel cell grade asbestos against the hydrogen electrode. The cells all contained the standard silver electrodes of the type used throughout the program, double tie rods for electrode alignment and 3/16" thick polysulfone endplates. Two of the cells contained ERC-type hydrogen electrodes with reticulated carbon foam as the electrode spacer and two of the cells contained nickel-foam composite hydrogen electrodes. Table V shows the weight breakdown of the individual stacks. Each of the cells was run through an acceptance test sequence of 5 charge/discharge cycles at 75% depth. Figures 28 through 31 show the voltage performance on the 5th cycle. After the completion of this test, the cells were shipped to NASA-Lewis for further test.

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TABLE III

20 AHR Cell Weight Breakdown

	Nickel Sinter I.E.R				NO I.E.R.				Nickel Foam Hydrogen Electrode				Porous Plastic I.E.R			
	Cell #1				Cell #5				Cell #7				Cell #9R			
Components	Unit Wt.	Qty.	Wt. (gms)	Total (gms)	Unit Wt.	Qty.	Wt. (gms)	Total (gms)	Unit Wt.	Qty.	Wt. (gms)	Total (gms)	Unit Wt.	Qty.	Wt. (gms)	Total (gms)
Silver Elect.	4gm/AHR	10	7.00	70.00	4gm/AHR	10	7.00	70.00	4gm/AHR	10	7.00	70.00	4gm/AHR	10	7.00	70.00
Silver Grid	.21gm/in²	10	0.75	7.50	.21gm/in²	10	0.75	7.50	.21gm/in²	10	0.75	7.50	.21gm/in²	10	0.75	7.50
Silver Tab		10	1.05	10.50		10	1.05	10.50		10	1.05	10.50		10	1.05	10.50
Astropower Separator		20	1.47	29.40		20	1.47	29.40		20	1.47	29.40		20	1.47	29.40
Hydrogen Elect.		20	0.94	18.80		20	0.92	18.40		11	4.16	45.76		20	0.90	18.00
Nickel Tab		20	.917	18.34		20	.917	18.34		11	.917	10.09		20	.917	18.34
Electrolyte Reservoir		11	3.76	41.36		11	0.23	2.53	--	--	-----	-----		11	1.80	19.80
Asbestos	--	--	-----	-----		20	0.60	12.00	--	--	-----	-----	--	--	-----	-----
End Plate		2	9.33	18.66		2	9.33	18.66		2	9.33	18.66		2	9.33	18.66
Tie Rod 2 Nuts & Tab		4	4.83	19.32		4	4.83	19.32		4	4.83	19.32		4	4.83	19.32
TOTAL STACK	--	--	-----	233.88	--	--	----	206.65	--	--	-----	211.23	--	--	-----	211.52
Pressure Vessel	--	1	-----	71.	--	1	----	71.	--	1	-----	71.	--	1	-----	71.
Ziegler Fittings	--	2	4.48	8.96	--	2	4.48	8.96	--	2	4.48	8.96	--	2	4.48	8.96
Threaded Rod	--	2	4.38	8.76	--	2	4.38	8.76	--	2	4.38	8.76		2	4.38	8.76
Electrolyte	--	10	7.15	71.50	--	10	5.70	57.0	--	10	11.19	111.90	--	10	6.12	61.2
Miscellaneous	--	--	----	15.00	--	--	----	15.0	--	--	-----	15.00	--	--	----	15.00
TOTAL	--	--	----	409.	--	--	----	368.	--	--	-----	427.	--	--	----	377.
WH/lb				24.4				27.2				23.8				26.5

	I				II				III			
	Baseline				Improved Silver Utilization				Improved Silver Reduced Area Filament Wound Vessel			
Components	Unit Wt.	Qty.	Wt. (gms)	Total (gms)	Unit Wt.	Qty.	Wt. (gms)	Total (gms)	Unit Wt.	Qty.	Wt. (gms)	Total (gms)
Silver Electrode	3.5 gms/Ahr	10	17.5	175.0	2.5 gms/Ahr	10	17.5	125	3.5 gms/Ahr	7	17.8	125
Silver Grid	.21gm/in^2	10	1.8	18.0	.21gm/in^2	10	1.8	18	.21gm/in^2	7	1.8	12.6
Silver Tab		10	1.5	15.0		10	1.5	15		7	1.5	10.5
Astropower Separator		20	3.6	72.0		20	3.6	72.0		14	3.6	50.4
Hydrogen Electrode		20	2.3	46.0		20	2.3	46.0		14	2.3	32.2
Nickel Tab		20	1.5	30.0		20	1.5	30.0		14	1.5	21.0
Gas Diffusion Screen		11	.57	6.3		11	.57	6.3		8	.57	4.6
Asbestos		20	1.5	30.0		20	1.5	30.0		14	.57	21.0
End Plate		2	18.0	36.0		2	18.0	36.0		2	18.0	36.0
Tie Rod - 2 Nuts & Tab		4	4.83	19.32		4	4.83	19.32		4	4.83	19.3
TOTAL STACK				447.62				397.62				332.6
Pressure Vessel		1		186.0		1		186.0		1		100.0
Ziegler Fittings		2	12.0	24.0		2	12.0	24.0		2	24.0	24.0
Threaded Rod		2	10.0	20.0		2	10.0	20.0		2	10.0	20.0
Electrolyte		10	14.0	140.0		10	14.0	140.0		10	14.0	98.0
Miscellaneous				25.0				25.0				25.0
TOTAL				842.62 (1.86 lbs)				792.62 (1.75 lbs)				599.6 (1.32 lbs)
ENERGY DENSITY Wh/lb				29				31				39.8

TABLE IV 50 AH CELL WEIGHT BREAKDOWN ANALYSIS

TABLE V

20 AMP. A_g-H_2 WEIGHT BREAKDOWN

10 ELECTRODE STACK

#1 Grams	#2 Grams		#3 Grams	#4 Grams
6.05	6.05	CARBON FOAM NICKEL FOAM	47.30	47.30
12.40	12.40	NEG. PT	2.00	2.08
29.60	29.60	NASA SEP.	29.60	29.60
12.00	12.00	SOFT SEP.	12.00	12.00
78.35	78.06	A_g POS. (10 pcs) A_g ONLY	79.77	77.19
1.00	1.00	INSULATORS	1.00	1.00
34.10	34.10	TABS	34.10	34.10
173.50	173.21	STACK WT.	205.77	203.19
30.00	30.00	END PLATES (2)	30.00	30.00
2.60	2.60	ABS TUBES (2)	2.60	2.60
27.20	27.20	CENTER RODS & NUTS(2)	27.20	27.20
5.00	5.00	MOUNTING TABS (2)	5.00	5.00
64.80	64.80	FIXTURE WT.	64.80	64.80
238.30	238.01	DRY WEIGHT TOTAL	270.57	267.99
88.6	82.6	ELECTROLYTE	86.0	80.0
326.9	320.61	ACTUAL WT. WET	356.50	345.50

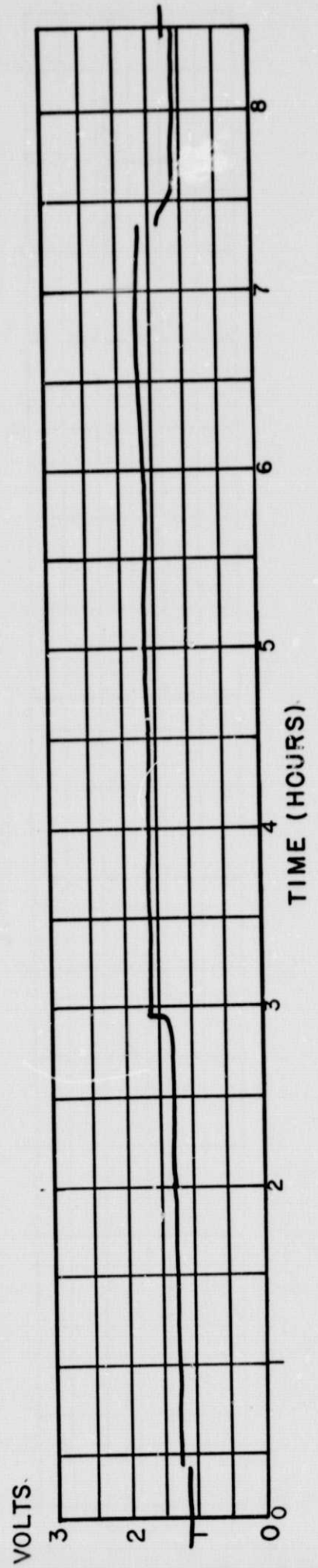


FIGURE 28. CELL NO. C-1 9-28-77 Ag-H_2 CYCLE NO. 5

FIGURE 29. CELL NO. C-2 9-28-77 Ag-H_2 CYCLE NO. 5

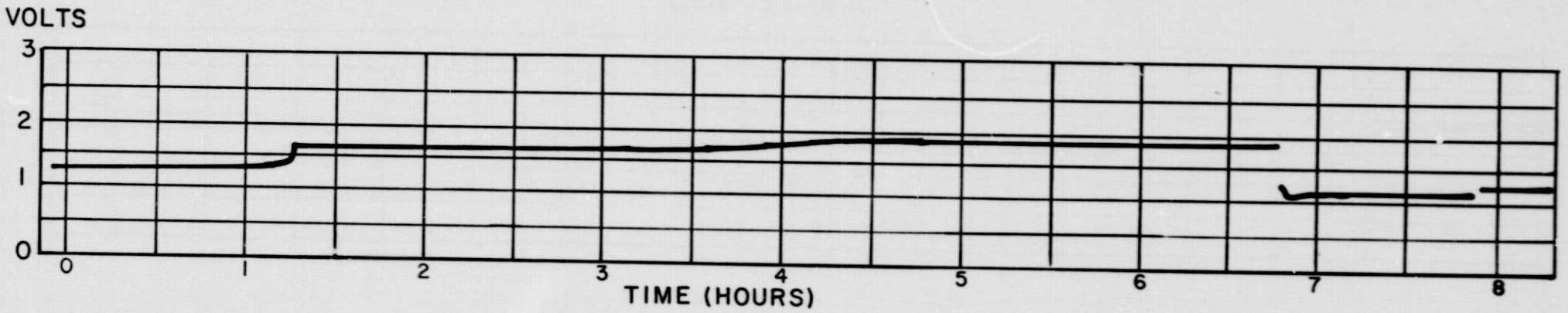


FIGURE 30. CELL NO. C-3 9-28-77 Ag-H_2 CYCLE NO. 5

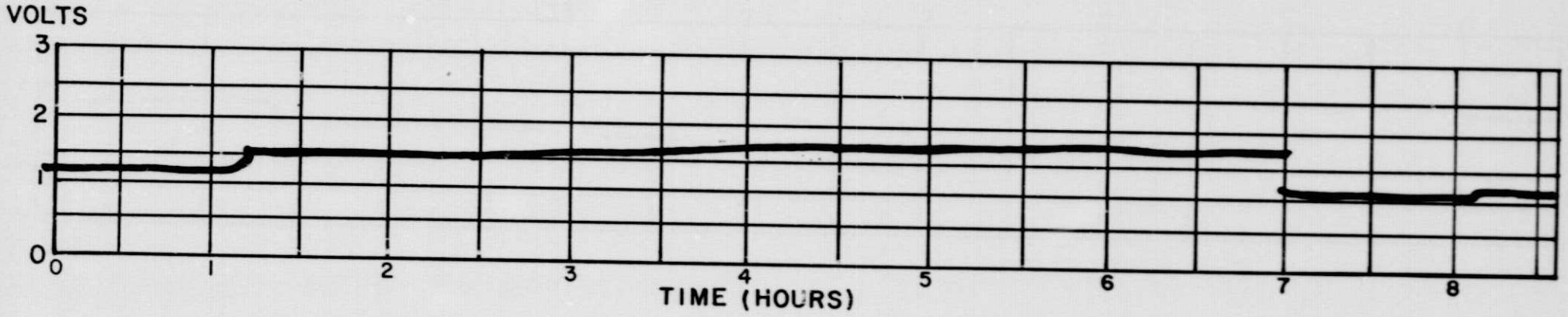
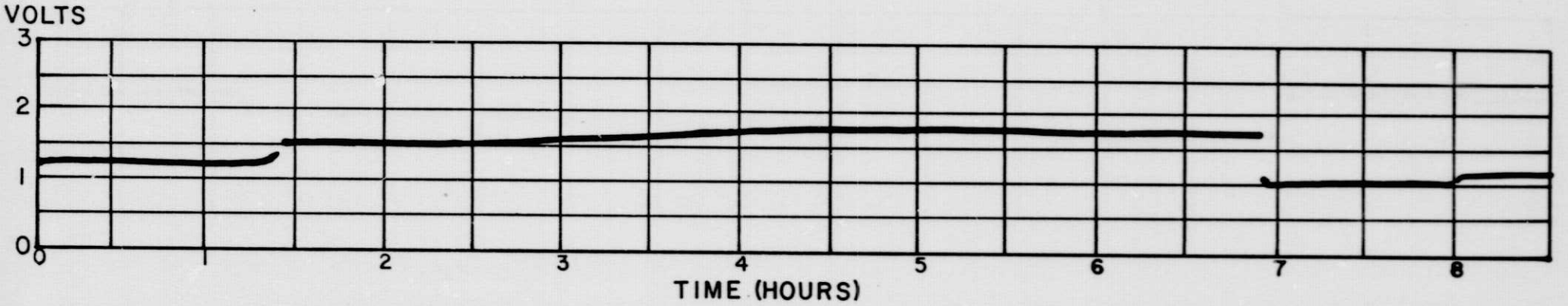


FIGURE 31. CELL NO. C-4 9-28-77 Ag-H_2 CYCLE NO. 5



4.0 CONCLUSIONS

The NASA-Lewis I.O. separator material appears acceptable for use in silver hydrogen cells and enables stable cycling in excess of 1,000 cycles. Decay in performance of silver hydrogen test cells was observed in a number of cases in the 900-1,000 cycle range. This decay appeared to be attributed to changes in the silver electrode. The exact mechanism of this capacity decay is not yet established, and additional work is recommended to define the changes that take place. In one case, the conditioning of silver electrode in free electrolyte enabled the cell to be rebuilt and acceptable performance was achieved.

It appears that it is not necessary to have an electrolyte reservoir within the stack configurations investigated to obtain stable performance on the test conditions utilized. This has the advantage of reducing stack weight and complexity. It also appears that within the testing done, electrolyte entrainment losses are not a dominant failure mechanism.

From thermal analysis of cell stacks, it appears that thermal problems could be encountered with silver hydrogen cells since the stack perimeter area is relatively small for the heat dissipation encountered in cycling. Two approaches were developed to extend the over-all stack height and therefore the electrode perimeter. One consisted of using a nickel foam metal as a composite gas diffusion spacer and hydrogen electrode support and the second approach was to utilize a reticulated carbon foam as a thick gas diffusion spacer. Both of these approaches were tested in multi electrode assemblies and performed satisfactorily.

Some difficulty was experienced throughout the program with the alignment of the stack components which resulted in cell shorting. It was concluded that one or two tie rods would considerably enhance the electrode stacking alignment and minimize shorting problems and this approach was taken in the final delivered stacks.

Weight analysis of light weight cells showed that the maximum weight reduction benefits could be achieved by improving the utilization of the silver electrodes and utilizing lighter weight pressure vessels than
improvements it is possible to project silver hydrogen cells capable of 40 watt hours per pound. A secondary battery approaching this energy density and capable of 500 deep charge-discharge cycles would make a competitive system when compared with sealed silver-zinc, nickel-cadmium and nickel-hydrogen cells for many applications.