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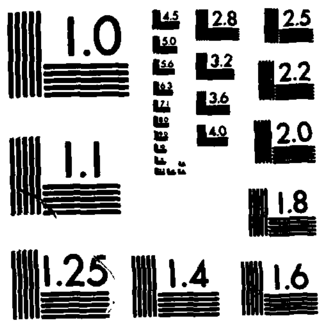

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NAVAL AIR ENGINEERING CENTER

REPORT NAEC-92-184

LAKEHURST, N.J.
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EVALUATION OF AIRCRAFT BATTERY CHARGE, DISCHARGE, AND ANALYZATION REQUIREMENTS FOR GROUND SUPPORT EQUIPMENT

Advanced Technology Office
Support Equipment Engineering Department
Naval Air Engineering Center
Lakehurst, NJ 08733

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EVALUATION OF AIRCRAFT BATTERY CHARGE, DISCHARGE, AND ANALYZATION REQUIREMENTS FOR GROUND SUPPORT EQUIPMENT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides an up-to-date listing of all aircraft batteries that are presently being used as well as those that will be used in the future. Test results and associated recommendations pertaining to the servicing requirements and associated charge, discharge, and analyzation equipment are delineated. Vented lead acid battery charging equipment performs satisfactorily and should continue to be utilized until these batteries are phased out by sealed lead acid batteries. The NBC-1A charges/discharges vented nickel

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) cadmium batteries. It performs well; any major change in battery servicing equipment should have strong justification and exceptional performance to warrant its utilization. Pulse charging and DC constant-current charging are equally effective in charging nickel cadmium aircraft batteries, however pulse charging equipment is more costly and produces more heat. Increased charging and discharging rates, rapid scanning of cell and battery voltages, notification of battery voltage stabilization, and automatic hard copy recording of cell and battery voltages for nickel cadmium batteries are all recommendations brought forth from this endeavor.

SUMMARY

A. PREFACE.

1. Battery chargers and analyzers are used in Navy servicing shops to charge and test secondary aircraft storage batteries. Although there are numerous applications and many sizes of batteries requiring maintenance, only two basic electrochemistries are presently used--nickel-cadmium (Ni-Cd) and lead-acid. Each electrochemical system has its own battery shop facilities including individualized charging/analyzing equipment and servicing procedures.

2. The present generation of aircraft battery servicing equipment was developed in the early to mid-1970's. Much of the equipment purchased at that time is approaching the end of its predicted service life. Also, there have been technological advances in aircraft and battery design as well as changes in maintenance concepts.

3. In order to maintain continuity in the charging/analyzing equipment available to the Fleet, the Naval Air Engineering Center, Lakehurst, New Jersey, initiated a program to determine what servicing equipment will be necessary to satisfy the Navy's requirements in the post-1984 time frame.

4. In accordance with reference (a), Naval Weapons Support Center (NAVWPNSUPPCEN) Crane, has examined the present and future needs of the Navy. This assignment consisted of two parts:

a. Identify the batteries which will be used in the post-1984 time frame.

b. Determine the aircraft battery charging/discharging/analyzing needs of the post-1984 time frame for consideration in future battery charger procurements.

5. NAVWPNSUPPCEN Crane, as Cognizant Field Activity for basic design and maintenance engineering of aircraft batteries, is continually involved in improving overall aircraft battery performance. This is accomplished by improving existing designs, adapting new technology for new or existing applications, and by improving battery maintenance procedures. Because of Crane's total involvement with batteries, it is believed that the projected list of aircraft batteries and their respective servicing needs included in this report are accurate and should be used with confidence in developing ground support equipment during the next 10 to 20 years.

B. DISCUSSION.

1. There are principally two battery chargers presently used to charge aircraft batteries. This equipment is located in all Aircraft Intermediate Maintenance Department (AIMD) battery servicing shops within the Navy. Complete servicing procedures for use with the equipment is included in the Navy battery servicing manual, Naval Aircraft Storage Batteries, NAVAIR 17-15BAD-1.

Ref: (a) Order for Work and Services Document No. N6833582WR28033 of 1 May 1982.

a. The Model 2400A-2 Battery Charger, designed and manufactured by Utah Research and Development Company (URDC), is currently used to charge all lead-acid batteries. The 2400A-2, initially procured in 1978, is a commercially-manufactured unit with an estimated service life of 10 years. It can be operated in either an automatic or manual mode and is used to charge aircraft batteries and ground support equipment batteries.

b. The NBC-1/1A Alkaline Battery Charger/Analyzer was designed by URDC and is manufactured by URDC and other companies. The NBC-1/1A, initially procured in 1971, has an estimated service life of 15 years. It can be operated in either an automatic or manual mode to service vented Ni-Cd aircraft batteries. In addition to battery charging, the unit also provides discharge and analyzing capability.

2. There are two points to be made with respect to lead-acid batteries.

a. There is an on-going engineering effort toward introducing sealed, lead-acid batteries into Navy aircraft. It is believed that these batteries will eventually replace all vented, lead-acid batteries, as well as selected Ni-Cds.

b. The Model 2400A-2 is presently being used to charge sealed, lead-acid batteries, but will most likely be replaced by a unit designed specifically for these batteries. The 2400A-2 is operating quite satisfactorily in support of vented, lead-acid batteries and can be expected to continue until all aircraft lead-acid batteries have been converted to the sealed design.

3. Because of the evolution currently taking place in the lead-acid area and the capability of the 2400A-2 to satisfactorily meet all vented, lead-acid needs in the foreseeable future, the bulk of the work performed during this program involved the servicing requirements of Ni-Cd batteries.

4. This report provides an up-to-date listing of all aircraft batteries that are now being used and that will be used in the future. It also provides test results and corresponding recommendations pertaining to the servicing requirements and associated charge, discharge, and analyzation equipment. The results of this study are to be used in future servicing requirement procurements.

C. SYNOPSIS.

1. Vented, lead-acid batteries which are in service now and are anticipated to be in service in the future are listed in Table 1. They are currently being charged by the Model 2400A-2 Battery Charger. Other miscellaneous direct current (DC) chargers may also be in limited use. It is believed that these chargers, the Model 2400A-2 in particular, will continue to perform satisfactorily until they are no longer needed, as sealed batteries completely replace vented batteries. Therefore, testing of vented, lead-acid batteries was not performed during this study.

2. A recent addition to the inventory of Naval aircraft storage batteries is the sealed, lead-acid battery.

a. Presently, there are two sizes of sealed, lead-acid batteries in use: the D8565/3-2, 15 ampere hours (Ah), and the D8565/4-1, 7.5 Ah. A 30-Ah battery will be available in 1 to 2 years. These batteries are designed to remain in the aircraft for up to 2 years without being removed for scheduled maintenance. However, the battery switch is occasionally left on for indefinite periods of time, usually discharging the battery completely. When this occurs, the battery must be removed from the aircraft and serviced. This is presently accomplished by routing the battery to the IMA lead-acid battery shop. The battery is then charged on existing lead-acid battery chargers that were designed to service large, vented, lead-acid batteries.

b. A small battery charger/tester could be built and made available to Fleet personnel for the purpose of restoring capacities to depleted batteries. The charger could be operated at the squadron level, thereby reducing and eventually eliminating the need for IMA shop services for lead-acid aircraft batteries. NAVWPNSUPPCEN Crane has already developed a specification for this type of unit and has initiated procurement for sample hardware.

3. Ni-Cd batteries which are anticipated to be in service in the future are listed in Table 1. These batteries are within the charge/discharge limits of the NBC-1/1A Alkaline Battery Charger/Analyzer.

a. A variety of charging rates and techniques were evaluated using several of the batteries listed in Table 1.

b. The NBC-1A Alkaline Battery Charger/Analyzer was included in the evaluation and provided baseline data for the test batteries. A great deal of effort was invested in the development of the NBC-1/1A and associated operating procedures. Results of charging and analyzing batteries using the NBC-1/1A are considered very good. Any major change to battery servicing equipment must be justified by exceptional performance in charging and analyzing batteries.

c. Two modifications were made to existing operating philosophy that is reflected in the design of the NBC-1/1A and the charging procedures incorporated in the NAVAIR 17-15BAD-1 manual. These modifications, which are discussed in the body of the report, were instituted at the beginning of this evaluation as known improvements in charge technique. One change is a simple equipment adjustment to raise maximum charge voltage. The other change can only be accommodated in the next generation of Ni-Cd battery charging equipment.

d. Two battery pulse chargers were included in the evaluation. The vented, lead-acid battery charger, Model 2400A-2 manufactured by URDC, provides a pulse charge output. The second charger, Model 3000A also manufactured by URDC, was designed with the capability of providing a variety of pulse charge outputs for evaluation. The outputs of these pulse chargers are characterized in the body of the report.

e. All of the charge, discharge, and analyzation equipment used in the evaluation was available at Crane. Together with DC power supplies, the NBC-1A and pulse chargers, a total of nine charge regimes were evaluated and are listed in Table 7. Each of these regimes and related data are discussed in the body of the report. Tables 8 through 10 and Figures 3A through 10B summarize the charge test results.

f. At the present time, the servicing procedures contained in NAVAIR 17-15BAD-1 pertaining to Ni-Cd batteries require that the batteries provide a minimum 1-hour rated capacity, as defined in the applicable military specification, when discharged at the 1C rate. Although this test is very common in evaluating battery capacity, specifically in determining reserve capacity as may be required in an in-flight emergency, it does not effectively evaluate the battery's capability to produce high rates of current, as required to start aircraft engines. High-rate discharge testing was performed on several Ni-Cd batteries with the intent of upgrading the Navy's overall battery evaluation techniques. Not only will a high-rate discharge test more realistically evaluate a battery's capability to start engines, it will enable battery shop personnel to turn around ready-for-issue (RFI) batteries in approximately 75 percent of the time normally required. High-rate discharge test data'is summarized in Figures 11A through 19C of the report.

g. The battery parameters that are presently monitored by the NBC-1/1A should remain essentially the same. However, as the ever increasing use of microprocessors and related components and peripheral equipment continues, automation of the charge, discharge, analyzation, and reporting functions should be considered.

(1) Battery terminal voltage must be monitored during charge and discharge. During charge, it is to ensure that the battery has reached its mode-change voltages and has stabilized. During discharge, it is to determine when the battery reaches its end-of-discharge cutoff voltage.

(2) Monitoring of current is required to insure that the battery is charged and discharged at the correct rate.

(3) Cell voltages must be monitored to insure that all cell voltages are balanced and are performing within specified limits. Implementation of a high-rate discharge test will necessitate rapid cell scanning to effectively measure rapidly changing cell voltages.

D. CONCLUSIONS.

1. Pulse charging and DC constant-current charging are equally effective in charging Ni-Cd aircraft batteries.

2. Heat buildup within the battery is two- to four-times greater when pulse charging is employed, as compared to DC constant-current charging. This could contribute to premature aging of the battery and may tend to limit charge acceptance. This is of particular concern when the ambient battery shop temperature greatly exceeds normally recommended limits, which commonly occurs aboard ship.

3. Pulse charging equipment is generally more complex as compared to constant-current, resulting in potentially higher procurement and support costs.

4. The constant-current charging rate can be safely increased from 1.0C to 1.5C which will allow for a modest reduction in overall time required to charge Ni-Cd batteries.

5. High-rate discharges (9C constant load) are extremely effective in determining battery performance--particularly for engine-starting applications.

6. Rapid scanning of cell and terminal voltages are required particularly for high-rate discharges.

a. Equipment must be able to determine when battery terminal voltage is stabilized during charge.

b. Equipment must be able to automatically print cell voltages and battery terminal voltages for immediate use and record keeping. During high-rate discharge, cell voltages may be changing rapidly, and therefore, all cells should be scanned within 1-second periods.

c. Cell scan fixtures must provide positive contact to cell terminals for accurate voltage readings.

E. RECOMMENDATIONS.

1. That the Model 2400A-2 Battery Charger and the Model 1410-2 Constant-Current Discharge Unit remain as the approved servicing equipment for vented, lead-acid aircraft batteries.

2. That the Navy continue with on-going effort to develop a portable charger/tester for sealed, lead-acid aircraft batteries for use at the Organizational Maintenance Level.

3. That constant-current charging be continued as the approved method for charging Ni-Cd aircraft batteries.

4. That the constant-current charge rate for Ni-Cd batteries be increased from 1.0C to 1.5C, resulting in a modest reduction in the amount of time required for charging.

5. That the next generation of charger/analyzer equipment incorporate microprocessor technology with preprogrammed flexibility for charge and discharge control, parameter monitoring, and data printout.

6. That determination for Ni-Cd battery charge completion be based upon the sensing of battery voltage rise and stabilization rather than as a function of time.

7. That a separate high-rate battery discharge unit be developed for use in Ni-Cd Intermediate level battery shops. The unit should be capable of subjecting Ni-Cd aircraft batteries to 3-minute, constant-resistance discharges at approximately the 9C rate (45A-270A).

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I. INTRODUCTION

A. An investigation of Navy aircraft battery servicing requirements was performed by the Naval Weapons Support Center, Crane, in accordance with reference (a). A comprehensive list of aircraft batteries that will be used in the post-1984 time frame is shown in Table 1. A discussion of test procedures and results relative to battery charge and discharge techniques is contained in the following paragraphs.

II. TEST CONDITIONS

A. Evaluation tests were performed at existing relative humidity, atmospheric pressure, and at room ambient temperature ($70^{\circ} \pm 10^{\circ}F$) unless otherwise indicated.

III. IDENTIFICATION AND DESCRIPTION OF NAVY AIRCRAFT BATTERIES

A. AIRCRAFT BATTERY IDENTIFICATION.

1. An up-to-date listing of all main aircraft batteries that are now being used, and that will be used in the future, is shown in Table 1. Not included are small avionics batteries that are not serviceable on Model NBC-1/1A or 2400A-2 equipment.

B. DESCRIPTION OF VENTED, LEAD-ACID AIRCRAFT BATTERIES.

1. Included in Table 1 are lead-acid batteries of the conventional vented design that are used aboard aircraft such as the P-3 and C-130.

a. Each battery consists of 12 cells (M83769/7-1 has only six cells) that are series-connected in two rows of six, which terminate at a quick-disconnect receptacle.

b. The cells are generally enclosed by a one-piece, plastic monobloc and a plastic, one-piece top which is secured to the monobloc with an epoxy cement. The plastic monobloc/inner case, with plastic top in place, is encased with a paint-coated, metallic (cast aluminum) container and removable paint-coated aluminum cover. The cavity between the plastic monobloc/inner case and metallic outer container is sealed with a rubber-based sealant.

c. The plastic top has 12 threaded holes to accommodate removable, non-spill vent plugs. The removable vent plug makes it possible to inspect and adjust the electrolyte level of each cell. The vent plug is also designed to allow gases to escape when the battery is upright and seal the cell when the battery is inverted or tilted.

d. The electrolyte is a sulfuric acid and water solution having a specific gravity of 1.285 at $80^{\circ}F$.

e. The battery capacities range from 8.4 Ah to 54 Ah.

TABLE 1. LISTING OF AIRCRAFT BATTERIES

Vented, Lead-Acid

Battery	Rating	NSN	Aircraft/Remarks
M83769/1-1	24V, 31 Ah	6140-00-406-2633	Alternate to battery M83769/5-1 if aircaft connector is changed.
M83769/2-1	24V, 18 Ah	6140-00-406-2634	NU-1B, U-6A, B-52, Alternate to battery M83769/4-1 if air-connector is changed.
M83769/3-1	24V, 8.4 Ah	6140-00-406-2635	C-141
M83769/4-1	24V, 18 Ah	6140-00-135-0229	T-34B, T-34C
M83769/5-1	24V, 31 Ah	6140-00-557-3873	A-3B, KA-3B, RA-3B, ERA-3B, NRA-3B, TA-3B, C-1A, EC-121M, DC-130A, C-130F, C-130H, KC-130F, LC-130F, EC-130G, EC-130Q, KC-130R, LC-130R, SP-2H, P-3A, EP-3A, RP-3A, VP-3A, P-3B, EP-3B, P-3C, EP-3E, TS-2A, US-2A, US-2B, US-2D, US-2G, T-28B, T-28C, QT-33A
M83769/5-2	24V, 31 Ah	Not available	Alternate to battery M83769/5-1.
M83769/6-1	24V, 31 Ah	6140-00-451-9713	Alternate to battery M83769/1-1 if cover labels and vent caps are changed.
M83769/6-2	24V, 31 Ah	Not available	Alternate to battery M83769/6-1.
M83769/7-1	12V, 54 Ah	6140-00-328-3854	C-117D, C-118B, VC-1118B, C-131F, T-33B
Varley 241925C	24V, 18 Ah	6140-00-467-6112	AV-8A, AV-8C, TAV-8A, TAV-8C
Varley 24114	24V, 2.5 Ah	6140-00-467-6106	AV-8A, AV-8C
R33	12V, 33 Ah	6140-00-328-3888	U-8D

Sealed, Lead-Acid

Battery	Rating	NSN	Aircraft/Remarks
D8565/3-2	24V, 15 Ah	6140-01-133-6851	AV-8B

TABLE 1 (continued)

Sealed, Lead-Acid

Battery	Rating	NSN	Aircraft/Remarks
D8565/4-1	24V, 7.5 Ah	6140-01-131-8104	F-18A, TF-18A
D8565/5-1	24V, 30 Ah		Presently being developed to replace M83769/1, /5, and /6 batteries.

Vented, Nickel-Cadmium

Battery	Rating	NSN	Aircraft/Remarks
M81757/7	24V, 10 Ah	6140-01-099-0252	CH-46A, HH-46A, UH-46A, CH-46D, UH-46D, CH-46E, CH-46F, U-8D, U-8F
M81757/8	24V, 20 Ah	6140-01-099-0253	C-2A, T-2C, T-39A, T-39B, T-39D, CT-39E, CT-39G, OV-10A
M81757/9	24V, 30 Ah	6140-01-110-3855	TC-4C, LC-130F, LC-130R, AH-1J, AH-1T, AT-1T (TOW), HH-1K, TH-1L, UH-1E, UH-1H, UH-1L, UH-1N, OV-1B, OV-1C, OV-1D, RV-1D
M81757/10	22.7V, 6 Ah	6140-01-104-9581	A-6A, EA-6A, A-6B, KA-6D, A-6E, A-6E (MOD)
M81757/11	24V, 20 Ah	6140-01-105-0077	HH-2D, SH-2D, SH-2F, HH-3A, UH-3A, VH-3A, SH-3D, VH-3D, HH-3E, SH-3G, SH-3H
MS-18045-75 (551-12800)	24V, 27 Ah	6140-00-301-0849 6140-00-119-4908 6140-00-301-0849	EA-3B
MS3337-2 (5M1004-3) (18NV01-1C11546)	21.6V, .4 Ah	6140-00-167-7467	A-4F, RA-5C, F-4B, RF-4B, F-4G, F-4J, F-4N, F-4S
MS3346-1 (C551-12227) (551-12227)	24V, 2.5 Ah	6140-00-410-3334	A-7A, A-7B, A-7C, TA-7C, A-7D, A-7E, RF-8G
MS3487-1 (BB-649A) (551-11743)	24V, 18 Ah	6140-00-980-0025	AH-1G
MS3319-1	24V, .75 Ah	6140-00-400-8289	HH-2D, SH-2D, SH-2F

TABLE 1 (continued)

Vented, Nickel-Cadmium (continued)

Battery	Rating	NSN	Aircraft/Remarks
MS3375-1 (28008)	24V, 7.5 Ah	Not available	TH-57A
BB-432A/A	24V, 10 Ah	6140-01-072-3125	U-8F
BB-476/A (29847P)	24V, 13 Ah	6140-01-061-2818	OH-58A
BB-507()/U (SM-D-649889)	6V	6140-01-034-3136	OV-1D, RV-1D
BB-716/A (29147-4)	25.3V, 5 Ah	6140-01-089-8134	SH-60B
ELDEC BA02-04	25.3V, 5 Ah	Not available	SH-60B
GPU-2/A (29325)	32.8V, 11 Ah	Not available	Gun Pod
GPU-2/A (43B006TB01)	32.8V, 6 Ah	6140-01-058-1817	Gun Pod
LTN-72 (27826-2) (CA-54)	24V, 5 Ah	6140-00-449-9839	Airborne Navigation
STCA-400	24V, 40 Ah	Not available	CT-39E, CT-39G
D8565/2-1 (43B030RB04)	24V, 30 Ah	6140-01-068-7749	C-12A, T-44A, OV-10D
23729-1	24V, 5 Ah	6140-00-224-7287 6140-00-893-3794	F-5E, F-5G, T-38A
29359-2	25.2V, 5 Ah	6140-01-026-7366	TA-7C
19V07LK	24V, 7 Ah	6135-00-616-4413	TAV-8A, TAV-8C
43B030RB03	24V, 30 Ah	Not available	UC-12B, T-44A
43B034LB03	14V, 40 Ah	6140-01-105-3178	C-9B

Sealed, Nickel-Cadmium

Battery	Rating	NSN	Aircraft/Remarks
D8565/1 (39411-001)	26V, 2 Ah	6140-01-086-3440	AV-8A, AV-8C

TABLE 1 (continued)

Sealed, Nickel-Cadmium (continued)

Battery	Rating	NSN	Aircraft/Remarks
MS17334-2	24V, .3 Ah	6140-00-866-6815	E-1B, EA-6B, US-2D
URDC 100 BSI-120	25.3V, 5 Ah	Not available	F-18, TF-18

2. Vented, lead-acid batteries were not included in the evaluation program because they are satisfactorily being serviced by the Model 2400A-2 charger and 1410-2 discharge unit. Additionally, vented, lead-acid batteries will be replaced in all Navy aircraft by sealed, lead-acid batteries which are now being developed and evaluated.

C. DESCRIPTION OF SEALED, LEAD-ACID AIRCRAFT BATTERIES.

1. A family of sealed, lead-acid batteries is being developed for use in Navy aircraft for both new applications and retrofit. There are three sizes of sealed, lead-acid batteries shown in Table 1. The D8565/3-2 is rated at 15-Ah capacity and was qualified for use on the AV-8B aircraft. The D8565/4-1 is rated at 7.5-Ah capacity and was qualified for use on the F/A-18 aircraft. It is also being retrofitted into H-46 helicopters and is being considered for use in A-6 aircraft. The D8565/5-1 is presently under development and will replace M83769/5 and M83769/6 30-Ah, vented, lead-acid batteries in all applications in which they are used. The 7.5 and 15-Ah batteries contain 12 sealed, lead-acid cells of a cylindrical design connected in series within a container to form a battery with a nominal voltage of 24.0 volts. The 12 cells used in the 30-Ah battery are prismatic in design. Each cell is sealed in a case to prevent acid, acid vapor, and water leakage. A pressure valve on each cell maintains sufficient internal pressure which allows recombination of the gases within the cell.

2. These batteries are designed to remain in the aircraft for up to 2 years without being removed for scheduled maintenance. However, the aircraft battery switch is occasionally left on for indefinite periods of time, usually discharging the battery completely. When this occurs, the battery must be removed from the aircraft and serviced. This is presently accomplished by routing the battery to the IMA lead-acid battery shop. The battery is then charged on existing battery chargers, which are designed to service large, vented, lead-acid batteries. As part of the overall engineering program to develop sealed, lead-acid batteries for use in Navy aircraft, battery servicing procedures were developed for use with the Model 2400A-2 charger and Model 1410-1 discharge unit. Therefore, sealed, lead-acid batteries were not included in this evaluation program.

3. Although the sealed, lead-acid batteries can be accommodated on existing charge/discharge equipment, a small battery charger/tester could be built and made available to Fleet personnel for the purpose of restoring capacity to depleted batteries. The charger could be operated at the squadron level,

thereby reducing and eventually eliminating the need for IMA shop services for lead-acid aircraft batteries. NAVWPNSUPPCEN Crane has developed a specification for this type of unit and has initiated procurement of sample hardware.

D. DESCRIPTION OF NI-CD AIRCRAFT BATTERIES.

1. Ni-Cd batteries which must be supported in the future by equipment such as the NBC-1/1A are listed in Table 1. Ni-Cds provide the greatest cold-temperature, high-rate discharge performance of all the battery types used in Navy aircraft today. They will continue to be used in applications which require battery power for starting of jet engines.

a. Ni-Cd aircraft batteries generally consist of 19 or 20 cells connected in series, resulting in an open-circuit voltage of approximately 24 volts.

b. Each cell is encased in a translucent nylon jar which has a non-spill, removable cap to permit venting of gas and for inspection and/or addition of water or electrolyte. The cells are assembled in steel containers coated with blue epoxy-based paint. The majority of Ni-Cd batteries in service are repairable, allowing replacement of individual cells that are weak or have failed. In the future, the majority of batteries procured will be made non-repairable by impeding the removal and replacement of individual cells. However, this will not impact design of ground support equipment.

c. The electrolyte is a 30 percent (by weight) solution of potassium hydroxide (KOH) with a specific gravity of 1.250-1.300.

2. The following types of batteries were used in the evaluation. These batteries are representative of those currently being used in the Fleet and that are anticipated to be used in the future. Ah capacities shown are battery ratings at the 1-hour discharge rate.

a. P/N 29359-2 is a 5-Ah battery manufactured by Marathon Battery Company. It contains 20 cells, series-connected in two rows of ten cells each which terminate at a quick-disconnect receptacle.

b. Type BB-716 is a 5-Ah battery manufactured by Marathon Battery Company. It contains 20 cells, series-connected in two rows of ten cells each which terminate at a quick-disconnect receptacle.

c. M81757/7-2 is a 10-Ah battery manufactured by SAFT America, Inc. It contains 19 cells, series-connected in two rows of seven cells each and one row of five cells which terminate at a quick-disconnect receptacle.

d. M81757/8-2 is a 20-Ah battery manufactured by SAFT America, Inc. It contains 19 cells, series-connected in two rows of eight cells each and one row of three cells which terminate at a quick-disconnect receptacle.

e. M81757/9-2 is a 30-Ah battery manufactured by SAFT America, Inc. It contains 19 cells, series-connected in two rows of eight cells each and one row of three cells which terminate at a quick-disconnect receptacle.

f. M81757/10-1 is a 6-Ah battery manufactured by SAFT America, Inc. It contains 18 cells, series-connected in three rows of six cells each which terminate at a quick-disconnect receptacle.

g. 43B030RB19 is a 30-Ah battery manufactured by GE. It contains 19 cells, series-connected in two rows of seven cells each and one row of five cells which terminate at a quick-disconnect receptacle.

h. Nineteen cells, type MS90321-78W, rated at 16 Ah, manufactured by Marathon Battery Company, were series-connected in two rows of eight cells each and one row of three cells in a M81757/8-2 battery container terminating at a quick-disconnect receptacle.

i. Nineteen cells, type M81757/1-4, rated at 20 Ah, manufactured by SAFT America, Inc., were series-connected in two rows of eight cells each and one row of three cells in a M81757/8-2 battery container terminating at a quick-disconnect receptacle.

IV. DESCRIPTION OF CHARGE/DISCHARGE EQUIPMENT

A. MODEL NBC-1/1A ALKALINE BATTERY CHARGER-ANALYZER.

1. DESCRIPTION. The NBC-1/1A is a system that is designed for maintenance of nominal 24-volt aircraft type Ni-Cd batteries. The system is capable of both automatic and manual operation. Its battery charge mode is either constant-current (1.0 to 30 amperes) or modified constant-potential (current limit adjustable to 30 amperes maximum). The NBC-1/1A is generally used to charge batteries at a two-step rate. Presently, the high rate is 1C and is automatically reduced to C/3 when a preset battery voltage trip level is reached. Its battery discharge mode is constant-current (1.0 to 30 amperes) and is used for battery testing. The system monitors both the total battery and the individual cell voltages and indicates any voltage which fails to meet a preset acceptance criteria. Cell-scan fixtures are provided for each of the required battery case types and are used in monitoring individual cell voltages during charge and capacity discharge tests. Ni-Cd battery equalization discharge fixtures provide individual resistive loads for each cell, adjusted for a maximum discharge rate of C/2 at nominal cell voltage.

a. Table 2 lists the system characteristics.

b. Based upon an inventory status of August 1982, there are 228 units in world-wide Fleet operation and 166 units in a supply status.

2. PURPOSE. The NBC-1A was included in the evaluation to provide comparative baseline data for all of the test batteries. Results of charging and analyzing batteries with the NBC-1/1A are considered quite good. Without the baseline data, a quantitative performance evaluation of other charge-discharge techniques would be difficult.

TABLE 2. SYSTEM CHARACTERISTICS OF NBC-1/1A ALKALINE BATTERY CHARGER/ANALYZER

Input Power Requirements	115 or 230 VAC (+10%) single-phase 50-60 Hz, 10A maximum
Constant-Current Charge Regulation	For each setting of the charge-current control over the range 1 to 30 amperes, the output current shall remain within ±2% of the value set for an output voltage of 0-30 volts.
Modified Constant-Potential Charge Regulation	For each setting of the battery-voltage control over the range of 10 to 30 volts, the output voltage shall remain within ±1% of the voltage set for a change in output current of 1 to 30 amperes. The current limit is adjustable between 1 to 30 amperes.
Constant-Current Discharge Regulation	For each setting of the discharge-current control over the range of 1 to 30 amperes, the discharge current shall remain within ±2% of the value set over a range of 12 to 30 volts.
Temperature Ranges	Operating: -20°C to 51°C, 0°F to 125°F Storage: -62°C to 70°C, -79°F to 160°F
Altitude	Operating: 0 to 6,000 feet Storage: 0 to 50,000 feet
Total Heat Dissipation	1150 watts maximum
Cooling	The unit is cooled by forced air from an internal fan.
Size	NBC-1: 21" height, 17" depth, 20" width NBC-1A: 24" height, 17" depth, 20" width
Weight	NBC-1: 106 lbs. exclusive of battery fixtures and cables. NBC-1A: 108 lbs. exclusive of battery fixtures and cables.

B. MODEL 2400-2 AUTOMATIC BATTERY CHARGER.

1. DESCRIPTION. The 2400A-2 is presently used in lead-acid battery shops to charge all vented and sealed, lead-acid aircraft batteries, as well as many lead-acid ground support equipment batteries. Once the unit has been preset by an operator, it automatically charges one battery at a time at a constant-current rate of 1-59 amperes. Battery voltage, temperature, and charging rates are continuously monitored, allowing unattended operation with minimal risk of overheating or overcharge. The 2400A-2 can provide a voltage-controlled, two-step charge to the battery. Once the charger switches from a high to a low charge rate, the amount of topping charge the battery receives is a preselected percentage of the main charge measured in ampere-hours.

a. Table 3 lists the system characteristics.

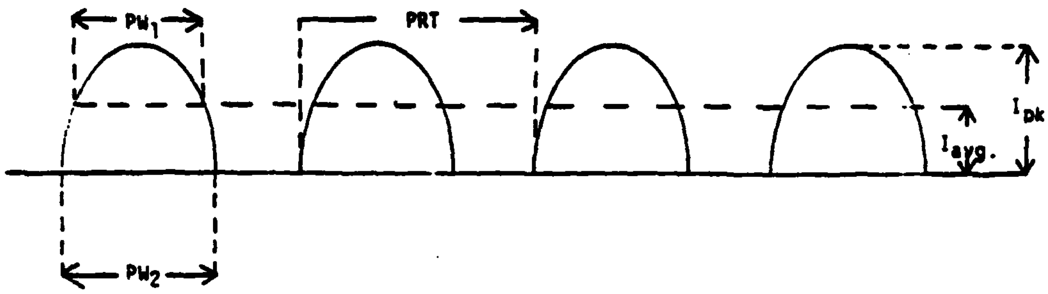
b. Although the Model 2400A-2 is presently used to charge lead-acid batteries, it is actually a pulse charger. Table 4, in conjunction with Figure 1, defines the characteristics of the charging pulse for each selectable setting of the charge-current control.

c. Based upon an inventory report of August 1982, there are 152 2400A-2 units in world-wide Fleet operations and 113 in a supply status.

2. PURPOSE. The 2400A-2 was included in the evaluation because of its pulse-charge output capability. The pulse-charge output was evaluated for its performance in charging various sizes of Ni-Cd aircraft batteries. Of special interest is the fact that this pulse charger is commercially available in production quantities and in fact, is already present in the Fleet for use in lead-acid battery shops. The 2400A-2 has no discharge or cell scan circuitry; consequently, these functions were performed by standard laboratory test equipment.

TABLE 3. SYSTEM CHARACTERISTICS OF 2400A-2 AUTOMATIC BATTERY CHARGER

Input Power Requirements	115 VAC, 40A max. or 230 VAC, 20A (nominal), 50-60 Hz
Charge Output	0-40 VDC, 1-59A average, 100A RMS (See Table 4 and Figure 1 for output pulse characteristics.)
Cooling	The unit is cooled by forced air from an internal fan.
Size	18.25" height, 13.0" depth, 10.75" width
Weight	115 pounds



PW_1 = Pulse Width @ 50% Level*

PW_2 = Pulse Width @ 0 Ampere*

PRT = Pulse Repetition Time = 8.33 ms

I_{avg} = Average Amperes*

I_{pk} = Peak Amperes*

*Values of these parameters are contained in Table IV.

Figure 1. Model 2400A-2 Output Waveform

TABLE 4. MODEL 2400A-2 OUTPUT PULSE PARAMETERS

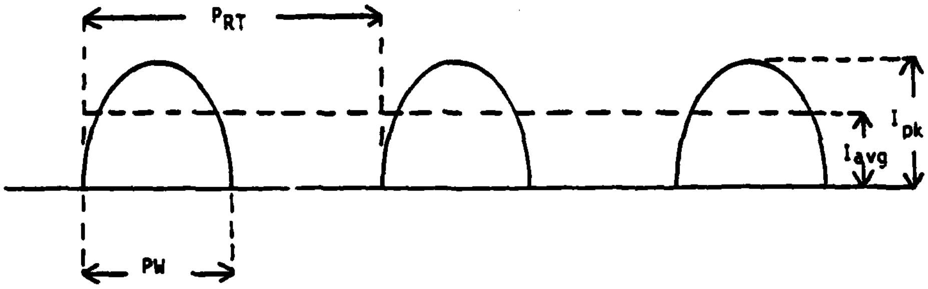
Averge Amperes (I avg.)	Pulse Width (PW)*		Peak Current (I pk)
	PW_1 @ 50% Ipk	PW_2 @ 0% Ipk	
1	0.8	1.0	12.5
2	0.9	1.3	20.0
3	1.1	1.4	26.0
4	1.2	1.6	31.0
5	1.3	1.7	36.0
6	1.3	1.8	42.0
7	1.3	1.9	46.0
8	1.4	2.0	50.0
9	1.5	2.2	54.0
10	1.5	2.2	58.0
15	1.8	2.5	75.0
20	2.0	2.8	92.0
25	2.2	3.0	106.0
30	2.2	3.2	120.0
35	2.4	3.4	132.0
40	2.4	3.5	148.0
45	2.4	3.6	160.0
50	2.4	3.8	180.0
55	2.4	3.8	200.0
59	2.4	4.0	210.0

*Pulse width (PW) is measured in milliseconds. PW_1 and PW_2 are illustrated in Figure 1.

C. MODEL 3000A AUTOMATIC BATTERY CHARGER.

1. DESCRIPTION. The 3000A was designed and manufactured by URDC as an automatic pulse charger for Ni-Cd batteries. It has a certain degree of built-in flexibility to enable evaluation of pulse-charge techniques. The operator can adjust the average charge current in the main and topping charge modes; the peak level of charge current; the mode change trip voltage level; and the percentage of overcharge in the topping charge mode. Once these values are set, the unit automatically charges one battery at a time, with half-sine wave pulses of 8.33 milliseconds (ms) in duration, with an average constant current of 0-50A, into a battery of up to 24V nominal.

a. Table 5 lists the system characteristics and Figure 2 defines the characteristics of the charging pulse. As noted in Figure 2, the pulse width is always constant at 8.33 ms, and the OFF time between consecutive pulses varies randomly to maintain the preset average charge-current value. Typically, the OFF time is 40-120 ms, depending upon the combination of peak current and average current seetings.



PW = Pulse Width = 8.33 ms

I_{pk} = Peak Current = 0-500 amperes

I_{avg} = Average Current = 0-50 amperes

PRT = Pulse Repetition Time: The off-time varies randomly to maintain the average charge current value.

Figure 2. Model 3000A Output Waveform

2. PURPOSE. The 3000A was included in the evaluation because of its pulse-charge output capability. The pulse-charge output was evaluated for its performance in charging various sizes of Ni-Cd batteries. The 3000A has no discharge or cell scan circuitry; consequently, these functions were performed by standard laboratory test equipment.

TABLE 5. SYSTEM CHARACTERISTICS OF 3000A AUTOMATIC BATTERY CHARGER

Input Power Requirements	115 VAC or 230 VAC, 40A maximum, 50-400 Hz
Charge Output	0-35 VDC, 0-50A average, 0-500A peak current (See Figure 2 for output pulse characteristics.)
Parameter Adjustability	Peak current (I_{pk}) = 0-500A Average current (I_{avg}) = 0-50A Percent ov overcharge = 0-100%

D. DC POWER SUPPLIES.

1. DESCRIPTION. The power supplies provide a precise and highly-regulated DC output, adjustable from 0-50 VDC and 0-300A. There are two basic operating modes: voltage and current. In the voltage mode, the voltage is held constant while the current varies with the load. In the current mode, the voltage varies, and the current is held constant. An automatic crossover feature enables the units to switch operating modes as a function of load requirements and preset voltage and current values.

2. PURPOSE. The power supplies were used to charge the test batteries using constant-current and constant-potential charge methods.

a. For constant-current charging, operation of the NBC-1/1A was essentially duplicated. Use of the power supplies enabled a greater number of batteries to be evaluated using constant-current charge techniques.

b. During the evaluation of high-rate discharge techniques, the batteries were occasionally charged at a constant-potential of 28.25 $\pm$0.25 VDC for the sake of reduced test time and convenience.

E. MODEL 1410 BATTERY ANALYZER/LOAD BANK.

1. DESCRIPTION. The 1410, designed and manufactured by URDC, is currently used in Navy battery shops to discharge and analyze lead-acid aircraft batteries. The 1410 is used in conjunction with the 2400A-2 battery charger to determine if the battery's actual capacity meets the minimum requirements. Termination of discharge can be either manual or automatic. In the automatic mode, discharge termination is dependent upon battery voltage under load.

a. System characteristics for the 1410 are shown in Table 6.

b. Based upon an inventory report of August 1982, there are eighty-seven 1410 units in world-wide Fleet operation and ninety-six in a supply status.

2. PURPOSE. The 1410 was utilized in the evaluation because of its capability to discharge batteries at constant-current rates. Unlike the NBC-1/1A, the 1410A has no cell scan and measurement capability; therefore, standard laboratory test equipment was used to monitor and record battery and cell data.

TABLE 6. SYSTEM CHARACTERISTICS OF 1410 BATTERY ANALYZER/LOAD BANK

1410 Input Power	115 VAC, 60 Hz
1410A Input Power	230 VAC, 50 Hz
Discharge Rate	0-50 Amperes
Cutoff Voltage	1-25V, adjustable with 10 turn pot
Accuracy	Current regulation ±2%, meters 2% of full scale
Cooling	Internal fan
Size	15-1/2" wide, 9-1/2" high, 14" deep
Weight	22 pounds

F. MODEL PSE^{2}L-1000, ELECTRONIC DC LOAD BANK.

1. DESCRIPTION. The PS^{2}L-1000 load bank, manufactured by ACME Electric Corporation, was designed for use in the laboratory. It provides static and dynamic DC loading capabilities for an infinite number of voltage-current combinations, both as constant-current and constant-resistance. It can dissipate a maximum of 1000 watts at a current level up to 110A, with 1 percent regulation.

2. PURPOSE. The PS^{2}L-1000 was utilized in the evaluation because of its capability to discharge batteries at constant-current rates. This unit has no cell scan and measurement capability; therefore, standard laboratory test equipment was used to monitor and record battery and cell data.

G. MODEL PBT 2000-24 BATTERY PROFILE TESTER.

1. DESCRIPTION. The PBT 2000-24 battery profile tester, manufactured by Propel, Inc., was designed for use in the laboratory to simulate a multitude of battery discharge load requirements. It can discharge a battery at rates up to 2000A within a voltage range of 4-24 volts, with maximum dissipation of 24 KW. The method of discharge can be any combination of constant-current, increasing/decreasing current ramps, constant-voltage, and constant-resistance.

2. PURPOSE. The PBT 2000-24 was used to evaluate high-rate discharge test methods for Ni-Cd aircraft batteries.

H. MISCELLANEOUS DATA MEASUREMENT AND RECORDING EQUIPMENT.

1. Following is a list of the miscellaneous test equipment used in the evaluation. All of the equipment was calibrated.

a. Monitor Labs Model 9300 data logger.

b. Data Precision digital panel voltage meters.

c. Doric Model DS 500 multichannel digital thermocouple indicator.

d. Curtis Model 10002 millivolt hour (ampere-hour) counter.

e. Gould Model 110 duel-channel recorder.

f. Tenney hot-cold temperature chamber.

g. Several sizes of millivolt-ampere current shunts.

V. TEST DESCRIPTIONS AND RESULTS - CHARGE TECHNIQUES

A. TEST MATRIX.

1. Shown in Table 7 is the combination of test battery sizes and charge methods that were evaluted.

TABLE 7. BATTERY CHARGING TEST MATRIX

Charge Rates/Methods	Battery Sizes 5-Ah	10-Ah	20-Ah	30-Ah
C/5 Constant-Current		X	X	X
1C Constant-Current	X	X	X	X
2C Constant-Current	X	X	X	X
1C Pulse - 2400A	X	X	X	X
1.5C Pulse - 2400A				X
2C Pulse - 2400A	X	X	X	
1C Pulse - 3000A	X	X	X	X
1.5C Pulse - 3000A				X
2C Pulse - 3000A	X	X	X	

B. TEST DATA.

1. All of the test data recorded during the evaluation of charge techniques are summarized in Tables 8 through 10 and in Figures 3A through 10B. Included in the tables and figures is information such as "charge ampere hours", "discharge ampere-hours", and the ratio of Ah out vs. Ah in--considered as a "charge efficiency" from 0-100 percent, and "battery temperature" rise as a function of charge technique. The data graphs are consolidated by battery type with the various charge rates displayed sequentially as performed. The graphs include discharge capacity, the amount of charge into the battery at the high charge rate, the subsequent amount of charge at the low charge rate, and the total charge input to the battery.

C. BATTERY EQUALIZATION.

1. Prior to each cycling regime, the respective test batteries were subjected to an equalization discharge. This was accomplished by discharging the batteries at the 1C rate to 18.0V and continuing the discharge of each cell to 0.0V using individual 0.5-ohm resistors. The batteries were always maintained at 0.0V for a minimum of 24 hours.

D. C/5 CONSTANT CURRENT CHARGE.

1. Two batteries each of the 10-Ah, 20-Ah, and 30-Ah sizes were cycled as follows:

a. Equalize at 0.0V for minimum of 24 hours.

b. Charge at the constant-current C/5 rate of the battery (2A, 4A, 6A) until battery voltage stabilizes during a 1-hour period.

c. Rest open-circuit for 2 hours.

d. Check electrolyte levels and adjust as necessary.

e. Continue open-circuit rest for 20-68 hours.

f. Discharge at the constant-current 1C rate of the battery (10A, 20A, 30A) to 18.0V.

g. Repeat steps b through f for a total of five charge/discharge cycles.

2. The constant-current charge method at the C/5 rate was included in the evaluation to establish a data baseline for the batteries from which all charge techniques could be compared. It was the first charge regime of the evaluation and provided characterization data for each 10-, 20-, and 30-Ah battery tested. As indicated in the cycling procedure, the end of charge was not determined by an arbitrarily selected battery voltage, but occurred at a point when the battery could no longer convert energy efficiently.

TABLE 8. SUMMARY OF 10-AH BATTERY DATA

Charge Method	Constant Current C/5	Constant Current 1C	Constant Current 2C	2400 Pulse 1C	2400 Pulse 2C	3000 Pulse 1C	3000 Pulse 2C
Main Charge (A)	2.0	10.0	20.0	10.0	20.0	10.0	20.0
Topping Charge (A)	-	4.0	4.0	4.0	4.0	4.0	4.0
Main-Topping Trip (V)	-	29.5	31.0	29.5	31.0	29.5	31.0
Charge Time (Hrs)	8.90	2.07	1.33	2.0	1.31	1.93	1.42
Charge Input (Ah)	18.27	16.85	17.0	16.55	16.86	16.57	16.92
Discharge Output (Ah)	12.45	14.08	4.13	13.58	13.59	13.69	13.91
Battery Efficiency (%)	68.1	83.5	83.1	82.0	80.6	82.6	82.2
Temp Start Charge (^oF)	75.0	73.4	75.8	75.5	72.0	76.3	72.7
Temp End Charge (^oF)	77.1	76.5	80.3	83.1	84.9	86.6	88.0
Charge ΔT (^oF)	2.1	3.1	4.5	7.6	12.9	10.3	15.3
Temp Start Discharge (^oF)	74.8	79.5	79.8	80.6	79.9	81.1	81.1
Temp End Discharge (^oF)	87.4	88.7	90.7	95.1	94.5	92.6	94.7
Discharge ΔT (^oF)	12.6	9.2	10.9	14.5	14.6	11.5	13.6

TABLE 9. SUMMARY OF 20-AH BATTERY DATA

Charge Method	Constant Current C/5	Constant Current 1C	Constant Current 2C	2400 Pulse 1C	2400 Pulse 2C	3000 Pulse 1C	3000 Pulse 2C
Main Charge (A)	4.0	20.0	40.0	20.0	40.0	20.0	40.0
Topping Charge (A)	-	7.0	7.0	7.0	7.0	7.0	7.0
Main-Topping Trip (V)	-	29.5	31.0	29.5	30.0	29.5	30.0
Charge Time (Hrs)	7.20	1.88	1.26	1.73	1.25	1.85	1.18
Charge Input (Ah)	29.09	29.01	29.13	27.73	28.12	29.37	28.46
Discharge Output (Ah)	29.68	24.33	24.34	23.40	23.50	24.33	24.33
Battery Efficiency (%)	71.1	83.9	83.6	84.4	83.6	82.8	85.5
Temp Start Charge (°F)	75.8	74.1	75.5	74.0	75.1	74.3	75.5
Temp End Charge (°F)	80.4	77.1	81.3	81.0	85.8	83.8	83.6
Charge ΔT (°F)	4.2	3.0	5.8	7.0	10.7	9.5	8.1
Temp Start Discharge (°F)	75.4	82.7	83.2	82.8	83.1	83.2	82.3
Temp End Discharge (°F)	89.5	96.7	99.3	96.6	97.2	93.4	94.8
Discharge ΔT (°F)	14.1	14.0	16.1	13.8	14.1	10.2	12.5

TABLE 10. SUMMARY OF 30-AH BATTERY DATA

Charge Method	Constant Current C/5	Constant Current 1C	Constant Current 2C	2400 Pulse 1C	2400 Pulse 1.5C	3000 Pulse 1C	3000 Pulse 1.5C
Main Charge (A)	6.0	30.0	60.0	30.0	45.0	30.0	45.0
Topping Charge (A)	-	10.0	10.0	10.0	10.0	10.0	10.0
Main-Topping Trip (V)	-	29.5	31.0	29.5	30.0	29.5	30.0
Charge Time (Hrs)	8.20	2.0	1.33	2.0	1.56	1.94	1.38
Charge Input (Ah)	50.15	47.12	47.41	46.80	47.11	46.97	45.58
Discharge Output (Ah)	35.48	39.86	39.96	39.14	39.57	38.75	38.56
Battery Efficiency (%)	70.7	84.6	84.3	83.6	84.0	82.5	84.6
Temp Start Charge (°F)	76.6	76.0	76.0	76.8	77.5	76.2	77.3
Temp End Charge (°F)	81.3	78.3	83.4	85.5	90.0	84.5	86.3
Charge ΔT (°F)	4.7	2.3	7.4	8.7	12.5	8.3	9.0
Temp Start Discharge (°F)	74.9	84.1	84.2	85.6	84.9	83.6	83.4
Temp End Discharge (°F)	95.6	103.5	102.1	102.4	103.8	97.1	100.1
Discharge ΔT (°F)	20.7	19.4	17.9	16.8	18.9	13.5	16.7

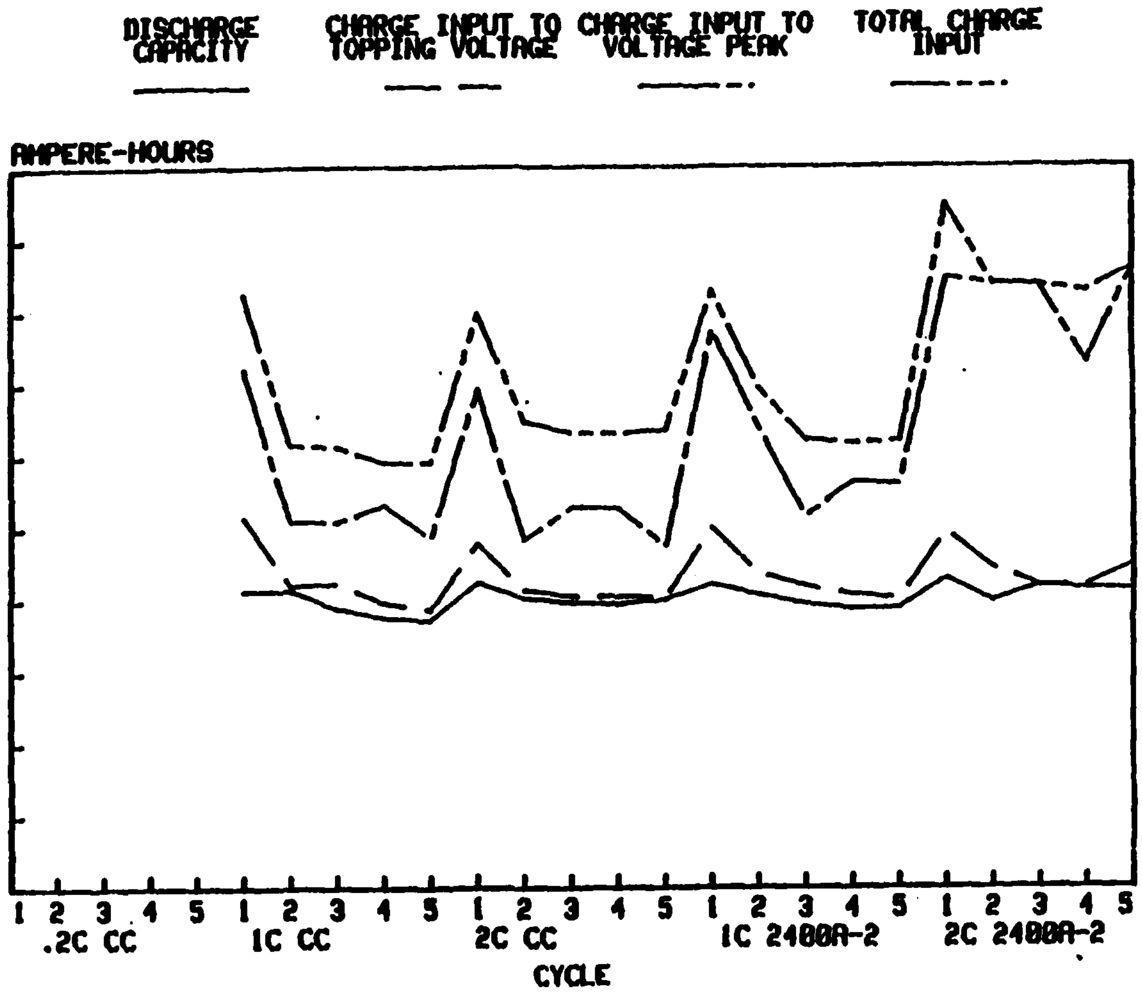


Figure 3A. Charge and Discharge Graph for Type BB-716/A Serial No. 8214380

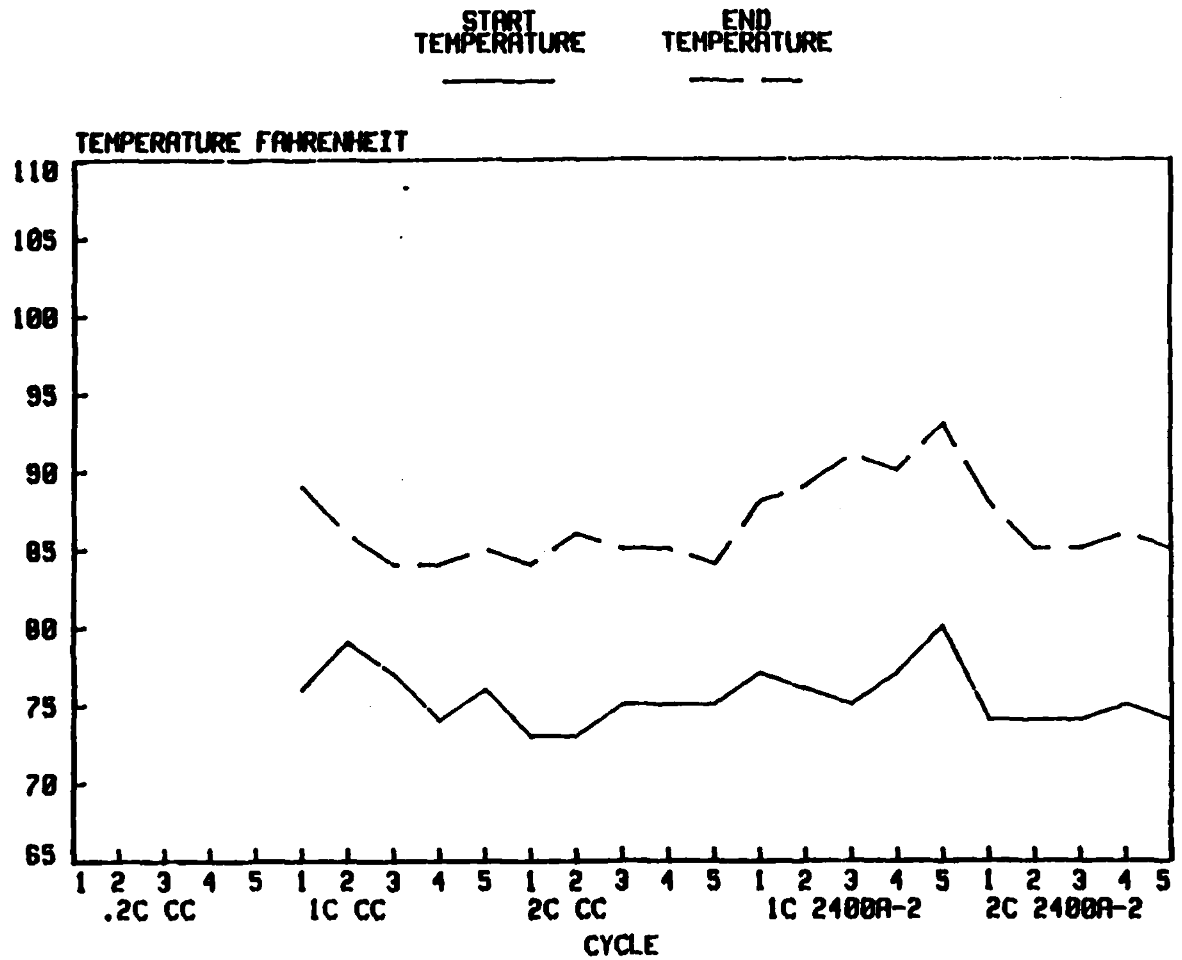


Figure 3B. Charge Temperature Chart for Type BB-716/A Serial No. 8214380

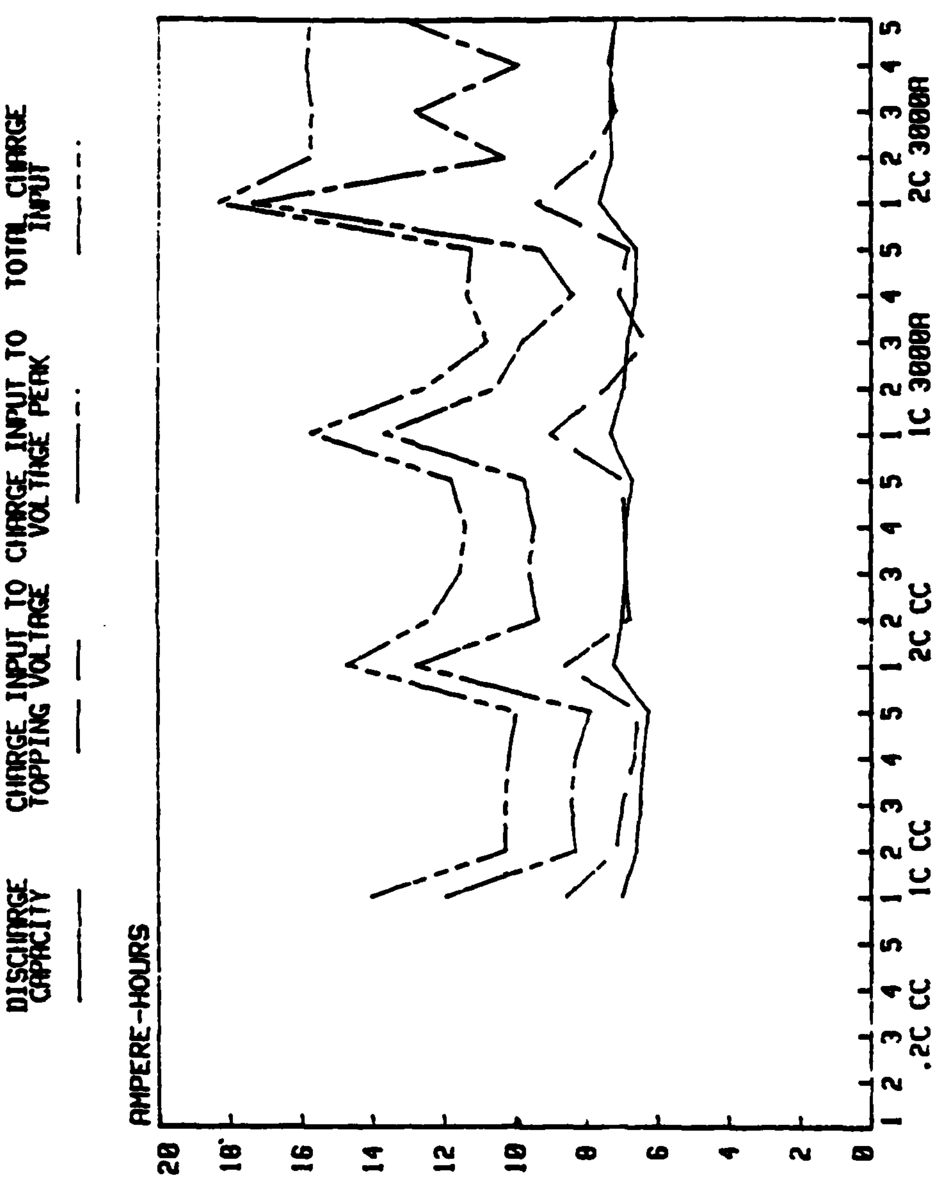


Figure 4A. Charge and Discharge Graph for Type 29359-2 Serial No. 8003389

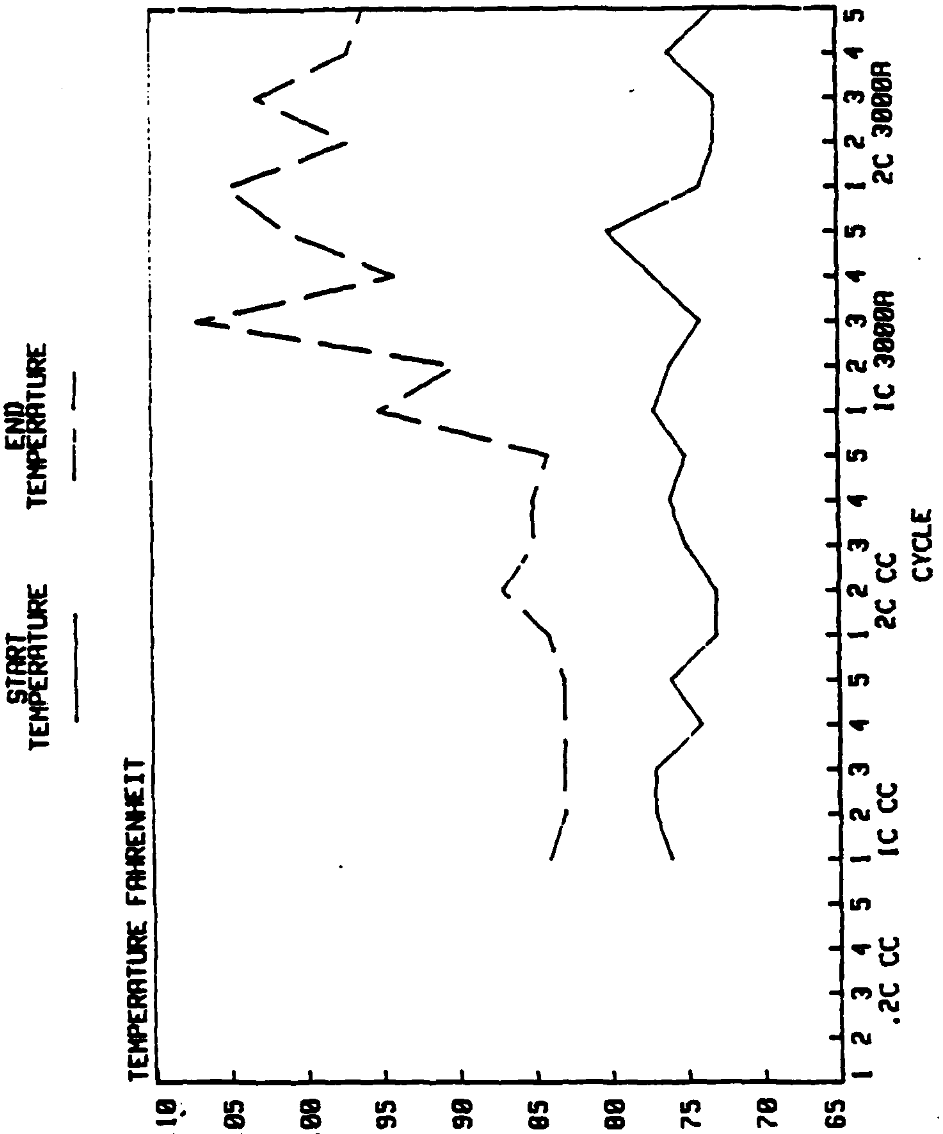


Figure 4B. Charge Temperature Chart for Type 29359-2 Serial No. 8003389

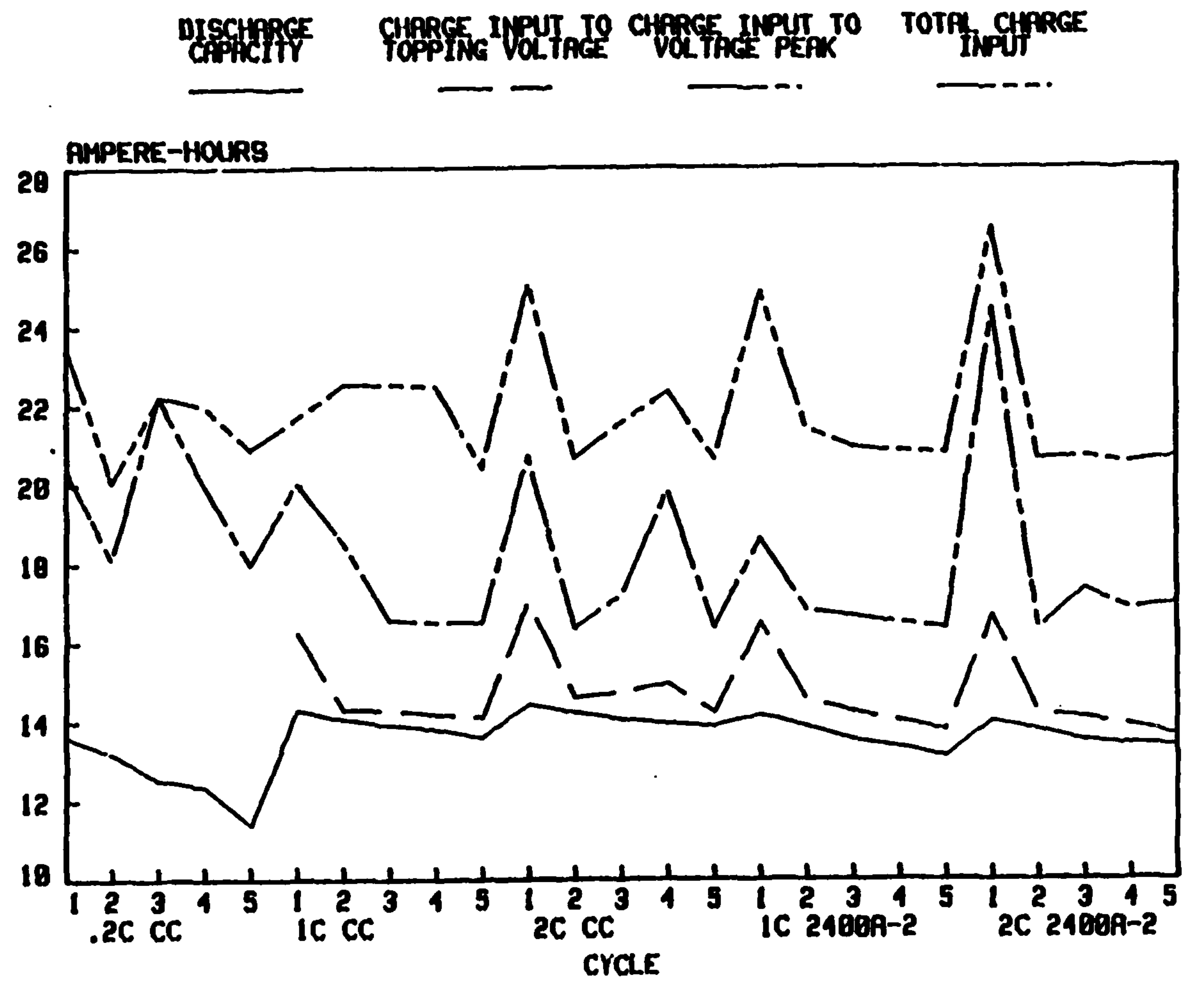


Figure 5A. Charge and Discharge Graph for Type M81757/7-2 Serial No. 76817

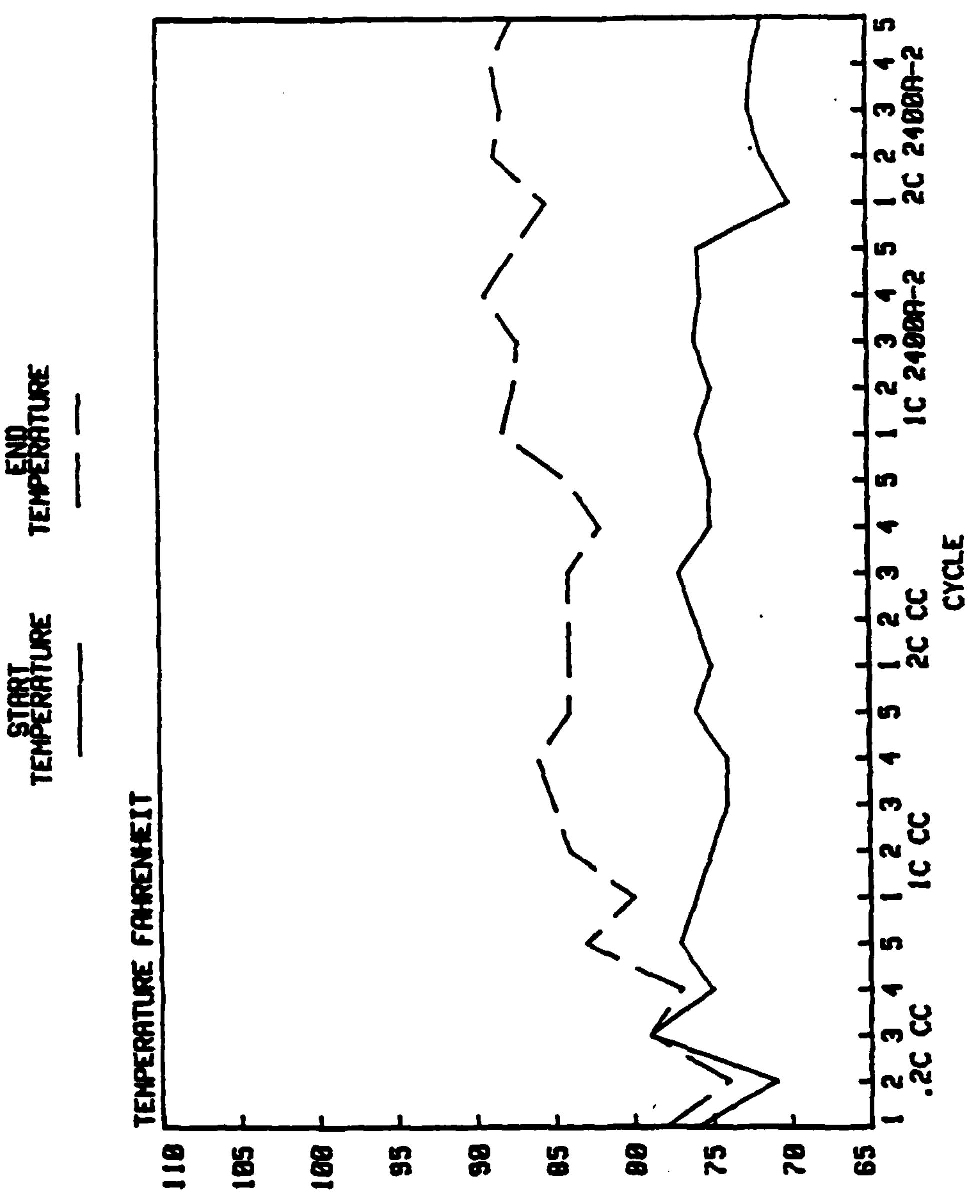


Figure 5B. Charge Temperature Chart for Type M81757/7-2 Serial No. 76817

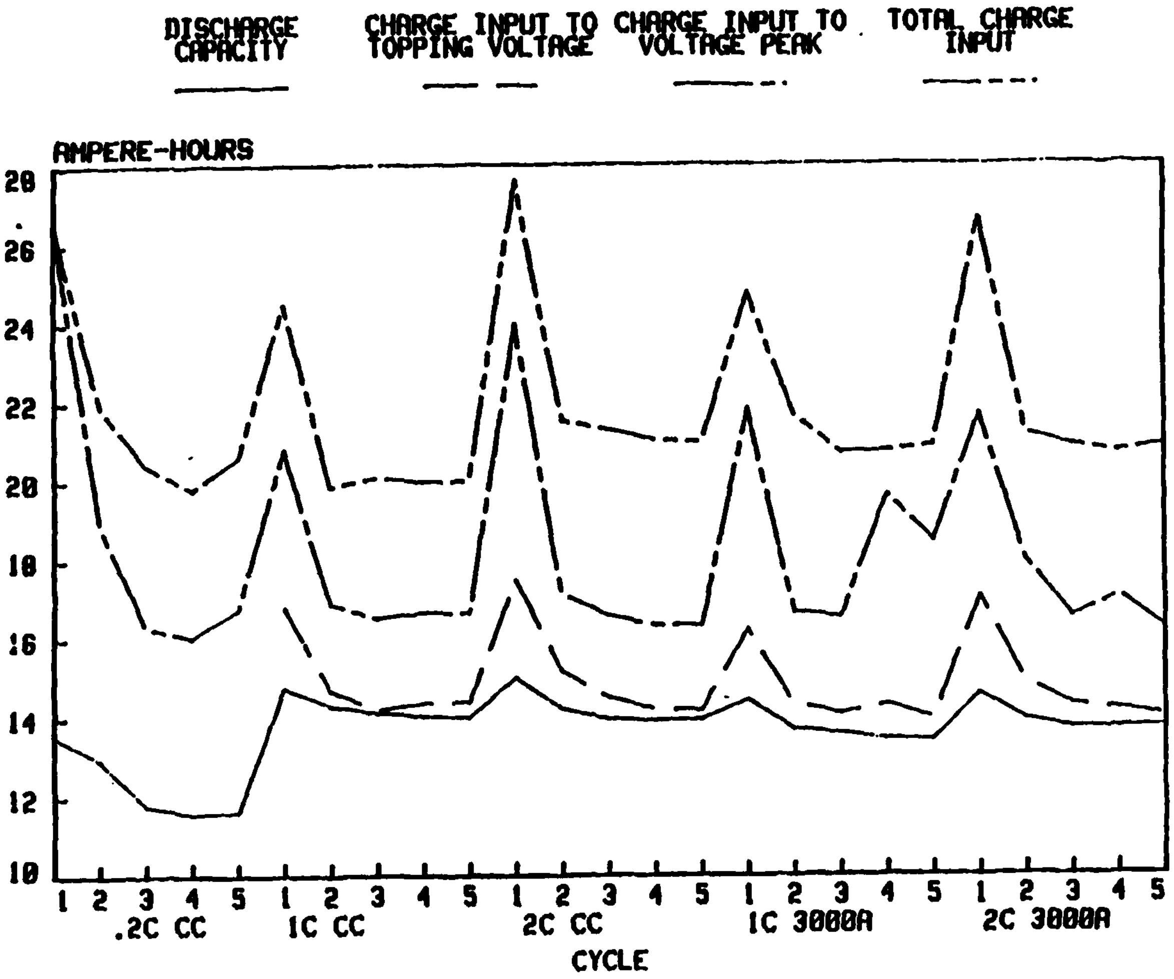


Figure 6A. Charge and Discharge Graph for Type M81757/7-2 Serial No. 76822

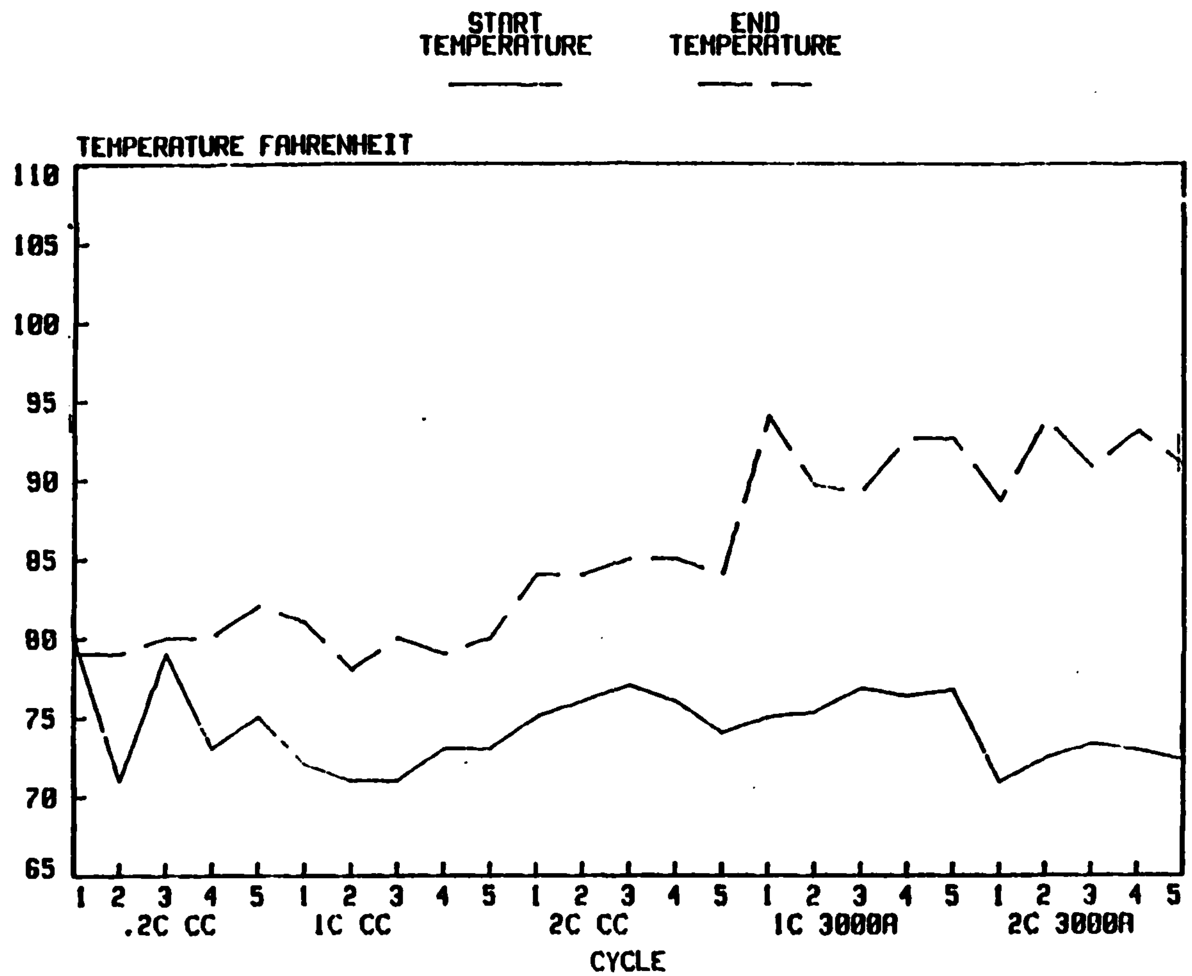


Figure 6B. Charge Temperature Chart for
Type M81757/7-2 Serial No. 76822

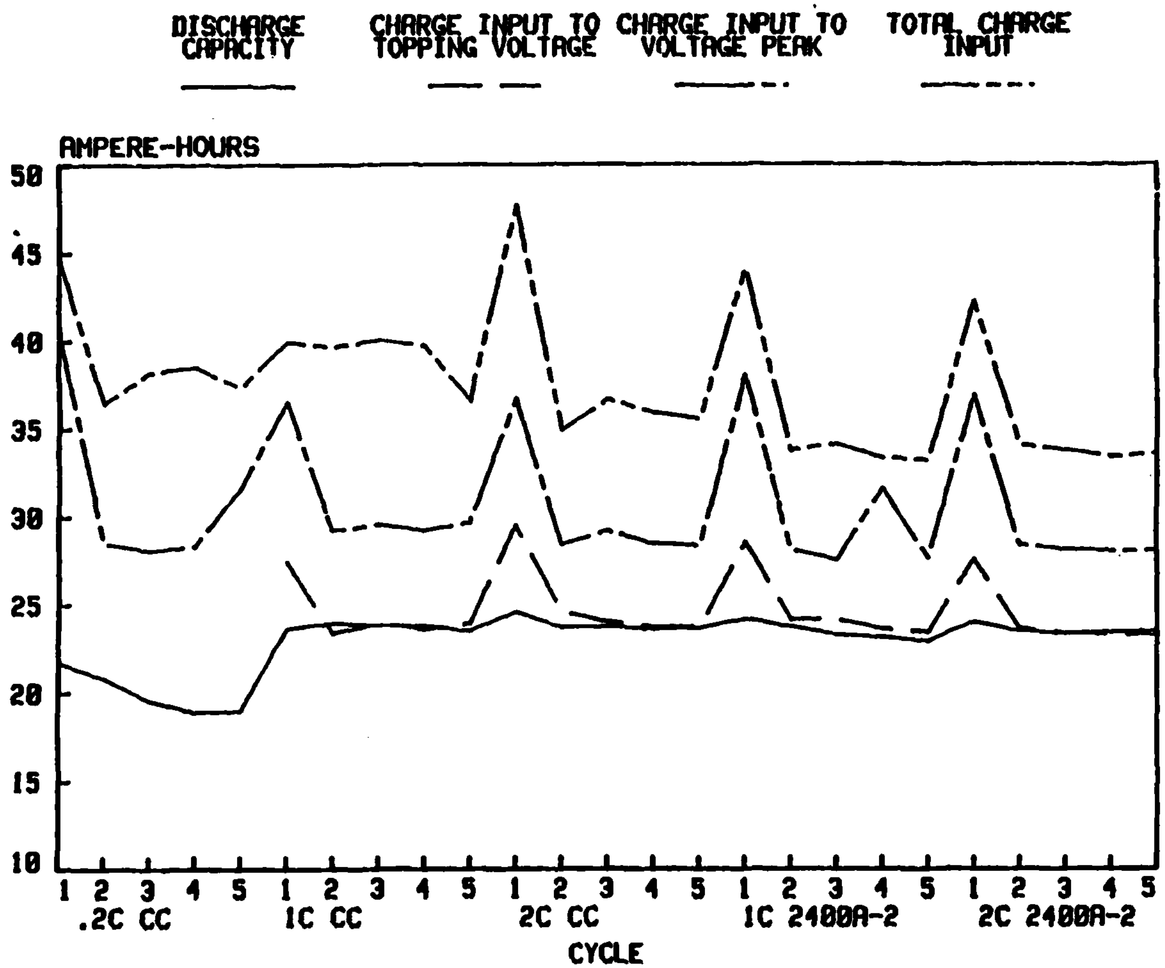


Figure 7A. Charge and Discharge Graph for
Type M81757/8-2 Serial No. 74227

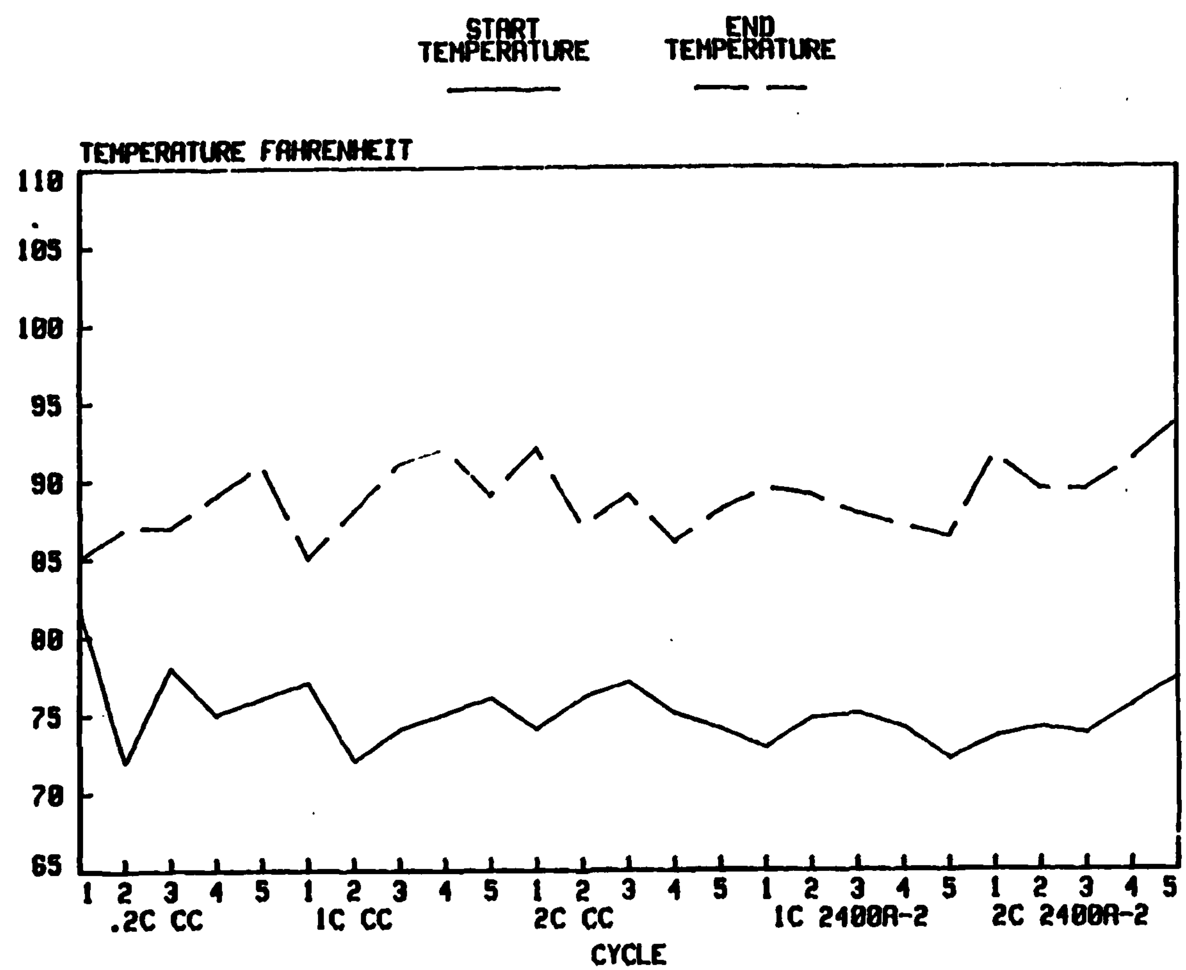


Figure 7B. Charge Temperature Chart for
Type M81757/8-2 Serial No. 74227

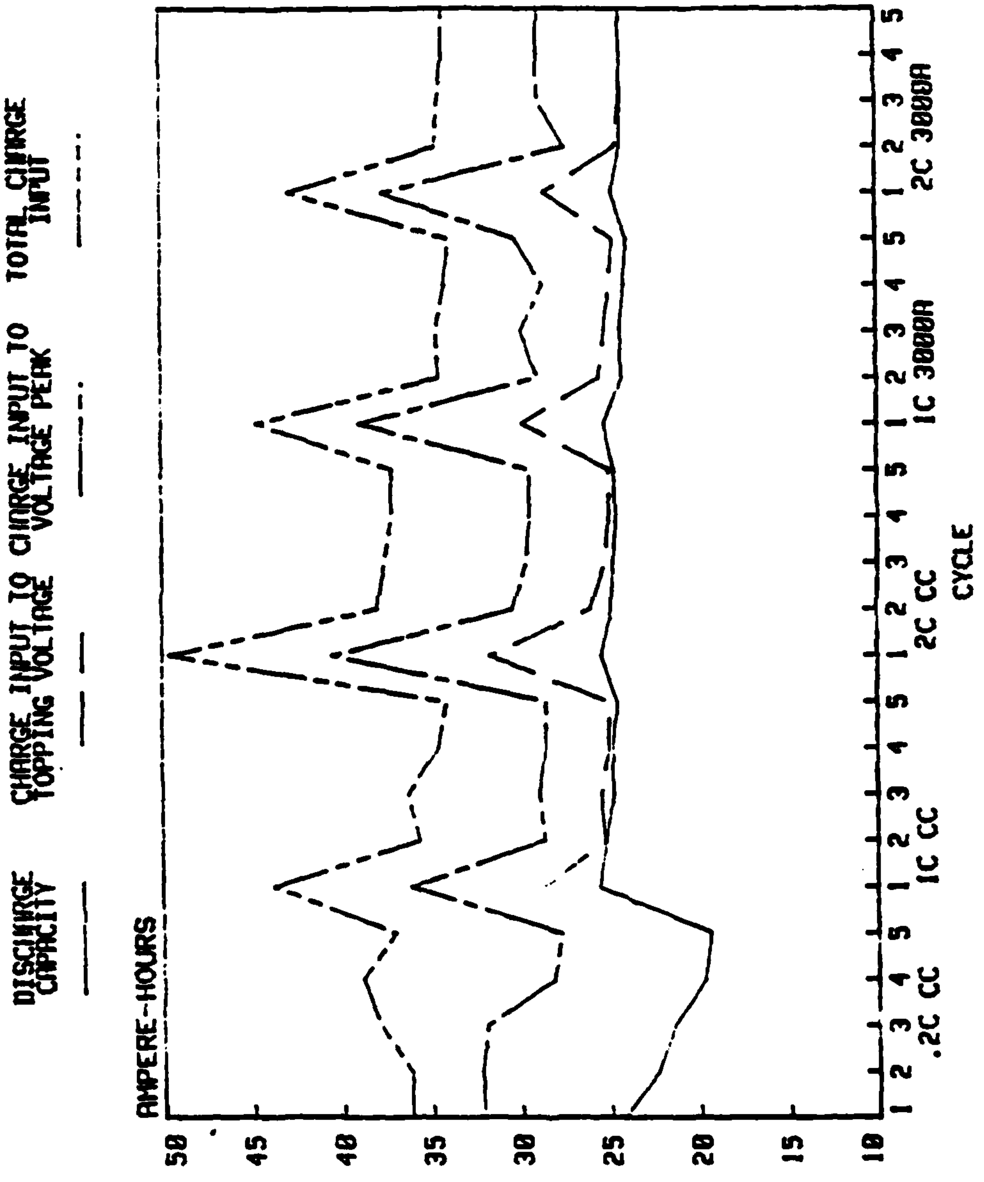


Figure 8A. Charge and Discharge Graph for Type M81757/8-2 Serial No. 74231

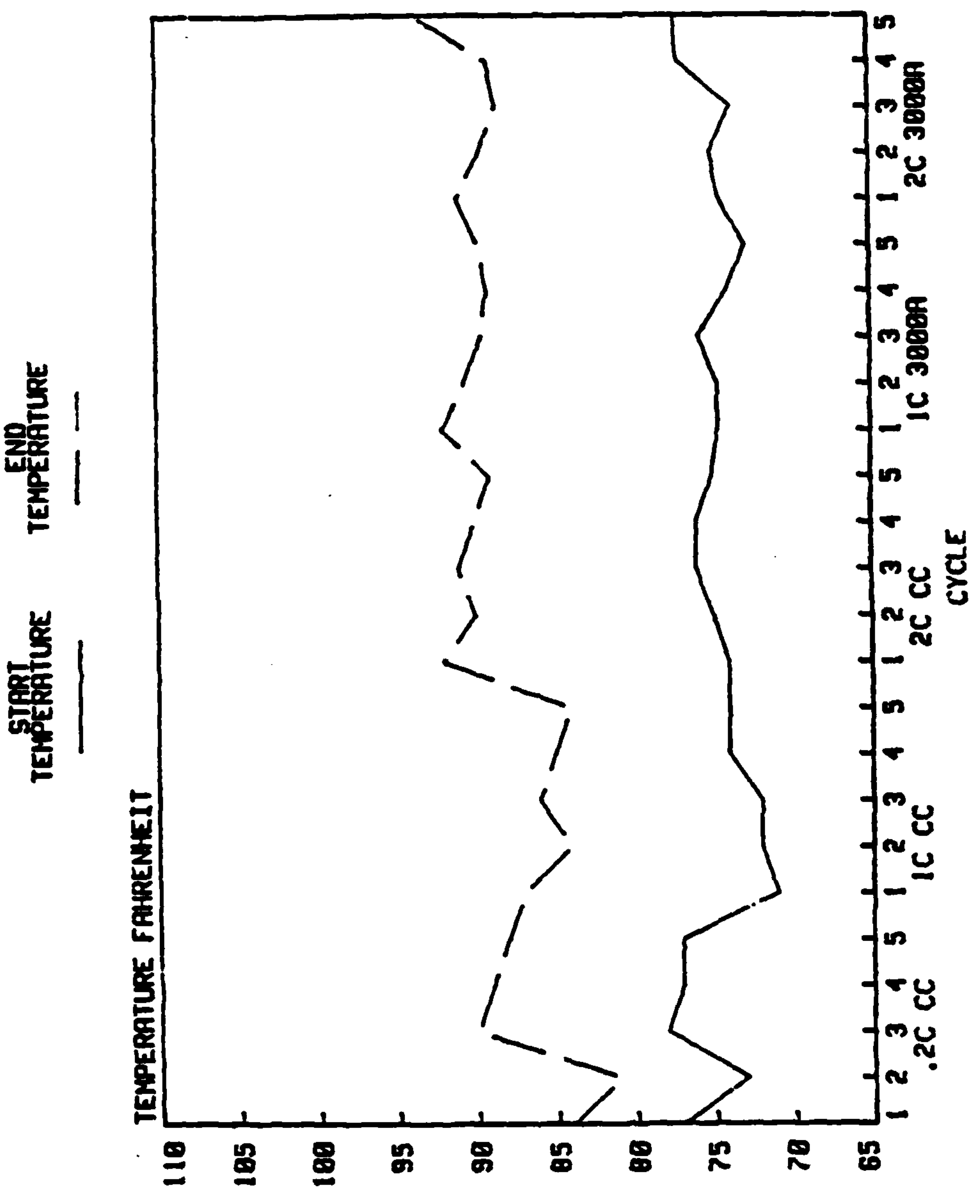


Figure 8B. Charge Temperature Chart for Type MB1757/8-2 Serial No. 74231

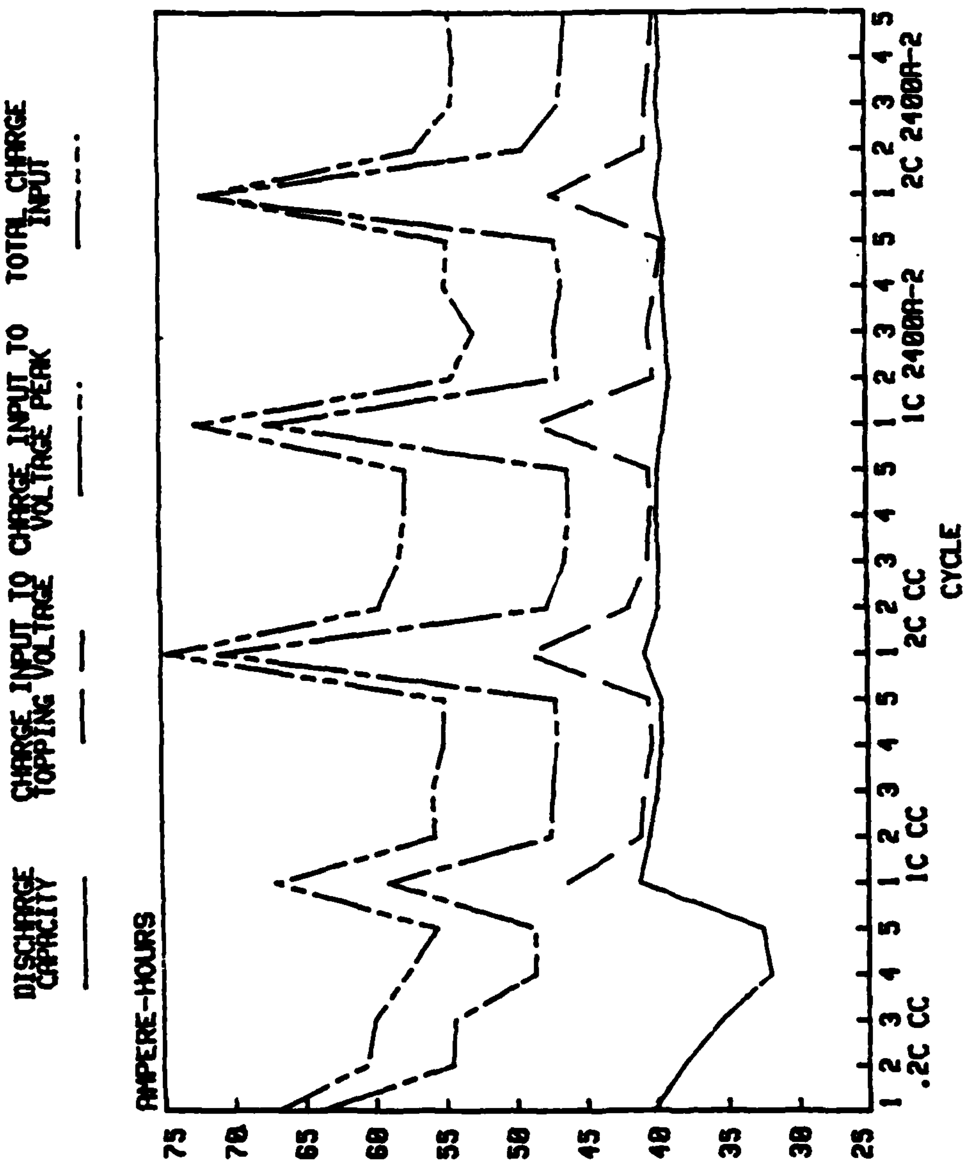


Figure 9A. Charge and Discharge Graph for Type M81757/9-2 Serial No. 57545

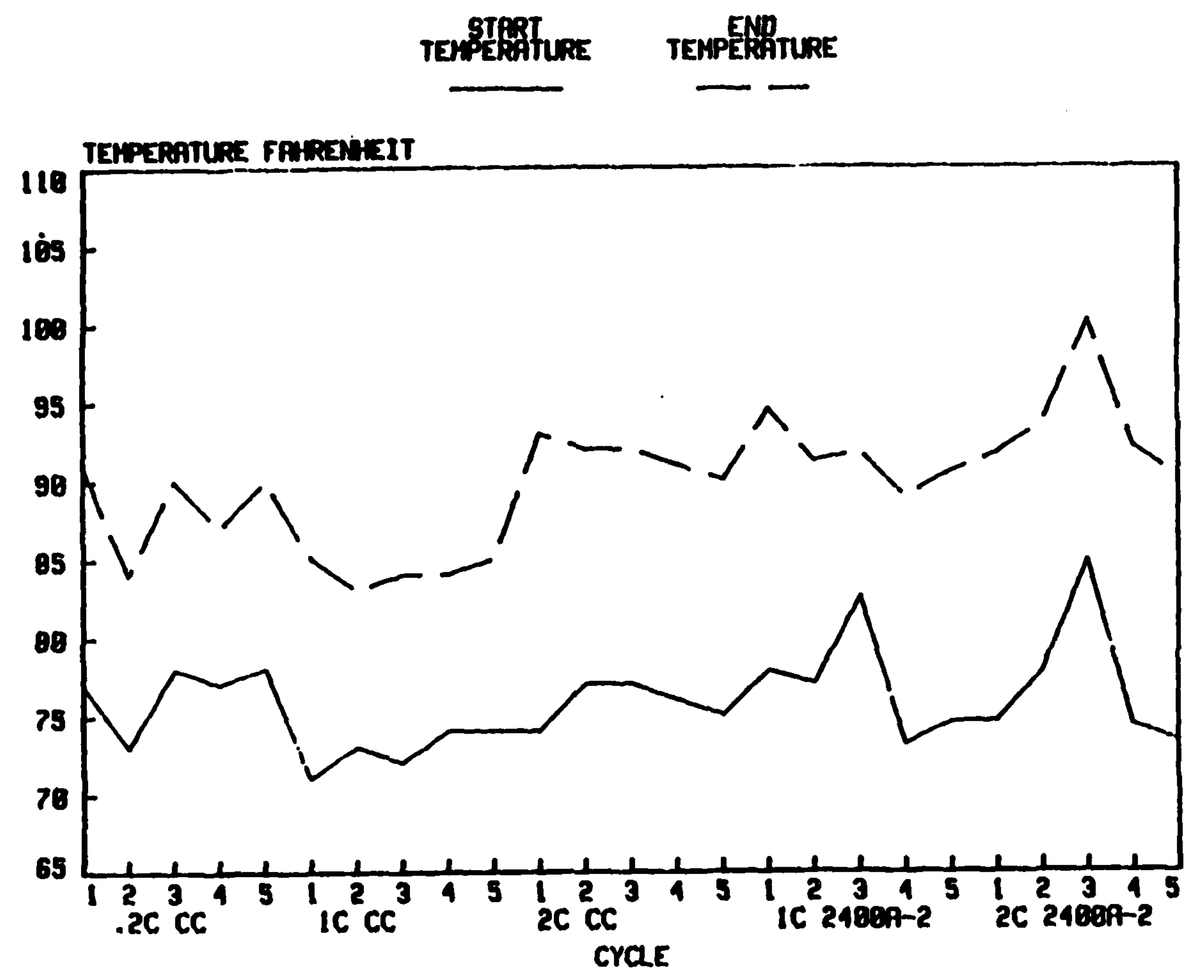


Figure 9B. Charge Temperature Chart for
Type M81757/9-2 Serial No. 57545

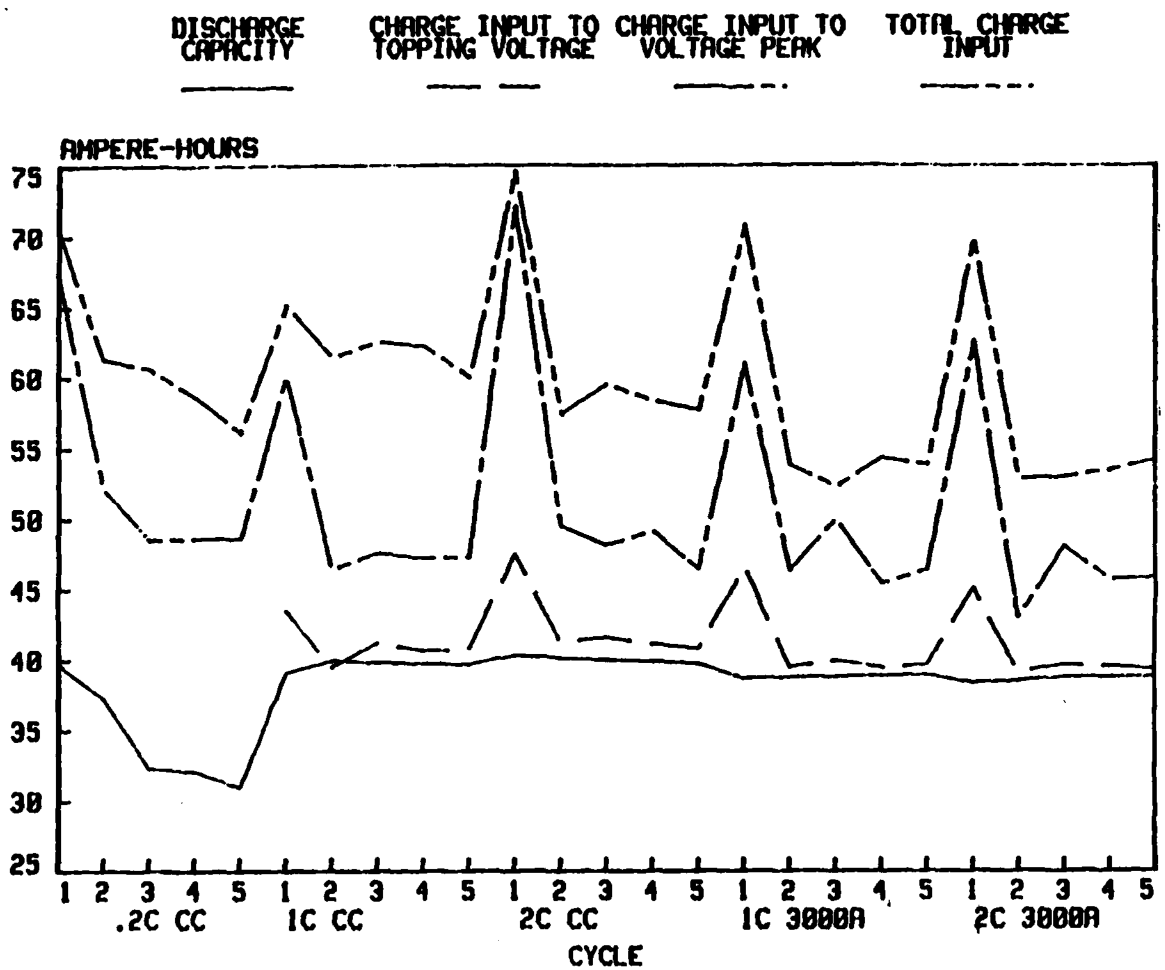


Figure 10A. Charge and Discharge Graph for Type M81757/9-2 Serial No. 57542

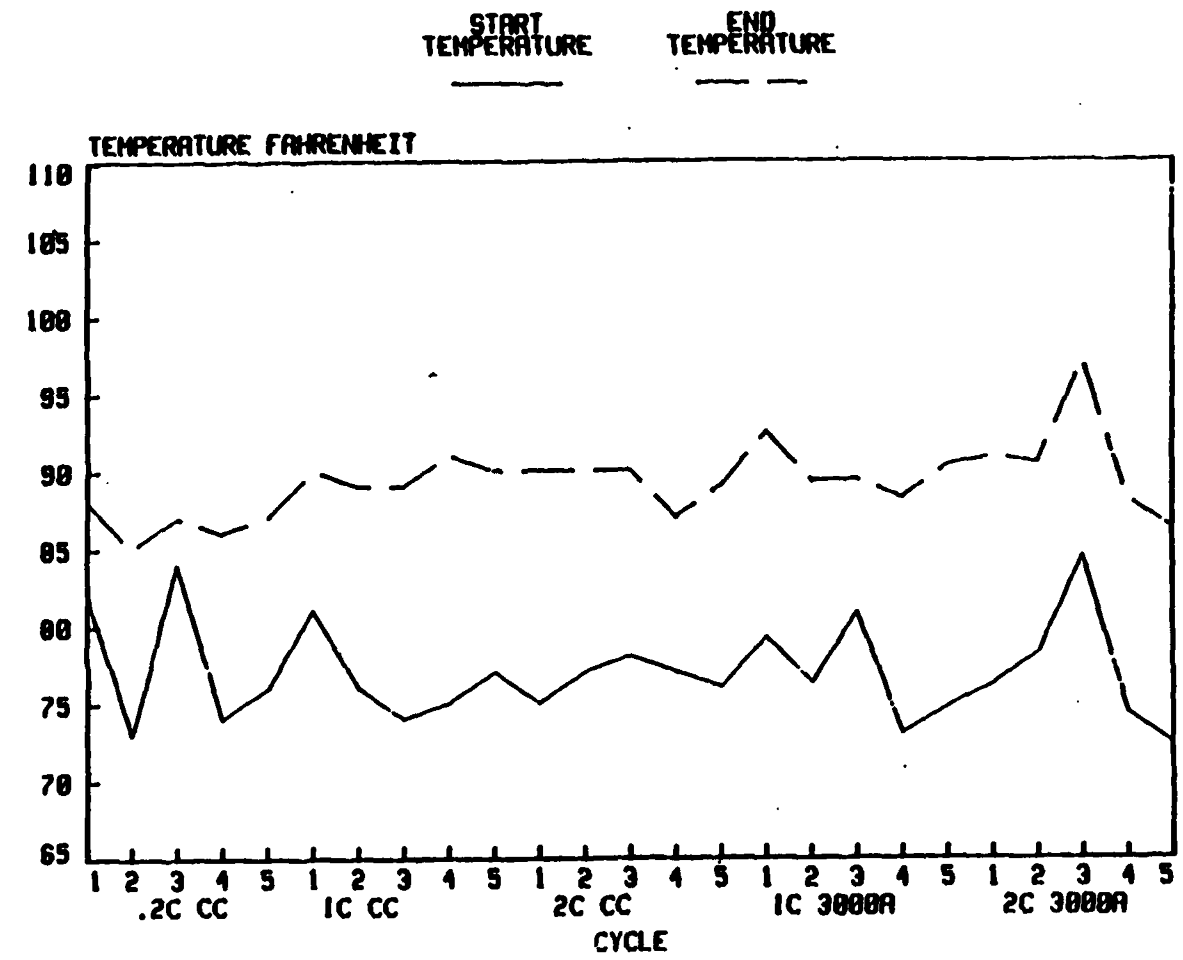


Figure 10B. Charge Temperature Chart for Type M81757/9-2 Serial No. 57542

3. As can be seen from Tables 8 through 10 and Figures 5A through 10B, the C/5 charge rate provided:

a. The lowest percent charge utilization resulting from a relatively-high charge input and a relatively-low discharge output.

b. The least temperature rise during charge.

c. The greatest capacity fading during the five charge/discharge cycle regime.

4. Because of the relatively poor results of the C/5 charge, this rate was not used for the 5-Ah batteries.

E. 1C CONSTANT-CURRENT CHARGE (NBC-1/1A).

1. Two batteries each of the 5-Ah, 10-Ah, 20-Ah, and 30-Ah batteries were cycled as follows:

a. Equalize at 0.0V for minimum of 24 hours.

b. Charge at the constant-current 1C rate of the battery (5A, 10A, 20A, 30A) until the battery terminal voltage reaches 29.5V for the 19-cell, 10-, 20-, and 30-Ah batteries and 31.0V for the 20-cell, 5-Ah batteries.

c. Once the required battery terminal voltage is reached, reduce the charge current to approximately the C/3 rate. This voltage is referred to as the battery mode change trip voltage. The reduced charge rates are shown below for each battery size.

(1) The reduced charge rate for the 5-Ah and 10-Ah batteries was 0.4C (2A and 4A).

(2) The reduced charge rate for the 20-Ah batteries was 0.35C (7A).

(3) The reduced charge rate for the 30-Ah batteries was 0.33C (10A).

d. Continue charging at the reduced rate until the battery terminal voltage stabilizes during a 1-hour period.

e. Rest open-circuit for 2 hours.

f. Check electrolyte levels and adjust as necessary.

g. Discharge at the constant-current 1C rate of the battery (5A, 10A, 20A, 30A) to a terminal voltage of 18.0V (19.0V for the 20-cell, 5-Ah batteries).

h. Repeat steps b through g for a total of five charge/discharge cycles.

2. The constant-current charge method at the 1C rate also provided baseline data. The use of the NBC-1/1A Charger/Analyzer has provided excellent results using the constant-current 1C charge technique. Therefore, any major change to charge equipment or technique must be justified by exceptional performance as compared to the NBC-1/1A.

3. Two modifications were made to the mode of operation that presently exists in the Ni-Cd battery shops. These modifications are reflected in the procedures for evaluating charge techniques.

a. Presently, the maximum charge voltage that is specified for charging 19-cell Ni-Cd's with the NBC-1/1A is 30.4V. It is believed that this voltage should be raised, particularly with the ever-increasing use of Ni-Cd's employing non-cellophane separator materials. During the evaluation, once the batteries reached the mode change trip voltage and charging continued at the reduced charge rates, the battery voltage was allowed to increase without limit while maintaining the appropriate constant-current charge value. Typically, the battery voltage reached 32-33V.

b. Presently, time is the controlling factor for ending charge. The time allocated for charging batteries at the two-step charge rate is 3 hours. This procedure adapts well to the NBC-1/1A and for the most part, charges batteries satisfactorily. However, with the possibility of procuring new charging equipment in the future, an improved method of determining the end of charge was incorporated in the evaluation. Once the battery mode change trip voltage is reached and the charge current is reduced to approximately the C/3 rate, charging continues until the battery terminal voltage stabilizes during a 1-hour period. The total charge time may require more than or less than 3 hours, depending upon the capability of each battery to accept charge. For charging equipment to be able to determine end-of-charge by means of battery voltage stabilization, it must periodically sample and compare battery voltage. When there is no additional voltage rise, during two consecutive 15-minute periods, for example, battery charging is to be terminated.

4. A deviation was taken to the procedure outlined in paragraph V.E.1. During cycle 1, one each of the 10-Ah, 20-Ah, and 30-Ah batteries was allowed to charge at the 1C rate (10A, 20A, and 30A) until the battery voltage stabilized. The charge current was not reduced at the predetermined terminal voltage. Toward the latter stages of charging, the batteries gassed excessively, spewing electrolyte from the cells.

5. As can be seen from Tables 8 through 10 and Figures 3A through 10B, constant-current charging at the 1C rate provided:

a. A slightly better than average percent charge utilization as compared to all of the charge techniques at the 1C rate or greater.

b. A correspondingly low battery temperature rise during charge. The battery temperatures increased by an average of only 3°F from beginning to end of charge. To minimize the temperature rise within a battery during charge is an important quality.

c. A correspondingly high battery capacity yield.

6. The total charge current and discharge capacity generally decreased slightly from cycles 1 to 5 as noted in Figures 3A through 10A. More charge current was required to charge the battery at the beginning of the test regime due to the battery equalization discharge preceeding cycle 1.

F. 2C CONSTANT-CURRENT CHARGE.

1. Two batteries each of the 5-Ah, 10-Ah, 20-Ah, and 30-Ah batteries were cycled as follows:

a. Equalize at 0.0V for minimum of 24 hours.

b. Charge at the constant-current 2C rate of the battery (10A, 20A, 40A, 60A) until the battery terminal voltage reaches 31.0V for the 19-cell, 10-, 20-, and 30-Ah batteries and 32.0V for the 20-cell, 5-Ah batteries.

c. Once the required battery terminal voltage is reached, reduce the charge current to approximately the C/3 rate. The reduced charge rates are shown below for each battery size.

(1) The reduced charge rate for the 5-Ah and 10-Ah batteries was 0.4C (2A and 4A).

(2) The reduced rate for the 20-Ah batteries was 0.35C (7A).

(3) The reduced rate for the 30-Ah batteries was 0.33C (10A).

d. Continue charging at the reduced rate until the battery terminal voltage stabilizes during a 1-hour period.

e. Rest open-circuit for 2 hours.

f. Check electrolyte levels and adjust as necessary.

g. Discharge at the constant-current 1C rate of the battery (5A, 10A, 20A, 30A) to a terminal voltage of 18.0V (19.0V for the 20-cell, 5-Ah batteries).

h. Repeat steps b through g for a total of five charge/discharge cycles.

2. A deviation was taken to the procedure outlined above. During cycles 1 and 2, one 20-Ah battery was charged at the 2C rate (40A) to end voltages of 31.35V and 31.7V, respectively. When the batteries were charged to these high voltages prior to reducing the charge current, they gassed excessively, spewing electrolyte from the cells.

3. As can be seen from Tables 8 through 10 and Figures 3A through 10B, constant-current charging at the 2C rate provided very similar results as compared to constant-current charging at the 1C rate. For example, the values for percent charge utilization and output capacity yield were very good. Also

the total time to achieve full charge from an 18V depth-of-discharge level was approximately 35 percent less than that required at the 1C charge rate. However, the battery temperature rise during charge was much greater, exceeding the temperature rise at the 1C rate by 100 percent. More importantly, the high rate of charge produced an unacceptable amount of gassing and electrolyte spewage prior to reaching the battery mode change trip voltage. Selection of a suitable trip voltage to minimize cell gassing was difficult. It is believed that this high rate of charge would cause unneccessary difficulties if implemented in Fleet battery shops.

4. A reduction in charge current to the 1.5C rate is achievable and would be much easier to implement. It would still result in modest savings in the amount of time required to fully charge batteries.

5. The total charge current and discharge capacity generally decreased slightly from cycles 1 through 5 as noted in Figures 3A through 10A. More charge current was required to charge the battery at the beginning of the test regime due to the battery equalization discharge preceeding cycle 1.

G. 1C PULSED CONSTANT-CURRENT CHARGE (2400A-2).

1. One battery each of the 5-, 10-, 20-, and 30-Ah batteries was cycled at the 1C pulsed constant-current method using the Utah Research Model 2400A-2 pulse charger. The cycling regime consisted of:

a. Equalize at 0.0V for minimum of 24 hours.

b. Charge at the 1C rate of the battery (5A, 10A, 20A, 30A) until the battery terminal voltage reaches 29.5V for the 19-cell, 10-, 20-, and 30-Ah batteries and 31.0V for the 20-cell, 5-Ah battery. The 2400A-2 provides a series of pulses, as shown in Figure 1, but also maintains a[illegible]verage constant-current as preselected on the unit's front panel. The actual parameters of the pulsed output for the charge current rates selected are given in Table 4.

c. Once the required battery terminal voltage is reached, reduce the charge current to approximately the C/3 rate. The reduced charge rates are:

(1) 0.4C (2A and 4A) for the 5- and 10-Ah batteries.

(2) 0.35C (7A) for the 20-Ah battery.

(3) 0.33C (10A) for the 30-Ah battery.

d. Continue charging at the reduced rate until the battery terminal voltage stabilizes during a 1-hour period.

e. Rest for 2 hours.

f. Check electrolyte levels and adjust as necessary.

g. Discharge at the constant-current 1C rate (5A, 10A, 20A, and 30A) of the battery to a terminal voltage of 18V (19V for the 5-Ah battery).

h. Repeat steps b through g for a total of five charge/discharge cycles.

2. It was difficult to determine when the battery voltage stabilized at the end of charge, particularly when charging the 5-Ah battery. This is attributed to the voltmeters not being synchronized with the charging pulse, sampling at various times during the pulse duty cycle.

3. As can be seen from Tables 8 through 10, and Figures 3A through 9B, pulse charging at the 1C rate using the 2400A-2 provided similar results as compared to conventional constant-current charging at the 1C rate. The values of percent charge utilization and output capacity yield were nearly the same, but slightly less. The major difference in battery performance was the amount of temperature rise during charge. It averaged 7.7°F for pulse charging and only 2.8°F for the standard constant-current charge technique.

4. The total charge current and discharge capacity generally decreased slightly from cycles 1 through 5 as noted in Figures 3A, 5A, 7A, and 9A. More charge current was required to charge the battery at the beginning of the test regime due to the battery equalization discharge preceeding cycle 1.

H. 1.5C AND 2C PULSED CONSTANT-CURRENT CHARGE (2400A-2).

1. One battery each of the 5-, 10-, 20-, and 30-Ah batteries was again subjected to a cycling regime using the 2400A-2 pulse charger. This time the main-mode charge rate was increased from 1C to 2C for the 5-, 10-, and 20-Ah batteries and from 1C to 1.5C for the 30-Ah battery. The 30-Ah battery was charged at the 1.5C rate in order to maintain comparative data with the Model 3000A Pulse Charger which has a maximum average current output capability of only 50A. The cycle regime consisted of the following:

a. Equalize at 0.0V for minimum of 24 hours.

b. Charge the 30-Ah battery at the 1.5C rate (45A) to a battery terminal voltage of 30.0V. The 5-, 10-, and 20-Ah batteries were charged at the 2C rate (10A, 20A, and 40A) to terminal voltages of 32V, 31V, and 30V, respectively. The parameters of the pulsed output for the charge current rates selected are given in Table 4.

c. Once the required battery terminal voltage is reached, reduce the charge current to approximately the C/3 rate. The reduced charge rates are:

(1) 0.4C (2A and 4A) for the 5-Ah and 10-Ah batteries.

(2) 0.35C (7A) for the 20-Ah battery.

(3) 0.33C (10A) for the 30-Ah battery.

d. Continue charging at the reduced rate until the battery terminal voltage stabilizes during a 1-hour period.

e. Rest for 2 hours.

f. Check electrolyte levels and adjust as necessary.

g. Discharge at the constant-current 1C rate (5A, 10A, 20A, and 30A) of the battery to a terminal voltage of 18V (19V for the 5-Ah battery).

h. Repeat steps b through g for a total of five charge/discharge cycles.

2. Again, little difference in battery performance was noted during these cycling tests, except for the significantly greater temperature rise attributed to the pulse charging. For the 1.5-2C charge rates using the 2400A-2, the battery temperature rise during charge was two times greater than the temperature rise of the 2C conventional constant-current charge and four times greater than that of the 1C conventional constant-current charge.

3. The total charge current and discharge capacity generally decreased slightly from cycles 1 through 5 as noted in Figures 3A, 5A, 7A, and 9A. More charge current was required to charge the battery at the beginning of the test regime due to the battery equalization discharge preceeding cycle 1.

I. 1C PULSED CONSTANT-CURRENT CHARGE (3000A).

1. One battery each of the 5-, 10-, 20-, and 30-Ah batteries was cycled at the 1C pulsed constant-current method using the Utah Research Model 3000A pulse charger. The cycling regime consisted of:

a. Equalize at 0.0V for minimum of 24 hours.

b. Charge at the 1C rate of the battery (5A, 10A, 20A, 30A) until the battery terminal voltage reaches 29.5V for the 19-cell, 10-, 20-, and 30-Ah batteries and 31.0V for the 20-cell, 5-Ah battery. The Model 3000A was adjusted to provide the average output currents at the 1C rate as indicated, with a peak current Ipk = 100A.

c. Once the required battery terminal voltage is reached, reduce the charge current to approximately the C/3 rate. The reduced charge rates are:

(1) 0.4C (2A and 4A) for the 5- and 10-Ah batteries.

(2) 0.35C (7A) for the 20-Ah battery.

(3) 0.33C (10A) for the 30-Ah battery.

d. Continue charging at the reduced rate until the battery terminal voltage stabilizes during a 1-hour period.

e. Rest for 2 hours.

f. Check electrolyte levels and adjust as necessary.

g. Discharge at the constant-current 1C rate (5A, 10A, 20A, and 30A) for the battery to a terminal voltage of 18V (19V for the 5-Ah battery).

h. Repeat steps b through g for a total of five charge/discharge cycles.

3. While charging with the 3000A, it was difficult to determine exactly when the battery voltage stabilized at the end of charge due to the voltage measurements occurring during various times of the pulse duty cycle.

4. As can be seen from Tables 8 through 10 and Figures 4A through 10B, pulse charging at the 1C rate using the 3000A provided similar results as compared to conventional constant-current charging at the 1C rate and pulse charging with the 2400A-2. The only significant difference in performance was the amount of battery temperature rise during charge. For comparison, the average values of battery temperature rise during charge at the 1C rate using the NBC-1, 2400A-2, and 3000A were 2.8°F, 7.7°F, and 9.3°F, respectively.

5. The total charge current and discharge capacity generally decreased slightly from cycles 1 through 5 as noted in Figures 4A, 6A, 8A, and 10A. More charge current was required to charge the battery at the beginning of the test regime due to the battery equalization discharge preceding cycle 1.

J. 1.5C AND 2C PULSED CONSTANT-CURRENT CHARGE (3000A).

1. One battery each of the 5-, 10-, 20-, and 30-Ah batteries was subjected to a cycling regime using the 3000A pulse charger, with the main-mode charge rate increased from 1C to 2C for the 5-, 10-, and 20-Ah batteries and from 1C to 1.5C for the 30-Ah battery. The maximum average current output capability of the 3000A is 50A; consequently, the maximum charge rate for the 30-Ah battery was 1.5C (45A). The cycle regime consisted of the following:

a. Equalize at 0.0V for minimum of 24 hours.

b. Charge the 30-Ah battery at the 1.5C rate (45A) to a battery terminal voltage of 30.0V. The 5-, 10-, and 20-Ah batteries were charged at the 2C rate (10A, 20A, and 30A) to terminal voltages of 32V, 31V, and 30V, respectively. The charger was adjusted to provide the average output currents as indicated, with a peak current Ipk = 100A.

c. Once the required battery terminal voltage is reached, reduce the charge current to approximately the C/3 rate. The reduced charge rates are:

(1) 0.4C (2A and 4A) for the 5- and 10-Ah batteries.

(2) 0.35C (7A) for the 20-Ah battery.

(3) 0.33C (10A) for the 30-Ah battery.

d. Continue charging at the reduced rate until the battery terminal voltage stabilizes during a 1-hour period.

e. Rest for 2 hours.

f. Check electrolyte levels and adjust as necessary.

g. Discharge at the constant-current 1C rate (5A, 10A, 20A, and 30A) of the battery to a terminal potential of 18V (19V for the 5-Ah battery).

h. Repeat steps b through g for a total of five charge/discharge cycles.

2. As can be seen from Tables 8 through 10 and Figures 4A through 10B, the only factor of significance is the amount of temperature rise during charge, attributable to the pulse charge method. In this cycling regime, the average temperature rise was 10.8°F.

3. The total charge current and discharge capacity generally decreased slightly from cycles 1 through 5 as noted in Figures 4A, 6A, 8A, and 10A. The pulse charge output of the Model 3000A had a more positive effect on checking battery capacity fading, particularly, for the 30-Ah battery. More charge current was required to charge the battery at the beginning of the test regime due to the battery equalization discharge preceeding cycle 1.

K. CAPACITY FADING TESTS.

1. Tests were performed to develop a battery capacity fading condition within certain batteries, and then to evaluate the effectiveness of restoring capacity using constant-current and pulse charge techniques. For example, two M81757/8-2 20-Ah batteries were cycled at 120°F as follows:

a. Constant potential charged at 28.0V for 2 hours.

b. Open circuit rest for 1.75 hours.

c. Discharged at the 1C rate (20A) for 15 minutes.

d. Repeated steps a through c twice each day for 7 days.

e. Removed the batteries from cycling regime in charged condition and stabilized at 70°F.

f. Discharged at the constant current 1C rate (20A) to a terminal potential of 18.0V. The battery capacities were 24.17 Ah and 23.80 Ah.

2. The batteries were returned to repetitive cycling at 120°F as follows:

a. Constant-potential charged at 28.0V for 2 hours.

b. Open-circuit rest for 1.75 hours.

c. Discharged at the 1C rate (20A) for 15 minutes.

d. Repeated steps a through c six times each day for 4 days.

e. Removed the batteries from cycling regime in charged condition.

f. Discharged at the constant current 1C rate (20A) to a terminal potential of 18.0V. The battery capacities were 22.37 Ah and 21.37 Ah.

3. The batteries were returned to repetitive cycling at 120°F.

a. The charge/discharge procedure, steps a through f of paragraph V.K.1 was repeated for an additional 24 cycles.

b. The battery capacities were 18.33 Ah and 18.72 Ah.

4. The batteries were returned to repetitive cycling at 120°F.

a. The charge/discharge procedure, steps a through f of paragraph V.K.1, was repeated for an additional 24 cycles.

b. The battery capacities were 15.67 Ah and 16.33 Ah.

5. The batteries were returned to repetitive cycling at 120°F.

a. The charge/discharge procedure, steps a through f of paragraph V.K.1, was repeated for an additional 18 cycles.

b. The battery capacities were 13.67 Ah and 14.0 Ah.

6. The batteries were not returned to cycling, but were charged using the two-step method as follows:

a. The first battery was constant-current charged using the NBC-1A.

(1) Charged at the 1C rate (20A) to a battery trip voltage of 29.5V.

(2) Charged at a reduced rate, 0.35C (7A), until battery voltage stabilized.

(3) Completed charge after 3.75 hours, with a total input of 25.48 Ah.

(4) Open-circuit rest for 2 hours.

(5) Discharged at the 1C rate (20A) to a battery teminal voltage of 18V. The battery provided 24.25-Ah capacity.

b. The second battery was given a pulsed constant-current charge using the 2400A-2. Refer to Table 4 for pulse parameters.

(1) Charged at the 1C rate (20A) to a battery voltage of 29.5V.

(2) Charged at a reduced rate, 0.35C (7A), until battery voltage stabilized.

(3) Completed charge after 3.75 hours, with a total input of 25.95 Ah.

(4) Open-circuit rest for 2 hours.

(5) Discharged at the 1C rate (20A) to a battery terminal voltage of 18V. The battery provided 25.0 Ah.

7. The results of these limited tests showed that DC constant-current and pulsed constant-current charge techniques were equally effective in restoring capacity to batteries that have experienced a temporary loss in capacity.

L. CHARGE/DISCHARGE TESTING OF FLEET CELLS.

1. Several 20-Ah cells (MS90321-78W and M81757/1-4) were submitted by different Naval Air Station battery shops for evaluation. These cells were removed from service and were to be discarded because of their failure to meet minimum electrical performance standards. An attempt was made to restore capacity to these cells using DC and pulse constant-current charge techniques.

2. The cells were initially washed, dried, and installed in battery containers as described under battery descriptions. All of the cells were equalized by discharging to 0 volts. The cells were shorted for a minimum of 24 hours prior to being tested.

3. Two types of cells were assembled as batteries and tests performed on them as follows:

a. Type MS90321-78W (one battery).

(1) Using the NBC-1A, charged at the 1C constant-current rate (20A) to 29.5V.

(2) Reduced charge current to 0.3C rate (6.6A).

(3) Continued charging at the reduced constant-current rate until the voltage stabilized.

(4) Open-circuit rest for 2 hours.

(5) Checked electrolyte and adjusted as necessary.

(6) Discharged at the constant-current rate (20A) to 18 volts.

(7) Steps 1 through 6 were repeated until the battery had been cycled three times.

(8) Charge at pulsed constant-current 1C rate (20A average) to 29.5V on the Model 3000A. The peak amplitude of the charge current was adjusted to 100 amperes.

(9) Reduced average charge current to 0.3C rate (6.6A).

(10) Continued charging at the reduced pulsed constant-current rate until the voltage stabilized.

(11) Open-circuit rest for 2 hours.

(12) Checked electrolyte and adjusted as necessary.

(13) Discharged at the constant-current rate (20A) to 18 volts.

(14) Equalized battery at 0V for 24 hours.

(15) Steps 8 through 13 were repeated two times.

b. Type M81757/1-4 cells (one battery).

(1) An identical cycling test was performed with the battery containing the M81757/1-4 cells, except that the Model 2400A charger was used in place of the 3000A.

4. TYPE MS90321-78W CELL TEST RESULTS.

a. Throughout the charge/discharge tests, two of the nineteen cells exhibited low end-of-charge cell voltages and low end-of-discharge capacities. Pulse charging had no positive effect on these cells. The performance of these two cells was indicative of degradated cell separator material. No amount of charging and cell equalization would improve their performance.

b. The performance of the remaining 17 cells appeared normal for both methods of charge. There was a slight increase in capacity when the battery was pulse charged, but the effect of cell equalization was even more positive.

5. TYPE M81757/1-4 CELL RESULTS.

a. All of the cells appeared normal throughout the charge/discharge tests for both charge techniques. The discharge capacities of all cells exceeded minimum requirements.

b. Battery performance was unaffected when pulse charged using the 3000A charger.

VI. TEST DESCRIPTIONS AND RESULTS - HIGH-RATE DISCHARGE

A. BACKGROUND.

1. The procedures that are contained in the NAVAIR 17-15BAD-1, pertaining to the servicing of Ni-Cd aircraft batteries, require that the batteries provide a minimum 1-hour rated capacity, as defined in the applicable military specification, when discharged at the 1C rate. Although this test is very common in evaluating battery capacity, specifically in determining reserve capacity as may be required in an in-flight emergency, it does not effectively evaluate the battery's capability to produce high rates of current, as required to start aircraft engines.

2. High-rate discharge testing was performed on several Ni-Cd batteries with the intent of upgrading the Navy's overall battery evaluation techniques. Not only will a high-rate discharge test more realistically evaluate a battery's capability to start engines, it will enable battery shop personnel to turn around ready-for-issue (RFI) batteries in approximately 75 percent of the time normally required.

3. All of the high-rate discharge tests performed during this evaluation were at the 9C rate. The 9C rate was chosen because of its commonality in aircraft battery testing. A large data base for batteries tested at the 9C rate exists and is available for reference. Also, discharge at the 9C rate will stress the battery sufficiently, but without requiring unnecessarily large power dissipation equipment. Depending upon battery size and application, discharge rates during engine start sequence usually range from 10C to 30C.

B. TEST BATTERIES.

1. There were 13 batteries included in the high-rate discharge evaluation representing five distinct types and four capacity ratings. The batteries are identified as follows:

TABLE 11. IDENTIFICATION OF BATTERIES SUBJECTED TO HIGH-RATE DISCHARGE TESTS

MS Type	Capacity Rating	Serial No.
M81757/10-1	6-Ah	81370
M81757/10-1	6-Ah	81372
M81757/7-2	10-Ah	76817
M81757/7-2	10-Ah	76822
MS90365-1	20-Ah	NAS Chase 1
M81757/8-1	20-Ah	NAS Chase 2
MS90365-1	20-Ah	NAS Chase 3
MS90365-1	20-Ah	NAS Chase 4
MS90365-1	20-Ah	NAS Pensacola 1
MS90365-1	20-Ah	NAS Pensacola 2
GE43B030RB19	30-Ah	001
M81757/9-2	30-Ah	57542
M81757/9-2	30-Ah	57545

C. TEST DATA.

1. Discharge characteristics for individual cells are shown in Figures 11A through 19C, representing nine of the battery high-rate discharge tests performed during the evaluation. For each of the nine discharges, there are three individual graphs depicting battery cell voltages under load. For example, the battery data displayed in Figures 11A, 11B, and 11C were generated by nineteen M81757/1-4 cells. Cells 1 through 7 are displayed in Figure 11A; cells 8 through 14 are displayed in Figure 11B; and cells 15 through 19 are displayed in Figure 11C.

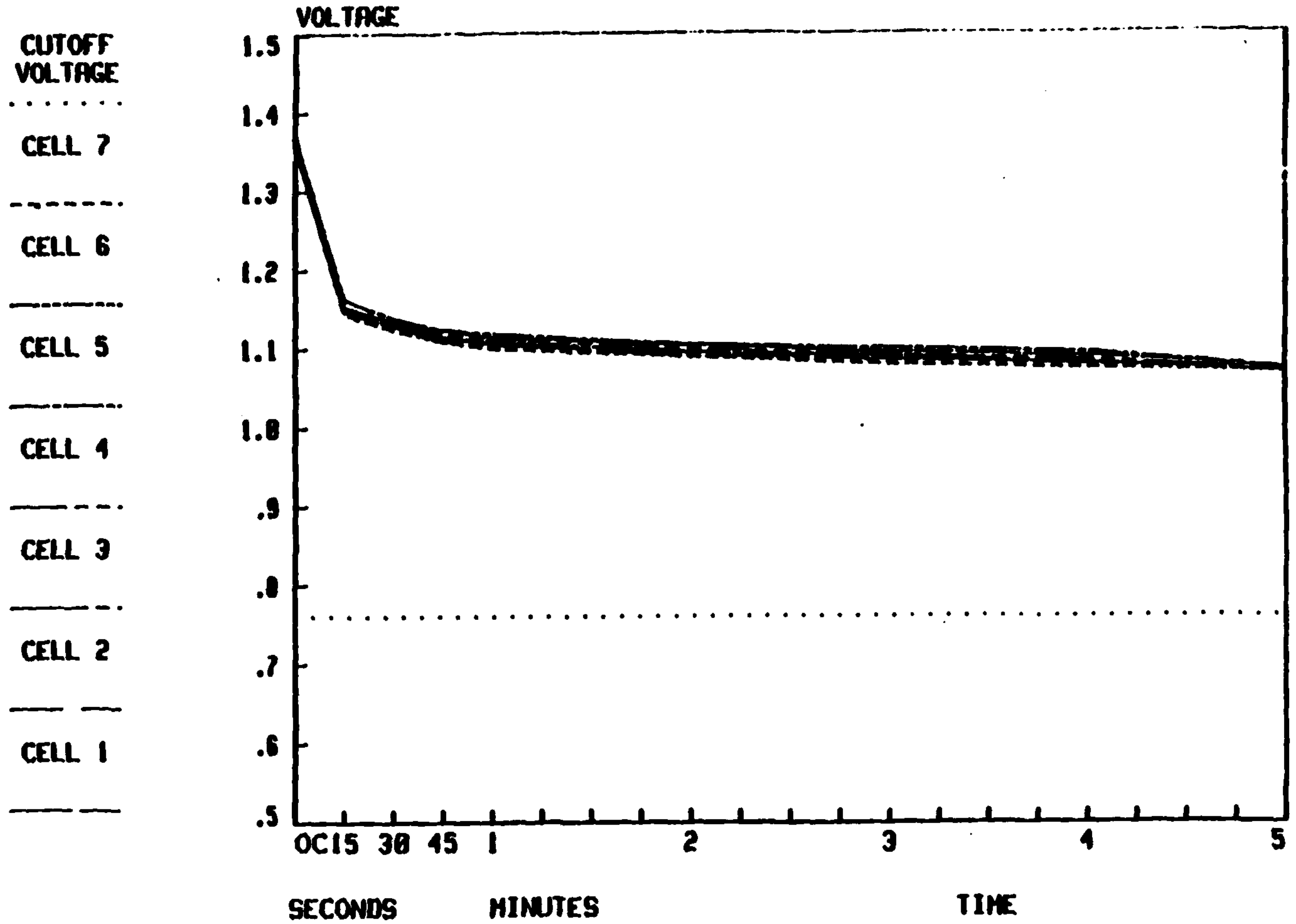


Figure 11A. 9C Discharge Rate for Type M81757/7-2
Cells 1-7 Serial No. 76817

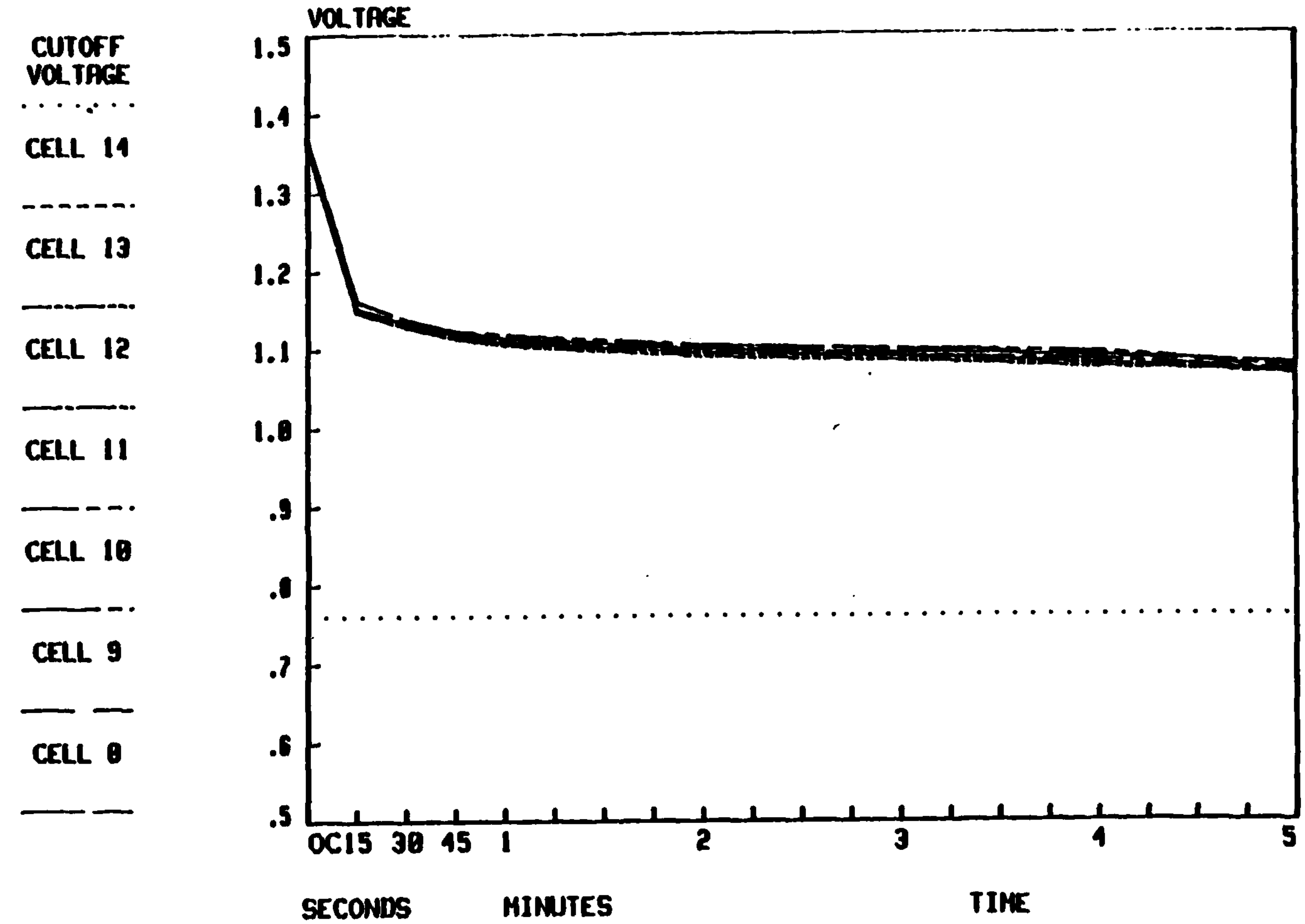


Figure 11B. 9C Discharge Rate for Type M81757/7-2 Cells 8-14 Serial No. 76817

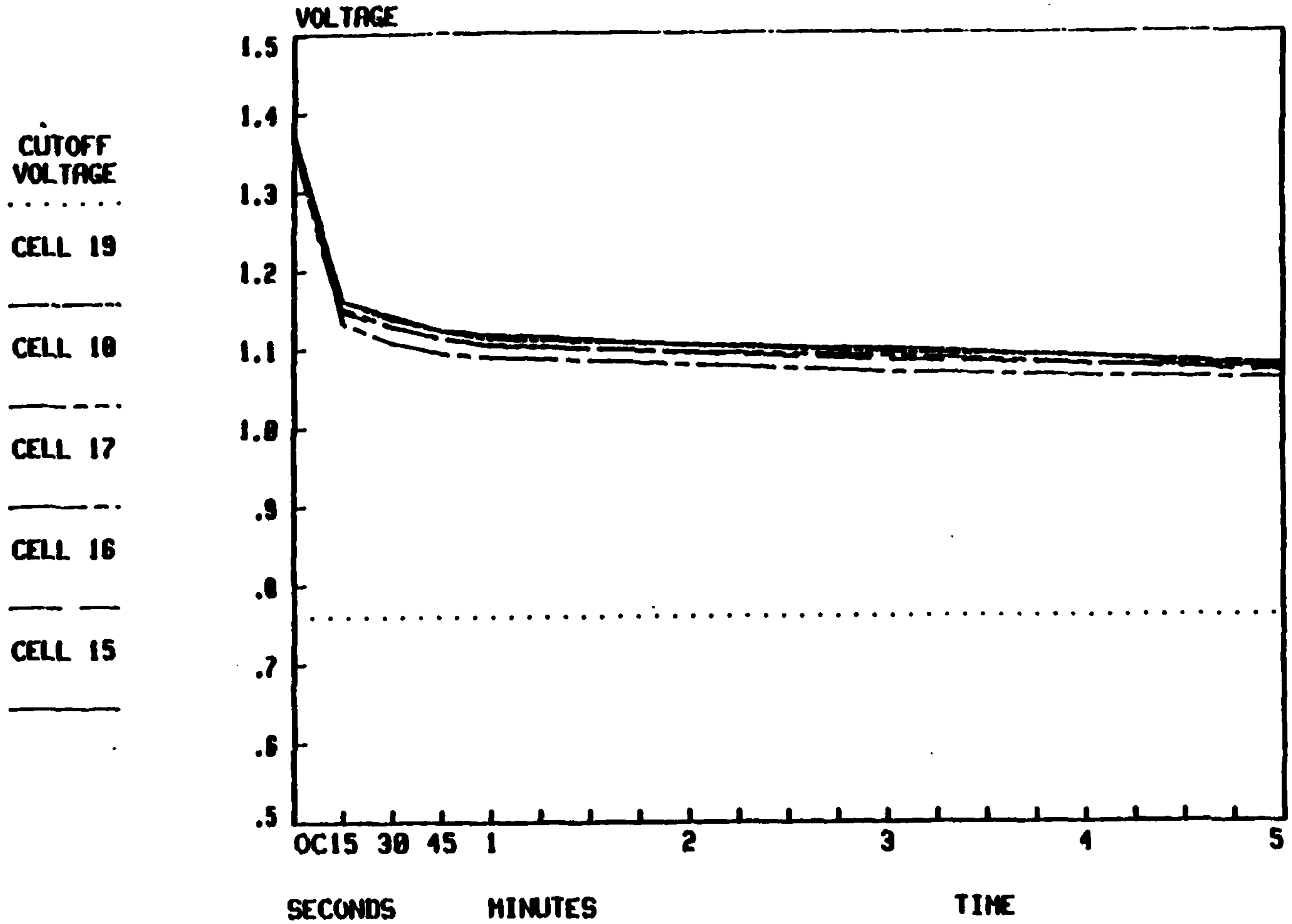


Figure 11C. 9C Discharge Rate for Type M81757/7-2
Cells 15-19 Serial No. 76817

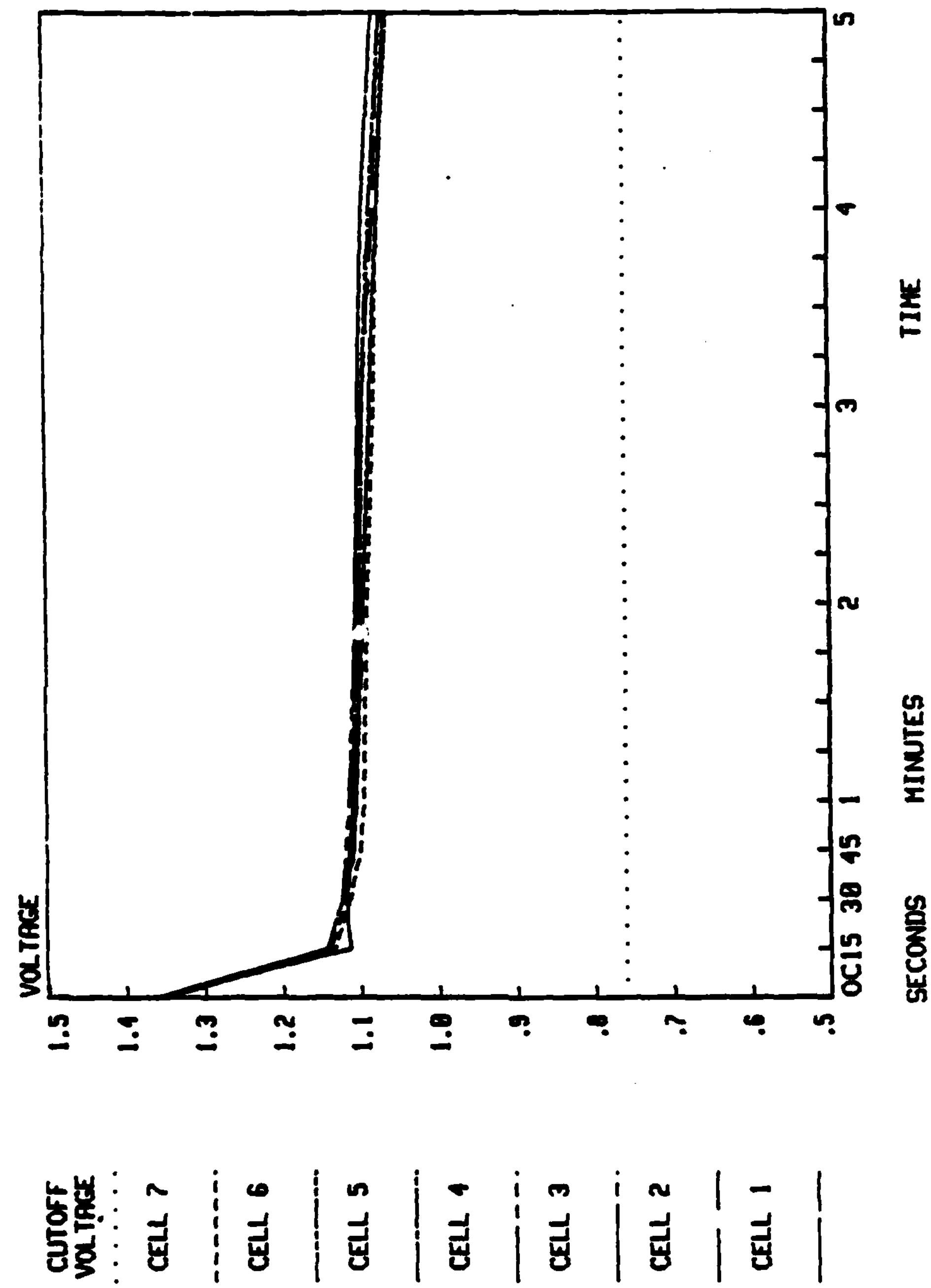


Figure 12A. 9C Discharge Rate for Type M81757/1-4 Cells 1-7 Serial No. NAS Chase 2

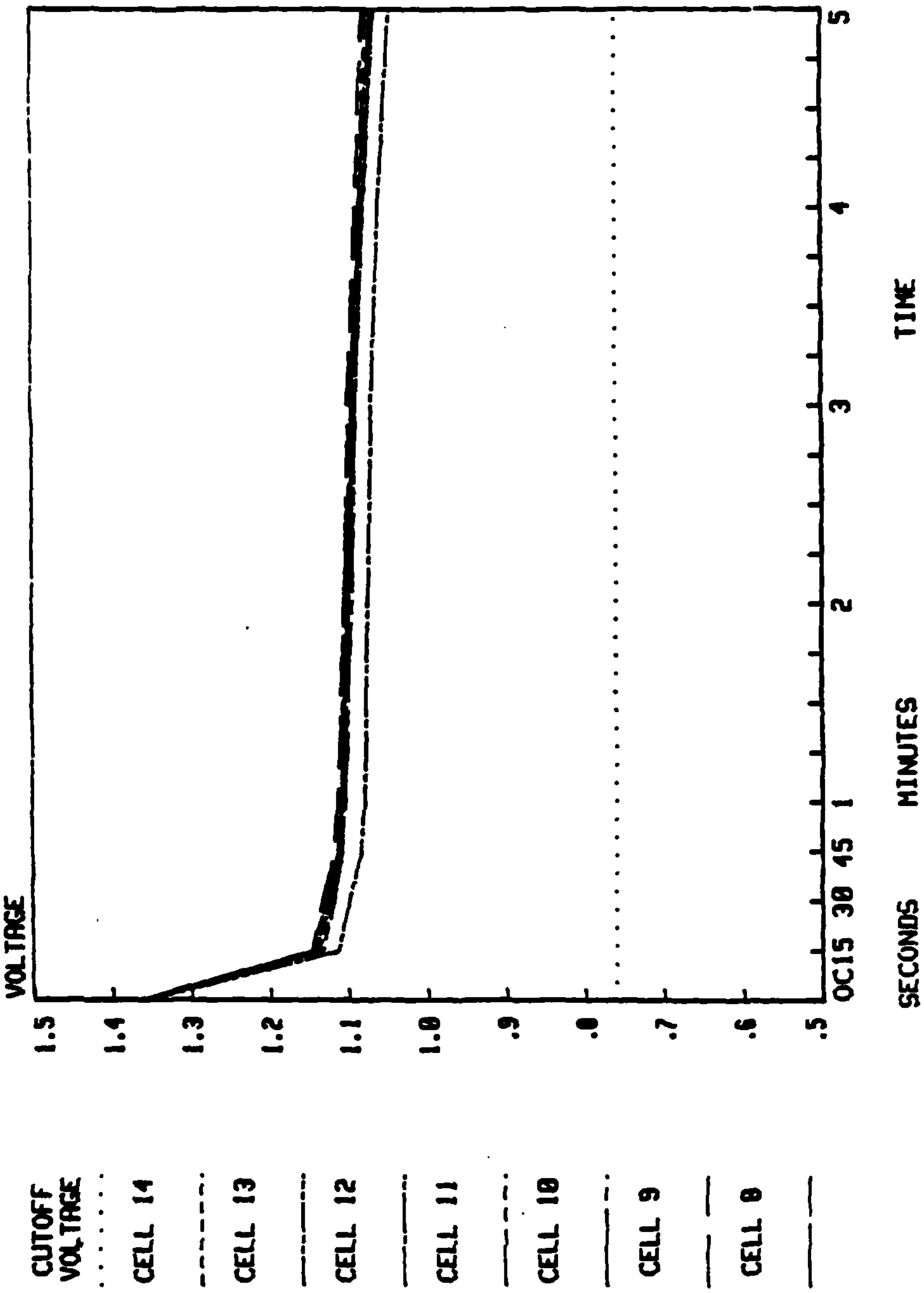


Figure 12B. 9C Discharge Rate for Type M81757/1-4
Cells 8-14 Serial No. NAS Chase 2

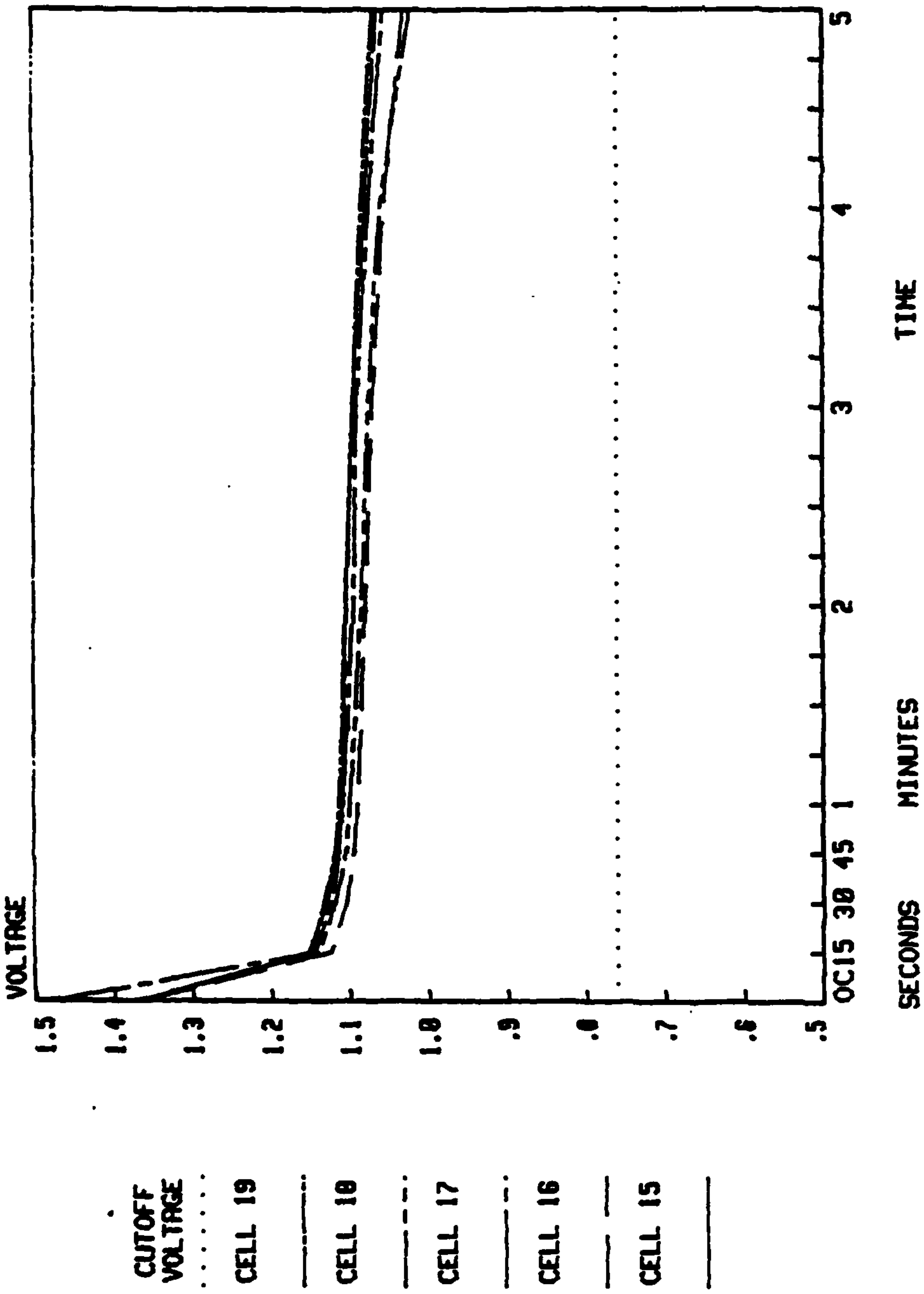


Figure 12C. 9C Discharge Rate for Type M81757/1-4
Cells 15-19 Serial No. NAS Chase 2

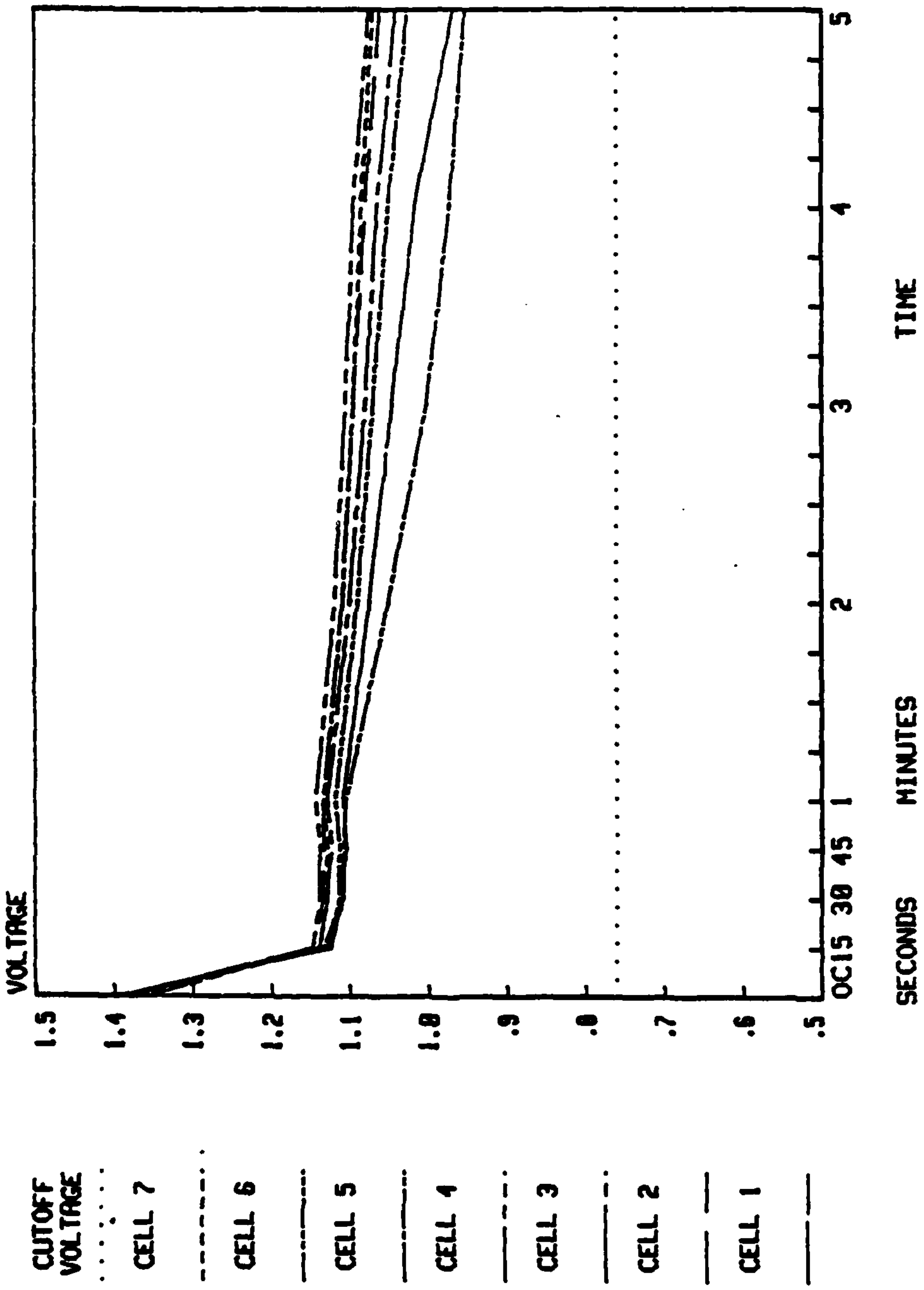


Figure 13A. 9C Discharge Rate for Type MS90321-78W Cell 1-7 Serial No. NAS Pensacola 1

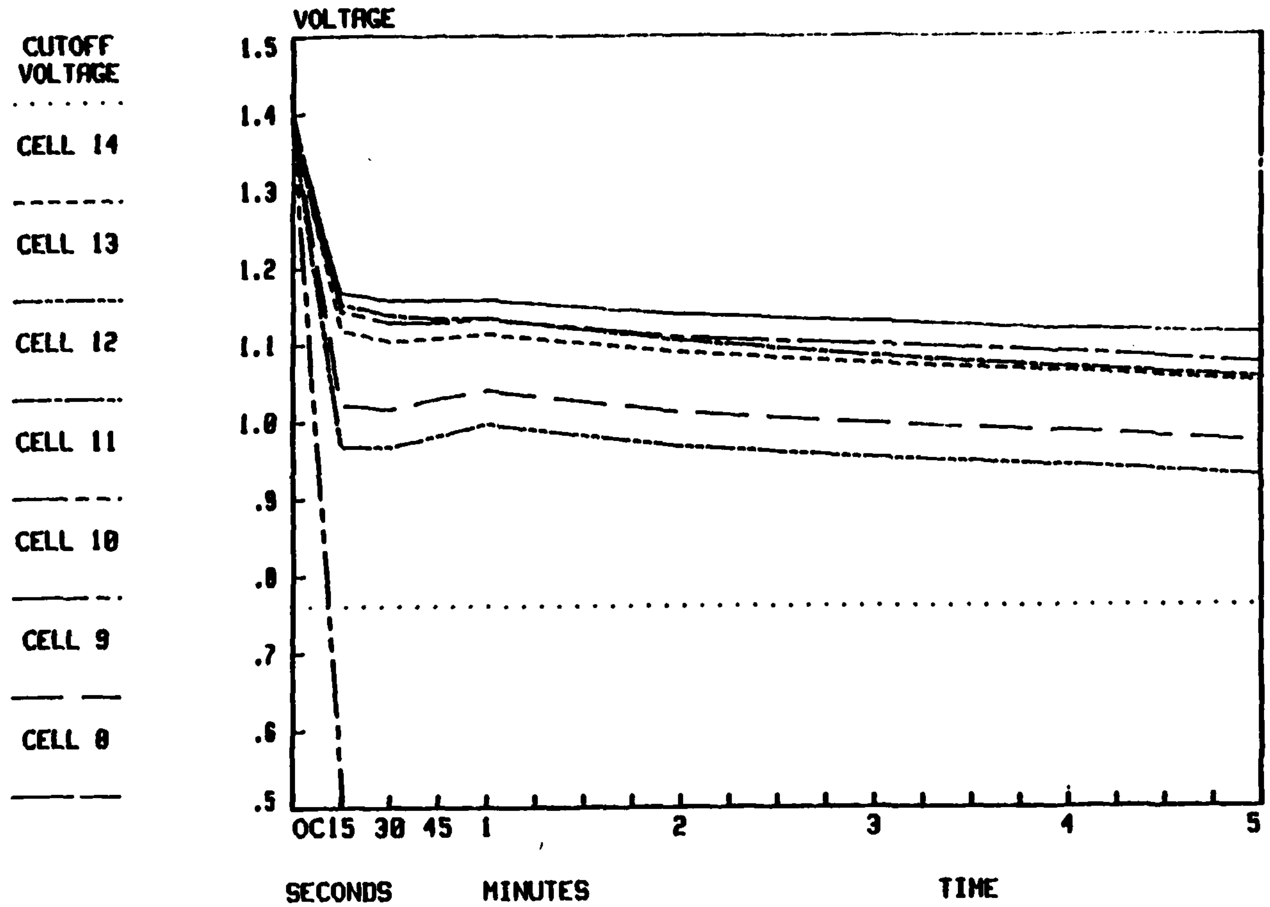


Figure 13B. 9C Discharge Rate for Type MS90321-78W Cells 8-14 Serial No. NAS Pensacola 1

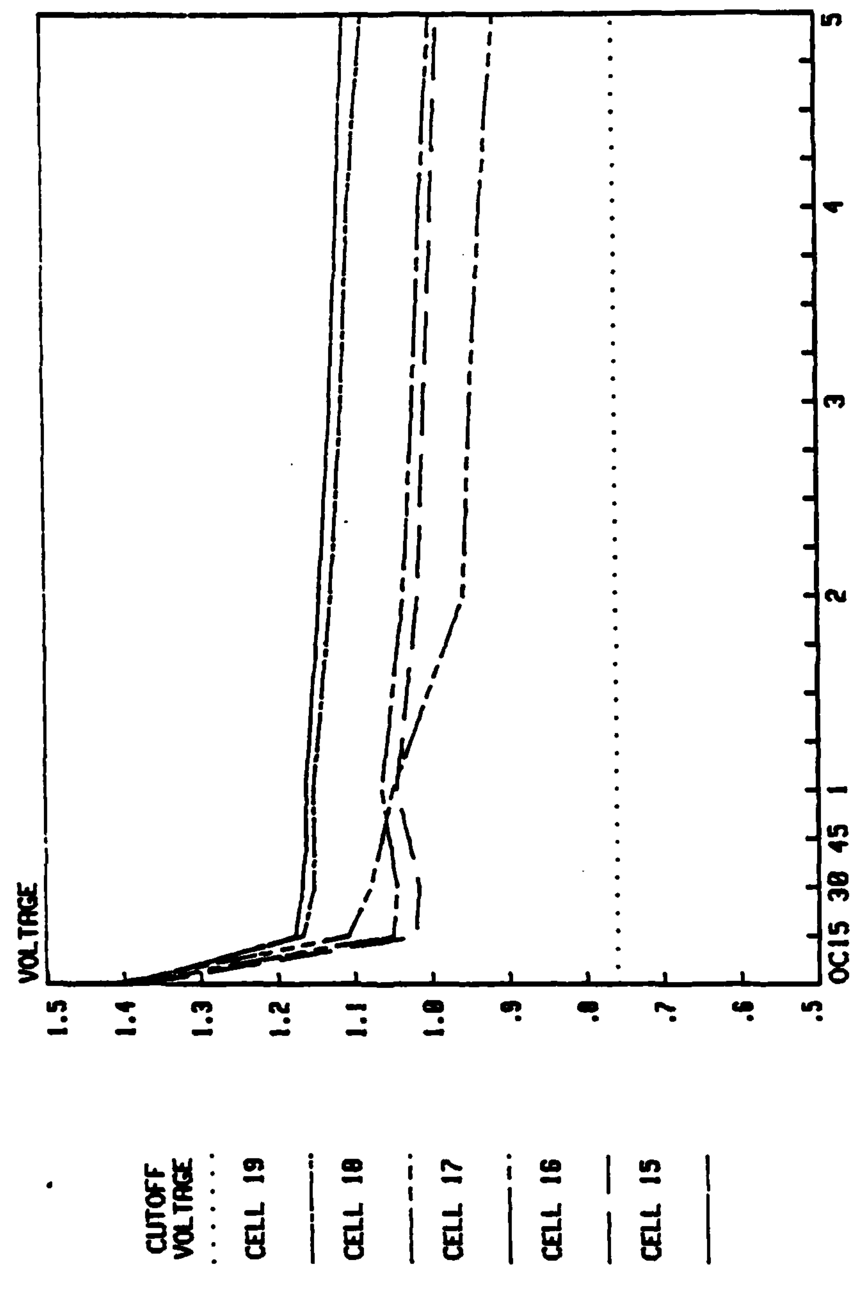


Figure 13C. 9C Discharge Rate for Type MS90321-78W
Cells 15-19 Serial No. NAS Pensacola 1

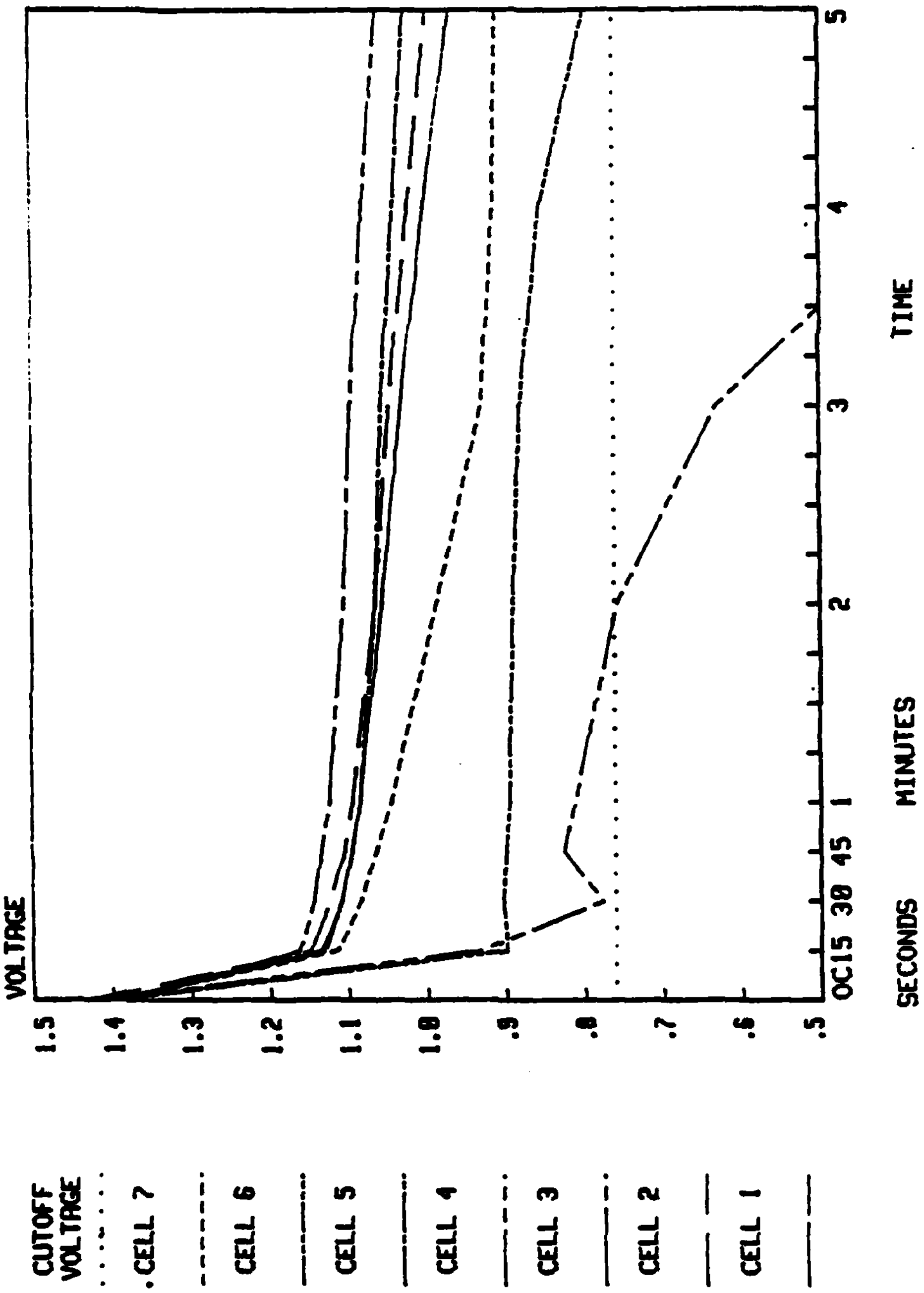


Figure 14A. 9C Discharge Rate for Type MS90321-78W
Cells 1-7 Serial No. NAS Chase 1

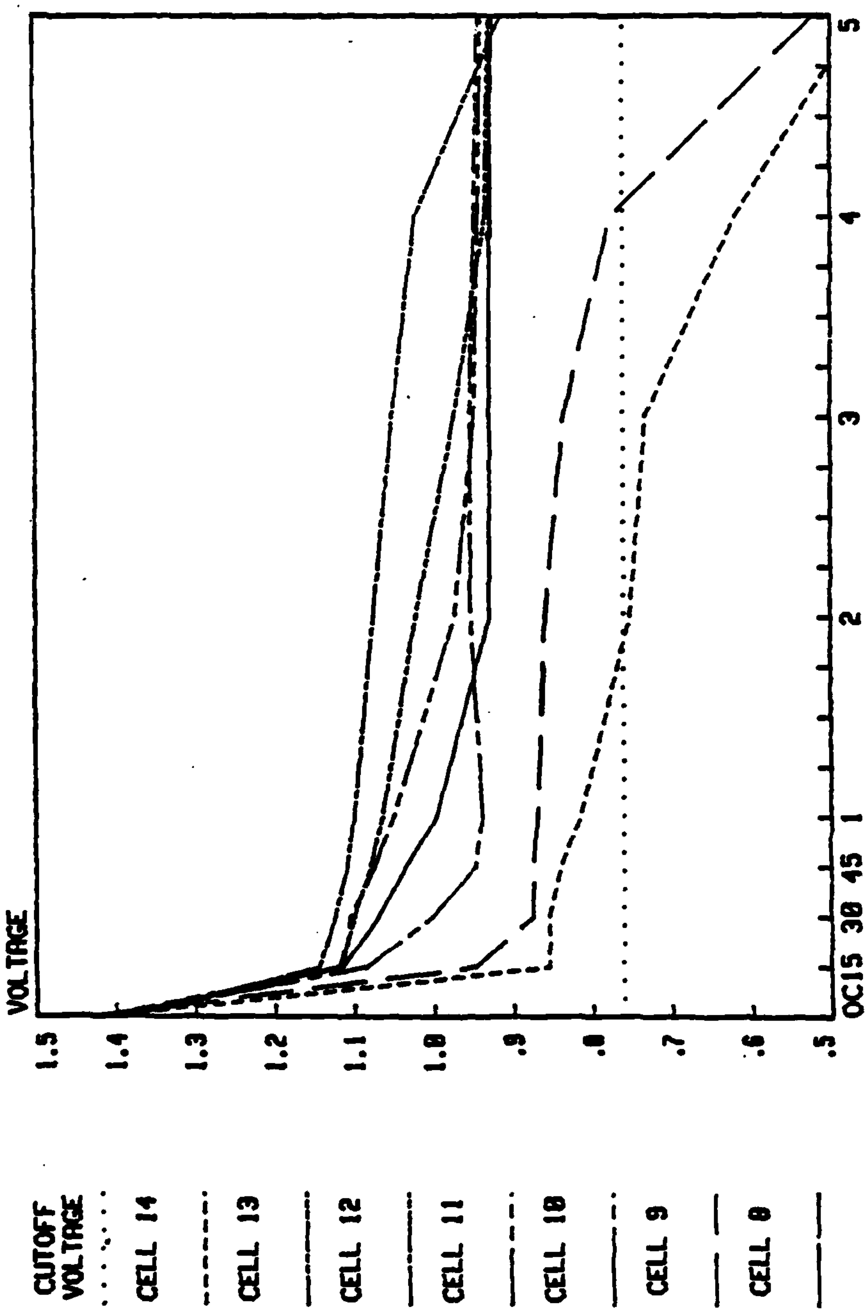


Figure 14B. 9C Dicharge Rate for Type MS90321-78W
Cells 8-14 Serial No. NAS Chase 1

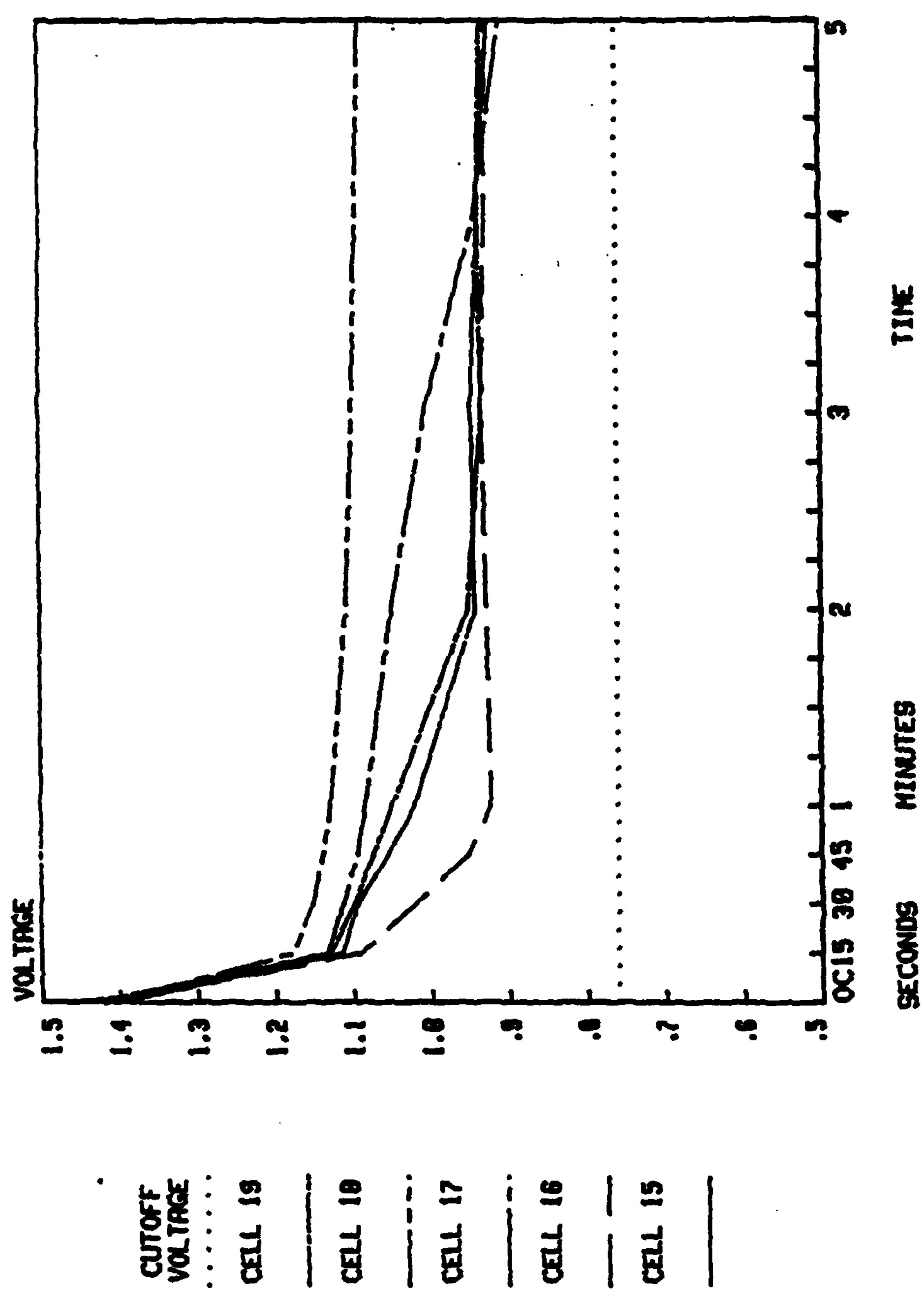


Figure 14C. 9C Discharge Rate for Type MS90321-78W
Cells 15-19 Serial No. NAS Chase 1

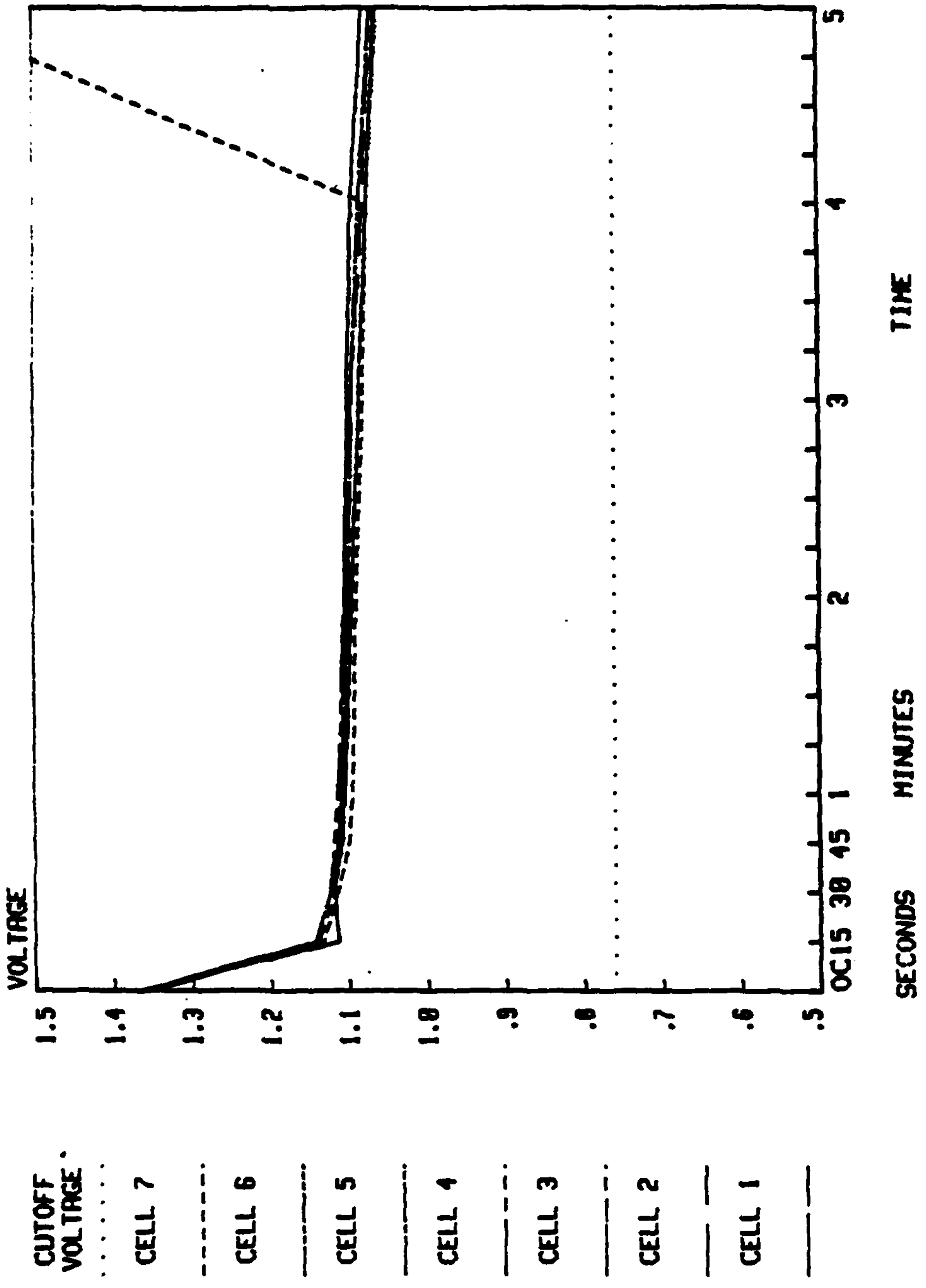


Figure 15A. 9C Discharge Rate for Type M81757/1-4 Cells 1-7 Serial No. NAS Chase 2

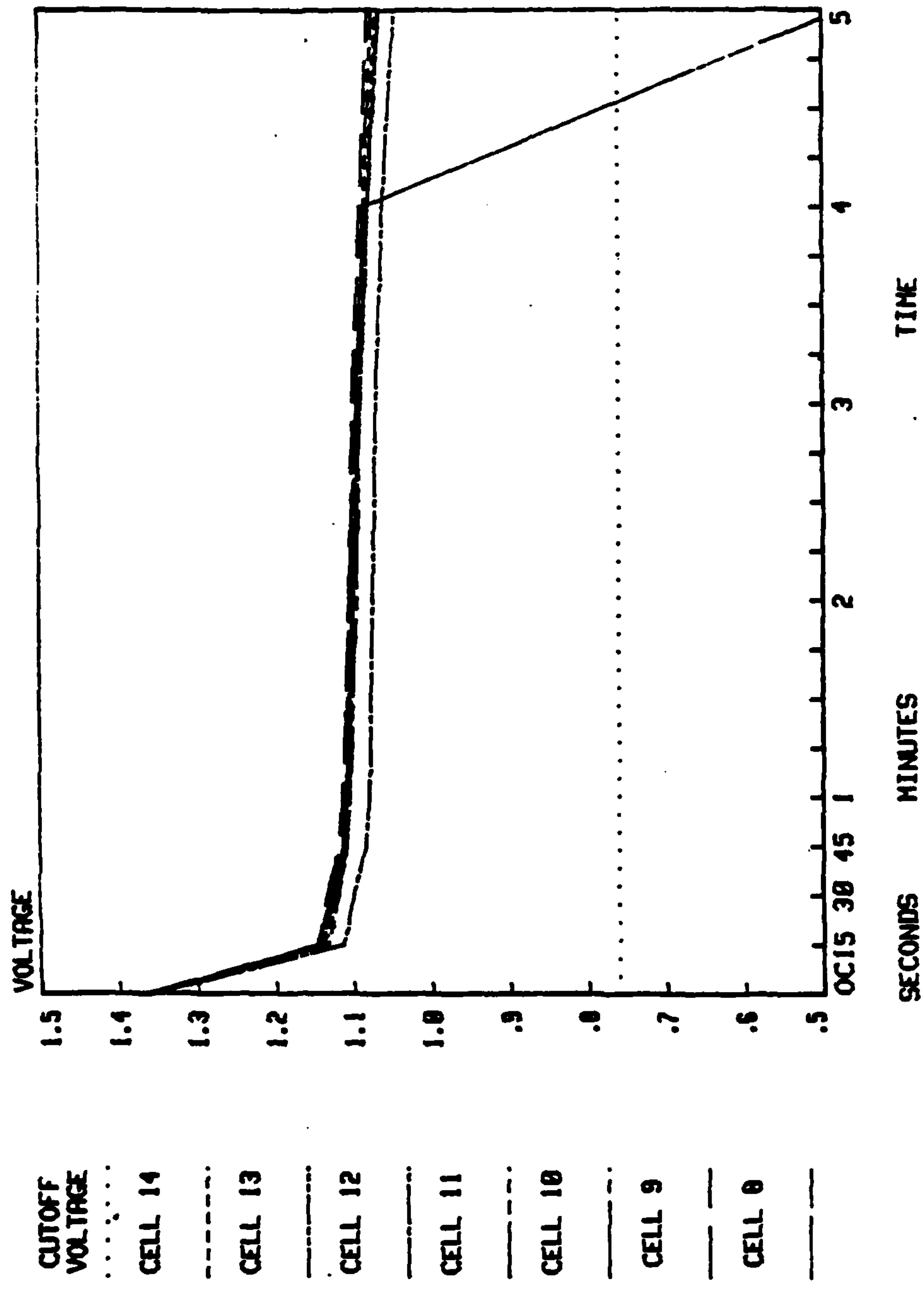


Figure 15B. 9C Discharge Rate for Type M81757/1-4
Cells 8-14 Serial No. NAS Chase 2

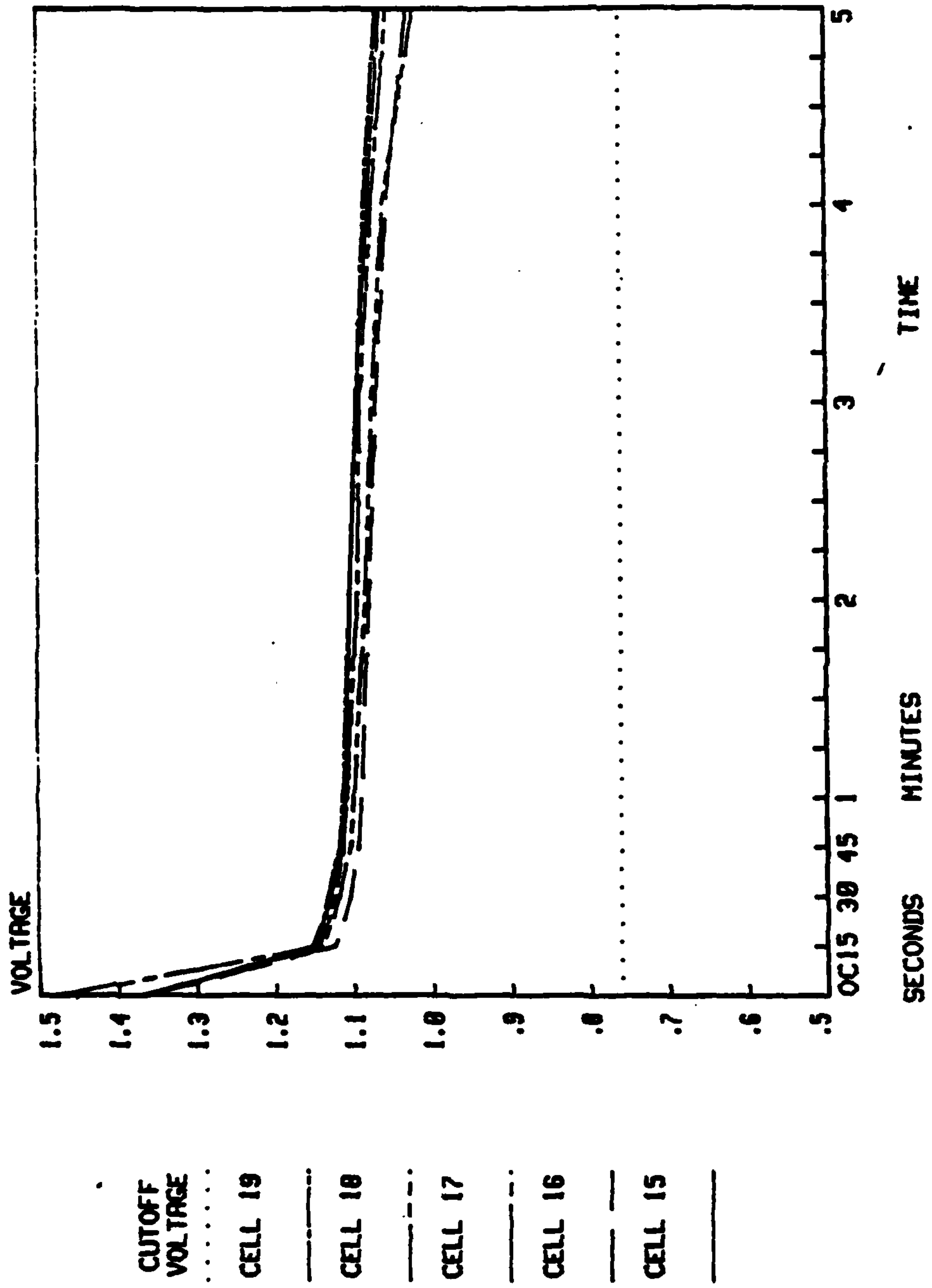


Figure 15C. 9C *Discharge Rate for Type* M81757/1-4
Cells 15-19 Serial No. NAS Chase 2

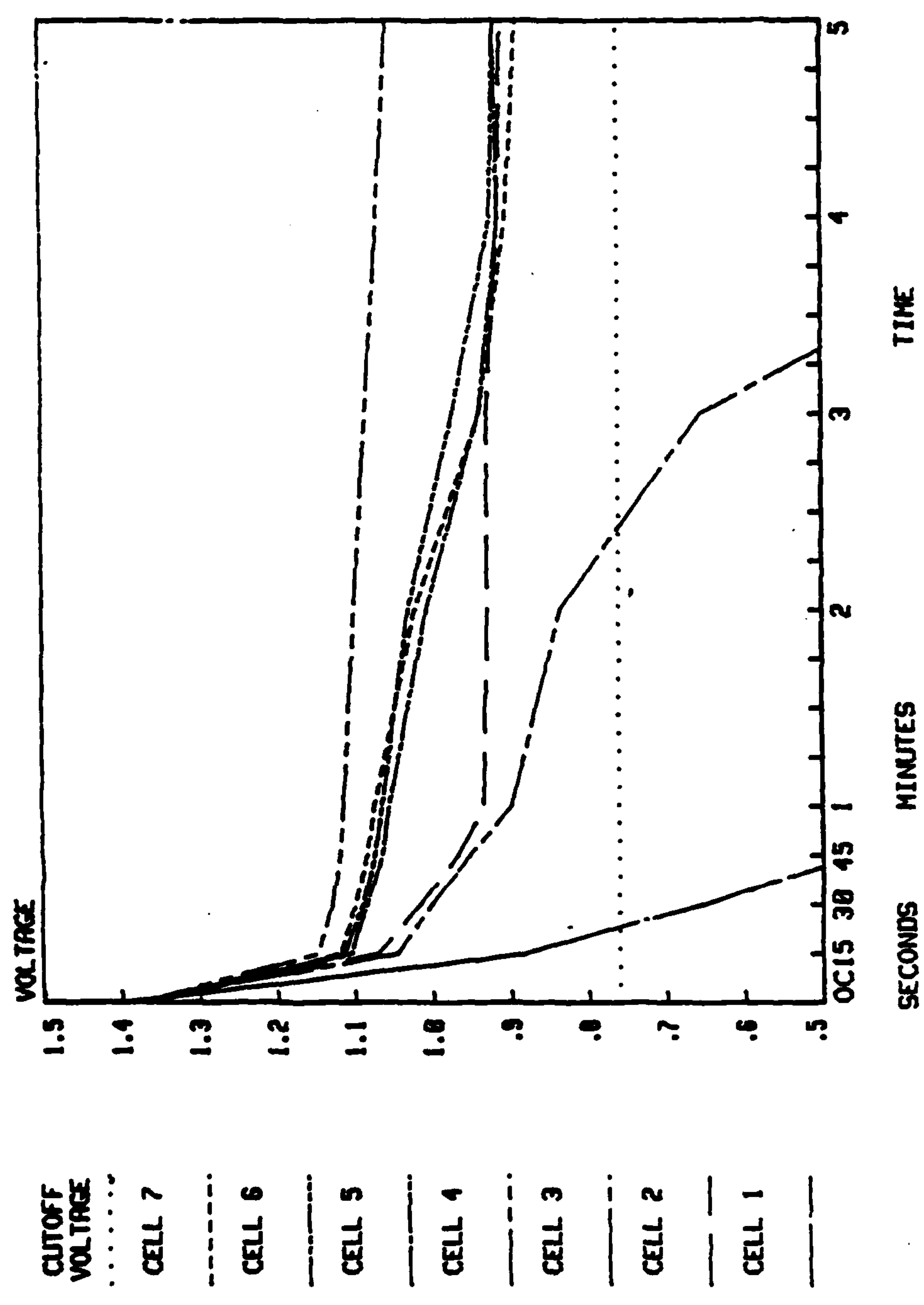


Figure 16A. 9C Discharge Rate for Type MS90321-78W Cells 1-7 Serial No. NAS Chase 3

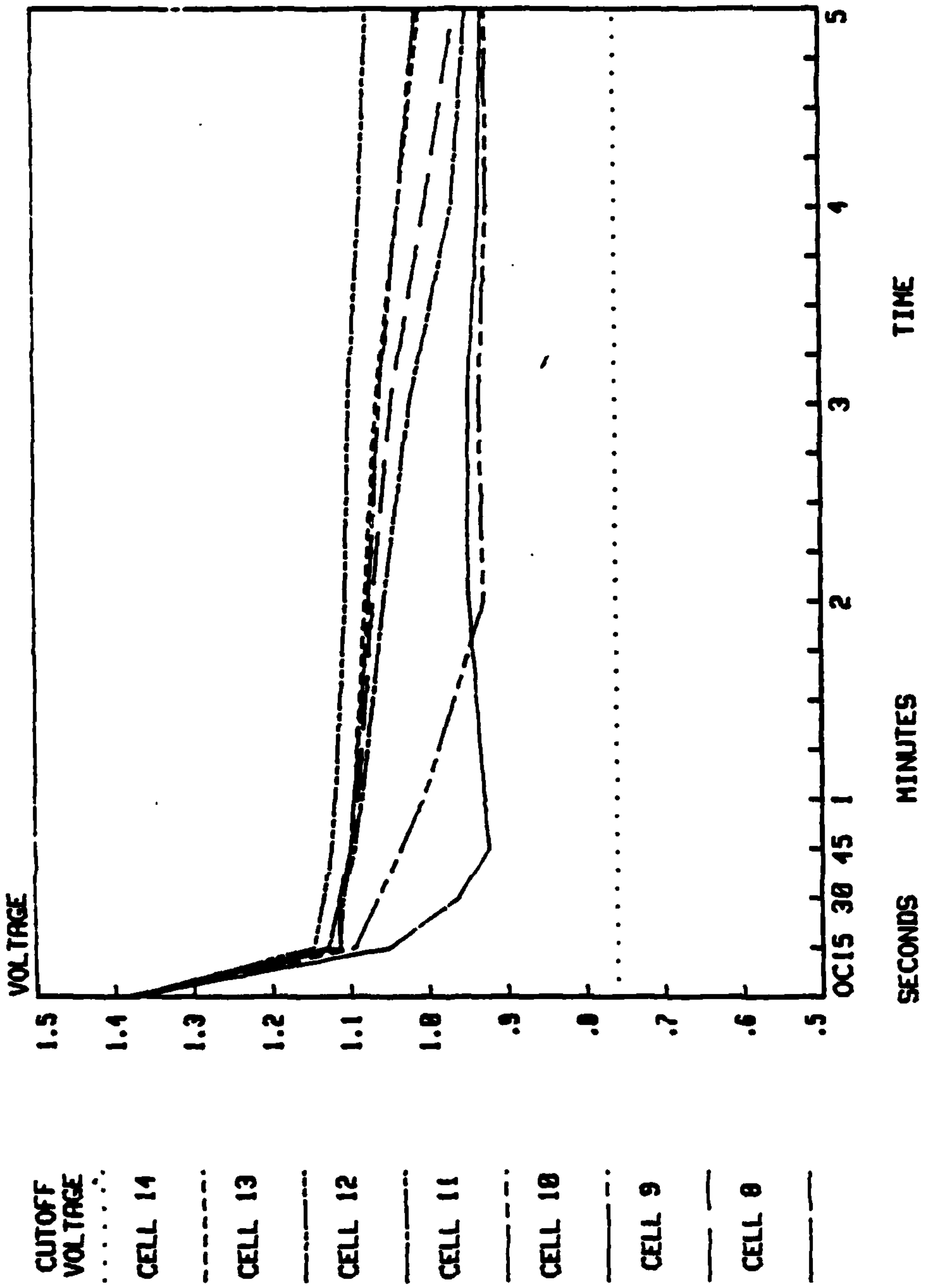


Figure 16B. 9C Discharge Rate for Type MS90321-78W
Cells 8-14 Serial No. NAS Chase 3

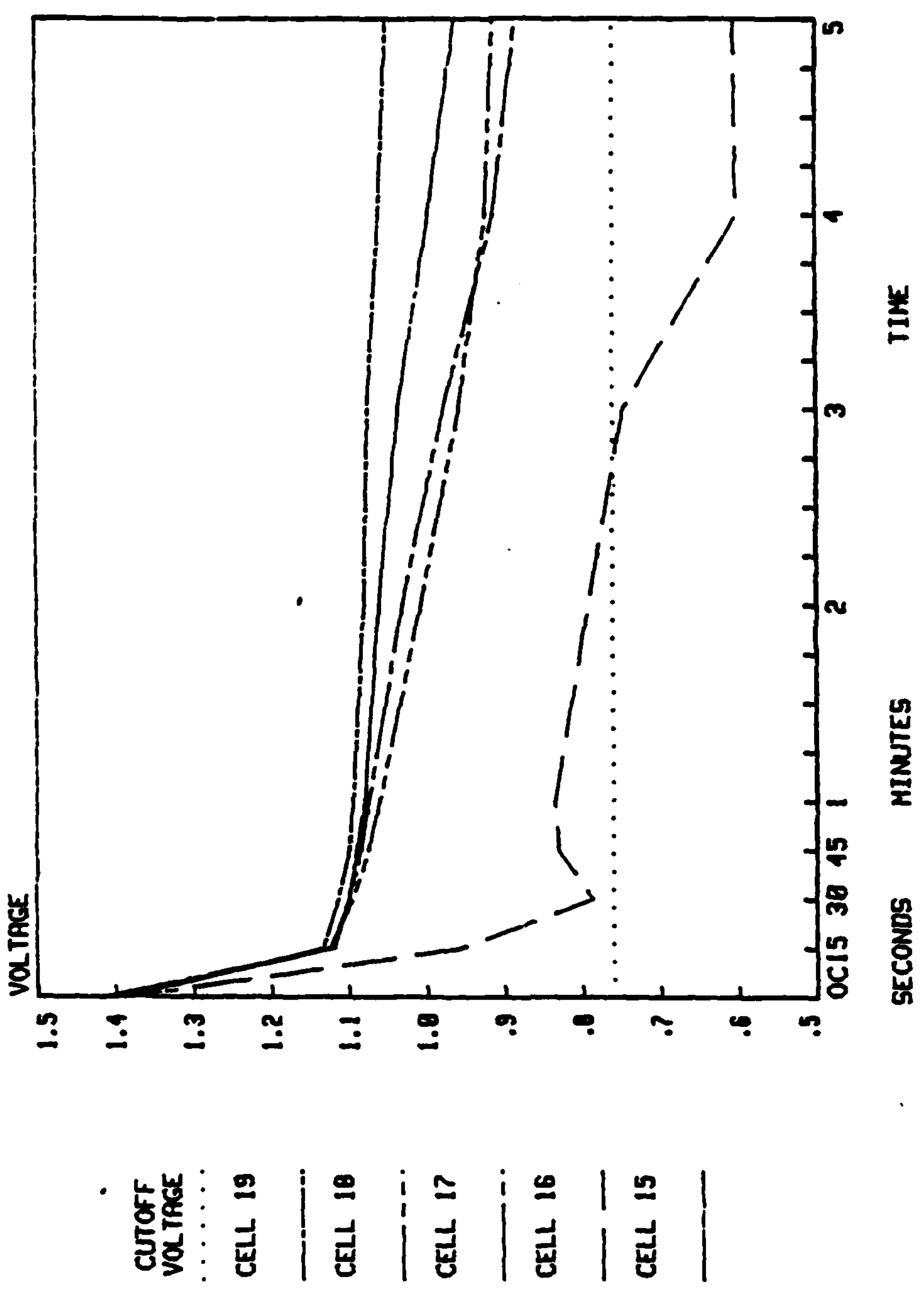


Figure 16C. 9C Discharge Rate for Type MS90321-78W
Cells 15-19 Serial No. NAS Chase 3

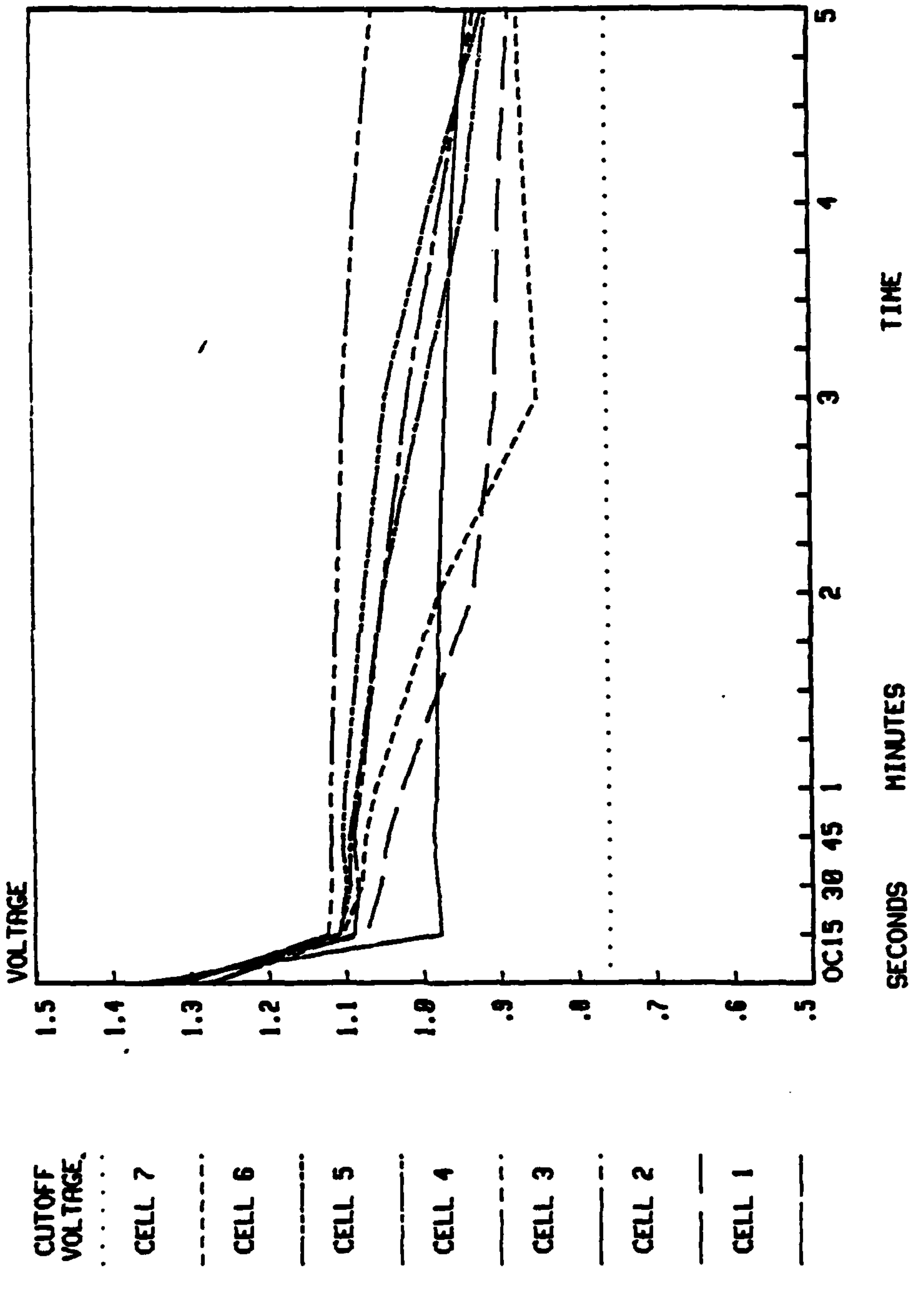


Figure 17A. 9C Discharge Rate for Type MS90321-78W Cells 1-7 Serial No. NAS Chase 4

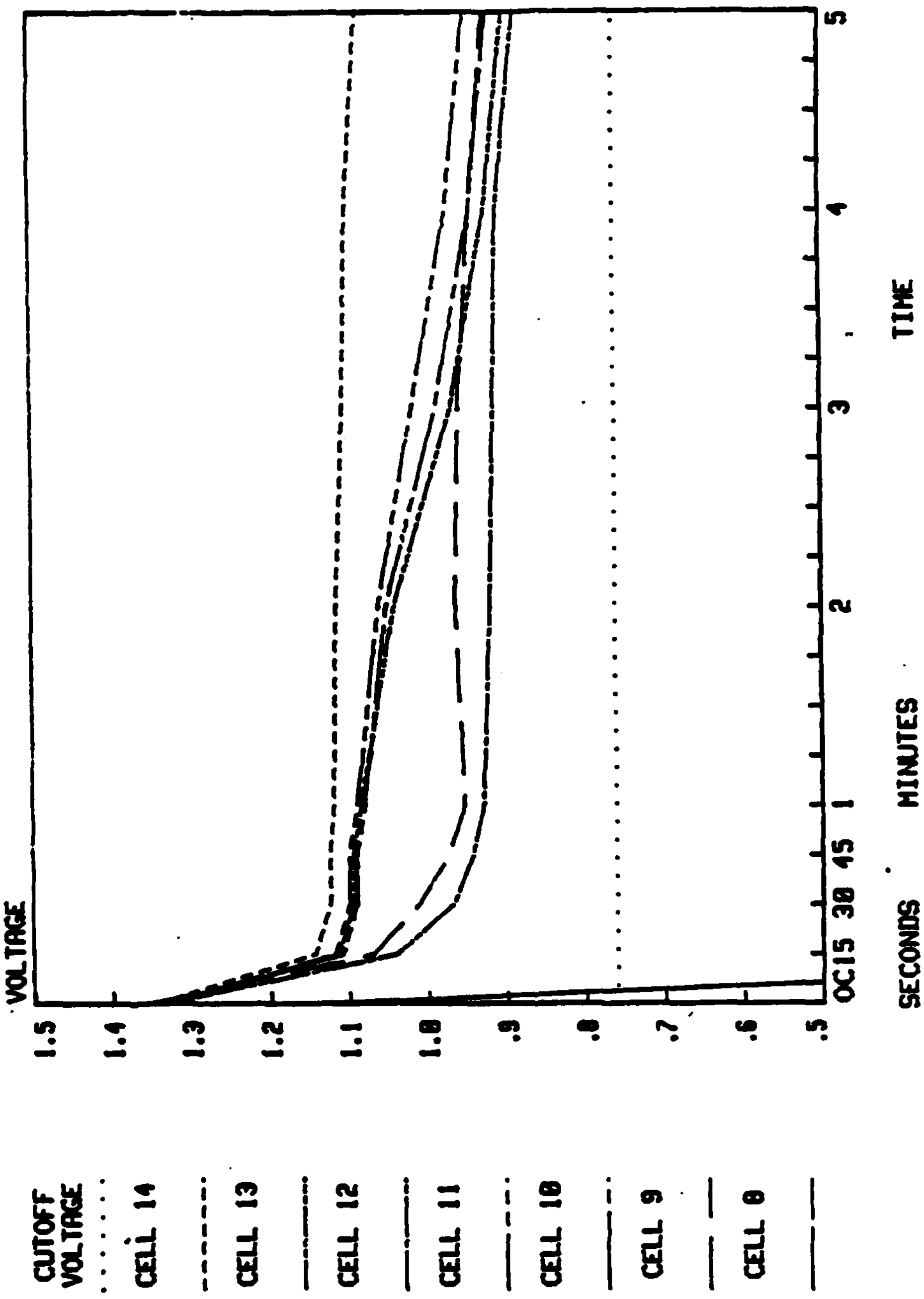


Figure 17B. 9C Discharge Rate for Type MS90321-78W
Cells 8-14 Serial No. NAS Chase 4

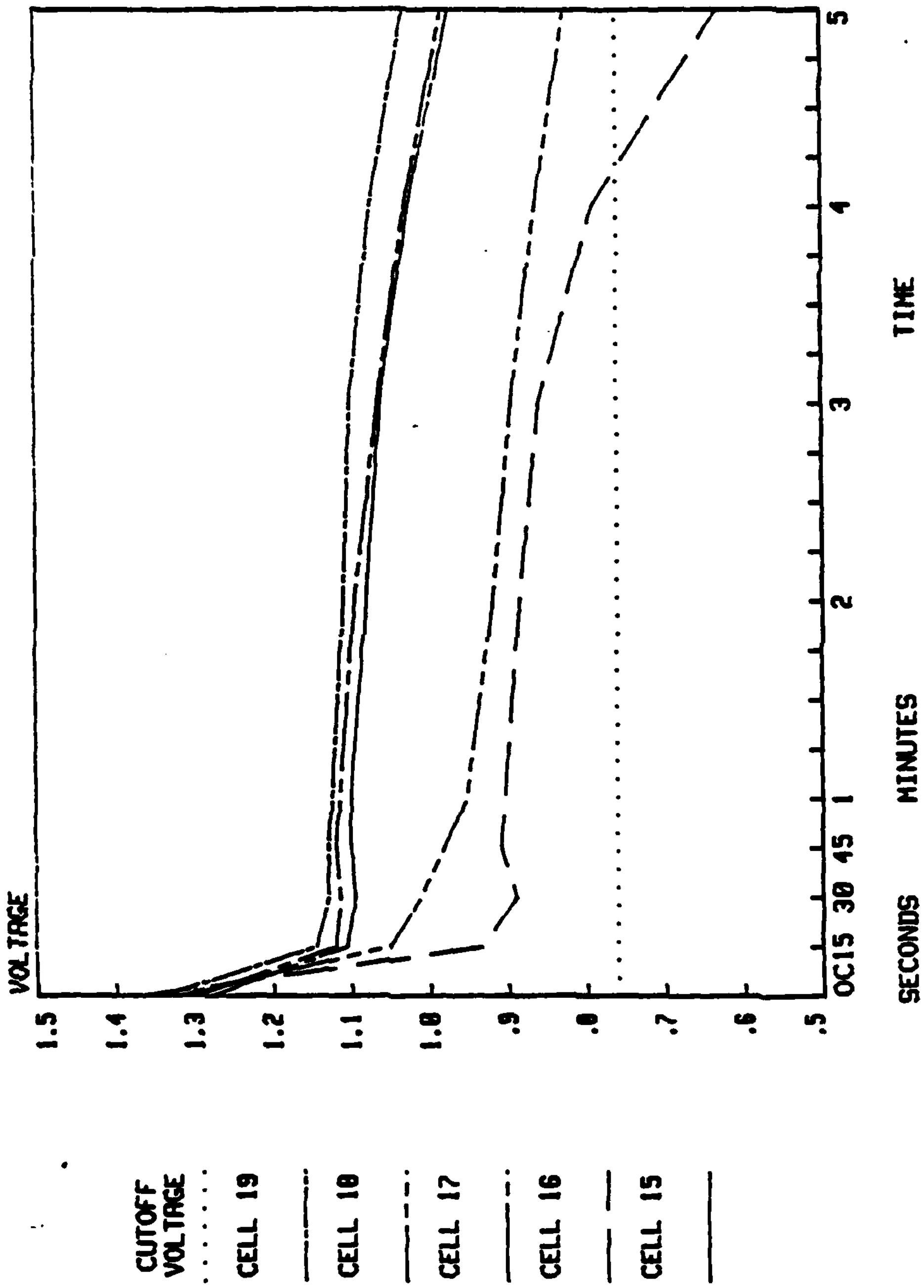


Figure 17C. 9C Discharge Rate for Type MS90321-78W Cells 15-19 Serial No. NAS Chase 4

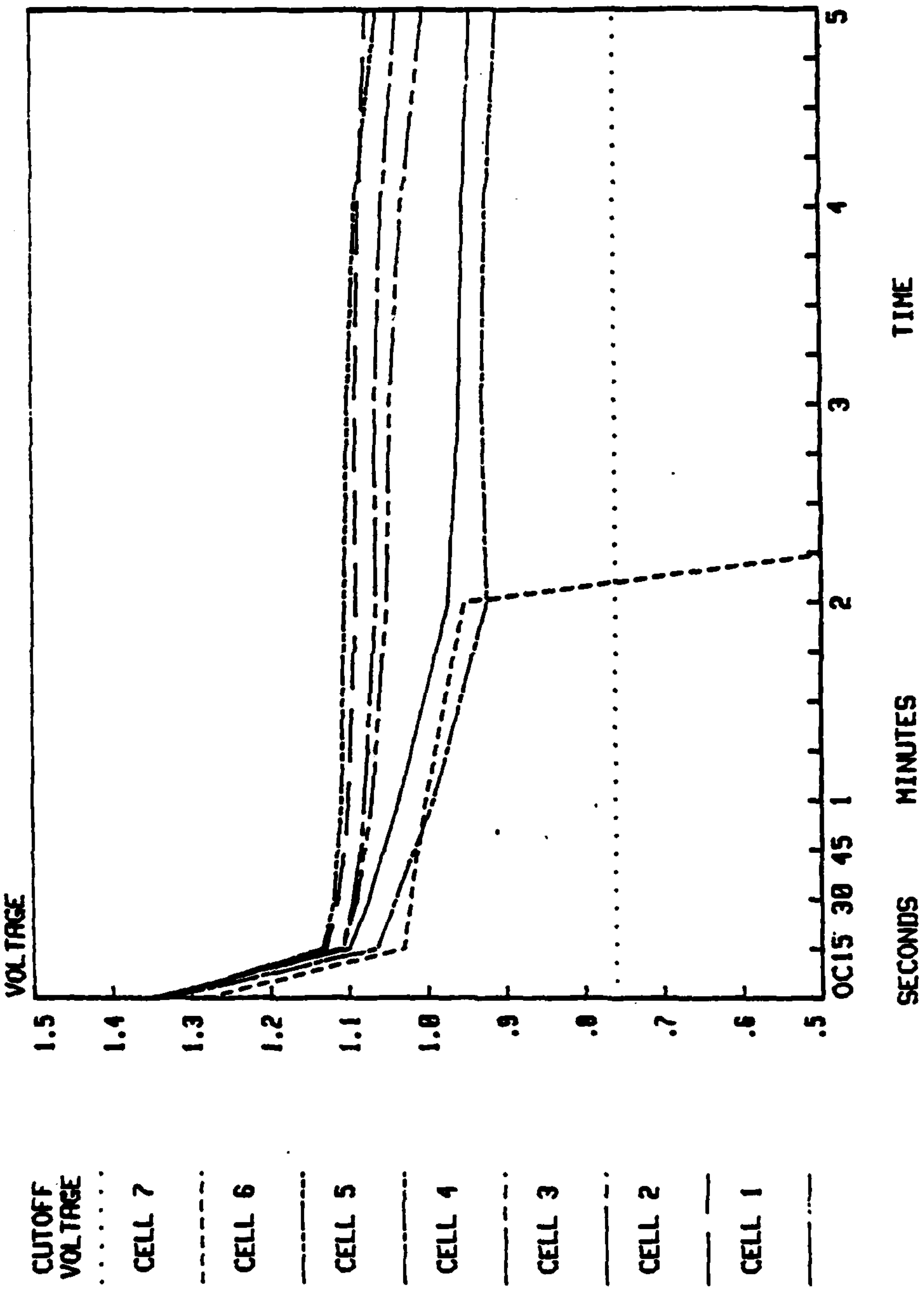


Figure 18A. 9C Discharge Rate for Type MS90321-78W
Cells 1-7 Serial No. NAS Pensacola 2

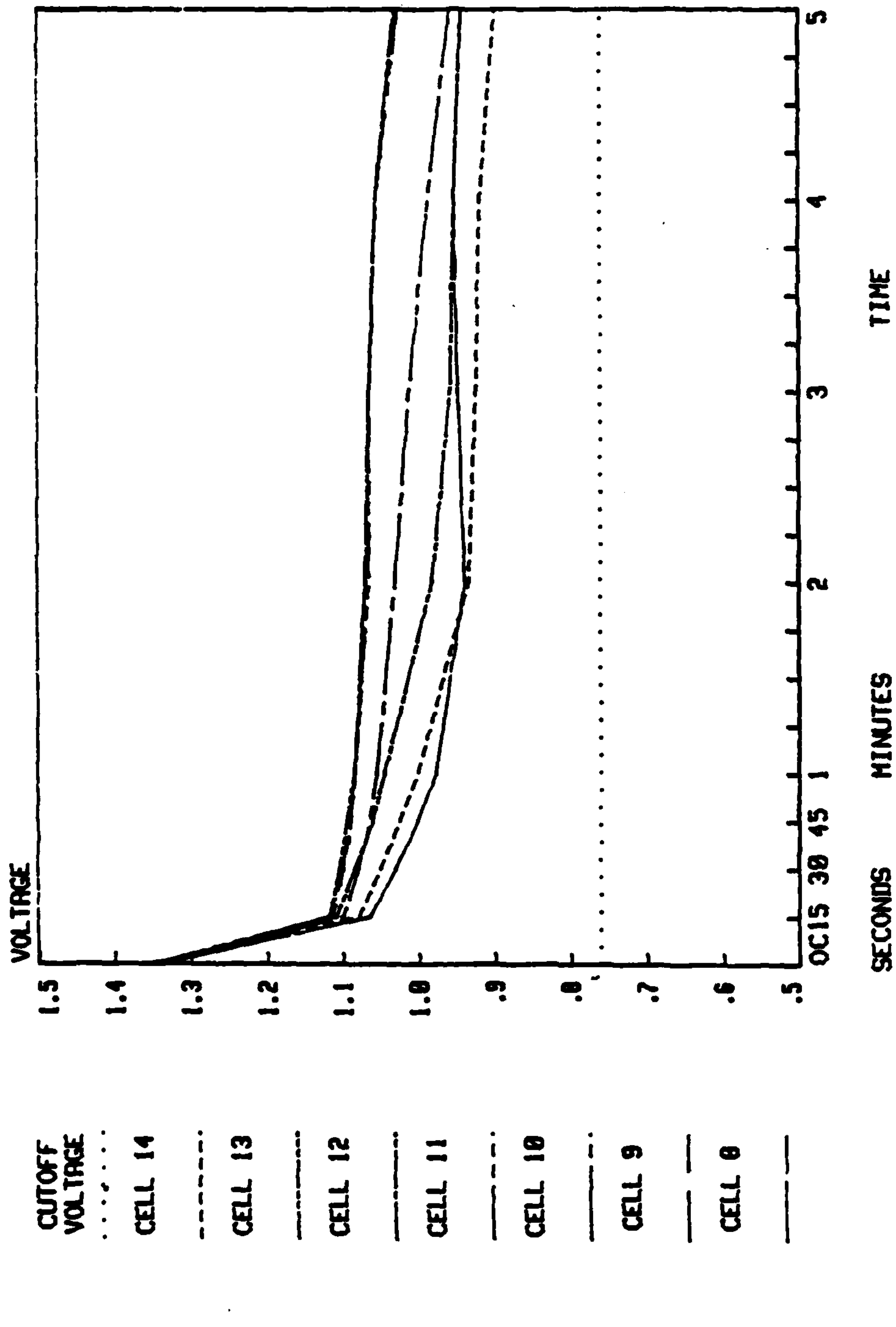


Figure 18B. 9C Discharge Rate for Type MS90321-78W Cells 8-14 Serial No. NAS Pensacola 2

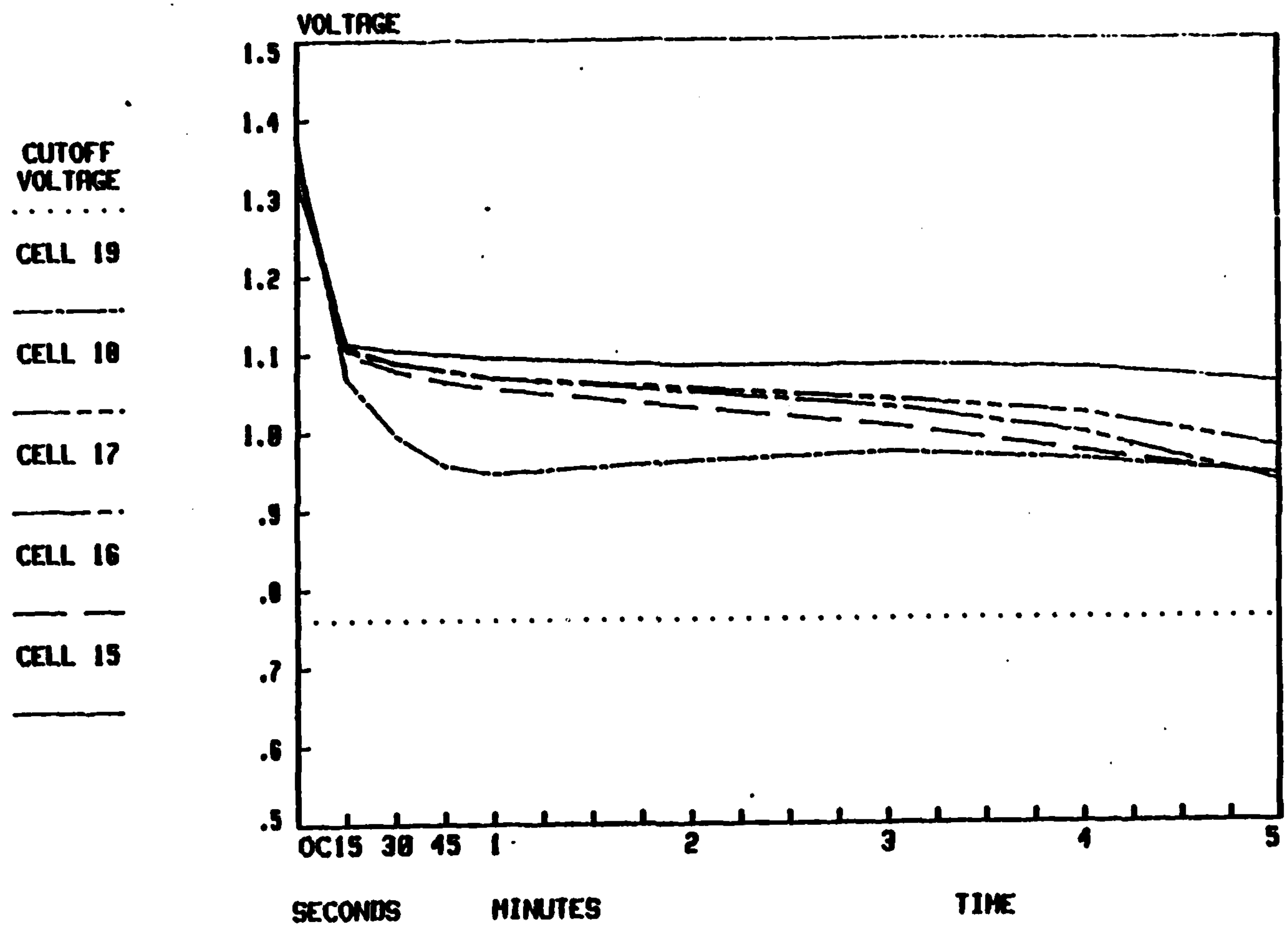


Figure 18C. 9C Dishcarge Rate for Type MS90321-78W
Cells 15-19 Serial No. NAS Pensacola 2

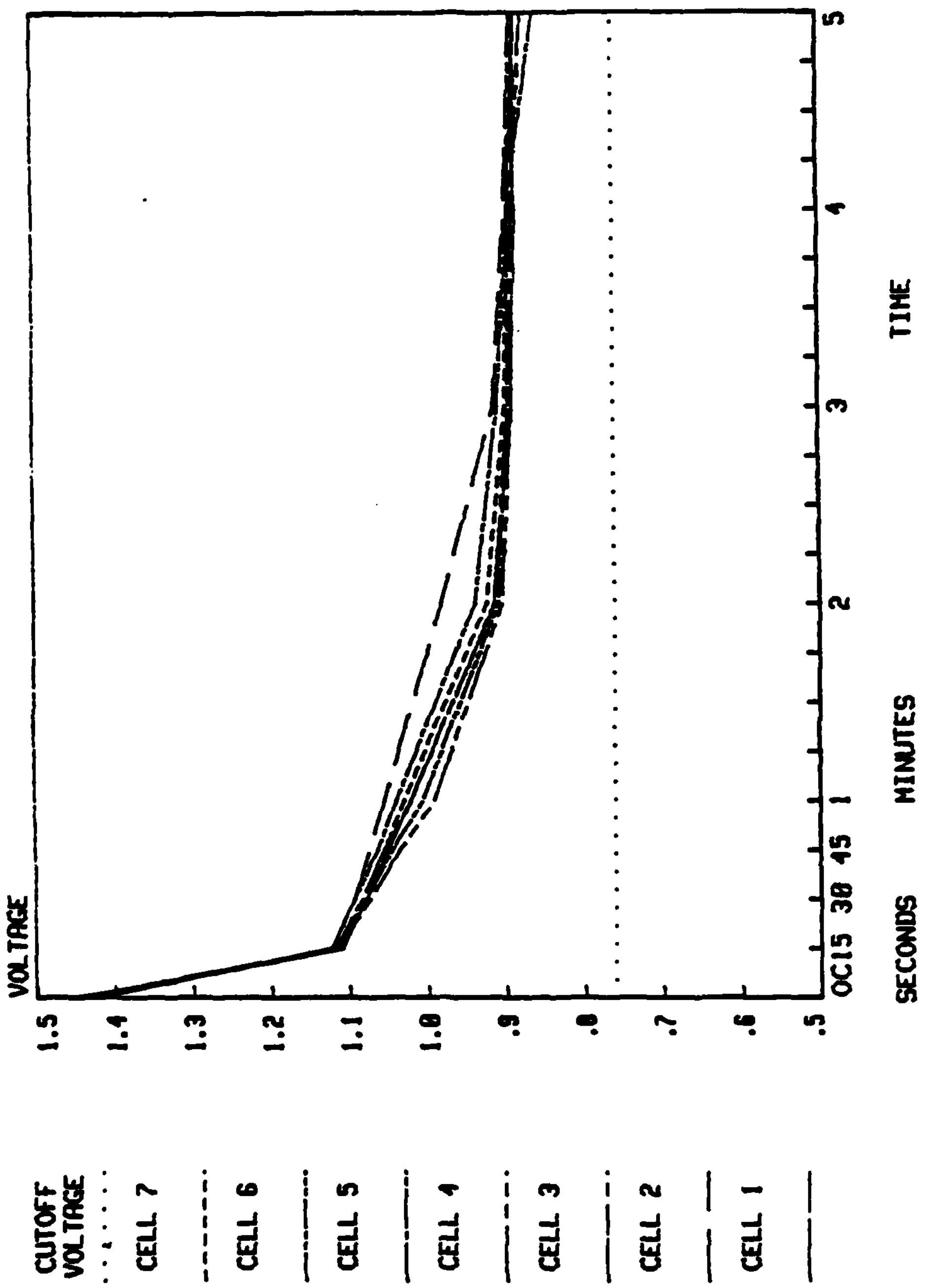


Figure 19A. 9C Discharge Rate for Type GE43B030RB19
Cells 1-7 Serial No. 0001

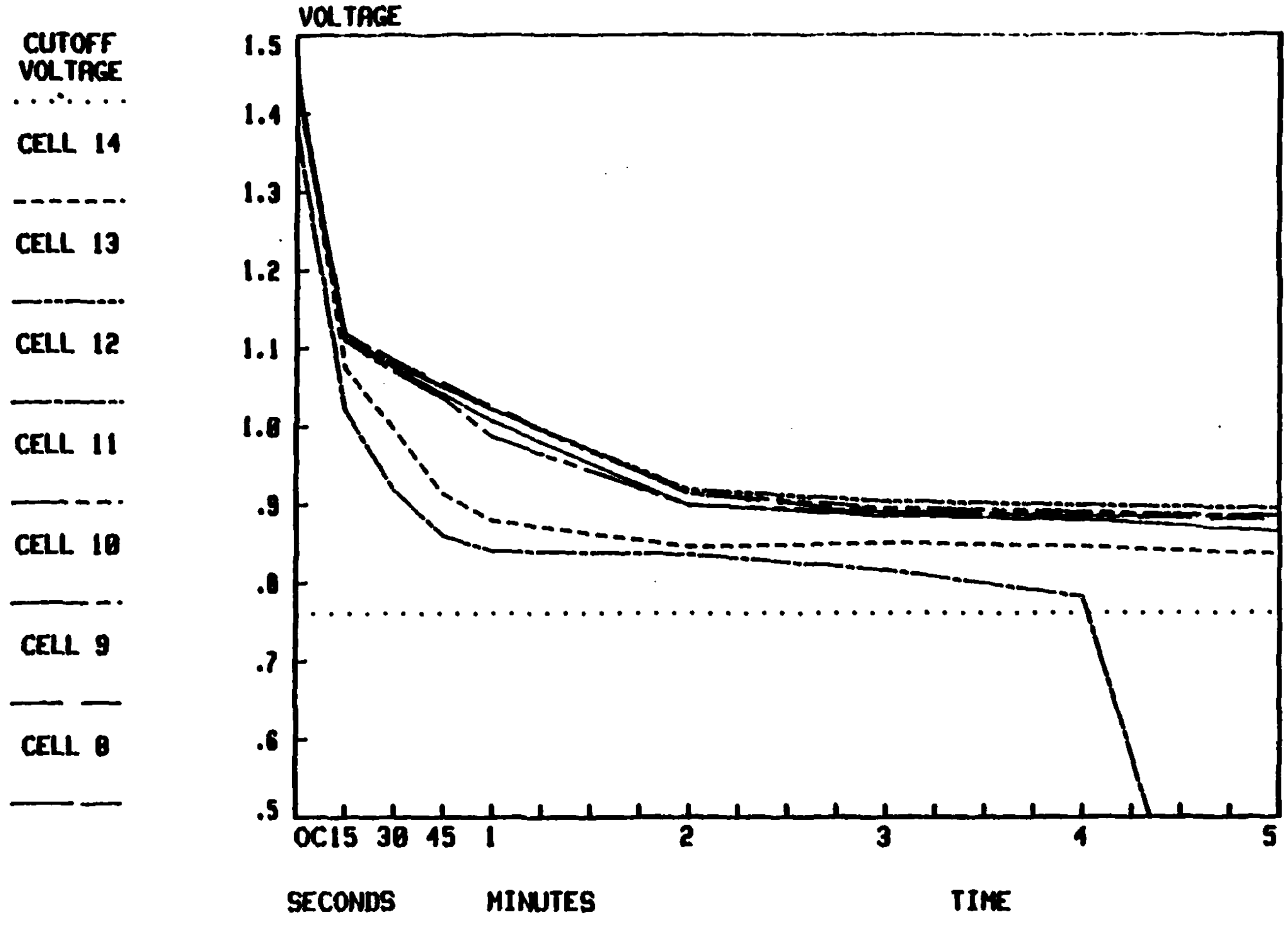


Figure 19B. 9C Discharge Rate for Type GE43B030RB19 Cells 8-14 Serial No. 0001

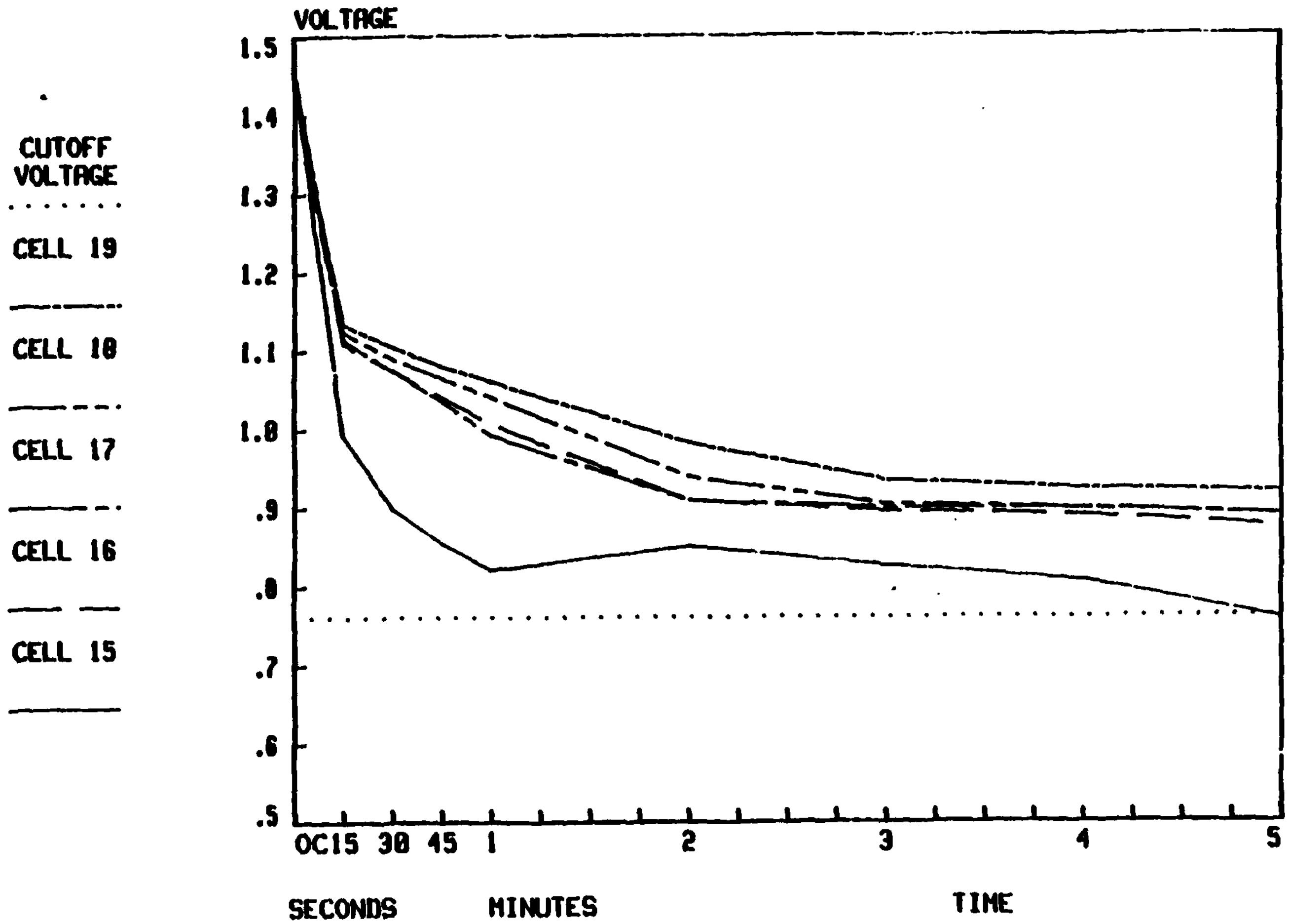


Figure 19C. 9C Discharge Rate for Type GE43B030RB19 Cells 15-19 Serial No. 0001

D. TEST PROCEDURE.

1. The following procedure was used to evaluate high-rate discharge test methods.

a. Determine battery capacity at the 1C discharge rate.

b. Charge battery at two-step DC constant-current rates for 3 hours or at a constant-potential of 28.5V for 5 hours.

c. Open-circuit rest for 2 hours.

d. Check electrolyte levels and adjust as required.

e. Discharge battery into a constant-resistance load equivalent to the 9C rate.

2. To perform the high-rate discharge, the constant-resistance loads were provided electronically by the Propel PBT 2000-24 battery profile tester, simulating the following resistance values.

a. 6-Ah battery - 0.336 ohm.

b. 10-Ah battery - 0.229 ohm.

c. 20-Ah battery - 0.115 ohm.

d. 30-Ah battery - 0.076 ohm.

The batteries were discharged until their terminal voltages decayed to 13.68V for the 18-cell M81757/10-1 battery and to 14.4V for all of the remaining 19-cell batteries, or until a total discharge time of 5 minutes had elapsed. Battery and cell voltage data were measured and recorded using an Analog Devices MACSYM II computer system. Data was printed out in 15-second intervals for analysis.

E. TEST RESULTS.

1. The intent of the high-rate discharge is to quickly and effectively screen cells and batteries that are incapable, without question, of performing engine starts aboard aircraft.

2. While conducting these tests, consideration was given to the difference between high-rate constant-current and high-rate constant-resistance methods. The constant-current method is specified for battery performance testing in accordance with all battery specifications. This method provides a constant stress on all cells for a full 5-minute period. However, this method also requires the use of a relatively sophisticated load bank. The alternate method, constant-resistance, would allow for the use of relatively simple discharge equipment, but does not provide for a constant stress throughout the entire discharge. As the battery voltage decreases, so does the load current, reducing

the overall stress upon each cell. This method, however, more closely simulates the actual starting conditions aboard aircraft.

3. In the final analysis, the constant-resistance method was chosen because of the desire to have less complex discharge equipment and because of its better simulation of actual engine starting conditions. Actually, the constant-resistance method is slightly more forgiving on marginally acceptable cells, thereby preventing the premature discard of usable cells.

4. The cell discharge characteristics shown in Figures 11A, 11B, and 11C are for 10-Ah cells within an M81757/7-2 battery. These curves, as well as the other discharge curves, display cell voltage as a function of time. Also shown for reference is the 0.76V cell cutoff voltage used to determine specification compliance during qualification tests. The discharge results of these cells were very good, indicative of new cells, and greatly exceeded minimum specification requirements. Generally, cell voltages at the end of the 5-minute discharge for new cells are 1.0 to 1.1 volts.

5. The cell discharge characteristics shown in Figures 12A, 12B, and 12C are also representative of very good cells, exceeding minimum specification requirements.

6. The remaining seven sets of figures (Figures 13A through 19C) display anomalies in cell voltages which lead to the establishment of a pass/fail criteria.

a. Cell 7 displayed in Figure 15A abruptly changed to a high value, indicating loss of contact between the cell scan fixture and the cell terminal post. This problem emphasizes the need for properly designed cell scan fixtures to insure good electrical contact with the cells for voltage monitoring.

b. During the discharge tests, several cells were unable to complete the 5-minute discharge time, dropping below the 0.76V cutoff voltage at times ranging from 5 seconds to 4.5 minutes. The cells identified in Table 12 are shown with their respective discharge times, i.e., the time the cells reached the 0.76V cutoff voltage.

c. From the cell discharge data shown, two questions come to mind:

(1) Should a cell that has been operating in the Fleet be required to meet similar test requirements of batteries undergoing design qualification testing? Perhaps a degree of relaxation can be tolerated.

(2) Does a cell test failure have to be experienced, or can it be predicted early within the high-rate discharge test, i.e., within 1 to 3 minutes?

d. To answer the first question, it is a fact that battery performance does degrade as a function of cycle life and environmental exposure. It is judged that a cell which can remain above the 0.76V cutoff voltage for approximately 4 minutes or greater would provide acceptable engine starting performance in the aircraft. The intent of this test is not to discard marginally acceptable cells, but rather to positively identify and remove weak cells that will fail in an engine starting application.

TABLE 12. CELLS FAILING TO MEET THE 0.76V, 5-MINUTE DISCHARGE REQUIREMENT

Figure	Battery I.D.	Cell No.	Discharge Time (Mins)
13B	NAS PNCLA 1	11	0.25
14A	NAS CHASE 1	4	2.0
14B	NAS CHASE 1	9	4.0
14B	NAS CHASE 1	14	2.0
15B	NAS CHASE 2	8	4.5
16A	NAS CHASE 3	3	2.4
16A	NAS CHASE 3	5	0.5
16C	NAS CHASE 3	16	2.75
17B	NAS CHASE 4	8	0.1
17C	NAS CHASE 4	16	4.2
18A	NAS PNCLA 2	7	2.1
19B	GE001	12	4.0

e. To answer the second question we must again look at the data. In order to predict that a cell will prematurely drop below the 0.76V cutoff voltage and not actually experience the failure, the cell must be evaluated at a slightly higher voltage level.

f. A cell voltage of less than 0.80V was the value selected for prediction of cell failure, with the determination being made exactly 3.0 minutes into the discharge.

g. In comparing this value with the cell voltage data displayed in Figures 11A through 19C, specifically for the cells listed in Table 12, we find that:

(1) All cells that dropped below the 0.76V cutoff voltage in 3.0 minutes or less are obvious failures.

(2) Each of the four cells which had discharge times of 4 minutes or greater were considered acceptable because their voltages at the 3-minute mark were greater than 0.8V. If their voltages would have been less than 0.8V, they would have been considered failures.

(3) It is probable that any cell that would fall below the 0.76V cutoff voltage cutoff level sometime between 3 and 4 minutes would also be predicted as a cell failure at the 3-minute mark.

h. In comparing the 0.8V, 3-minute voltage-time limit with all remaining cells displayed in Figures 11A through 19C, having met the 0.76V, 5-minute voltage-time limit, we find that all cells are acceptable--no cell would have been incorrectly predicted to fail.

i. In establishing a cell pass/fail prediction criteria at 3 minutes into the discharge, it is possible to incorrectly pass or fail a cell. However, the margin of error is believed to be quite small.

7. Comparisons were made of battery performance when discharged at the 1C rate and 9C rate. Many of the very weak cells were obvious failures at both discharge rates. However, there were cells which passed at the 1C rate, but failed at the 9C rate. Conversely, there were cells that passed at the 9C rate and failed at the 1C rate. However, in this case, these cells generally exhibited unacceptably low end-of-charge voltages and would be rejected for this reason.

8. Implementing the high-rate discharge method will not only save approximately 1 hour during the discharge mode, but will save approximately 1.5 hours in the charge mode. A total of 2.5 hours of servicing time can be saved for every battery discharge-charge cycle performed. The time saved in the charge mode is possible because only 45 percent of the total ampere-hours capacity is removed from the battery, rather than the usual 100 percent. Therefore, a much shorter recharge period is required.

9. It is suggested that the common 1C rate discharge test not be totally eliminated, but would be performed on batteries one or two times each year to positively certify that batteries have minimum acceptable reserve capacity.

10. To summarize the high-rate discharge test, batteries would be subjected to constant-resistance loads at approximately the 9C discharge rate for 3.0 minutes. At the end of the 3-minute period, just prior to discharge termination, all cells having voltages of 0.8V or greater would be considered acceptable for use in aircraft.

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