NON-PROPRIETARY
APS - PVNGS CRDR 240348
3/1/95

Equipment Root Cause of Failure Analysis
AT&T Lineage 2000 Round Cells in Unit 2

Event Date 10/1/94

Report Date: 1/31/95

This report has been abridged to exclude information which was viewed as proprietary to AT&T and the manufacturer who produced these battery cells for AT&T. A brief update has been included at the request of AT&T to document the results of testing that was performed subsequent to completion of the report. This update is included to clarify differences between the original Unit 2 batteries and the performance testing of cells obtained in support of the full replacement of the Unit 2 batteries. Pages 21 through 26 have been removed pending review by the battery manufacturer.

Equipment Root Cause of Failure Analysis

AT&T Lineage 2000 round Cells

UPDATE - 3/1/95

This information is being provided as an update and not part of the original report since that report was based on the performance of the original unit 2 cells. However, significant testing results have been obtained on the replacement cells since the report was completed.

Since the Equipment Root Cause of Failure Analysis (ERFCA) was performed on the Palo Verde Unit 2 cells additional testing has been performed to determine the cause for discharge testing results noted during the dedication testing of cells obtained for replacement of the unit 2 class batteries. Several of the replacement cells were observed to lose capacity during testing at Palo Verde. In order to ascertain if this cause of capacity loss was related to the original unit 2 problem, discussed in the following report, a "capacity recovery" test method was specified by AT&T.

A sample of twelve cells from a replacement string was boost charged (@ 2.5 to 2.6 volts/cell for 100 hours following 1.5 months on open circuit) and then subjected to a performance test at the two hour rate (514 Amps). The string had originally been subjected to four discharge tests. The capacity was noted to drop on each discharge as shown below:

Capacity 1st Discharge	Capacity 2nd Discharge	Capacity 3rd Discharge	Capacity 4th Discharge	Boost Charge	6 cell-Capacity 5th Discharge
104%	97.5%	87.6%	81%	100 hours	119%

The results of this testing indicates that the performance of the replacement cells is most likely attributable to the type of recharge done between successive discharges or the repetition of discharges over a short time period. It also appears that the performance of these cells was not a result of poor production controls as is suspected in the performance of the original Unit 2 cells.

This information is being provided as an update and not part of the original report since that report was based on the performance of the unit 2 cells. The fact remains that the original unit 2 performance test results were obtained after the cells had been on float for a considerable length of time. Additionally, the unit 2 cells performance was substantially different then the Unit 1 and 3 cells performance. Therefore, it would be premature to conclude that the success in recharging the replacement cells alters the conclusions reached in the ERCFA. AT&T and APS are entering in a joint testing program to determine the role of recharging methods on subsequent discharge capacity losses. One part of this program will be to apply the same "boost" recharging method, used on these replacement cells, to some of the replaced Unit 2 cells to determine if the capacity is recoverable.

EQUIPMENT ROOT CAUSE OF FAILURE ANALYSIS

CATEGORY A

AT&T LINEAGE 2000 Round Cells
2EPKAF11, 2EPKBF12
2EPKCF13, 2EPKDF14

February 22, 1995

Revision 1

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Executive Summary

Failure Description: The 60 month battery discharge test, 32ST-9PK04, was performed on 2EPKAF11 and 2EPKCF13 (battery banks A and C) during the 9/94 Unit 2 mid-cycle outage. The test was performed on the Class 1E batteries to satisfy the IEEE Standard 450-1980 requirement to perform a capacity discharge test on new batteries within the first two years of service. The discharge test, 32ST-9PK04, performed on 9/23/94 indicated a battery capacity of 91.6% and 90.6% for 2EPKAF11 and 2EPKCF13, respectively. While the test results met the Technical Specification 4.8.2.1.e requirement of a minimum of 90% capacity, the capacities of the battery banks were lower than expected. As a result of the lower than expected discharge test results for 2EPKAF11 and 2EPKCF13, the Unit 2 B and D batteries were tested on 9/29/94 to determine if their performance was acceptable or degrading. The capacities for the first discharge tests performed at PVNGS in 1/94 on battery banks B and D were both approximately 100%. These capacities were less than the capacities from the commercial grade dedication discharge tests performed by the manufacturer prior to shipment. The measured capacities for 2EPKBF12 and 2EPKDF14 were 89.0% and 88.3% on 9/29/94, respectively. Unit 2 battery banks B and D were declared inoperable because the capacity of both batteries was below the Technical Specification 4.8.2.1.e limit of 90%. On 10/7/94 Unit 2 battery banks A and C were declared inoperable because projected test results anticipated degradation of the batteries below the Technical Specification 4.8.2.1.e. minimum limitation of 90% capacity.

Based on testing of the Unit 2 spares, the degradation mechanism appears to be aggravated by charge/discharge cycling of the cells and is not age related. The loss of positive plate capacity from deep discharge cycling of the cells results in a loss of capacity for the Round Cells in Unit 2. Each subsequent cycle degrades about the same fraction of capacity. The test results indicate that the battery capacities tend to stabilize at approximately 55% after 6 capacity discharge tests.

Root Cause determination: The failure mode results from a step decline in capacity probably caused by a loss of positive active material due to improper curing or contamination during fabrication. The loss of capacity was probably due to poor production control during manufacturing. No credible mechanism for sudden discharge failure has been found.

Corrective Actions Taken: Immediate corrective actions were taken to justify the operability of the Unit 2 batteries. The NRC issued Amendment No. 71 to Facility Operating License No. NPF-51 for PVNGS Unit 2, on 10/13/94 to allow batteries 2EPKAF11, 2EPKBF12, 2EPKCF13 and 2EPKDF14 to be declared operable. To eliminate transportability to Units 1 and 3, previous battery test data from Units 1 and 3 were reviewed and compared to the Unit 2 battery performance data. Additional testing on the Unit 1 and 3 spares assured that the observed Unit 2 failure was not transportable to Unit 1 or 3.

Because the discharge data shows that capacity loss occurs after each charge/discharge cycle; changes have been made to the dedication testing to assure that replacement cells will have acceptable performance prior to installation. Two commercial grade dedication discharge tests (instead of one) will be performed at the factory prior to shipment to PVNGS. Engineering will evaluate test data and determine acceptable cells for shipment. PVNGS Nuclear Assurance must witness both tests at the factory and review all material test results confirming traceability to the factory corporate lab, which has been successfully audited by the joint utility NUPIC organization. Nuclear Assurance and Procurement Engineering have conducted an in-depth surveillance of the manufacturing processes. Surveillance of the manufacturing processes must be reverified by Nuclear Assurance as part of the dedication testing for replacement cells.

The long term corrective action is to replace all the Unit 2 battery cells during the fifth refueling outage (U2R5) scheduled for 2/4/95. Additionally, AT&T will be conducting a long term testing program to provide an in-depth evaluation of the replacement cell performance test results that will better model the high specific gravity Round Cell performance characteristics. CRDR 2-5-0039 has been initiated to evaluate the replacement cell performance test results, document the results of the AT&T testing program and implement corrective actions, as required.

Equipment Description

Four Class 1E 125 VDC power subsystems designated A, B, C and D are provided in each Unit. Subsystem A and B provide control power for alternating current load groups 1 and 2, respectively. These subsystems also provide vital instrumentation and control power for channels A and B, for Reactor Protection, Engineered Safety Features (ESF) systems, and diesel generators A and B. Subsystems C and D provide vital instrumentation and control power for channels C and D, for Reactor Protection, ESF systems and other safety-rated loads as referenced in UFSAR, Table 8.3-6, *Class 1E DC System Loads*. Each Class 1E DC subsystem consists of one 125 VDC battery composed of 60 cells, one battery charger and one distribution panel, which is supplied with 480 VAC power from separate motor control centers. The battery chargers are designed to supply at least 400 Amps for battery banks A and B, and 300 Amps for banks C and D at 125 volts for at least eight hours. Four inverters, which are supplied from the DC subsystems, provide four independent 120 VAC vital instrumentation and control power supplies for the banks of Reactor Protection and ESF systems. The Class 1E 125 VDC power system has two backup chargers. Backup charger "AC" is capable of providing 125 VDC power to battery bank A or C. Backup charger "BD" is capable of providing 125 VDC power to battery bank B or D.

The Class 1E 125 VDC systems are designed for normal operation at a charger float voltage of 135 DC. During normal operation, the normal battery charger supplies power to its associated 125 VDC control center. In addition to carrying the loads on the DC control center, the normal battery charger provides a float charge to the battery to keep the battery fully charged. The battery is available as a standby DC source to carry the control center load automatically in case of loss of the charger. The common backup battery charger is connected through a manual transfer switch to the DC control center. In case of loss of AC power to the normal battery charger, or unavailability of the normal battery charger due to maintenance or testing, the backup battery charger is manually connected to the control center to supply control loads and provide a float charge to the battery. In case of complete loss of AC power, each DC control center will be fed by its battery for a minimum of two hours. Upon restoration of AC power, the battery charger is operated in the equalize mode to supply all the steady state loads and the charging current required to restore the battery from the design minimum charge state to the fully charged state within 12 hours.

Each Unit has four batteries EPKAF11, EPKBF12, EPKCF13 and EPKDF14. Each battery is compromised of 60 AT&T LINEAGE 2000 Round Cells, model KS-20472. Each is a high specific gravity, 1850 ampere-hour (AH) lead-acid battery. The cells, each having a nominal ICV (individual cell voltage) of 2.08 VDC, are series connected to provide the 125 VDC battery bank voltage. Each Unit has four spare cells, which are located in the bank A battery room. The spares are tested and maintained the same as the four battery banks. The spares are recharged following testing on a separate charger. The spare battery chargers are designed to supply 50 Amps at 125 volts for at least eight hours.

Overall battery performance is defined by two types of tests: the performance (capacity or deep discharge) test and the service (load profile) test. The capacity discharge test is performed prior to shipment, during the first available outage following installation (within 2 years of installation) and at 60 month intervals thereafter. The purpose of this test is to provide an in-depth analysis of the condition of the cell and a method to estimate when the battery must be replaced. The battery is connected to a test load bank, referred to by the manufacturer's name as the Alber. This test draws a fixed current (514 amps corrected for temperature) starting from the initial voltage of 125 VDC. As the test proceeds the battery voltage decreases. The time it takes to reach 105 VDC is recorded (along with the ICVs). The acceptance criteria for this test is the capacity of the battery relative to 2 hours. Thus, if it takes exactly 2 hours for the battery to reach 105 VDC the capacity is 100%. In the case of the two batteries in Unit 2, this time was less then 2 hours. The other test performed on the station batteries is the service test (32ST-9PK03). This test is used to verify that the battery is capable of meeting the safety analysis load capacity. This tests the batteries to a defined load profile based on the expected loading on the batteries during an actual accident condition.

Although relatively new in nuclear applications, the AT&T LINEAGE 2000 low specific gravity Round Cells have been available for nearly twenty years. High specific gravity cells have been available since 1990. There are more that 500,000 Round Cells in service in both high discharge rate uninterruptible power supply (UPS) applications and low discharge rate (standby reserve) applications.[1] Approximately 2000 high specific gravity cells have been manufactured for UPS and nuclear applications

The AT&T LINEAGE 2000 Round Cell has a conventional pasted plate construction similar to other lead-acid batteries. However, the Round Cell design is unique in that the pure lead grids are circular and maintained in a horizontal configuration, which creates a radial uniform growth rate ≅ 2% over 70 years. Because each concentric ring of the grids in the Round Cell grows at the same rate, good contact with the active material (paste) is maintained over the life of the battery. The conversion of the pure lead grid offsets, to some degree, the corrosion effects that limit the life of the cell. Therefore, capacity is predicted to increase over the life of the battery.

AT&T LINEAGE 2000 Round Cells operate in the same manner as conventional lead-acid storage batteries. The 60 cell battery provides electrical power by converting its stored chemical energy into electrical energy. The energy conversion is achieved by a chemical reaction in the battery that releases electrons. The process is reversible in a stationary battery; electrical energy directed into the battery reverses the chemical reaction and restores the battery to a fully charged condition.

The generation of electrical current from a battery cell originates from a difference in electrochemical potential between two compounds (the positive and negative plates) inside the battery that are not in direct contact, but are connected by an electrically conducting medium (electrolyte). The electrochemical process between the plates and electrolyte creates a voltage difference between the positive and negative plates of the cell. The voltage difference between the plates constitutes an electromotive force that causes electrons to flow from the negative to the positive plates, if connected together by an external load. The battery continues to generate electrical current until the materials involved in the

reaction are depleted or the external connection is removed. In a lead-acid battery, the positive plate (active) material is lead dioxide (PbO_2) and the negative plate material is lead (Pb). The chemical reaction in a lead-acid cell is in terms of the reaction occurring at each plate.[2] From left to right, these equations represent the discharge process (from right to left, the charging process):

Positive Plate	$PbO_2 + SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$PbSO_4 + 2\,H_2O$
Negative Plate	$Pb + SO_4^{2-}$	$\rightleftharpoons$	$PbSO_4 + 2e^-$

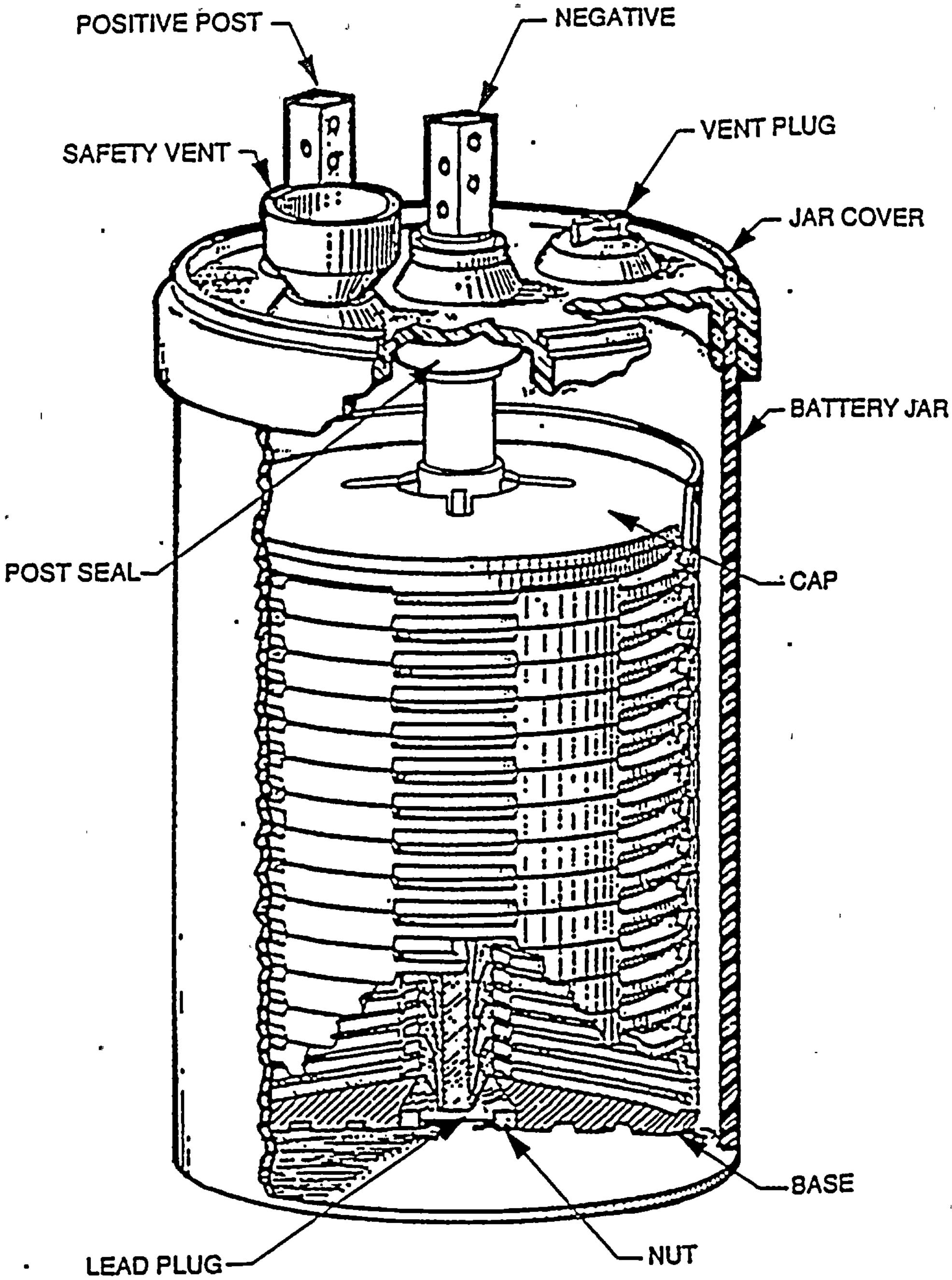


FIGURE 1.0 AT&T LINEAGE 2000 Round Cell

Failure Description

The 60 month battery discharge test, 32ST-9PK04, was performed on 2EPKAF11 and 2EPKCF13 (battery banks A and C) during the 9/94 Unit 2 mid-cycle outage. The test was performed on the Class 1E batteries to satisfy the IEEE Standard 450-1980 requirement to perform a capacity discharge test on new batteries within the first two years of service. The discharge test, 32ST-9PK04, performed on 9/23/94 indicated a battery capacity of 91.6% and 90.6% for 2EPKAF11 and 2EPKCF13, respectively. While the test results met the Technical Specification 4.8.2.1.e requirement of a minimum of 90% capacity, the capacities of the battery banks were lower than expected. As a result of the lower than expected discharge test results for 2EPKAF11 (A battery) and 2EPKCF13 (C battery), the Unit 2 B and D batteries were tested on 9/29/94 to determine if their performance was acceptable or degrading. The measured capacities for 2EPKBF12 and 2EPKDF14 were 89.0% and 88.3%, respectively. Unit 2 battery banks B and D were declared inoperable because the capacity of both batteries was below the Technical Specification 4.8.2.1.e limit of 90%. On 10/7/94 Unit 2 battery banks A and C were declared inoperable because projected test results anticipated degradation of the batteries below the Technical Specification 4.8.2.1.e. minimum limitation of 90% capacity.

The capacities for the first discharge tests performed at PVNGS in 1/94 on battery banks B and D were both approximately 100%. These capacities were less than the capacities from the commercial grade dedication discharge tests performed at the factory prior to shipment. When the Unit 2 battery banks B and D were tested during the mid-cycle outage, cells 17 and 36 reached end voltages of 1.15 VDC and 1.28 VDC, respectively. The calculated capacity for cells 17 and 36 was 83.3% and 66.6%, respectively. The overall battery bank (60 cells) capacity was 100%. All acceptance criteria for the ST was met. According to CRDR 2-4-0070 (see Attachment 1), Plant Electrical Engineering concurred with the following AT&T's recommendations:

1.) Replace cells 17 and 36 during U2R5 with two tested spare cells (reference CRDR 2-4-0070 and WO 00649332). According to data taken on 2/4/94, after the battery bank was charged, float voltages measurements for all 60 cells in battery bank 2EPKDF14 were normal. Battery bank 2EPKDF14 has excess capacity for its design load. The final overall bank voltage at the end of the load profile (service) test, following initial battery installation, was 123 VDC. Using this data and assuming the worst case scenario, both cells failure to reverse voltage (reverse polarization), the two hour service discharge (which simulates actual plant load demands) battery bank end voltage would be approximately equal to 115 VDC. It was concluded; therefore, the 2EPKDF14 battery bank capacity would not be adversely affected if cells 17 and 36 were not replaced until U2R5.

2.) Retest the degraded two cells. If the retest proved the cells were degraded (rather than an error in the test setup) the cells would be shipped back to the factory for root cause analysis after U2R5 (reference CRDR 2-4-0070, action 1).

The following tables summarize the history of the capacity and load profile tests completed on the installed cells in Units 1, 2 and 3.

Comparison of the History of Unit 1, 2, and 3 Batteries

Unit 1	Unit 2	Unit 3
Manufactured	Manufactured	Manufactured
Charged @ the factory	Charged @ the factory	Charged @ the factory
Factory Discharge Test (passed)	Factory Discharge Test (passed)	Factory Discharge Test (passed)
Recharged @ the factory	Recharged @ the factory	Recharged @ the factory
Shipped	Shipped	Shipped
Conduct 32ST-9PK03 (Service Test)	Conduct 32ST-9PK03 (Service Test)	Conduct 32ST-9PK03 (Service Test)
Recharge @ PVNGS	Recharge @ PVNGS	Recharge @ PVNGS
Conduct 32ST-9PK04 (Full Discharge) Equal to or better capacity	**Conduct 32ST-9PK04 (Full Discharge) Diminished Capacity of 10 - 15%**	Conduct 32ST-9PK04 (Full Discharge) Equal to or better capacity

Charge / Discharge / Testing Completed on Installed Cells

Battery Cell Location	Factory Discharge #1	Recharge	Factory Discharge #2	Recharge	32ST-9PK03 Load Profile	Recharge	32ST-9PK04 Full Discharge (530A)	Recharge
Unit 1	X 530 Amps	70A/20hrs. 5A/3days	X (Banks B&D)	70A/20hrs 5A/3days	Passed	2.33 V (Current limit of 300/400A) until <10 Amps 2.5V/8hrs	Bank Capacity A 108.6% B 105.4% C 105.7% D 106.6%	2.33 V (Current limit of 300/400A) until <10 Amps 2.5V/8hrs.
Unit 2	X 530 Amps	70A/20hrs. 5A/3days	X (120 cells) 530 Amps	70A/20hrs 5A/3days	Passed	2.33 V (Current limit of 300/400A) until <10 Amps 2.5V/8hrs	Bank Capacity A 91.6% B 100% / 89% C 90.6% D 100% / 88.3%	2.33 V (Current limit of 300/400A) until <10 Amps 2.5V/8hrs.
Unit 3	X 530 Amps	70A/20hrs. 5A/3days	N / A	N /A	Passed	2.33 V (Current limit of 300/400A) until <10 Amps 2.5V/8hrs	Bank Capacity A 105.6% B 110% C 109.2% D 112.9%	2.33 V (Current limit of 300/400A) until <10 Amps 2.5V/8hrs.
Spares (Units 1 & 3)	X 530 Amps	70A/20hrs. 5A/3days	N / A	N /A	Passed	2.25V (Current limit of 50A)/ Float duration	Unit 1: >106% Unit 3: >103%	2.25V (Current limit of 50A) /Float duration
Spares (Unit 2)	X 530 Amps	70A/20hrs. 5A/3days	X 530 Amps	X 530 Amps	Passed	2.25V (Current limit of 50A)/ Float duration	91.6 %	2.25V (Current limit of 50A) /Float duration

Sequence of Events

4/91	Duke Power McGuire acquired 2 batteries, 58 cells per battery bank. (During the course of the investigation communications have been conducted with the battery system engineer).
1/92 to 2/92	PVNGS Unit 1 cells procured.
3/92	2 additional batteries bought by McGuire.
7/92 to 8/92	PVNGS Unit 3 cells procured.
10/92	AT&T LINEAGE 2000 Round Cell production at the factory increased.
12/92 to 3/93	Cells were put on hold at the factory because of "loose white pellets". The total number of cells with white pellets increased.
1/93	PVNGS Unit 2 cells procured. Two banks of Unit 2 cells had shipment stopped due to white pellets.
2/93	Joint AT&T/Manufacturer Investigation of loose white pellets was undertaken to (1) determine and correct the root cause of the problem and (2) to determine the effect on the float characteristics of the cell active material. Remaining Unit 2 cells shipped to PVNGS after rework.
3/93 - 5/93	The factory implements corrective actions from joint AT&T/Manufacturer Investigation (2/93).
12/93	Braidwood bought 2 batteries, 59 cells per battery bank.
1/12/94	Letter from AT&T: "Identification & Elimination of the Root Causes of Loose White Pellets in KS-20472 AT&T Lineage 2000 Round Cells during manufacturing."(The AT&T investigation was conducted in February - March, 1993).
7/94	Braidwood bought 2 additional batteries, 59 cells per battery bank and 4 spares. 23 new cells used by PVNGS as Unit 2 replacement cells were manufactured (shipped from the factory 10/5/94).
9/23/94	During the performance of capacity discharge test 32ST-9PK04, the battery capacity for 2EPKAF11 and 2EPKCF13 was 91.6% and 90.6%, respectively. The 90% capacity minimum stated in Technical Specification 4.8.2.1.e was met, no action was required.
9/27/94	Data reviewed and evaluated. Contacted AT&T. Suspected error in testing results and/or test setup.

9/28/94	Retested Unit 2 spares. NRC (Dyle Acker) informed of situation.
9/29/94	Confirmed data taken 9/23/94 was NOT due to incorrect method or testing errors. APS and AT&T inspect batteries at PVNGS. Because the capacity for banks A and C were lower than expected, capacity discharge tests were performed on battery banks B and D. The battery capacity for 2EPKBF12 and 2EPKDF14 was 89.0% and 88.3%, respectively. The B and D battery banks were declared inoperable because the measured capacity was less than the required 90% capacity stated in Technical Specification 4.8.2.1.e.
10/1/94	Assembled task force to perform cell and battery bank degradation prediction. Capacity discharge tests were performed on the spares in Units 1 and 3. Compared to previous test data, the measured capacity for each of the 8 spare cells increased or remained the same (exceeded 100%). Transportability to Units 1 and 3 was eliminated.
10/2/94	APS began root cause of failure investigation. Procurement of 244 new replacement cells from the factory began.
10/5/94	23 new cells shipped from the factory, installed in Unit 2.
10/7/94	Representatives from PVNGS and FPI arrive at the factory to assist in the root cause of failure investigation. Unit 2 battery banks A and C were declared inoperable because projected test results anticipated degradation of the batteries below the Technical Specification 4.8.2.1.e. 90% capacity minimum. 71 new cells (HG-12) shipped from the factory to PVNGS. No dedication capacity discharge testing was performed at the factory (testing performed at PVNGS instead). Cells not shipped via "air ride". Cell #10 from PVNGS Unit 2, was discharged and disassembled (witnessed by representatives from AT&T, FPI, APS and the factory).
10/8/94	"Good" cell, manufactured in July 1994, disassembled at the factory. Sent samples from cell #10 and "good" cell to Lancaster Labs and FPI.
10/9/94	NRC arrived at the factory.
10/11/94	APS met with NRC in Washington DC.
10/12/94	APS returned to the factory.
10/13/94	Cells #6 and #36 from PVNGS Unit 2 were disassembled. Conference call made with the factory, AT&T, FPI and APS to discuss data from samples taken from cell #10. FPI preliminary analysis were as follows; calcium was present on the negative plate, there were differences in porosity between the negative plates of the "good" and #10 cell and no differences could be identified between the positive plates.

10/18/94	At PVNGS, HG-12 was divided to 3 groups (A, B, and C). HG-12 cells were maintained in an environment that can see a 15 °F change prior to testing (Cells inside the Units are temperature controlled). The dedication discharge test was performed on HG-12, Group A using jumpers (instead of intercell connectors). Capacity = 104%. Recharged PVNGS method; recharging at 2.25 Volts at the charger current limit (150 Amps) until 2.5 volts is reached, then 2.5 volts for 5 hours.
10/19/94	At PVNGS, the dedication discharge test was performed on HG-12, Groups B and C using jumpers (instead of intercell connectors). Capacity for Group B = 110%. Capacity for Group C = 105.8%. Recharged PVNGS method. At the factory, the dedication discharge test was performed on HG-13 and HG-14 using intercell connectors. Capacity for HG-13 = 106%. Capacity for HG-14 = 110%. Both strings were recharged the factory method; the amount of current removed is calculated to recharge at a rate necessary to replace 130% of the Amp-hours removed in 20 hours (≈ 60-70 Amps for 20 hours) followed by trickle charging for 3 days at 5 Amps.
10/25/94	At the factory, the dedication discharge test was performed on HG-15 using intercell connectors. Capacity = 108%. Recharged the factory method. Cell damaged in shipment was sent from PVNGS to the factory, in the charged state, for disassembly. Disassembled cell at the factory and samples were sent to FPI and AT&T.
10/27/94	PVNGS shipped another bad cell to the factory for disassembly.
10/31/94	The second dedication discharge test was performed on HG-12, Group A at PVNGS using jumpers. Capacity = 97.5%. Recharged PVNGS method.
11/1/94	The second dedication discharge test was performed at the factory on HG-13 using intercell connectors. Capacity = 107%. Recharged the factory method. 70 cells from HG-13 were sent to the PVNGS "PK battery facility" (temperature controlled room). Several were damaged during shipment (were not shipped via "air ride"). Suspected all 70 may also have been damaged. 28 cells were returned to the factory for additional testing (HG-13, Group A). The remainder at PVNGS were divided into three groups (B, C and D) for additional testing only (string HG-13 was not accepted for Unit 2 cell replacement). Group D (22 cells) was set aside at the PVNGS "PK battery facility" for future testing, as required. The second dedication discharge test was performed at the factory on HG-14 using jumpers. Capacity = 102%. Because of problems with the charger the capacity measured only 102%. A third discharge test was scheduled to replace the lower than expected results from this test. Recharged the factory method.

11/3/94 Conference call with the factory, AT&T, FPI and APS to discuss ERCFA. Concurrence regarding the root cause of failure conclusions are summarized as follows:

- The failure of the APS Unit 2 cells is probably a result of "less positive plate activity" due to "PbO_2 grain isolation".
- PbO_2 grain isolation is most probably a result of manufacturing process problem encountered during the time the Unit 2 cells were made.
- There is no evidence of a sudden discharge failure mechanism.

As a result of these conclusions, the Unit 2 failures are not transportable to Unit 1 and 3 batteries.

11/5/94 HG-12 moved to the "PK battery facility."

11/14/94 The second dedication discharge test was performed at the factory on HG-15 using intercell connectors. Capacity = 108%. Recharged the factory method. 70 cells from HG-15 were shipped to the PVNGS "PK battery facility."

11/17/94 The second dedication discharge test was performed on HG-12, Group B at PVNGS using jumpers. Capacity = 96.7%. Recharged PVNGS method.

11/19/94 The second dedication discharge test was performed on HG-12, Group C at PVNGS using jumpers. Capacity = 95%. Recharged the factory method.

11/21/94 The third discharge test was performed at the factory on HG-14 using intercell connectors. Capacity = 108%. Recharged the factory method. 62 cells from HG-14 were shipped to the PVNGS "PK battery facility."

11/22/94 The third discharge test was performed on HG-12, Group A at PVNGS using jumpers. Capacity = 87.6%. Recharged the factory method.

11/30/94 At the factory, the dedication discharge test was performed on HG-18 using intercell connectors. Capacity = 115%. Recharged the factory method.

12/1/94 The third (first at PVNGS) discharge test was performed on HG-13, Groups B (10 cells) and C (10 cells) at PVNGS using jumpers. Capacity for Groups B = 103%. Capacity for Group C = 103%. Group B was recharged the factory method. Group C was recharged the PVNGS method.

12/3/94 The third discharge test was performed on HG-12, Group C at PVNGS using jumpers. The project capacity for Group C = 85% (test equipment failure after 1.5 hours). Recharged the factory method.

12/4/94	The fourth discharge test was performed on HG-12, Group A at PVNGS using jumpers. Capacity = 81%. Engineering reviewed the individual cell voltage curves for all discharge tests performed on HG-12. Because the cells from HG-12 exhibited voltage loss towards the end of the discharge and a step decline in capacity with subsequent discharges, it was concluded that the cells would not be used as Unit 2 replacement cells. Nine were returned to the factory for testing and the remainder have been set aside for additional testing.
12/8/94	The fourth discharge test was performed on HG-13, Group C at PVNGS using jumpers. Capacity = 91.6%. Recharged PVNGS method.
12/11/94	The fourth discharge test was performed on HG-13, Group B at PVNGS using jumpers. Capacity = 98.1%. Recharged the factory method.
12/17/94	At PVNGS, HG-15 was divided into 2 groups (HG-15 and HG-15x). The third (first at PVNGS) discharge test was performed on HG-15 (64 cells) using intercell connectors. Capacity = 110%. Recharged the factory method.
12/20/94	The second dedication discharge test was performed at the factory on HG-18 using intercell connectors. Capacity = 110%. Because the capacity of the string degraded approximately 5% from the first test, a third discharge test was scheduled to replace the results from this test. Recharged the factory method.
12/21/94	The third discharge test was performed on HG-13, Group A at the factory using intercell connectors. Capacity = 104.1%. Recharged the factory method.
12/22/94	The fourth (first at PVNGS) discharge test was performed on HG-14 using intercell connectors. Capacity = 105.2%. Recharged the factory method.
12/23/94	The third (first at PVNGS) discharge test was performed on HG-15x (4 cells) using intercell connectors. Capacity = 104.8%. Recharged PVNGS method.
12/28/94	The fourth discharge test was performed on HG-15 at PVNGS using intercell connectors. Capacity = 101.7%. Recharged the factory method. HG-15 was divided into 3 groups, HG-15 (56 cells), HG-15y (4 cells) and HG-15z (4 cells) for additional testing.
1/4/95	The fourth discharge test was performed on HG-15x at PVNGS using intercell connectors. Capacity = 94%. Recharged the factory method. Engineering reviewed the individual cell voltage curves for all discharge tests performed on HG-15. Because the cells from HG-15 exhibited voltage loss towards the end of the discharge and a step decline in capacity with subsequent discharges, it was concluded that the cells would not be used as Unit 2 replacement cells.

1/5/95	The third discharge test was performed at the factory on HG-18 using intercell connectors. Capacity = 107.5%. Recharged the factory method. 66 cells from HG-18 were shipped to the PVNGS "PK battery facility." The fourth discharge test was performed on HG-13 Group A at the factory using intercell connectors. Capacity = 100%. Recharged the factory method.
1/16/95	At the factory, the dedication discharge test was performed on HG-16 (67 cells) using intercell connectors. Capacity = 115%. Recharged the factory method.
1/18/95	At the factory, the dedication discharge test was performed on HG-1 (67 cells) using intercell connectors. Capacity = 115%. Recharged the factory method.
1/25/95	The second dedication discharge test was performed at the factory on HG-16 using intercell connectors. Capacity = 113%. Recharged the factory method. Cells from HG-16 were shipped to the PVNGS "PK battery facility."
1/26/95	The second dedication discharge test was performed at the factory on HG-1 using intercell connectors. Capacity = 115%. Recharged the factory method. Cells from HG-1 were shipped to the PVNGS "PK battery facility."

Failure Mode Investigation

The failure mode investigation includes tests and analysis to determine the root cause for the AT&T Round Cell failure in Unit 2. This investigation includes the;

1.) location and extent of the failure by inspection, analysis and testing (summarized in this *Failure Mode Investigation* Section),

2.) summary of all credible failure modes (see the *Failure Mode Summary Table* at the end of this *Failure Mode Investigation* Section),

3.) elimination of unrelated failure modes (see the *Troubleshooting Plan* and *Troubleshooting Results* Sections of this report) and

4.) examination of models to explain the loss of capacity (see the *Root Cause Determination* Section of this report).

SUDDEN DISCHARGE FAILURE:

In order to assure safe operation during the next four months it is necessary to demonstrate that the observed phenomenon is not indicative of a "Sudden Discharge" failure. It must be demonstrated that the rate of capacity loss is not so excessive that the capacity of the battery will drop below that which is required during accident conditions. Through calculation and testing, it can be predicted the Unit 2 batteries will behave similar to a 100% capacity battery under an actual load profile demand. An evaluation of the required capacity during accident conditions is presented in Attachments 2 and 3.

TRANSPORTABILITY TO UNITS 1 AND 3:

The AT&T Round Cells for Unit 1 battery banks A and C, which were installed by DCP 1XE-PK-037, were shipped from the manufacturer in 1/92. Due to charger problems at the factory, the Round Cells purchased for Unit 1 battery banks B and D failed their first commercial grade dedication test (two hour capacity discharge test). After a second test was performed (2/92), the cells used in battery banks B and D were shipped to PVNGS. The Round Cells purchased for the Unit 3 battery banks were shipped between 7/92 and 8/92. Between 11/91 and 8/92, there were no recorded major changes in the testing or manufacturing processes at the factory. The battery capacities from the commercial grade dedication tests for all of the Unit 1 and 3 cells were above 100%. The first discharge tests performed at PVNGS on the battery banks in Unit 1 in 10/93 and in Unit 3 in 4/94 measured the following capacities.

Bank	Unit 1 Capacity	Unit 3 Capacity
A	108.6%	105.6%
B	105.4%	110.0%
C	105.9%	109.2%
D	106.6%	112.9%
spare-1	106.0%	104.2%
spare-2	108.0%	104.2%
spare-3	108.0%	104.2%
spare-4	107.5%	104.2%

Review of these capacity discharge test results indicates the capacities for the Unit 1 and 3 batteries have remained approximately the same (exceeded 100%), as expected for newly installed Round Cells.

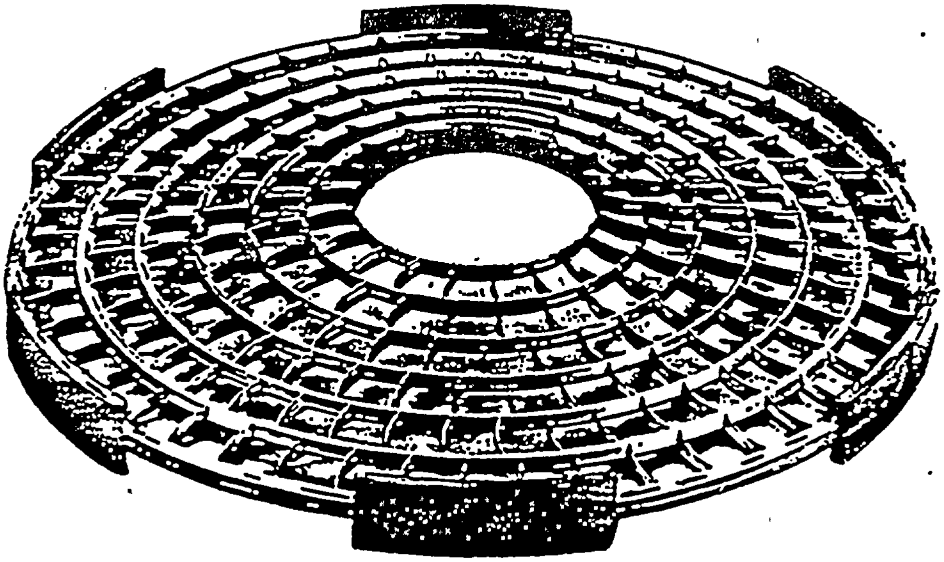
To confirm that the Unit 2 capacity loss was not transportable to Units 1 and 3, capacity discharge tests were performed on the spares in Units 1 and 3 in 10/94 with the following results.

Bank	Unit 1 Capacity	Unit 3 Capacity
spare-1	108.8%	107.9%
spare-2	107.1%	116.7%
spare-3	106.7%	108.7%
spare-4	107.1%	103.7%

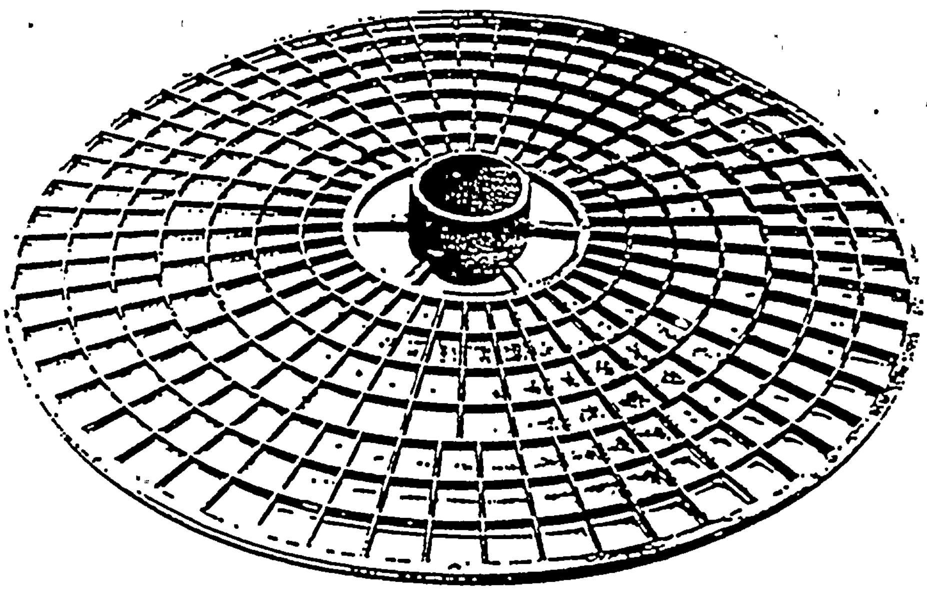
Compared to previous test data, the measured capacity for each of the 8 spare cells remained approximately the same (exceeded 100%). To assure that the observed Unit 2 failure was not transportable to Unit 1 or 3, engineering reviewed the individual cell voltage curves for all discharge tests performed on Unit 1 and 3 batteries. None of the cells exhibited an increased voltage loss towards the end of the discharge or a step decline in capacity with subsequent discharges. Successful discharge testing of Unit 1 and 3 batteries and the associated spares has demonstrated the operability Unit 1 and 3 batteries.

SUCCESSIVE DISCHARGE/CHARGE CYCLING OF UNIT 2 SPARE:

The discharge test performed on 9/23/94 indicated a battery capacity of 91.6% and 90.6% for 2EPKAF11 and 2EPKCF13, respectively. Because the capacity of both battery banks was lower than expected, errors in testing results and/or test setup were suspected. The first retest on the Unit 2 spares was performed to verify or refute test induced problems. Successive testing on the Unit 2 spares showed that the cells degrade a certain percentage each time they are discharge tested. The test results indicate that the battery capacities tend to stabilize at approximately 55%, after 6 capacity discharge tests. Analysis of the discharge testing of Unit 2 spares (see Attachment 4) shows the degradation mechanism is probably related to loss of positive plate activity that is aggravated by charge/discharge cycling of the cells and not age related.



POSITIVE GRID



NEGATIVE GRID

FIGURE 2.0 AT&T LINEAGE 2000 Round Cell - Positive and Negative Grids

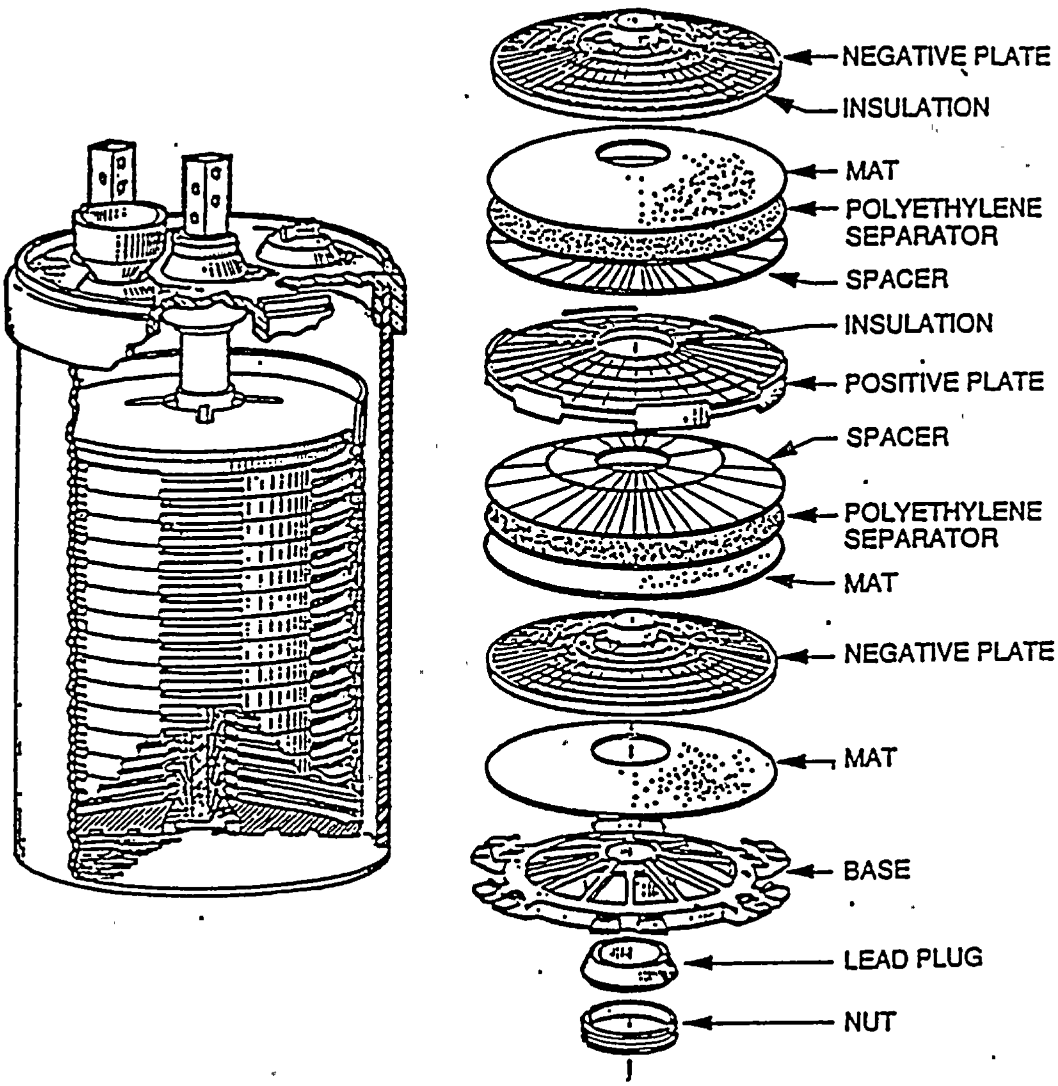


FIGURE 3.0 AT&T LINEAGE 2000 Round Cell - Exploded View

MOST PROBABLE FAILURE MODES:

The following tables summarize the most probable failure modes based on the evaluation of the information and facts summarized in the preceding *Failure Mode Investigation* Section.

LOSS OF POSITIVE GRID ACTIVITY	
1 Positive Plate Morphology • Curing Process Impact - Inadequate CO_2 during curing • PbO_2 Pellet Isolation: Loss of interconnection between pellets within plate • Improper TTB conversion/initial charging process	*- 12/92 the factory placed cells on hold because of loose pellets seen between plates. (AT&T Root Cause Rpt)* *- Inter-pellet contamination - any cells that had white pellets 1/8" should be re-jarred. (later corrected to 1/4" by AT&T)* *- Curing process: the factory says not a factor; AT&T says could be a factor.* *- CO_2 injection not increased during increased positive plate production* *- Incomplete curing and drying of positive plate noted by AT&T in 2/93. (AT&T Root Cause Report)*
2 Contamination • Calcium - Small amounts of calcium can act as a passivation agent, causing electrical isolation of active material	*- Ca contaminated compound between lattice and pellets on "bad" positive plate. (FPI lab results)*
HIGH SPECIFIC GRAVITY CELL DESIGN	
3 Test, charge and discharge methods • Comparison of the factory vs. PVNGS methods • Electrolyte stratification	*- Completely discharged cells that are recharged too quickly (at normal rate) lose capacity.* *- Electrolyte stratification affects cell capacity.*
4 Reliability history not available	*- Small deviations in manufacturing cause large capacity problems.* *- Cells are combined by adding electrolyte charging & discharging as low specific gravity cells. High specific gravity cells are converted from low specific gravity cells.*

Failure Mode Summary

Failure Mode	Effects on Battery Performance	Physical Indications	Observations
Loss of negative grid activity	Depends on extent, believed to be slow	Poor morphology of material on grid; "slimy" material Visible contamination	Cell #10 not negative limited
Loss of positive grid activity	Loss of capacity Loss depends on integrity of material	Poor morphology of material on grid; loose material Visible contamination	Cell #10 positive limited, based on 1/2 cell voltage readings Cell capacity at 70%
Degradation of separator	Internal shorting Loss of capacity (potentially rapid)	Low cell internal resistance Degraded appearance	Not significant*
Excessive sediment	Internal shorting Loss of capacity (potentially rapid)	Large amounts of material visible at bottom of cell	Not significant*
Excessive sulfation	Loss of capacity (slow loss)	Crystals may be visible upon disassembly	Not significant*
Increasing cell resistance	Loss of capacity (depends on rate)	Partial or incomplete interplate connections	Not significant*
Electrode shorting	Loss of capacity (potentially rapid)	Dendritic growth excessive sediment	Not significant*
Fractured components	Loss of capacity	Breakage will be visible on disassembly	Not significant*
Low cell weight	Loss of capacity	Not applicable	Correct cell weight verified*
Improper electrolyte gravity or level	Reduced performance	Not applicable	Correct gravity/ correct level verified*
Contaminated electrolyte	Loss of capacity Deactivation of grid materials Internal shorting	Discoloration of grids and straps	Not significant*

* Results verified during teardown and inspection of 3 failed cells

Troubleshooting Plan

A number of actions were initiated during the early portion of the evaluation when it was recognized that the condition of the A and C batteries brought into question the status of the other batteries on site and at other Nuclear Utilities using the AT&T LINEAGE 2000 Round Cells. Shortly after the Unit 2 problem was identified a multi-discipline team including maintenance personnel, along with maintenance, design and system engineers was assembled. The root cause investigation plan was divided into 4 steps:

1.) Gather physical and test data.

To validate the test methods, the spare cells on the A battery were retested (Note: the Unit 2 B and D batteries were tested using the same procedure as the Train A test. The Spare cells on the Unit 1 and 3 batteries were tested using the same procedure.)

Three engineers from Procurement Engineering, Maintenance and Vendor Quality were sent to the factory to review specific procurement and fabrication records. This action had been taken early on to identify any manufacturing anomalies and/or process variations that could provide an indication of differences in the Unit 2 cells.

With the support of AT&T and FPI, a plan (shown below) was developed to conduct the examination of three defective cells at the factory. The results of the examination and analysis of the defective cells are discussed later. Chemical and morphological analyses of all battery components have been conducted at FPI, Lancaster Labs and the factory corporate lab. Communications with the engineer responsible for batteries at McGuire and Braidwood, two known nuclear plants who have the same type of AT&T batteries, are ongoing.

The information and facts gathered during the root cause investigation are listed in Attachment 7.

2.) Rule out/confirm sudden discharge failure potential.

3.) Develop models to explain observed battery behavior.

See the *Failure Mode Summary* table

4.) Rule out/ confirm models utilizing chemical/material analysis.

FPI was contacted to participate in the Equipment Root Cause of Failure Analysis (ERCFA).

1.0 Initial review at PVNGS

1.1 Confirmation testing and charging method

1.2 Checkout of testing and charging equipment

1.3 Testing of alternate batteries

1.4 Testing of spares

2.0 Development of failure scenarios in conjunction with FPI, AT&T and the manufacturer

3.0 Manufacturing Process Investigation (Test/Teardowm inspection plan prepared by AT&T and reviewed by the manufacturer)

3.1 Cell examinations

3.1.1 Receipt of cells #36, #10 and #6 at the factory

3.1.2 External physical data gathered

3.1.3 Cell characteristics determined

3.1.4 Cells placed on float charge

3.1.5 Confirmation of discharge characteristics

3.2 Interviews with the factory personnel

3.2.1 Process Engineer

3.2.2 HR Manager

3.2.3 Production Supervisor

4.0 Chemical analysis

4.1 Electrolyte analysis for contamination (the factory corporate lab and Lancaster Labs) compare with a "good" cell

4.1.1 Standard analysis (Cu, Sb, Fe, Zn, Cl, Ti, etc.)

4.1.2 Organic Analysis (antifreeze, tobacco, expander, etc.)

4.1.3 GC mass spectrometer scan (search against entire Organic library)

4.1.4 Separator Resistance (the factory corporate lab only)

4.1.4.1 Active material analysis (the factory corporate lab and Lancaster Labs)

4.1.4.2 Atomic absorption spectrometry

4.1.4.3 X-ray diffraction

4.1.4.4 Porosity measurements

4.1.4.5 Scanning electron microscope (morphology exam - at FPI)

5.0 Development of analytical model that describes the observed results

5.0.1 AT&T and FPI participated in developing various models to describe the affects of the observed behavior and analytical results. These models are discussed in detail in the *Root Cause Determination* Section of this report.

Troubleshooting Results

No credible mechanism for sudden discharge failure has been found. The three sudden discharge failure modes are; 1.) open or "near" open circuit, 2.) low impedance short circuit and 3.) massive contamination of electrode active material. Teardown of the three cells revealed some signs of poor workmanship, but there was no evidence that the diminished capacity could attributed to physical damage of the cell internal components. Examination of the three cells indicated a lack of fractured components, poor welds or corroded current collector, which eliminates an open or "near" open circuit as a probable failure mode. The cell examinations also ruled out low impedance short circuit as a failure mode due to the absence of damaged plates, high sediment levels, damaged separators, dendrites, "mossy" deposits or conductive active material. Cell examinations, chemical analysis and morphological examinations ruled out massive contamination of electrode active material. The dependence of the deliverable capacity on the number of charge/discharge cycles rather than on time rules out grid corrosion as the dominate failure mode. This also eliminates the possibility of a sudden failure due to severe grid corrosion during float charging. Other sudden failure modes have been ruled out as a result of findings during the disassembly of the cells at the factory and the initial capacity discharge test results. Therefore, the mechanism causing the decline in capacity will not produce a sudden discharge type failure.

Half cell voltage data collected from discharge tests performed on cells from Unit 2 at PVNGS and the factory (prior to cell disassembly) indicates that the positive plate is the electrode limiting the capacity of the cell, thereby eliminating the possibility of a loss of negative grid activity as a failure mode. No loose or "mushy" active material was found on the positive plates. There was some evidence of loose pellets of active material but not enough to account for the loss in capacity.

Discharge data shows that capacity loss occurs after each charge/discharge cycle and is not significantly affected by float time. Degradation of the battery occurs during the second hour of the two hour capacity discharge test. The discharge test results indicate the loss in capacity is associated with an increased voltage loss towards the end of the discharge and not with a constant voltage loss over the full discharge of the cell (See Attachment 9). Chemical and microscopic analyses performed on the samples of plates from the disassembled cells showed normal pore size. No film on the particles was noted. This would indicate that the active material is electrically rather than physically isolated. Factors that can cause a higher resistance for some of the active material are incomplete formation of active material or incomplete curing. At the time the Unit 2 cells were manufactured, problems were identified with the formation and curing processes at the factory.

Review of the capacity discharge tests performed on Unit 1 and Unit 3 batteries at the factory and PVNGS indicates the battery capacities have remained the same or increased with subsequent discharges. Since the test methods and maintenance of the Round Cells is the same in all three Units, transportability to Units 1 and 3 due to a failure mode of improper maintenance or testing at PVNGS has been eliminated as a probable cause of failure. The failure mode, as seen in Unit 2, is displayed as a loss in capacity as a result of deep discharge cycling the batteries. Successful discharge testing of Unit 1 and 3 cells and their associated spares proves that this failure mode is not present (transportable) in Units 1 and 3.

Root Cause Determination

A review of the credible failure modes and the results of the teardown of three AT&T Round Cells at the factory, led the root cause investigation team to conclude the failure mode of Unit 2 cells is probably loss of positive plate activity. The mechanism for producing the loss of positive plate activity is most likely related to manufacturing process deficiencies. At the time the Unit 2 cells were manufactured, problems were identified with the positive plate formation and curing processes at the factory. Two possible sources have been identified; incomplete curing and the presence of contaminants. Both cause increased impedance between the grains and the grain to grid interface of the positive plate active material. Factors that can cause a higher resistance for some of the active material are incomplete formation of active material (the presence of contaminants could be a causal factor) or incomplete curing.

Utilization of the active material is a function of the discharge current density, the rate of electrolyte diffusion, the total surface area of the active material, the degree of electrical contact between the grains and the grain to grid interface, and the intrinsic electrochemical activity of the grains themselves. These factors change during a given discharge cycle and as result of charge/ discharge cycling the battery. Research testing has shown that charge/ discharge cycling causes a physical change in the active material.[6] Repeated capacity discharges cause the paste material to change its characteristics and lose its crystalline structure. The result is a decline in battery capacity caused by the electrical isolation of unconverted PbO_2.

MECHANISTIC CAUSES:

The failure mode results from a step decline in capacity due the loss of positive plate activity. All the failed Unit 2 cells exhibited this step decline in capacity after a second deep discharge test. The capacity discharge test data has shown an increased loss of capacity with subsequent discharges. The cell discharge curves showed an increased voltage loss towards the end of the discharge cycle. The differences in the discharge curves between the first and subsequent discharge cycles can be explained in terms of a uniform (a build-up of distributed electronic resistance within the active material) and a non-uniform (areas of high and low resistances) models.

Areas of high and low resistances and/or a build-up of a distributed resistance in the active material can cause individual grains to become electrically isolated from each other in the active material and from the current collecting grid (see Attachment 10). Electrical isolation of active material refers to the build-up of electrical resistance.

Sulfation (the presence of large $PbSO_4$ particles deposited in between PbO_2 particles) and/or the presence of contaminates that form insulating films (such as corrosive films on the surface of the grid) can cause high electrical resistance. The discharge characteristics of the high resistance areas and "well" connected grains can be explain in terms of the non-uniform model. "Well" connected grains will convert first with low voltage losses. Poorly connected grains (areas of high resistance) are

converted last (at the end of the discharge cycle) causing the capacity to drop a predictable amount with subsequent discharge tests. Capacity fades on cycling due to nucleation of poorly connected grains and results in an increased voltage loss at the end of each discharge.

High resistance can also be caused by poor connections between particles of active material (grain to grain contact resistance) and between the particles and grid (grain to grid contact resistance).

Grain to Grain Contact Resistances:

Discharge reactions proceed as a result of two types of processes; electron and electrolyte (ionic) current flow. For lead acid batteries, the current distribution is mostly determined by the resistances of the solid and the electrolyte (not the resistance at the electrolyte/electrode interface). For the electrolyte, the ionic resistance is dominated by the resistance of the electrolyte in the pores of the electrode. The electronic resistance in the solid (positive plate electrode) is dominated by the contact resistance between PbO_2 particles. The electronic current in the positive plate flows from the grid inwards (in the direction parallel to the electrode plane) into the pellet (see Attachment 10) and from the center of the electrode outwards to the bottom and top surface of the pellet (in the direction perpendicular to the electrode plane).

The current flow in the direction perpendicular to the electrode plane and how it changes with the increase of contact resistances between grains stacked on top of each other is described as follows; the electrons flow easily to the surface and the acid has easy access on the surface to sustain the discharge reaction when the electronic resistances are low. When the electronic resistances are very high, relative to the ionic (electrolyte) resistance the electrons remain deep inside the electrode. Consequently the acid must diffuse deeper into the pores of the active material to sustain the discharge reaction due to slow kinetics. The voltage loss increases as the impedances associated with it build up as the discharge proceeds. The voltage loss is more pronounced when the diffusion rate of the acid is low, the diffusion path is long or the discharge rate is high. The discharge curve can be calculated using a transmission line as an equivalent circuit to describe the current flow into the electrode (see Attachment 11).

The contribution to contact resistances by the grains stacked side by side increases by a value proportional to the number of grains attached to the side of the grain (in the direction parallel to the electrode plane). Therefore, the electronic resistance in the transmission line is highest and the electrolyte penetration is the deepest for grains furthest away from the grid.

The electrode utilization profile for uniform contact resistance near the positive plate grid is closer to the surface of the pellet. Near the center of the electrode, the electron utilization is closer to the inside of the pellet. A uniform increase in the contact resistances would force the utilization profile to become steeper and penetrate deeper into the pellet towards the center of the pellet. The discharge curve would show a more pronounced voltage loss at the end of the discharge.

Grid to Grain Contact Resistances:

The grid to grain contacts represent a series resistor placed outside the transmission line, if the grain to grain contact resistances do not dominate the electrode resistance and the grid to grain resistances are uniform. The discharge curve would show a constant voltage loss over the duration of the discharge cycle.

Loss of Capacity due to Charge/ Discharge Cycling:

Charge/ discharge cycling causes a physical change in the active material. In other words, the size, shape, position, etc. of the grains change. The grain boundary resistance is sensitive to pressure (bonding) changes in curing and/or condition processes differences. When the grains are not well connected at the start, due to improper curing or contamination introduced during the manufacturing process, the charge/discharge cycling can cause break-up of the grains. This results in an increase in the number of grain to grain contacts, which causes the overall contact resistance of the positive plate to increase. Battery capacity is affected by the degree of connection between PbO_2 grains within the active material. An increase of the contact resistance in the positive plate is a common cause of failure of positive plates in lead-acid batteries.[7]

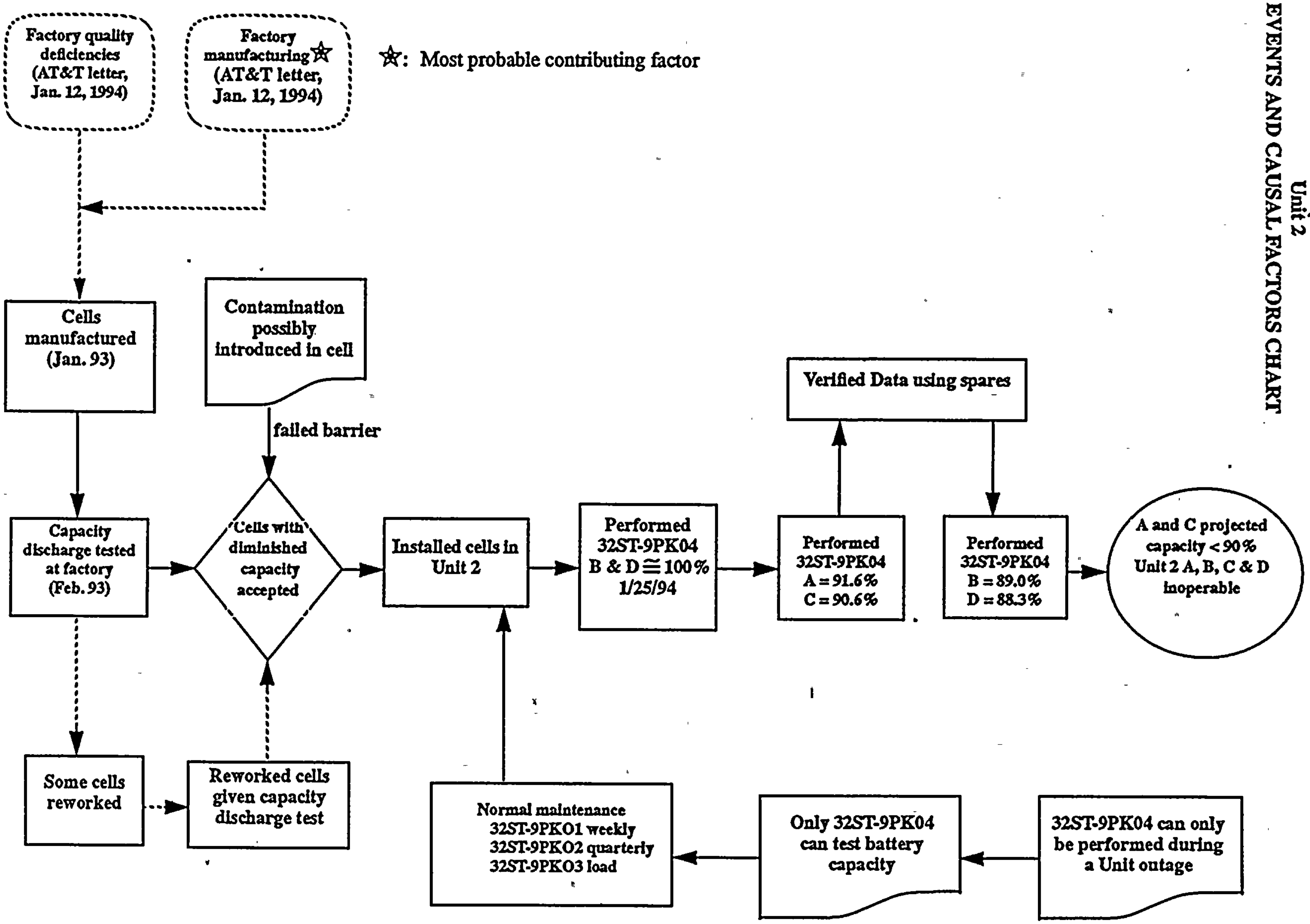
PRODUCTION CONTROLS AND LOSS OF CAPACITY:

Electronic resistances can result from poor curing, incomplete formation of positive starting material, grid corrosion and the presence of contaminants. The cause of the loss of capacity appears to be related to manufacturing process deficiencies. Two possible sources have been identified; incomplete curing and the presence of contaminants. Evidence on the role of curing is circumstantial and is based on the knowledge of the sensitivity of curing conditions and the observations made at the factory at the time the Unit 2 cells were manufactured. Contaminates at the interface between the grains and the grid can also reduce cell capacity. Calcium contaminates, which was observed using SEM/EDX, could cause increased impedance at the active material/grid interface.

Very little documented research regarding the affects of calcium contamination of this type could be found. According to the "Calcium Passivation Model" developed by FPI (see Attachment 12), a small quantity of calcium in the positive grid has the capability of passivating the grid-active material interface. The calcium acts as a catalyst to form lead sulfate crystals ($PbSO_4$ particles). The passivation mechanism involves the formation of large insulating (non-conductive) lead sulfate crystals with subsequent discharge cycles. The premature capacity loss is due to the formation of $PbSO_4$ crystals that "passivate the lead dioxide active material by breaking its conductivity path in the matrix." Increased voltage loss at the end of each discharge is due to diffusion of sulfuric acid into the active material and the delayed reaction of the lead sulfate crystals, which are deeply embedded in the active material matrix.

Based on the Unit 2 spares, the degradation mechanism appears to be aggravated by charge/discharge cycling of the cells and is not age related. Each subsequent cycle degrades about the same fraction of capacity. The test results indicate that the battery capacities tend to stabilize at approximately 55% after 6 capacity discharge tests.

Unit 2
EVENTS AND CAUSAL FACTORS CHART



Determination of Other Suspectable Equipment

There have been no similar events previously reported pursuant to 10CFR50.73.

The actions necessary to define the transportability have been completed and it is concluded that the condition identified in Unit 2 has not affected the Unit 1 and 3 batteries. The bases for this conclusion is provided in Attachment 13..

Communications with the engineers responsible for batteries at McGuire and Braidwood, two known plants that have the same type of AT&T batteries, is ongoing. The first capacity discharge test for the Braidwood Round Cells is scheduled for fall 1995. See the attached correspondence with McGuire (see Attachment 14). Edmonton Power (fossil power plant) in Alberta Canada recently preformed a capacity discharge test on their AT&T batteries. The Round Cells tested were manufactured at the factory approximately the same time the PVNGS Unit 2 cells were made. Edmonton Power cell #1 was replaced in July 1994, under warranty, due to physical damage noted during a routine maintenance inspection. According to the plots in Attachment 15, all the cells tested had significantly diminished capacities, except for cell #1.

Corrective Actions

The NRC issued Amendment No. 71 to Facility Operating License No. NPF-51 for PVNGS Unit 2, on 10/13/94 to allow batteries 2EPKAF11, 2EPKBF12, 2EPKCF13 and 2EPKDF14 to be declared operable. The safety evaluation for the amendment delineated the compensatory actions to be implemented while the amendment is in affect. The amendment, which was issued on an emergency basis, consisted of modifying Technical Specification (TS) 4.8.2.1.e to specify that the provisions of TS 4.0.1 and 4.0.4 are not applicable to the battery capacity requirements until entry into Mode 4 coming out of the fifth refueling outage or upon any deep discharge cycle of the battery (see Attachments 16 and 17.

Twenty-three new cells, purchased from AT&T in conjunction with the Unit 1 and 3 spares, were used to replace several cells in Unit 2 in order to comply with Technical Specifications. The 23 new cells were capacity discharge tested once at the factory prior to installation in Unit 2. The capacity of an another string of cells manufactured approximately two months prior to these cells had a measured capacity of 97.5%, which is a 7.5% decrease in capacity from their first discharge test. Since the 23 new cells in Unit 2 can not be retested again to determine the existence of a similar effect, the estimated current capacity of the Unit 2 batteries with the cells was revised. With the replacement of 11 cells in bank A, 4 cells in bank B, 12 cells in bank C and 4 cells in bank D, analysis shows that the projected capacity to be in excess of the required capacity of the most limiting battery bank (bank A requires approximately 56% capacity). Since no discharge testing will be performed before battery replacement during the fifth refueling outage, the Unit 2 battery capacity will remain above that needed for the safety-related loads.

Of the 23 cells removed from Unit 2, 16 cells were separated into four groups of four cells each. The four "control groups" were scheduled to be tested at approximately 30 day intervals according the schedule in Attachment 16. Load profile testing was performed on each of the "control groups" to assure the degradation mechanism is due to discharge/recharge cycling the batteries and not age related. The results of the load profile test performed on groups 1, 2 and 3 are shown in Attachment 18. Each plot shows the following curves; 1.) 100% capacity, 2.) battery A projected degradation, 3.) control group test results on 9/94, 4.) actual group test results, 5.) control group projected degradation, 6.) minimum control group projected degradation and 7.) battery A load profile. Tests performed on "control groups" 1, 2 and 3 passed (the control group results exceeded the bank A service load profile and no individual cell reversal occurred). The performance of each "control group" was better than projected.

During the fifth refueling outage (U2R5) scheduled for 2/4/94, the Round Cells in all four batteries (240 cells + 4 spares) will be replaced. In addition, two other cells in Unit 1, which were from the same lot as the original Unit 2 cells, will be replaced during U1R5 in April 1995.

The failure mode results from a step decline in capacity due to active material isolation, though the exact cause (due to contamination or improper curing) may never be determined. All the failed Unit 2 cells exhibited this step decline in capacity after a second deep discharge test. Discharge data shows

that capacity loss occurs after each charge/discharge cycle and is not significantly affected by float time. As a result, changes have been made to the dedication testing to assure that replacement cells will have acceptable performance prior to installation. Two commercial grade dedication discharge tests (instead of one) must be performed at the factory prior to shipment to PVNGS. The capacity of the string must be greater than 100%. The acceptance criteria for the first discharge test is the individual cell end voltages must be greater than or equal to 1.75 volts at the two hour reading. The acceptance criteria for the second discharge test is the individual cell end voltages must be greater than or equal to the first discharge at the two hour reading. Cells with a lower two hour voltage are evaluated by plotting the cells performance during the discharge tests to determine if a degrading capacity problem exists. Engineering will evaluate test data and determine acceptable cells for shipment. PVNGS Nuclear Assurance must witness both tests at the factory and review all material test results confirming traceability to the factory corporate lab, which has been successfully audited by the joint utility NUPIC organization. Nuclear Assurance and Procurement Engineering have conducted an in-depth surveillance of the manufacturing processes. Surveillance of the manufacturing processes must be reverified by Nuclear Assurance as part of the dedication testing for replacement cells.

Two commercial grade dedication discharge tests were performed on the Unit 2 replacement cells (cells from the factory strings designated HG-14, HG-18, HG-16 and HG-1). The tests are summarized in the *Sequence of Events* Section of this report. Because the capacity of HG-18 degraded approximately 5% between the first and second discharge tests, a third discharge was performed. Calculation of current and projected capacities for each of the replacement cells (from HG-14, HG-18, HG-16 and HG-1) have been performed to assure the Unit 2 battery bank capacities are 100% or greater.

Several cells from HG-13 were damaged in shipment from the factory to PVNGS. Because AT&T and PVNGS engineering suspected the other cells may have also sustained damage, none of the cells from HG-13 were accepted as Unit 2 replacement cells.

Many of the cells from HG-12 and HG-15 exhibited a decline in capacity with subsequent discharge cycles. Individual cell and half cell voltage curves for discharge tests performed on each string were reviewed (see Attachment 19) and compared with the Unit 2 graphs (see Attachments 6 and 9). In most of the Unit 2 half cell plots, the positive to reference electrode voltage curve converges rapidly toward the negative to reference electrode voltage curve. In the HG-12 and HG-15 plots, the positive to reference electrode voltage curve is more parallel to and does not seem to converge as rapidly toward the negative to reference electrode voltage curve. However, similar to Unit 2, many of the HG-12 and HG-15 ICV curves showed a voltage decline with subsequent discharge tests. Because the cause for the capacity loss could not be adequately explained, the decision was made to not use HG-12 and HG-15 as Unit 2 replacement cells. AT&T will be conducting a long term testing program to provide an in-depth evaluation of the replacement cell performance test results that will better model the high specific gravity Round Cell performance characteristics. Cells from HG-12, HG-13, HG-14 and HG-15 will be used, as required, for addition testing to support AT&T's evaluation. CRDR 2-5-0039 has been initiated to evaluate the replacement cell performance test results, document the results of the AT&T testing program and implement corrective actions, as required.

Additional discharge tests have been performed on HG-15 to determine the optimal recharge method (PVNGS vs. factory). The discharge data showed the factory recharge method is preferred for discharge/recharge cycling AT&T Round Cells over a short time frame (i.e. one week) and is the recommended recharge method for commercial grade dedication discharge testing.

Corrective Action Performance Monitoring

No additional monitoring (other than CATS, TSCCR, CRDR, etc.) is necessary to track the performance of the corrective actions specified in this report. The current performance programs are deemed sufficient to monitor the completion of corrective actions specified in this report. All corrective actions not accomplished by the issue date of this report will be entered into CATS to ensure task completion.

References

1. VTM-A894-0001, "AT&T Bell Laboratories Product Manual for LINEAGE 2000 Round Cell Battery, Model KS-20472."

2. *EPRI Stationary Battery Maintenance Guide*, Final Report, December 1992.

3. A. G. Cannone, D.O. Feder and R.V. Biagetti, "Positive Grid Design Principles," *The Bell System Technical Journal*, Vol. 49, pp 1279-1303 (September 1970).

4. R.V. Biagetti and M.C. Weeks, "Tetrabasic Lead Sulfate as a Paste Material for Positive Plates," *The Bell System Technical Journal*, Vol. 49, pp 1305-1319 (September 1970).

5. D.E. Koontz, D.O. Feder, L.D. Babusci and H. J. Luer, "Reserve Batteries for Bell System Use: Design of the New Cell," *The Bell System Technical Journal*, Vol. 49, pp 1253-1278 (September 1970).

6. K. Harris, R.J. Hill, and D.A.J. Rand, "Quantitative Phase Analysis of Crystalline and Amorphous Components of Positive Plates in Lead-Acid Batteries Operated under Simulated Electric-Vehicle Service," *J. Electrochem. Soc.*, March 1984.

7. J. Bouet et J.P. Pompon, "Analyse des Causes de Degradation des Plaques Positives de Batteries au Plomp," *Electrochimica Acta.*, Novembre 1980.

Attachments

1. CRDR 2-4-0070.
2. Unit 2 Class 1E Batteries - Justification for Operability.
3. Memo - Impact of Dedication Testing Results of the New Round Cells on Margin Calculations.
4. Graph of Unit 2 Spare Discharge Tests.
5.* Test and Teardown Inspection Report.
6. Unit 2 1/2 Cell Voltage Plots.
7.* Facts and Information.
8.* Production History at the factory.
9.* Unit 2 ICV Discharge Test Plots.
10. Pellets with "Electrically Isolated" Grains.
11. Internal Resistance of Porous Electrode.
12. FPI Failure Mechanism of Round Cell Batteries.
13.* Transportability.
14.* McGuire Correspondence.
15.* Edmonton Power Plots.
16. Issuance of Emergency Amendment for the Palo Verde Nuclear Generation Station Unit No. 2 (TAC No. M90581), October 13, 1994.
17. Revision to Compensatory Actions Regarding 125V DC Batteries at Palo Verde Nuclear Generation Station Unit No. 2 (TAC No. M90581), November 3, 1994.
18. Control Group Test Result - Projected Battery Degradation vs. Load Req., Actual Test Results vs. Load Requirements.
19.* HG-12 and HG-15 ICV Discharge Test and 1/2 Cell Voltage Plots.

* Attachment is not included.

ATTACHMENT 1

CRDR TRANSMITTAL/ACTION REQUEST

CRDR NUMBER: 24 070 DRAFT DUE: N/A PRIORITY 3 CATEGORY: SERCFA

To: HESSER FINAL DUE: 5/10/94

Sta: ____

Ext: ____

SOED CONTACT	
S. Karimi	X5680
T. O'Keefe	X5682
C. Kelsey	X5686
~~P. Schwimmer~~	~~X5677~~
J. Locicero	X5454

From: Station Operating Experience Department (SOED)
Building "B"; 3rd Floor, Sta 7965
Ext: 82-5788/82-5758 (Control Desk)

[✓] Enclosed, please find the original CRDR and CRDR Review Form referenced above.
The Condition Report has been assigned to your Department for Completion. Please complete the:

- ( ) Incident Investigation Report and return to SOED (under Numbered Memoranda).
- ( ) CRDR Evaluation Report and return to SOED.
- ( ) CATS Action Notification Sheets for EER ________ and return to SOED.
- (✓) Action described below and return to SOED.

DO NOT MAIL OR SHUTTLE ORIGINAL CRDR'S

[✓] Comments/Actions: CAT 5 "D" ERCFA

Additional Instructions:

- [ ] Complete CATS Action Notification Sheets for all proposed corrective actions and return with your response.
- [ ] Senior Manager Concurrence is required on your response.
- [ ] Oversight Group Concurrence Required, From: ____

QA Concurrence Review

( ) Conditions which indicate the existence of a basic design deficiency discovered subsequent to completion of the Design Verification Process.

( ) Conditions which have occurred at a frequency which indicates past corrective actions have been ineffective.

( ) Conditions indicative of major programmatic or implementation breakdown in the QA program.

( ) All category 1 2, or 3 CRDRs

( ) CRDRs initiated by QA/QC Personnel (including ISE)

( ) Conditions pertaining to an NOV (including potential NOV)

( ) A condition, which if not corrected, would:
a. Allow breaching of a primary boundary.
b. Prevent the plant from achieving and/or maintaining safe shutdown
c. Increase dose at the site boundary.
With a single active failure other than the identified condition

( ) As requested by QA

RW Review

( ) Is the scope of the requested actions clear

( ) If the source of the action(s) is an EER, has the EER been completed, does the scope of the actions match the scope of the EER disposition, have the actions been accepted by the appropriate responsible organization.

cc:			
NRA	(6148)	[X] Originator J FIX	7824
NIA	(1560)	[ ] Trip Reduction Committee	(1686)
Plant Engineering	(7516)	[X] Hadley Riley	
QA & M	(6795)	[X] NRC RESIDENT	7078

Organizations Contacted: ____

QR: No (Yes) (ND/QD)

Codes: N/A 03 ____ 99 ____ 20 [ ][ ][X][ ] 09 ____ 01 ____ (PROG ORG)

Oversight Group: ( ) ISE ( ) NDS ( ) NRA ( ) SAFETY ( ) ____

Keywords: ____

References: ____

(2-03) Controlled by 90DP-0LP03

CONDITION REPORT/ DISPOSITION REQUEST REVIEW FORM

(PLEASE PRINT)

CRDR 2-4-0070

SHIFT SUPERVISOR

ADDITIONAL INTERIM ACTIONS TAKEN/OTHER COMMENTS:

CONTINUATION PAGES ATTACHED? ☐ YES ☐ NO

TECH SPEC ACTION ENTERED? ☐ NO ☐ YES. SECTION ____

OTHER UNITS/ ORGANIZATIONS NOTIFIED: ☐ NO. ☐ YES, LIST UNITS/ORGANIZATIONS ____

[A] PLANT STATUS NOT APPLICABLE

PLANT MODE 1 2 3 4 5 6 Defueled (Circle One)

RX POWER: ____ %

RX TRIP: ☐ YES ☐ NO

ESF ACTUATION: ☐ YES ☐ NO

NOTIFICATION REQUIRED? ☐ YES ☐ NO

NOTIFICATION MADE ____/____ (DATE/TIME)

SHIFT SUPERVISOR (OPERABILITY/IMMEDIATE NOTIFICATION) DATE:

SOED

REPORT REQUIRED: ☒ NO ☐ POTENTIALLY REPORTABLE

POTENTIAL PLANT TRIP HAZARD? ☐ YES ☒ NO

QUALITY CLASSIFICATION: ☐ NQR ☒ QR

SYSTEMS: PK

RECOMMENDED CONDITION CLASSIFICATION: 5E, Eng

SOED INITIALS: CJC

DATE: 2/8/94

SENIOR MGR/SOED

CONDITION CLASSIFICATION (Select one (1) block, THEN select Category/Method)

FORMAL ROOT CAUSE REQUESTED
- ☐ CATEGORY 1
- ☐ CATEGORY 2
- ☐ CATEGORY 3
- ☐ CATEGORY 4 CRDR EVALUATION
- ☐ CATEGORY 4 HPES
- ☐ CATEGORY 4 ERCFA (A, B, C)

ADDITIONAL EVALUATION REQUIRED:
- ☐ REPORTABILITY ONLY
- ☐ OTHER - (SEE COMMENTS BELOW)

APPARENT CAUSE
- ☐ CATEGORY 5 CRDR EVALUATION
- ☒ CATEGORY 5 ERCFA (D)

☐ ROUTINE WORK (see comments below)

CRDR CLOSED -

☐ TREND ONLY (see comments below)

RESPONSE DUE: ☐ 36-HOUR SUMMARY ☐ 10 DAY DRAFT/25 DAY FINAL ☐ 30 DAYS ☐ 60 DAYS ☒ 90 DAYS

☐ OTHER ____ ASSIGNED TO: Hessen

SENIOR MANAGER CONCURRENCE REQUIRED? ☐ YES ☒ NO

COMMENTS

COMPLETED BY: [signature]

TITLE: DIR SITE TECH SUPPORT

DATE: 2-9-94

QA/OVERSIGHT GROUP CONCURRENCE REQUIRED ☐ YES ☒ N/A

BY:

SOED INITIALS: [illegible]

DATE: 2/9/94

CONDITION REPORT/ DISPOSITION REQUEST

(PLEASE PRINT)

REFER TO BACK OF FORM FOR INSTRUCTIONS

CRDR 2-4-0070

1] DESCRIPTION OF CONDITION/DISPOSITION REQUESTED:
During two hour capacity discharge testing of battery 2EPKDF14 on 1-31-94 per 32ST-9PK04 (W.O.#647513), cells 17 and 36 were found to have only 90% of capacity. Cells 17 and 36 each reached 1.75 VDC at approximately 100 minutes into the test. The lowest voltages reached on cells 17 and 36 during the test were 1.15 VDC and 1.28 VDC respectively. The overall battery bank (60 cells) capacity was measured to be 100%. All acceptance criteria was for the ST was met. The vendor (AT&T) was contacted and confirmed it would would be satisfactory to leave cells 17 and 36 in service since he did not believe there was anything significantly wrong with the two cells. However, as a conservative measure, cells 17 and 36 will be replaced with new spare cells. This CRDR is being initiated to track a category 5 apparent root cause evaluation to be performed on the reduced capacity of cells 17 and 36.

REFERENCES (ATTACH IF AVAILABLE):
W.O.#647513

[X] CONTINUATION PAGE(S) ATTACHED

2] REQUIREMENT VIOLATED (IF KNOWN):
No requirements were violated since acceptance criteria is based on capacity of the entier (re) battery bank which was measured to have 100% capacity.

3] LOCATION (BLDG/ELEV/ROOM):	4] AFFECTED EQUIPMENT (TAG NO.):	5] UNIT NO:
Unit 2, 100' Control Bldg, Train B Swgr rm	2EPKDF14 (cells 17 & 36)	Unit 2

6] DISCOVERY DATE:	TIME:	7] CONDITION DATE:	TIME:
1-31-94	1400	Unknown	Unknown

8] ORIGINATOR (Please Print):	9] DEPARTMENT:	10] EXT.:	11] STA
James F. Fix	Plant Engineering-Electrical	5275	7524

12] SUGGESTED ACTION/RESOLUTION (including notifications made):
Replace cells 17 & 36 with new spare cells. Perform a 90 day category 5 apparent root cause evaluation to determine the reason for the reduced capacity of cells 17 and 36.

[ ] CONTINUATION PAGE(S) ATTACHED

13] ORIGINATOR'S SIGNATURE:	DATE:	TIME:
x James F. Fix	2-7-94	0930

14] SUPERVISOR REVIEW:
CRDR ISSUED TO DOCUMENT ROOT CAUSE EVALUATION. NO SAFETY CONCERN SINCE ST WAS MET

[ ] CONTINUATION PAGE(S) ATTACHED

15] SUPERVISOR'S RECOMMENDATION (CHECK ONE)
NO ACTION REQUIRED - CLOSE CRDR [ ] ACTION TAKEN/COMPLETED - CLOSE CRDR [ ]
ACTION RECOMMENDED: ENHANCEMENT [ ] CORRECTIVE [ ] FURTHER EVALUATE [X]

16] SUPERVISOR'S SIGNATURE:	DATE:	TIME:	DELIVER TO
[signature]	2-7-94	1020	[X] SOED [ ] CONTROL ROOM

PV419-04EM (10/92) 00AC-0IP04

CRDR EVALUATION/RESPONSE - CATEGORY 5

1) CRDR 2 4 0070

2) PREPARER:	DEPARTMENT:	EXT.:	DATE:
James F. Fix	STS-Electrical	5275	5-5-94

3) AFFECTED SYSTEMS:	4) FAILED COMPONENT EQID (ERCFA only):	5) CAUSE CODE (ERCFA only):
PK	N/A	

6) EVALUATION

See continuation sheet.

7) APPARENT CAUSE OF THE CONDITION

NOTE: ACTIONS COMPLETED AND ACTIONS NOT COMPLETED ARE TO BE IDENTIFIED ON ATTACHED EVALUATION/RESPONSE - ACTION/APPROVAL FORM.

CRDR 2 — 4 — 0070

CRDR CONTINUATION SHEET

CONDITION REPORT/DISPOSITION REQUEST

CAUSE CODE

EVALUATION:

During two hour capacity discharge testing of Battery 2EPKDF14 on 1-31-94 per 32ST-9PK04 (W.O.# 647513), cells 17 and 36 were found to have significantly low capacity compared to the other 58 cells in the battery string. Cell 17 reached the nominal minimum 1.75 VDC in approximately 100 minutes and cell 36 reached 1.75 VDC in approximately 80 minutes during the 120 minute test. These measurements indicate a capacity of only 83.3% and 66.6% for cells 17 and 36 respectively. For these cells to have 100% capacity, they would have to go 120 minutes before dropping to a cell voltage of 1.75 VDC. The overall capacity of the entire battery (60 cells) was 100% meaning some cells had an individual cell voltage (ICV) higher than 1.75 VDC at the end of the two hour capacity test. All acceptance criteria for the surveillance test was met since acceptance is based on the capacity of the entire battery bank, which measured 100% capacity, rather than the capacity of individual cells. Factory test data on cells 17 and 36 indicate they each had a minimum of 100% capacity prior to shipment to PVNGS. The batteries are the AT&T round cells which were installed during the spring outage in 1993.

AT&T was contacted regarding the above problem (AT&T letter is attached). The AT&T engineers do not know the root cause for degraded capacity of cells 17 and 36 since they state they have never seen significant degradation of capacity like this in any AT&T round cell during the past 25 years. Normally, these cells increase in capacity for a number of years and are expected to still have a minimum of 100% capacity after 40 years. AT&T feels there is a 90% probability that there was a problem with the test connections or test setup during the capacity test which could have given erroneous readings for cells 17 and 36. To eliminate the concern for degraded cells 17 and 36, AT&T recommends that these two cells be replaced with two tested spare cells which are presently being maintained in Unit 2 Battery Room A. Degraded cells 17 and 36 could then be retested at PVNGS to determine if the cells have actually degraded or if there was an error in the data during the original test performed on 1-31-94. Then, if retest on cells 17 and 36 still indicate degraded capacity, AT&T recommends these two cells be shipped back to the factory for root cause analysis.

Plant Engineering-Electrical concurs with AT&T's recommendation to replace cells 17 and 36. This would avoid any potential for future long term degradation of cells 17 and 36 which could impact the future capacity of Battery 2EPKDF14. Replacement of the two cells would consist of the following:

1) Perform a 2 hour capacity discharge test on the two spare cells presently located in Battery Room A. This test would not have any impact on plant operations since the spare cells are not connected to any operable equipment. NOTE: This action was completed in March, 1994.

2) Removal of degraded cells 17 and 36 of Battery 2EPKDF14 and installation of the two tested spare cells into 2EPKDF14. The cell replacement activity would require Battery 2EPKDF14 to be disconnected from its charger and be inoperable. Based on a conversation with Rich Jennings (Unit 2 Electric Shop Foreman), Battery 2EPKDF14 would be disconnected for a maximum of 8 hours to complete the replacement of the two cells. There is a high probability the cell replacement could be completed in significantly less than 8 hours provided all of the non-battery outage activities for replacement were pre-staged ahead of time.

CRDR CONTINUATION SHEET

CRDR 2 — 4 — 0070

CONDITION REPORT/DISPOSITION REQUEST

The following is a justification for leaving cells 17 and 36 in service until outage 2R5 in 1995:

1) Battery 2EPKDF14 has excess capacity for the designed load on this channel. The battery could be justified to operate with just 58 cells per a Temp Mod if cells 17 and/or 36 were to fail significantly and cause the Battery to become inoperable. The failed cells would be jumpered out with the Temp Mod.

2) Cells 17 and 36 will probably not degrade any further meaning the overall capacity of the entire battery bank will remain at least 100%. AT&T engineers have stated they are very confident that cells 17 and 36 will not degrade any further, if they are degraded at all, and operability of the battery will not be at risk. Under the very worst scenario, which is extremely unlikely, cell 17 and/or 36 would go to reverse voltage. Under reverse voltage conditions a cells' voltage would go to the opposite polarity and reduce the overall battery voltage by approximately 4.0 VDC rather than add 2.0 VDC to the battery as a good cell normally does. However, there is no reason to believe either cell 17 or 36 would go to reverse voltage.

3) The previous service test (32ST-9PK03) performed on 2EPKDF14 following initial battery installation on 4-3-93 indicated the minimum voltage measured on the battery was 123.0 VDC during the entire 2 hour service load profile test. Using this data, the very worst case condition of having both cell 17 and 36 fail to reverse voltage would result in an overall minimum battery voltage of approximately 115 VDC (123.0 VDC minus 2 x 4.0 VDC = 115 VDC) at the end of two hours with the designed loads on the battery. This far exceeds the minimum acceptance criteria of 105 VDC for the two hour service test.

4) There is a possibility there was a problem in the test setup during the 1-31-94 capacity discharge test which gave a false indication of degradation of cells 17 and 36. This would mean cells 17 and 36 did not degrade. AT&T engineers have stated they believe there is a 90% probability of a problem with the test data.

Root cause on cells 17 and 36 should be performed after 2R5 to determine if there was an actual degradation and if so, the reason for degradation. This could be very useful information for future performance monitoring on all the PK batteries.

1) CRDR 2 ----- 4 ----- 0070
PAGE ______ OF ______

EVALUATION/RESPONSE - ACTIONS/APPROVAL

2) PREPARER:	DEPARTMENT:	EXT:	DATE:
James F. Fix	STS-Electrical	5275	5-5-94

8) ACTION(S) COMPLETED

#	TEXT OF ACTION COMPLETED	ACTION CLOSURE DOCUMENT
1	Spare cells SP1 and SP2 in the 2EPKA battery room have been capacity discharge tested. These two cells are intended to eventually replace cells 17 and 36 in battery 2EPKDF14.	W.R. 86557-1
2	W.O. 649332 has been added to the next Unit 2 mid-cycle outage (2B05) to replace cells 17 and 36 in battery 2EPKDF14. If the cells are not replaced during outage 2B05, W.O. 649332 will automatically roll into the scope of refueling outage 2R5 scheduled to begin 2/95.	Primis for outage 2B05

9) ACTIONS NOT COMPLETE

#	PRIORITY	ACTION DESCRIPTION/EXPECTED DISPOSITION DOC	ASSIGNED/ACCEPTED BY	DUE
1		Perform root cause for capacity degradation of cells 17 and 36 in battery 2EPKDF14 following removal from the battery.	Mark Hypse [signature]	6-30-95

10) KEYWORDS	10) REFERENCES
AT%T, Round Cell, Battery, Capacity	N/A

CONTINUATION PAGES ATTACHED ☐ YES ☒ NO

11) EVALUATION/RESPONSE COMPLETED BY:	DATE:	12) APPROVAL BY CRDR OWNER:	DATE:
X James F. Fix	5-5-94	X [signature]	5-6-94
13) CONCURRENCE SENIOR MANAGER WHEN REQUIRED:	DATE:	14) QA/OVERSIGHT CONCURRENCE WHEN REQUIRED:	DATE:
X N/A		X N/A	

2EPKDF14 00647513 31-Jan-94 BATTERY TEMPERATURE 69

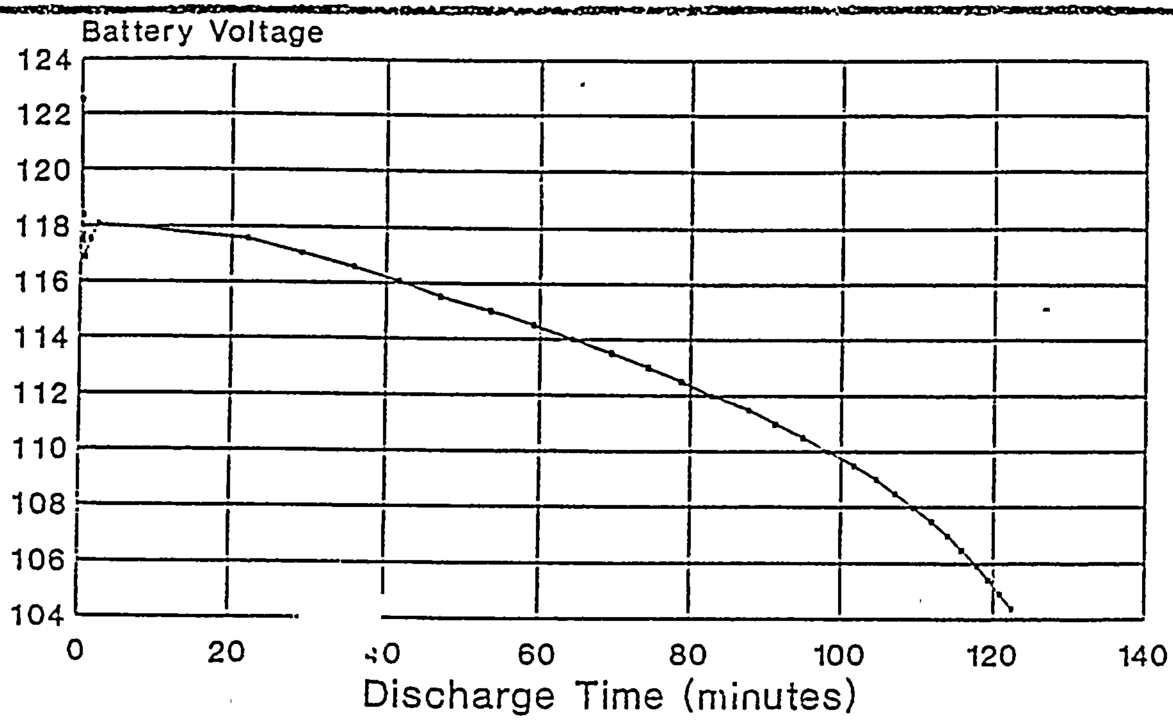
BATTERY VOLTAGE			BATTERY CURRENT			LOWEST ICV			
SEC	VOLTS	MIN	SEC	AMPS	MIN	CELL	ICV	CELL	ICV
0	133.2	0.0	0	7.2	0.0	1	1.73	31	1.76
6	122.5	0.1	0	4.1	0.0	2	1.82	32	1.81
19	118.4	0.3	2	814.4	0.0	3	1.69	33	1.82
33	116.9	0.6	3	543.5	0.1	4	1.75	34	1.77
81	117.5	1.4	5	539.5	0.1	5	1.75	35	1.78
142	118.1	2.4	7	535.8	0.1	6	1.61	36	1.28 -
1321	117.6	22.0	8	532.2	0.1	7	1.79	37	1.75
1735	117.1	28.9	10	528.7	0.2	8	1.75	38	1.78
2145	116.6	35.8	12	526.3	0.2	9	1.81	39	1.74
2496	116.1	41.6	18	528.4	0.3	10	1.61	40	1.69
2823	115.5	47.1	24	532.8	0.4	11	1.68	41	1.81
3215	115.0	53.6	26	531.5	0.4	12	1.73	42	1.73
3547	114.5	59.1	29	529.4	0.5	13	1.77	43	1.82
3864	114.0	64.4	80	530.6	1.3	14	1.72	44	1.74
4167	113.5	69.5	121	528.9	2.0	15	1.75	45	1.78
4463	113.0	74.4	127	527.1	2.1	16	1.76	46	1.79
4728	112.5	78.8	131	525.8	2.2	—17	1.15	47	1.79
4972	112.0	82.9	132	527.0	2.2	18	1.79	48	1.80
5260	111.5	87.7	135	525.5	2.3	19	1.81	49	1.79
5472	111.0	91.2	137	523.9	2.3	20	1.82	50	1.80
5694	110.5	94.9	139	522.4	2.3	21	1.79	51	1.80
5896	110.0	98.3	142	521.0	2.4	22	1.77	52	1.70
6102	109.5	101.7	142	519.8	2.4	23	1.73	53	1.82
6274	109.0	104.6	146	518.1	2.4	24	1.82	54	1.73
6423	108.5	107.1	148	516.6	2.5	25	1.77	55	1.80
6573	108.0	109.6	152	515.0	2.5	26	1.76	56	1.80
6712	107.5	111.9	155	513.6	2.6	27	1.80	57	1.78
6841	107.0	114.0	157	512.0	2.6	28	1.71	58	1.81
6951	106.5	115.9	165	510.4	2.8	29	1.74	59	1.78
7071	105.9	117.9	167	532.9	2.8	30	1.79	60	1.78
7159	105.4	119.3	180	531.6	3.0				
7247	104.9	120.8	181	528.2	3.0				
7345	104.4	122.4	183	526.3	3.1				
			184	524.9	3.1				
			185	523.4	3.1				
			186	522.0	3.1				
			187	520.8	3.1				
			188	519.4	3.1				
			190	518.1	3.2				
			191	516.7	3.2				
			193	515.2	3.2				
			195	513.9	3.3				
			197	511.4	3.3				
			343	510.1	5.7				
			672	508.9	11.2				
			769	510.5	12.8				
			985	509.3	16.4				

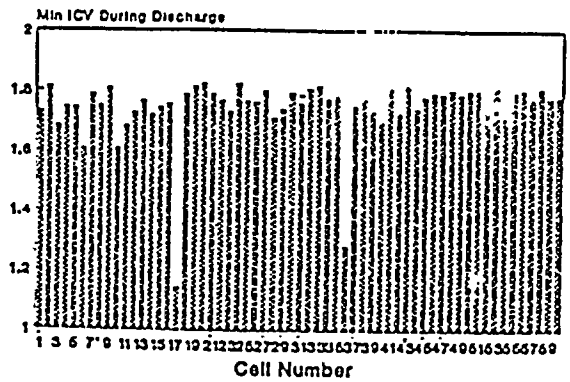
cell 17 serial# 83267
cell 36 serial# 83488

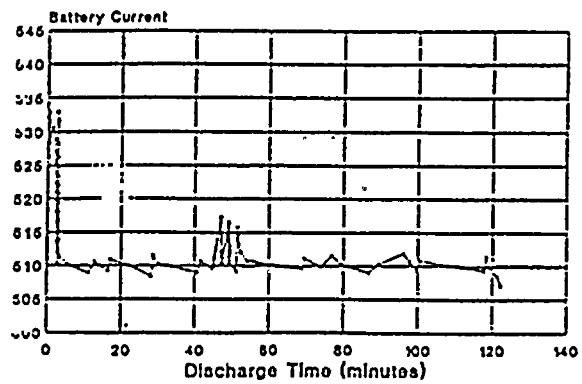
2EPKDF14 00647513 31-Jan-94 BATTERY TEMPERATURE 69

BATTERY VOLTAGE			BATTERY CURRENT			LOWEST ICV			
SEC	VOLTS	MIN	SEC	AMPS	MIN	CELL	ICV	CELL	ICV
			1021	510.9	17.0				
			1426	509.6	23.8				
			1670	508.4	27.8				
			1699	509.6	28.3				
			1710	511.5	28.5				
			1798	510.3	30.0				
			2439	509.0	40.7				
			2487	510.8	41.5				
			2686	509.5	44.8				
			2820	517.2	47.0				
			2825	512.1	47.1				
			2835	510.4	47.3				
			2953	516.5	49.2				
			2957	510.5	49.3				
			3067	509.3	51.1				
			3091	515.7	51.5				
			3100	514.5	51.7				
			3110	513.2	51.8				
			3142	512.0	52.4				
			3237	510.8	54.0				
			4135	509.5	68.9				
			4176	511.1	69.6				
			4432	509.9	73.9				
			4605	511.5	76.8				
			4760	510.3	79.3				
			5197	509.0	86.6				
			5348	510.3	89.1				
			5760	511.9	96.0				
			5854	510.6	97.6				
			5980	509.4	99.7				
			6025	510.8	100.4				
			7060	509.4	117.7				
			7096	511.4	118.3				
			7126	510.0	118.8				
			7279	508.5	121.3				
			7334	507.2	122.2				

2EPKDF14 CAPACITY
STWO 647513 JANUARY 31, 1994

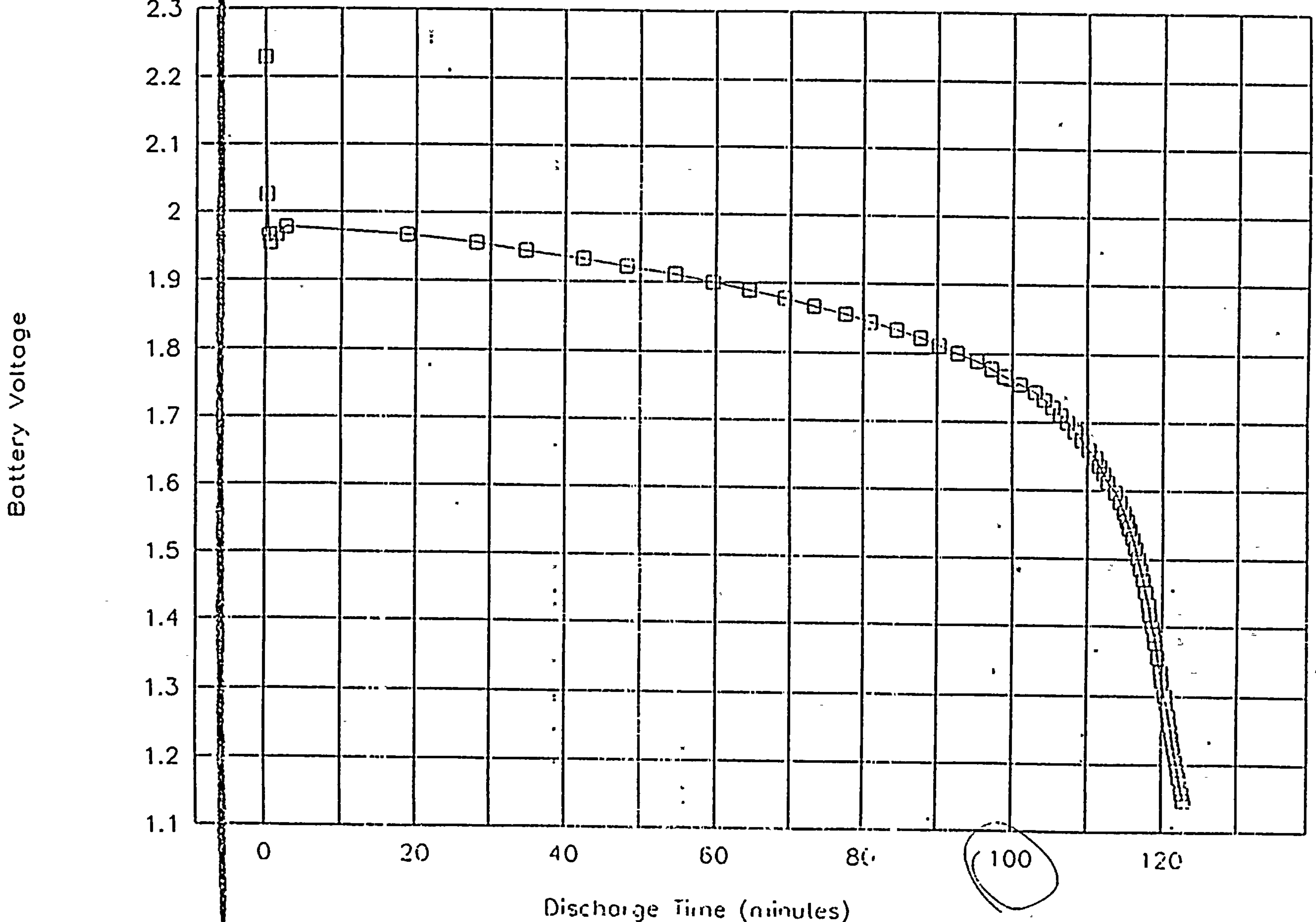






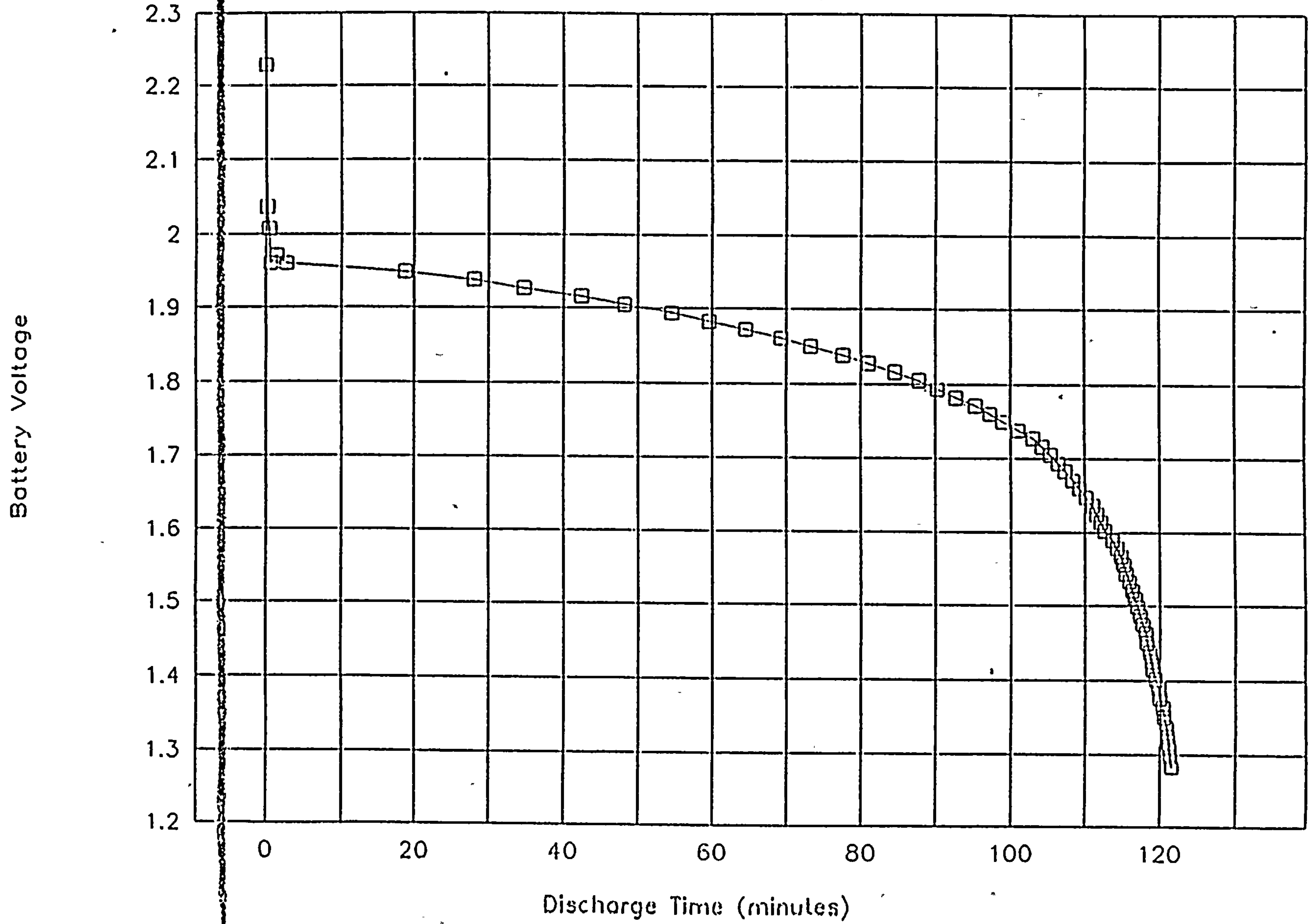
2EPKDF14 CAPACITY CELL 17

STWO 647513 JANUARY 31, 1994



2EPKDF14 CAPACITY CELL 36

STWO 647513 JANUARY 31, 1994



WMC003 C03 SIMS WORK ORDER (CM) CHANGE 05/10/94 13:47:29

WO# 00649332 WR# 865571 UNIT 2 SYS PK WORK CENTER RENG PRIORITY 5
MODEL# RPTD DATE & TIME 020394 1141 WORK TYPE CM DUE 020794
TASK# TASK REV 00 CHARGE TYPE O WBS# MT2CM44B
EQ 2EPKDF14 BATTRY EQ QUAL N NPRDS REPORTABLE
EQ DESC 125 VDC CL 1E BATT, D EQ LOC ZJ1B APPROVAL STATUS W
AMENDMENT IND N REV 00 STATUS DLAY
QUAL CLASS Q SEISMIC CAT 1 EQ CAT EM ASME CODE N WK QR Y MODEL QR
TSCCR# RESTRICT MODE 0 FIRE WATCH N MAINT TAG IND Y
EQ MODE INS PLANT MODE 1234XX7890 EQ LIST N CNTL ROOM DEF LOG
LOC 506 DLAY CODE 6 SECTION XI REPAIR N IND SFTY N TECH SPEC Y
DOC# N/A SPEC COND
WORK DESC CELLS #17 - #36 PASSED 32ST-9PK04. THEY SHOW SIGNS
OF DEGRADATION. ENGINEERING WANTS TO CONDUCT A ROOT CAUSE ON THE
CELLS INDEPENDENT OF THE BATTERY. CHANGE OUT THE 2 CELLS.
QC RQRD N OPTEST RQRD N ENG RQRD N SAFETY RQRD N CODE/UNQ TEST RQRD N
SPECIAL/RETEST RQMTS N/A
CLEAR RQRD N CONFND SPACE RQRD N
REP RQRD N SCTY RQRD N MATLS RQRD Y W/B RQRD N
COMMENTS SEE COMMENTS SCREEN (C-PF3). JRD PEN&INK N
PROCEDURE# TECH MAN#
DRAW# REFER TO ECDVF
VERIFIED RESP NAME HAGA,GERALD B. RESP USERID Z99862 EXT 1655
DISCP ELEC EST CREW SIZE 2 EST MHRS 0040 EST DUR(HRS) 20 RCS PERT B

==========================OPTIONS==========================

ENTER -PROC CHG PF1 -WCP PF2 -ACTV UPDTE PF3 -NXT SCRN PF4 -CL TAG
PF5 -ENG UPDT PF7 -NXT WO WR PF8 -WR PF11 -CLEAR
PF12 -WO CLOSE PF13 -CHG REF (R,E) PF14 -EQ INQ PF17 -ACCT CHG
PF18 -APP SIGN PF19 -MODEL INQ PF20 -WO DELAY PF21 -SCHED
PF22 -REVIEW STEPS PF23 - RTN TO TSCCR DOC PF24 HELP
REFDOC IMPCT EXISTS N610/

WMC029 C29 SIMS WORK ORDER CHAINING UPDATE 05/05/94 07:47:50

WO# 00649332 WR# 865571 WORK TYPE CM PRI 5
WORK DESC CELLS #17 - #36 PASSED 32ST-9PK04. THEY SHOW SIGNS
OF DEGRADATION. ENGINEERING WANTS TO CONDUCT A ROOT CAUSE ON THE
CELLS INDEPENDENT OF THE BATTERY. CHANGE OUT THE 2 CELLS.
EQ 2EPKDF14 BATTRY
EQ DESC 125 VDC CL 1E BATT, D LOC ZJ1B

(A/C/D) WO# WR#

=====OPTIONS=====

ENTER - PROCESS (A/C/D) PF1 - UPDATE WO
PF3 - NEXT SCREEN PF4 - UPDATE CLR TAGS
PF7 - NEXT WO# WR# PF8 - MORE
PF23 - RTN TO APPRV LIST
PF24 - HELP

-8/94 15:19 NO.415

AT&T

AT&T Bell Laboratories

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Mesquite, Texas 75149
214 284-2000

52 75

Mr. Jim Fix
Arizona Public Service
PVNGS, (MS-7524)
5801 South Winterburg Road
Tonopah AZ-85354

February 10, 1994

Sub: Two list 1SH Round Cells with low capacity.
Ref: Our telephone conversations and the data you faxed me (2EPKDF14).

The above string of cells were installed about an year ago. They were also discharge tested at the factory at a 2 hour rate, before they were shipped. All the cells that were shipped, passed the discharge capacity test at the factory. A service test was conducted on this string of batteries on April 8, 1993 at a discharge current of 190 A for about two hours and the string passed the test. No apparent difference in the discharge behavior of cell #s 17 and 36 were found compared to the rest of the cells in the string.

The cells were floating at 2.25 V/cell since the installation. All the cells are floating normal. There are no crystals in any of the cells in the string. A 2 hour discharge test was conducted on January 31 on the string. The string capacity was more than 100% while the capacities of the cell #17 and #36 were less.

Out of two different data you sent me for the discharge conducted on January 31, you confirmed the one sent on February 9, 1994 is the correct one. Cells #17 and #36 have significantly low capacity compared to the rest of the cells in the string. The root cause of this problem is not known at this time and the following is recommended to identify the root cause.

Replace cell #17 and 36 with two good cells you have. Float charge cell #17 and 36 for a month and conduct a two hour discharge test. Forward the discharge test data to me for further analysis. Data obtained during the tests conducted at the factory and at APS on January 31, 1994 will be compared with the above data to identify the root cause of this problem.

If you have any questions please call me.

K.A. Murugesamoorthi

K.A. Murugesamoorthi

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214 284-2000

-5275

Mr. Jim Fix
Arizona Public Service
PVNGS, (MS-7524)
5801 South Winterburg Road
Tonopah AZ-85354

February 12, 1994

Sub: Two list 1SH Round Cells with low capacity.
Ref: My letter dated February 10, 1994.

With reference to the above letter you requested over phone if there will be any adverse effect if you leave cell #s 17 and 36 in the string on float. As per the data taken on February 4, 1994, after the cells were charged, all the cells in the string are floating normal and there are no crystals. The specific gravity of the cells are normal too. Hence, we do not expect any adverse effect in leaving the above two cells in the string. We would like to know the root cause of low capacity in these two cells and hence, we request you to send us data of future discharges.

If you have any questions please give me a call.

K.A. Murugesamoorthi
K.A. Murugesamoorthi
(214)284-2954

Copy to:

K. Bullock
J. Dishman
W. Ives
P. Larkin
W. Trent

Given to NRC (AL McDUGAL) 10/19/94

<u>UNIT 2 AT&T BATTERY PERFORMANCE TESTING FACTS</u>

- Original factory test of the four strings of batteries installed in Unit 2 varied from 106% to 112% as documented in a 1993 memo from the System Engineer. Cells installed in the B and D channels in Unit 2 were a significant mix of cells from all four strings tested at the factory.

- The January, 1994 capacity test results of Unit 2 B and D battery channels would have been very difficult to compare to the factory test results since the four original factory strings were mixed in all four Unit 2 channels. The only way a meaningful comparison could have been made was to perform a very man-hour intensive analysis of the serial number of each cell tested at the factory and compare that cell to the test results of the same cell (serial number) installed in Unit 2.

- Testing methods used at the factory are different than those used at Palo Verde which could contribute to differences in test results. Palo Verde uses Alber test equipment which automatically measures the voltage of each cell at the same time and intercell bar connectors are used to connect the cells. The factory takes all data by hand one cell at a time (total of 72 cells in one test string) and jumper cables are used to connect the cells to each other. In addition, Palo Verde adds an extra 5 amperes to the required load current during discharge testing to be conservative for test equipment tolerances. The factory does not add the extra 5 amperes to the required current. This extra 5 amperes alone accounts for 1% less capacity when tested at Palo Verde.

- AT&T has stated in a memo that shipping causes an approximate 3% loss in capacity. This loss will eventually come back after the cells have been on float voltage for a period of time. The cells are suppose to gradually increase in capacity over a number of years.

- The Unit 2 B and D channel batteries had only been on float for approximately 8 months when tested in January, 1994. This is considerably less float time when compared to the 18 months Unit 1 batteries were float prior to their capacity test performed in September/October, 1993.

- The Unit 1 four channels of Batteries tested onsite in September/October, 1993, at 108.6%, 105.4%, 105.9%, and 106.6%. It was thought at the time that the extra 10 months of float voltage on the Unit 1 batteries may have contributed up to 3% of the difference in capacity test results between Unit 1 test results and the January, 1994 Unit 2 B and D channel capacity tests.

- The AT&T engineers responsible for the round cells were consulted after the Unit 2 January B & D tests. AT&T was not concerned that the banks tested at just slightly over 100% capacity. This conclusion was based on the fact that the Unit 2 batteries had been in service and on float for significantly less time than the Unit 1 batteries. AT&T was just concerned over the low capacity of cells 17 and 36 in the D channel. The poor performance of these two cells could have accounted for approximately 2% less capacity in the overall capacity of the D channel.

ATTACHMENT 2

UNIT 2 CLASS 1E BATTERIES - JUSTIFICATION FOR OPERABILITY

BACKGROUND DISCUSSION:

During the current Unit 2 outage to conduct steam generator eddy current testing, Palo Verde performed capacity testing on the Class 1E batteries. Battery banks A and C were capacity discharged tested per surveillance test procedure 32ST-9PK04 to satisfy the requirements of IEEE Standard 450-1980 to capacity test new batteries within the first two years of service. The Unit 2 AT&T round cell batteries were installed in the May, 1993 period, at which time a service profile test was successfully performed per surveillance procedure 32ST-9PK03. Capacity tests performed on September 23, 1994 on battery banks 2A and 2C had capacity test results of 91.6% and 90.6% respectively. While test results met the Technical Specification limit of 90% capacity, the capacity of the two battery banks were below that expected. As a result, the 2B an 2D battery banks were tested on 10/1/94 with measured capacities of 89.0% and 88.3% respectively. The 2B and 2D battery banks were subsequently declared inoperable because they did not meet the 90% capacity required by Technical Specification 4.8.2.1.e. The 2B and 2D banks were both capacity discharge tested per 32ST-9PK04 in January, 1994 with capacity test results of 100 -101% for each bank. Although preliminary test results indicated that battery banks 2A and 2C were satisfactory, on October 6, 1994, they also were declared inoperable because a projection of the test results. Based upon anticipated degradation, the indications were they would not meet the 90% criteria of Specification 4.8.2.1.e. Currently, Unit 2 is complying with Action a. of Specification 3.8.2.2, DC Sources - Shutdown.

JUSTIFICATION FOR OPERABILITY:

Palo Verde Engineering personnel have determined that the degradation mechanism of the Unit 2 Class 1E batteries is primarily from capacity discharge testing. Testing has indicated the batteries degrade a certain percentage each time they are discharge tested. Testing on cells removed from Unit 2 indicates that capacities tend to stabilize at 50 - 60% after 6 -7 discharge tests. Through analysis (see Attachment 1), Palo Verde Engineers have determined the projected present capacities of banks 2A, 2B, 2C, and 2D, without replacing any cells, would be 78.82%, 82.49%, 76.73% and 81.75% respectively. Additional analysis showed (see Attachment 1) that the projected future capacities of banks 2B and 2D would be 85.58% and 85.81% respectively by replacing the four weakest cells in each bank with tested spare cells from Units 1 and 3 (already completed). In addition, the analysis showed (see Attachment 1) that the projected future capacities of banks 2A and 2C would be 85.47% and 85.74% respectively by replacing the 11 weakest cells in 2A and 12 weakest cells in 2C with new tested cells from the factory (this replacement in 2A and 2C is in progress as of October 12, 1994 and will be completed prior to changing plant modes).

Based on the projected capacities 85.47%, 85.58%,85.74%, 85.81% for banks 2A, 2B, 2C, and 2D respectively, there is considerable capacity margin in each battery bank to meet the load actual profile demand of each battery (see Attachment 2). The load profile is essentially the service test

performed per procedure 32ST-9PK03 to meet the surveillance requirements of Technical Specification 4.8.2.1.d. Engineering analysis (Attachment 2) has determined the excess projected margin in each battery to be: 2A - 54.73%; 2B - 23.89%; 2C - 155.46%; and 2D - 185.58%. For battery 2B, the recently revised calculation which is presently under technical review, indicates the 2B margin to increase from 23.89% to 73.62% for the projected capacity of the 60 cell bank.

As indicated above, the projected capacities of all four Unit 2 battery banks have significant margin above what is required to meet a load profile service test (surveillance procedure 32ST-9PK01) which is based on the requirement to meet plant emergency loads for two hours during a station blackout coincident with a steam generator tube rupture. Additional analysis (see Attachment 3) has indicated the projected capacity of bank 2A (projected 2 on Attachment 3) can supply plant emergency loads for over 4 hours without going below the minimum required 1.84 volts per cell. This is more than twice as long than the design basis requirement of 2 hours. The 2A bank profile was used because it is the most demanding of the four battery banks. Recent load profile service testing (bank 2A profile) on three of the weakest cells removed from bank 2A have shown the minimum voltage reached during the first two hours was 1.86 VDC. These three cells had previous actual capacity test results of 50 - 61.7%.

CONCLUSION:

Surveillance requirement 4.8.2.1.d is satisfied, based on previous capacity discharge testing, capacity discharge testing of replacement cells, and engineering analysis of cell configuration. The configuration of battery banks 2A, 2B, 2C and 2D have sufficient capacity to supply and maintain actual or simulated loads for the design duty cycle

ATTACHMENT 1

INDIVIDUAL CELL AND BATTERY CAPACITY EVALUATION

ATTACHMENT 1

The attached data sheets consist of a number of columns of data. Below is an explanation of the data in each column and the methodology used to obtain the data.

S/N COLUMN: This column contains the serial number of each cell installed in Unit 2. The cells are manufactured with sequential serial numbers at the factory. All of the Unit 2 serial numbers are in the 83000 series.

STRING COLUMN: This column identifies the 72 cell group as it was tested at the factory. Each group of cells has its own unique string number.

CELL COLUMN: This column identifies the cell number of each cell. Each of the four banks has 60 cells (#1 through #60).

FACTORY COLUMN: This column represents the calculated capacity of each cell when it was tested at the factory with the two hour rating of 530 amps (corrected for temperature). The factory data includes individual cell voltages (ICV) of each cell at the end of two hours or later (i.e., $\geq$120 minutes). Eleven millivolts was subtracted from each ICV to compensate for the nominal voltage drop across the intercell connectors installed on the cells at Palo Verde. This subtraction then allows the factory ICVs to be comparable to ICVs measured during capacity discharge testing at Palo Verde. Therefore, a fair comparison of capacity could be made.

Cell capacity is calculated by taking the time (minutes) it took for a cell to reach 1.75V divided by 120 minutes when the manufacturer's 2 hour rating of 530 ampere is discharged through each cell. A cell which reached 1.75V in 120 minutes would have exactly 100% capacity. A cell which takes longer than 120 minutes to reach 1.75V has greater than 100% capacity and a cell which reaches 1.75V before 120 minutes has less than 100% capacity. The time that each ICV at the factory reached 1.75V was taken then divided by 120 minutes to obtain capacity. For cells which were still above 1.75V at the last reading when the test ended, final projected capacities were extrapolated.

Extrapolation was performed by taking the time(minutes) and ICV of the cell's last reading and comparing it to the capacity curve of a known good reference cell.(cell #21 in Unit 1 Battery Bank 1B). Various data points (voltage versus time) of the reference cell were tabulated using capacity test data taken at Palo Verde using the Alber BCT 100 test equipment. The Alber records the ICV of each cell many times during the capacity test. This data is used to extract an ICV versus time curve for the cell and can also provide the data numbers in tabular form. The reference cell reached 1.75V at 120 minutes which makes it a cell with exactly 100% capacity. For extrapolation, the reference cell data was used to predict the time a Unit 2 cell would reach 1.75V. Time was either added or subtracted to determine capacity. For example: if a cell reached 1.81V at 120 minutes and the test ended, the capacity would have to be extrapolated. The reference cell data was then reviewed to determine the point in time it reached 1.81V (105.3 minutes). The difference between the time the reference cell reached 1.81V (105.3 minutes) and

the time it reached 1.75V (120.0 minutes) was then calculated 120.0 - 105.3 = 14.7 minutes. This difference (14.7 minutes) was then added to the 120 minutes it took for the cell to reach 1.81V (120.0 + 14.7 = 134.7 minutes). Thus, the projected capacity of the cell equals 134.7 minutes divided by 120 minutes equals 112.25%. The accuracy of this extrapolation method was verified by taking extrapolated capacities for several high and low capacity cells and comparing those values to actual known capacities of the same cells. This confirmed that the capacity curve of the reference cell had a typical slope which could be used for extrapolation of other cells. No extrapolation or very little extrapolation was used for the lower capacity cells since actual test data was available to indicate the time the cell reached 1.75V.

DELTA COLUMN: This column represents the decline in cell capacity between the factory test and the first capacity test performed at Palo Verde. Note the A&C battery banks had only one onsite capacity test which was performed in September 1994.

1/94, 10/94 COLUMNS: This column contains the calculated capacity values of each cell in 2B and 2D during their Palo Verde January and October tests respectively. These capacities are calculated using data points obtained by the Alber test equipment. For cells which did not have a data time point for reaching 1.75V, the above mentioned extrapolation methods was used to determine capacity for cells above and below 100% capacity.

09/94 COLUMNS: This column contains the calculated capacity values of each cell during their Palo Verde September tests. These capacities are calculated using data points obtained by the Alber test equipment. For cells which did not have a data time point for reaching 1.75V, the above mentioned extrapolation methods was used to determine capacity for cells above and below 100% capacity.

PROJECTED-1 COLUMN: This column contains the projected present capacity (%) of each existing cell in Bank 2A, 2B, 2C, and 2D. This projected value is based on the average slope of degradation between the factory capacity values and the Palo Verde tests. The same rate (slope) of degradation in capacity is then used to project the capacity expected if another capacity test was to be performed on the cell. For example: if the factory test value was 105% and the Palo Verde test value was 95%, the degradation rate would be 10% for each discharge test. The projected capacity would then be 95% - 10% = 85%.

PROJECTED-2 COLUMN: For Battery 2A this column contains the projected present capacity (%) of each existing cell in the bank plus replacement of 11 of the lowest performing cells in the bank with 11 new cells from the factory, and project present capacity for battery 2C (with replacement of the 12 lowest performing cells). The new replacement cells in this column can be easily determined because the capacity of each new cell is listed as a 95.00%. The capacity of each new replacement cell is conservatively assumed to be an average of 95.00% and is not expected to degrade in capacity during future discharge testing. This capacity has been confirmed by test prior to the installation of the replacement cells.

R-FIT TEST: "Goodness of Fit" test results.

LR PROJECTED: Linear regression projected cell capacities for each cell.

MIN LR-P1: The lower cell capacity of the two projection methods (either LR Projected or Projected -1).

MIN LR-P1 PROJECTED-2: For Batteries 2B and 2D this column contains the projected present capacity (%) of each existing cell in the bank using the Min LR-P1 for the individual cell capacity.

AVERAGE (listed at bottom of row): These numbers represent the average capacity (%) of all 60 cells in the battery. For example: an average capacity of 85.47% at the bottom of PROJECTED-2 column for Bank 2A represents the capacity of each of the 60 cells added together and then divided by 60. Thus, 85.47% would represent expected overall capacity for the entire bank of 60 cells.

INDIVIDUAL CELL CAPACITIES FOR BATTERY 2C

S/N	STRING	CELL		FACTORY	DELTA	09/94	DELTA	PROJECTED-1	PROJECTED-2	PROJECTED-3
83484	3-6-93-37	9		111.5		110.3	1.2	109.10	109.10	
83590	3-9-93-63	58		110.5		107.8	2.7	105.10	105.10	
83541	3-6-93-24	8		112.9		108.4	4.5	103.90	103.90	
83469	3-9-93-65	35		110.2		106.3	3.9	102.40	102.40	
83567	3-6-93-20	3		115.0		107.7	7.3	100.40	100.40	
83474	3-6-93-3	21		107.6		103.7	3.9	99.80	99.80	
83477	3-9-93-64	59		112.7		106.0	6.7	99.30	99.30	
83577	3-9-93-28	31		110.5		103.1	7.4	95.70	95.70	
83523	3-9-93-12	43		110.5		102.7	7.8	94.90	94.90	
83486	3-9-93-8	41		108.8		101.5	7.3	94.20	94.20	
83448	3-9-93-59	17		110.5		102.3	8.2	94.10	94.10	
83473	3-6-93-10	39		108.6		100.9	7.7	93.20	93.20	
83505	3-6-93-41	7		111.7		102.2	9.5	92.70	92.70	
83386	3-6-93-48	24		105.7		98.4	7.3	91.10	91.10	
83512	3-9-93-56	36		103.2		96.6	6.6	90.00	90.00	
83468	3-9-93-58	15		109.3		99.5	9.8	89.70	89.70	
83348	3-6-93-13	53		103.7		95.6	8.1	87.50	87.50	
83514	3-9-93-60	18		111.8		99.3	12.5	86.80	86.80	
83542	3-6-93-44	1		110.1		98.2	11.9	86.30	86.30	
83288	3-6-93-58	25		105.2		95.4	9.8	85.60	85.60	
83520	3-6-93-11	38		109.2		97.2	12.0	85.20	85.20	
83462	3-9-93-5	42		111.3		98.0	13.3	84.70	84.70	
83329	3-6-93-67	40		108.9		96.8	12.1	84.70	84.70	
83344	3-6-93-53	37		103.6		94.1	9.5	84.60	84.60	
83547	3-9-93-1	16		107.8		96.0	11.8	84.20	84.20	
83487	3-6-93-16	10		109.6		96.6	13.0	83.60	83.60	
83532	3-6-93-42	6		106.6		94.8	11.8	83.00	83.00	
83554	3-6-93-38	49		109.1		94.7	14.4	80.30	80.30	
83378	3-6-93-28	46		107.6		93.7	13.9	79.80	79.80	
83566	3-9-93-21	45		105.7		92.4	13.3	79.10	79.10	
83303	3-9-93-15	60		103.8		90.8	13.0	77.80	77.80	
83470	3-6-93-61	56		108.2		92.9	15.3	77.60	77.60	
83259	3-6-93-40	4		108.7		93.1	15.6	77.50	77.50	
83564	3-6-93-2	19		107.6		92.3	15.3	77.00	77.00	
83460	3-6-93-4	22		106.6		90.7	15.9	74.80	74.80	
83370	3-6-93-22	50		106.6		90.4	16.2	74.20	74.20	
83457	3-9-93-23	28		108.3		90.7	17.6	73.10	73.10	
83281	3-9-93-29	30		104.3		88.4	15.9	72.50	72.50	
83306	3-6-93-39	52		105.6		88.6	17.0	71.60	71.60	
83394	3-6-93-1	20		111.7		89.9	21.8	68.10	68.10	
83356	3-6-93-47	23		103.7		85.8	17.9	67.90	67.90	
83335	3-6-93-17	2		108.6		88.1	20.5	67.60	67.60	
83389	3-6-93-26	13		108.1		87.7	20.4	67.30	67.30	
83395	3-6-93-35	54		101.7		83.9	17.8	66.10	66.10	
83568	3-9-93-53	34		109.0		87.4	21.6	65.80	65.80	
83585	3-9-93-54	33		104.8		84.9	19.9	65.00	65.00	
83390	3-6-93-49	48		107.6		86.3	21.3	65.00	65.00	
83515	3-9-93-22	26		105.7		85.1	20.6	64.50	64.50	
83357	3-6-93-23	51		108.1		85.3	22.8	62.50	95.00	
83301	3-6-93-21	5		106.0		83.3	22.7	60.60	95.00	
83307	3-9-93-24	27		103.8		81.8	22.0	59.80	95.00	
83351	3-9-93-31	29		104.8		82.1	22.7	59.40	95.00	
83498	3-6-93-57	14		110.2		82.5	27.7	54.80	95.00	
83287	3-6-93-50	47		103.6		78.7	24.9	53.80	95.00	
83582	3-9-93-7	44		109.0		80.8	28.2	52.60	95.00	
83293	3-6-93-36	55		104.5		77.6	26.9	50.70	95.00	
83282	3-9-93-30	32		105.8		77.2	28.6	48.60	95.00	
83376	3-6-93-25	11		107.1		75.5	31.6	43.90	95.00	
83510	3-6-93-15	12		103.6		67.9	35.7	32.20	95.00	
83443	3-9-93-16	57		105.2		62.9	42.3	20.60	95.00	
	AVERAGE:		0.00	107.70		92.21		76.73	85.74	

INDIVIDUAL CELL CAPACITIES FOR BATTERY 2B

S/N	STRING	CELL	FACTORY	1/94	10/94	r - fit test	LR PROJECTED	PROJECTED-1	Min LR - P1	Min LR - P1 PROJECTED-2
83339	293-92-35	52	120.0	116.3	112.3	-0.9999	108.48	108.45	108.45	108.45
83355	290-92-10	12	110.0	83.9	75.0	-0.9620	54.63	57.50	54.63	107.10
83373	290-92-54	60	111.5	91.0	77.8	-0.9923	59.73	60.95	59.73	107.10
83354	290 92-11	57	110.7	89.7	79.9	-0.9787	62.63	64.50	62.63	106.70
83251	289-92-7	6	106.5	106.7	105.4	-0.7857	105.10	104.85	104.10	104.10
83352	290-92-9	10	110.0	90.3	79.1	-0.9876	62.23	63.65	62.23	103.75
83330	290 92-52	21	113.0	95.1	83.3	-0.9930	67.43	68.45	67.43	67.43
83467	293-92-39	28	119.7	99.8	88.2	-0.9886	71.07	72.45	71.07	71.07
83243	289-92-6	25	111.6	96.7	85.4	-0.9969	71.70	72.30	71.70	71.70
83248	289-92-66	24	108.2	94.0	83.9	-0.9953	71.07	71.75	71.07	71.07
83274	289 92-69	29	108.2	97.9	83.6	-0.9956	71.97	71.30	71.30	71.30
83318	289-92-61	32	108.7	94.4	85.0	-0.9930	72.33	73.15	72.33	72.33
83528	293-92-9	40	118.0	101.0	86.4	-0.9990	70.20	70.60	70.20	70.20
83496	293-92-1	19	114.8	102.4	84.7	-0.9948	70.57	69.68	69.68	69.68
83316	289-92-51	48	107.2	96.9	85.4	-0.9995	74.70	74.50	74.50	74.50
83511	290-92-5	11	113.0	101.3	94.1	-0.9907	83.90	84.65	83.90	83.90
83245	289-92-65	5	113.0	101.5	87.5	-0.9984	75.17	74.75	74.75	74.75
83342	290-92-16	59	115.8	98.3	84.7	-0.9974	68.50	69.15	68.50	68.50
83255	289-92-50	47	109.8	108.7	104.6	-0.9488	102.50	102.00	102.00	102.00
83589	293-92-29	33	119.0	113.9	107.5	-0.9979	101.97	101.75	101.75	101.75
83483	293-92-62	37	117.0	113.1	106.4	-0.9886	101.57	101.10	101.10	101.10
83338	293-92-33	51	120.0	114.5	107.0	-0.9961	100.83	100.50	100.50	100.50
83273	289-92-31	42	108.6	107.5	103.2	-0.9462	101.03	100.50	100.50	100.50
83291	293-92-40	20	119.2	110.1	105.3	-0.9844	97.63	98.35	97.63	97.63
83501	293-92-31	34	111.5	106.9	101.7	-0.9994	96.90	96.80	96.80	96.80
83254	289-92-70	31	111.0	108.2	101.0	-0.9692	96.73	96.00	96.00	96.00
83083	289-92-38	22	108.2	106.4	99.6	-0.9480	96.13	95.30	95.30	95.30
83388	293-92-34	49	116.5	110.1	102.1	-0.9979	95.17	94.90	94.90	94.90
83503	293-92-30	36	115.8	108.7	101.1	-0.9998	93.87	93.78	93.78	93.78
83592	293-92-23	35	118.0	109.2	101.3	-0.9995	92.80	92.95	92.80	92.80
83600	293-92-13	4	112.8	107.3	98.9	-0.9925	92.47	91.98	91.98	91.98
83241	289-92-33	43	110.5	104.5	97.7	-0.9993	91.43	91.30	91.30	91.30
83353	290-92-3	13	110.0	102.0	97.5	-0.9876	90.60	91.18	90.60	90.60
83364	289-92-3	56	112.9	105.4	96.5	-0.9988	88.53	88.30	88.30	88.30
83497	293-92-59	7	119.0	109.7	98.3	-0.9983	88.30	87.95	87.95	87.95
83374	289-92-2	26	112.9	103.2	96.4	-0.9949	87.67	88.15	87.67	87.67
83598	293-92-3	38	116.5	106.8	96.5	-0.9999	86.60	86.50	86.50	86.50
83295	289-92-62	55	104.7	99.9	92.0	-0.9902	86.17	85.65	85.65	85.65
83444	293-92-12	39	119.6	108.8	96.8	-0.9995	85.60	85.40	85.40	85.40
83367	289-92-30	41	106.5	98.6	92.0	-0.9987	84.53	84.75	84.53	84.53
83315	289-92-49	45	108.9	101.4	92.4	-0.9986	84.40	84.15	84.15	84.15
83309	289-92-40	14	108.2	98.6	92.1	-0.9939	83.53	84.05	83.53	83.53
83551	293-92-60	8	118.2	109.1	95.0	-0.9923	84.23	83.40	83.40	83.40
83284	293-92-37	50	115.2	106.2	94.0	-0.9962	83.93	83.40	83.40	83.40
83371	289-92-4	23	113.0	104.6	92.9	-0.9956	83.45	82.91	82.91	82.91
83375	289-92-27	54	107.7	99.3	90.5	-0.9999	81.99	81.92	81.92	81.92
83328	289-92-67	27	108.2	98.3	90.3	-0.9981	81.03	81.35	81.03	81.03
83256	289-92-21	46	109.4	97.9	90.3	-0.9931	80.10	80.75	80.10	80.10
83246	289-92-39	30	111.6	101.7	90.2	-0.9991	79.77	79.50	79.50	79.50
83324	289-92-48	3	105.0	95.3	88.0	-0.9967	79.10	79.50	79.10	79.10
83186	289-92-8	2	110.0	100.0	89.3	-0.9998	79.07	78.95	78.95	78.95
83336	289-92-46	53	109.4	98.6	88.2	-0.9999	77.53	77.60	77.53	77.53
83451	290-92-68	58	111.0	97.6	88.9	-0.9925	77.07	77.85	77.07	77.07
83586	293-92-14	9	115.5	102.4	89.7	-1.0000	76.73	76.80	76.73	76.73
83257	289-92-41	17	106.5	97.9	86.1	-0.9959	76.43	75.90	75.90	75.90
83279	289-92-72	1	108.2	97.8	86.3	-0.9996	75.53	75.35	75.35	75.35
83334	289-92-29	16	108.2	96.4	86.5	-0.9987	75.33	75.65	75.33	75.33
83369	289-92-42	15	106.5	94.2	85.8	-0.9941	74.80	75.45	74.80	74.80
83314	289-92-32	44	108.9	94.7	86.8	-0.9867	74.70	75.75	74.70	74.70
83363	289-92-43	18	104.3	94.4	83.3	-0.9995	73.00	72.80	72.80	72.80
	AVERAGE:		111.89	101.78	92.53		82.70	82.85	82.49	85.58

INDIVIDUAL CELL CAPACITIES FOR BATTERY 2A

S/N	STRING	CELL	FACTORY	09/94	DELTA	PROJECTED-1	PROJECTED-2	PROJECTED-3
83458		48	109.5	106.5	3.0	103.50	103.50	
83263		6	111.2	107.1	4.1	103.00	103.00	
83185	3-6-93	21	113.8	107.4	6.4	101.00	101.00	
83591		42	110.5	105.7	4.8	100.90	100.90	
83645		50	110.5	105.2	5.3	99.90	99.90	
83513		31	106.9	103.1	3.8	99.30	99.30	
83493		18	113.3	105.8	7.5	98.30	98.30	
83471		49	112.9	105.3	7.6	97.70	97.70	
83482		45	107.8	102.5	5.3	97.20	97.20	
83480		19	107.3	102.1	5.2	96.90	96.90	
83594		27	113.8	104.6	9.2	95.40	95.40	
83463	3-9-93	41	111.5	102.5	9.0	93.50	93.50	
83331	3-6-93	1	107.7	99.9	7.8	92.10	92.10	
83479	3-9-93	30	108.0	99.8	8.2	91.60	91.60	
83569		12	116.0	103.6	12.4	91.20	91.20	
83478		59	108.0	99.1	8.9	90.20	90.20	
83648	3-9-93	9	111.0	100.6	10.4	90.20	90.20	
83466		38	109.3	99.6	9.7	89.90	89.90	
83452		43	111.0	100.3	10.7	89.60	89.60	
83549		10	111.5	100.4	11.1	89.30	89.30	
83475		24	102.5	93.9	8.6	85.30	85.30	
83521		46	108.7	96.9	11.8	85.10	85.10	
83270		55	106.4	95.6	10.8	84.80	84.80	
83580		11	110.2	97.1	13.1	84.00	84.00	
83244	3-6-93	13	107.2	95.4	11.8	83.60	83.60	
83546		40	101.2	92.0	9.2	82.80	82.80	
83540		36	103.7	92.9	10.8	82.10	10.00	
83358		56	108.1	95.0	13.1	81.90	81.90	
83381		54	109.2	95.4	13.8	81.60	81.60	
83545		20	106.8	93.9	12.9	81.00	81.00	
83308	3-6-93	53	107.6	94.2	13.4	80.80	80.80	
83333		15	111.7	96.2	15.5	80.70	80.70	
83290		4	103.0	91.8	11.2	80.60	80.60	
83536		25	101.6	91.0	10.6	80.40	80.40	
83491		28	104.6	92.3	12.3	80.00	80.00	
83360		7	109.2	93.8	15.4	78.40	78.40	
83543	3-9-93	17	104.8	90.9	13.9	77.00	77.00	
83574	3-9-93	57	108.3	92.3	16.0	76.30	76.30	
83459		26	106.1	91.0	15.1	75.90	75.90	
83553	3-9-93	37	110.5	92.4	18.1	74.30	74.30	
83517		60	105.7	89.9	15.8	74.10	74.10	
83518		58	102.6	88.1	14.5	73.60	73.60	
83579	3-6-93	39	105.7	88.8	16.9	71.90	71.90	
83575		16	102.2	86.3	15.9	70.40	70.40	
83571		44	105.2	87.7	17.5	70.20	70.20	
83495	3-6-93	29	103.7	86.4	17.3	69.10	69.10	
83529		23	102.6	85.5	17.1	68.40	68.40	
83445		47	106.3	87.0	19.3	67.70	67.70	
83385		52	107.2	85.0	22.2	62.80	62.80	
83377		5	104.9	83.6	21.3	62.30	95.00	
83322		51	104.3	81.2	23.1	58.10	95.00	
83465		34	103.9	80.5	23.4	57.10	95.00	
83343		3	106.8	81.2	25.6	55.60	95.00	
83531		32	102.1	78.7	23.4	55.30	95.00	
83526		2	108.1	81.4	26.7	54.70	95.00	
83516		14	105.2	78.9	26.3	52.60	95.00	
83346		8	105.0	78.8	26.2	52.60	95.00	
83539		35	104.7	75.7	29.0	46.70	95.00	
83292	3-6-93	33	101.8	71.0	30.8	40.20	95.00	
83525	3-9-93	22	102.3	70.3	32.0	38.30	95.00	
	AVERAGE	0.00	107.22	93.02		78.82	85.47	

INDIVIDUAL CELL CAPACITIES FOR BATTERY 2D

S/N	STRING	CELL	FACTORY	1/94	10/94	r - fit test	LR PROJECTED	PROJECTED-1	Min LR - P1	Min LR - P1 PROJECTED-2
83294	290-92-19	10	108.0	89.8	77.5	-0.9938	61.27	62.25	61.27	116.70
83065	289-92-54	2	115.2	114.2	112.1	-0.9797	110.73	110.55	110.55	110.55
83267	289-92-60	17	109.9	86.4	80.8	-0.9423	63.27	66.25	63.27	108.70
83372	290-92-21	6	113.0	83.3	68.3	-0.9824	43.50	45.95	43.50	108.70
83488	293-92-67	36	115.2	69.3	63.2	-0.9147	30.57	37.20	30.57	107.90
83500	293-92-20	20	116.7	115.4	108.9	-0.9333	105.87	105.00	105.00	105.00
83262	289-92-59	33	112.3	112.3	105.4	-0.8660	103.10	101.95	101.95	101.95
83425	290-92-30	24	115.0	116.2	108.7	-0.7819	107.00	105.55	101.20	101.20
83260	290-92-25	43	116.0	113.8	105.4	-0.9474	101.13	100.10	100.10	100.10
83317	289 92-24	49	109.4	109.6	103.1	-0.8522	101.07	99.95	99.95	99.95
83321	289-92-19	16	103.3	102.6	100.9	-0.9723	99.87	99.70	99.70	99.70
83319	289-92-16	30	111.2	109.6	102.9	-0.9425	99.60	98.75	98.75	98.75
83269	289-92-25	58	114.1	111.1	102.9	-0.9659	98.17	97.30	97.30	97.30
83247	289-92-53	9	114.7	111.8	103.1	-0.9608	98.27	97.30	97.30	97.30
83368	289-92-10	50	114.1	112.0	102.9	-0.9406	98.47	97.30	97.30	97.30
83494	293-92-15	19	116.7	114.8	103.1	-0.9233	97.93	96.30	96.30	96.30
83587	293-92-72	53	117.1	115.2	102.9	-0.9210	97.53	95.80	95.80	95.80
83345	290-92-28	41	116.0	112.9	102.5	-0.9546	96.97	95.75	95.75	95.75
83252	289-92-15	7	107.0	107.5	100.9	-0.8300	99.03	97.85	94.30	94.30
83350	289-92-11	32	114.1	110.4	100.1	-0.9649	94.20	93.10	93.10	93.10
83280	289-92-64	60	108.5	107.5	97.6	-0.9045	93.63	92.15	92.15	92.15
83599	293-92-17	27	113.7	109.6	98.1	-0.9645	91.53	90.30	90.30	90.30
83538	293-92-48	47	113.3	110.0	97.6	-0.9483	91.27	89.75	89.75	89.75
83264	289-92-68	51	113.6	111.4	97.6	-0.9224	91.53	89.60	89.60	89.60
83261	289-92-45	59	109.4	106.5	95.8	-0.9493	90.30	89.00	89.00	89.00
83481	293-92-25	46	113.3	109.1	95.8	-0.9578	88.57	87.05	87.05	87.05
83297	290-92-37	22	108.7	105.1	93.9	-0.9588	87.77	86.50	86.50	86.50
83570	293-92-28	18	115.2	108.7	95.9	-0.9827	87.30	86.25	86.25	86.25
83555	293-92-56	48	115.0	109.2	95.8	-0.9749	87.47	86.20	86.20	86.20
83552	293-92-42	56	115.2	110.7	95.8	-0.9553	87.83	86.10	86.10	86.10
83502	293-92-44	55	116.0	110.7	95.8	-0.9644	87.30	85.70	85.70	85.70
83332	289-92-44	57	110.4	106.2	93.3	-0.9595	86.20	84.75	84.75	84.75
83258	289-92-57	34	111.5	105.7	93.3	-0.9788	85.30	84.20	84.20	84.20
83327	289-92-17	8	103.6	103.0	90.1	-0.8850	85.40	83.35	83.35	83.35
83361	290-92-40	38	115.2	106.8	93.3	-0.9911	83.20	82.35	82.35	82.35
83265	289-92-13	35	114.1	106.1	91.8	-0.9870	81.70	80.65	80.65	80.65
83379	290-92-20	13	115.2	104.1	91.8	-0.9996	80.30	80.10	80.10	80.10
83646	293-92-71	45	112.2	106.7	90.1	-0.9604	80.90	79.05	79.05	79.05
83537	293-92-27	26	113.5	104.9	90.4	-0.9893	79.83	78.85	78.85	78.85
83311	289-92-18	1	107.5	100.6	87.9	-0.9857	79.07	78.10	78.10	78.10
83490	293-92-45	21	115.2	107.8	90.4	-0.9740	79.67	78.00	78.00	78.00
83305	290-92-39	14	108.6	99.1	87.9	-0.9989	77.83	77.55	77.55	77.55
83359	290-92-12	4	115.2	101.7	90.2	-0.9989	77.37	77.70	77.37	77.37
83326	289-92-14	37	110.4	102.4	87.9	-0.9864	77.73	76.65	76.65	76.65
83325	290-92-60	42	108.6	98.6	87.3	-0.9994	76.87	76.65	76.65	76.65
83268	289-92-52	31	110.9	101.3	87.3	-0.9943	76.23	75.50	75.50	75.50
83391	290-92-71	15	112.2	100.0	87.4	-1.0000	75.07	75.00	75.00	75.00
83283	290-92-27	11	112.5	95.1	88.2	-0.9703	74.30	76.05	74.30	74.30
83366	290-92-51	44	112.2	99.9	86.3	-0.9996	73.57	73.35	73.35	73.35
83276	290-92-58	29	110.6	100.2	85.4	-0.9950	73.53	72.80	72.80	72.80
83548	293-92-18	25	112.0	103.5	85.8	-0.9801	74.23	72.70	72.70	72.70
93249	289-92-56	23	106.3	99.3	83.7	-0.9767	73.83	72.40	72.40	72.40
83387	290-92-55	5	115.2	101.3	86.4	-0.9998	72.17	72.00	72.00	72.00
83447	290-92-8	39	109.0	99.3	81.7	-0.9863	69.37	68.05	68.05	68.05
83323	289-92-22	52	106.0	95.4	80.4	-0.9951	68.33	67.60	67.60	67.60
83556	293-92-43	54	110.7	98.9	80.8	-0.9927	66.90	65.85	65.85	65.85
83650	293-92-19	28	112.2	91.7	80.8	-0.9848	63.50	65.10	63.50	63.50
82278	290-92-18	12	112.2	96.4	79.6	-0.9998	63.47	63.30	63.30	63.30
83313	289-92-55	3	108.6	94.0	78.3	-0.9998	63.33	63.15	63.15	63.15
83453	290-92-6	40	112.2	92.6	75.4	-0.9993	56.60	57.00	56.60	56.60
	AVERAGE:		112.08	103.99	92.14		82.80	82.17	81.75	85.81

ATTACHMENT: 2

Unit 2 Battery Capacity Margin
(Reflects Planned Addition of 23 Cells in 2A and 2C)

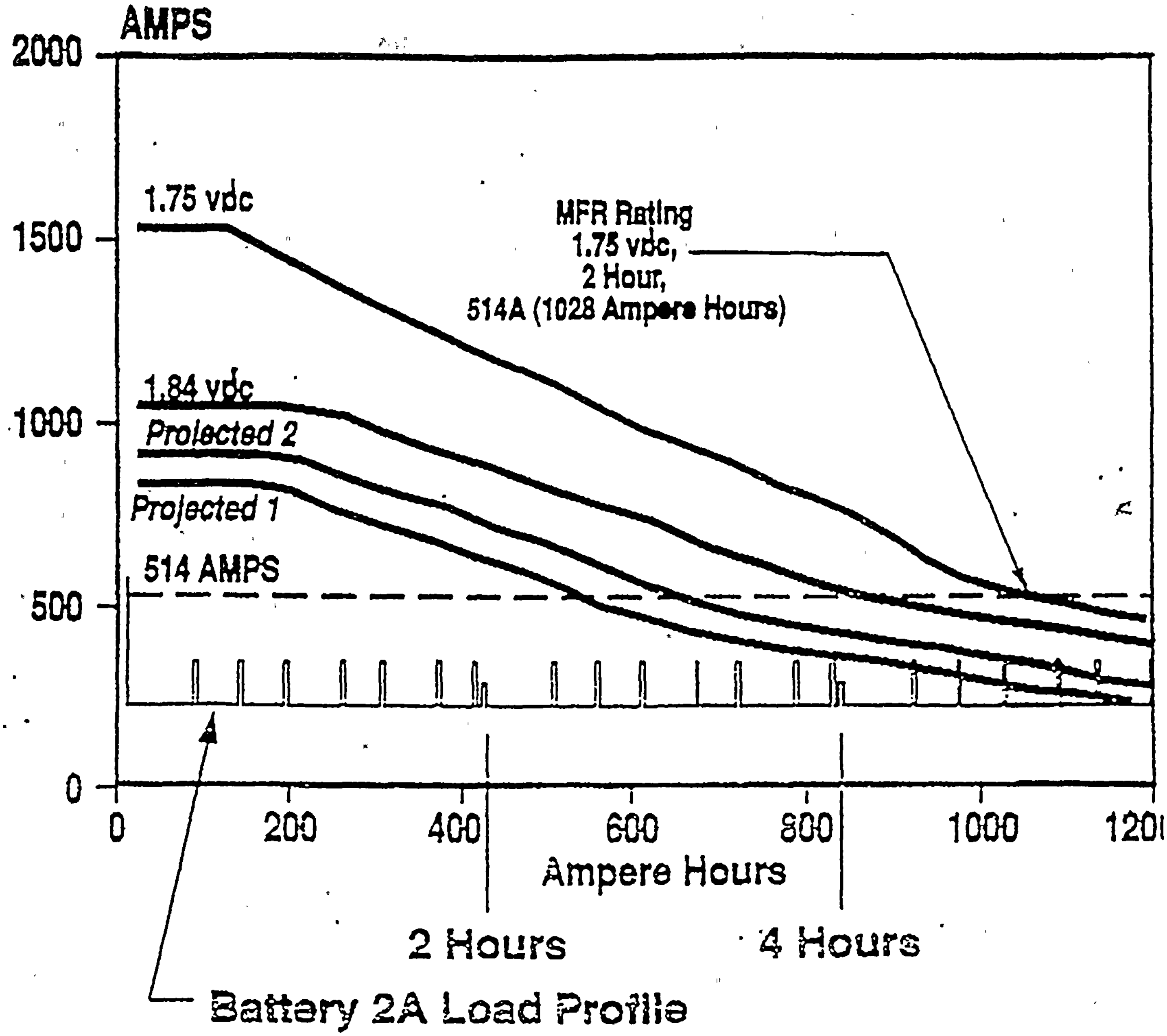
Battery	Test Cap.	Proj. Cap.	Req. Cap.	AT&T Cap. (# of Positive Plates)	Margin
2A**	16.49	*****15.38	9.94	18	5.44 (54.73%)
2B*	16.02	****15.40	12.43	18	2.97 (23.89%)
2B***	16.02	****15.40	8.87	18	6.53 (73.62%)
2C*	16.31	*****15.43	6.04	18	9.39 (155.46%)
2D*	15.89	****15.45	5.41	18	10.04 (185.58%)

NOTE:
* represents calculation 13-EC-PK-202, R. 6.
** represents new calculation, 02-EC-PK-207, R. 0.
*** represents calculation results currently in technical review.
**** reflects changeout of 4 cells/battery, completed on 10/05/94
*****reflects addition of 11 cells in "A" and 12 cells in "C"

The new calculation will correspondingly show increases in battery capacity and margin for batteries B, C, and D. Due to time restrictions, the new calculations for batteries B, C, and D are currently in process. Nevertheless, as the worst case, Battery A has the lowest margin and envelops the margins of the other batteries.

LEGEND:
- Test Cap.: The capacity measured during the most recent surveillance test.
- Proj. Cap.: The worst case projected capacity based on cell capacity tables.
- Req. Cap.: The capacity required based on IEEE 485. (i.e. the load profile requires 9.94 of the plates available).
- Des. Cap.: The Number of Positive Plates for 1850AH AT&T Round Cell
- Margin: The excess capacity above the minimum required to satisfy the load requirement. (=Projected Capacity minus Required Capacity)
- (% Margin): Margin divided by the Required Capacity

Projected Battery Degradation vs. Load Requirements



Projected 1: 78.32% Capacity
Projected 2: 85.47% Capacity

SOURCE: Document 13-ENO5OA-AO29

ATTACHMENT 3

APS

Arizona Public Service Company

Company Correspondence

ID #: 102-03183-AKK/DRL
Date: November 22, 1994

To: File
Sta.#:
Ext.#:

From: A. K. Krainik
Sta.#: 7636
Ext.#: 82-5421

File: 94-042-404
Subject: **Impact of Dedication Testing Results of the New Round Cell Batteries on Margin Calculations**

On Monday, October 31, 1994, twenty three of the seventy one replacement cells for the safety-related 125VDC batteries on site at Palo Verde were capacity discharge tested for the second time, in accordance with the approved commercial-grade dedication plan (Material Engineering Evaluation 1180). As a result of this test, it was noted that capacities of the twenty three cells had decreased as a string by approximately 7.5 percent to 97.5 percent.

A different set of twenty three cells were previously received and were installed as replacements in the Unit 2. These batteries were manufactured within the prior two months and could potentially exhibit similar performance. As these cells were only capacity discharge tested once, and can not be tested again to determine the existence of a similar effect in these cells, it was decided to perform a revised estimate of the current capacity of the Unit 2 batteries with the replacement cells assumed to be degraded to 50 percent capacity. Fifty percent capacity has been the lowest capacity exhibited by cells during our root cause investigation.

As a result of those assumptions and calculations, which are contained in the attachment, it has been concluded that adequate capacity exists in the Unit 2 batteries to perform their intended safety function.

AKK/DRL/rv

Attachment

INDIVIDUAL CELL CAPACITIES FOR BATTERY 2A

S/N	STRING	CELL		FACTORY	09/94	DELTA	PROJECTED-1	PROJECTED-2	PROJECTED-3	PROJECTED-4	PROJECTED-5
83458		48		109.5	106.5	3.0	103.50	103.50	103.50	103.50	103.50
83263		6		111.2	107.1	4.1	103.00	103.00	103.00	103.00	103.00
83485	3-6-93	21		113.8	107.4	6.4	101.00	101.00	101.00	101.00	101.00
83591		42		110.5	105.7	4.8	100.90	100.90	100.90	100.90	100.90
83645		50		110.5	105.2	5.3	99.90	99.90	99.90	99.90	99.90
83513		31		106.9	103.1	3.8	99.30	99.30	99.30	99.30	99.30
83493		18		113.3	105.8	7.5	98.30	98.30	98.30	98.30	98.30
83471		49		112.9	105.3	7.6	97.70	97.70	97.70	97.70	97.70
83482		45		107.8	102.5	5.3	97.20	97.20	97.20	97.20	97.20
83480		19		107.3	102.1	5.2	96.90	96.90	96.90	96.90	96.90
83594		27		113.8	104.6	9.2	95.40	95.40	95.40	95.40	95.40
83463	3-9-93	41		111.5	102.5	9.0	93.50	93.50	93.50	93.50	93.50
83331	3-6-93	1		107.7	99.9	7.8	92.10	92.10	92.10	92.10	92.10
83479	3-9-93	30		108.0	99.8	8.2	91.60	91.60	91.60	91.60	91.60
83569		12		116.0	103.6	12.4	91.20	91.20	91.20	91.20	91.20
83478		59		108.0	99.1	8.9	90.20	90.20	90.20	90.20	90.20
83648	3-9-93	9		111.0	100.6	10.4	90.20	90.20	90.20	90.20	90.20
83466		38		109.3	99.6	9.7	89.90	89.90	89.90	89.90	89.90
83452		43		111.0	100.3	10.7	89.60	89.60	89.60	89.60	89.60
83549		10		111.5	100.4	11.1	89.30	89.30	89.30	89.30	89.30
83475		24		102.5	93.9	8.6	85.30	85.30	85.30	85.30	85.30
83521		46		108.7	96.9	11.8	85.10	85.10	85.10	85.10	85.10
83270		55		106.4	95.6	10.8	84.80	84.80	84.80	84.80	84.80
83580		11		110.2	97.1	13.1	84.00	84.00	84.00	84.00	84.00
83244	3-6-93	13		107.2	95.4	11.8	83.60	83.60	83.60	83.60	83.60
83546		40		101.2	92.0	9.2	82.80	82.80	82.80	82.80	82.80
83540		36		103.7	92.9	10.8	82.10	10.00	10.00	10.00	10.00
83358		56		108.1	95.0	13.1	81.90	81.90	81.90	81.90	81.90
83381		54		109.2	95.4	13.8	81.60	81.60	81.60	81.60	81.60
83545		20		106.8	93.9	12.9	81.00	81.00	81.00	81.00	81.00
83308	3-6-93	53		107.6	94.2	13.4	80.80	80.80	80.80	80.80	80.80
83333		15		111.7	96.2	15.5	80.70	80.70	80.70	80.70	80.70
83290		4		103.0	91.8	11.2	80.60	80.60	80.60	80.60	80.60
83536		25		101.6	91.0	10.6	80.40	80.40	80.40	80.40	80.40
83491		28		104.6	92.3	12.3	80.00	80.00	80.00	80.00	80.00
83360		7		109.2	93.8	15.4	78.40	78.40	78.40	78.40	78.40
83543	3-9-93	17		104.8	90.9	13.9	77.00	77.00	77.00	77.00	77.00
83574	3-9-93	57		108.3	92.3	16.0	76.30	76.30	76.30	76.30	76.30
83459		26		106.1	91.0	15.1	75.90	75.90	75.90	75.90	75.90
83553	3-9-93	37		110.5	92.4	18.1	74.30	74.30	74.30	74.30	74.30
83517		60		105.7	89.9	15.8	74.10	74.10	74.10	74.10	74.10
83518		58		102.6	88.1	14.5	73.60	73.60	73.60	73.60	73.60
83579	3-6-93	39		105.7	88.8	16.9	71.90	71.90	71.90	71.90	71.90
83575		16		102.2	86.3	15.9	70.40	70.40	70.40	70.40	70.40
83571		44		105.2	87.7	17.5	70.20	70.20	70.20	70.20	70.20
83495	3-6-93	29		103.7	86.4	17.3	69.10	69.10	69.10	69.10	69.10
83529		23		102.6	85.5	17.1	68.40	68.40	68.40	68.40	68.40
83445		47		106.3	87.0	19.3	67.70	67.70	67.70	67.70	67.70
83385		52		107.2	85.0	22.2	62.80	62.80	62.80	62.80	62.80
83377		5		104.9	83.6	21.3	62.30	94.67	86.67	80.47	50.00
83322		51		104.3	81.2	23.1	58.10	95.06	87.06	80.86	50.00
83465		34		103.9	80.5	23.4	57.10	95.06	87.06	80.86	50.00
83343		3		106.8	81.2	25.6	55.60	96.38	88.38	82.18	50.00
83531		32		102.1	78.7	23.4	55.30	94.83	86.83	80.63	50.00
83526		2		108.1	81.4	26.7	54.70	97.18	89.18	82.98	50.00
83516		14		105.2	78.9	26.3	52.60	96.08	88.08	81.88	50.00
83346		8		105.0	78.8	26.2	52.60	95.70	87.7	81.50	50.00
83539		35		104.7	75.7	29.0	46.70	95.96	87.96	81.76	50.00
83292	3-6-93	33		101.8	71.0	30.8	40.20	96.83	88.83	82.63	50.00
83525	3-9-93	22		102.3	70.3	32.0	38.30	97.68	89.68	83.48	50.00
	AVERAGE:		0.00	107.22	93.02	14.20	78.82	85.65	84.18	83.04	77.22

ATTACHMENT

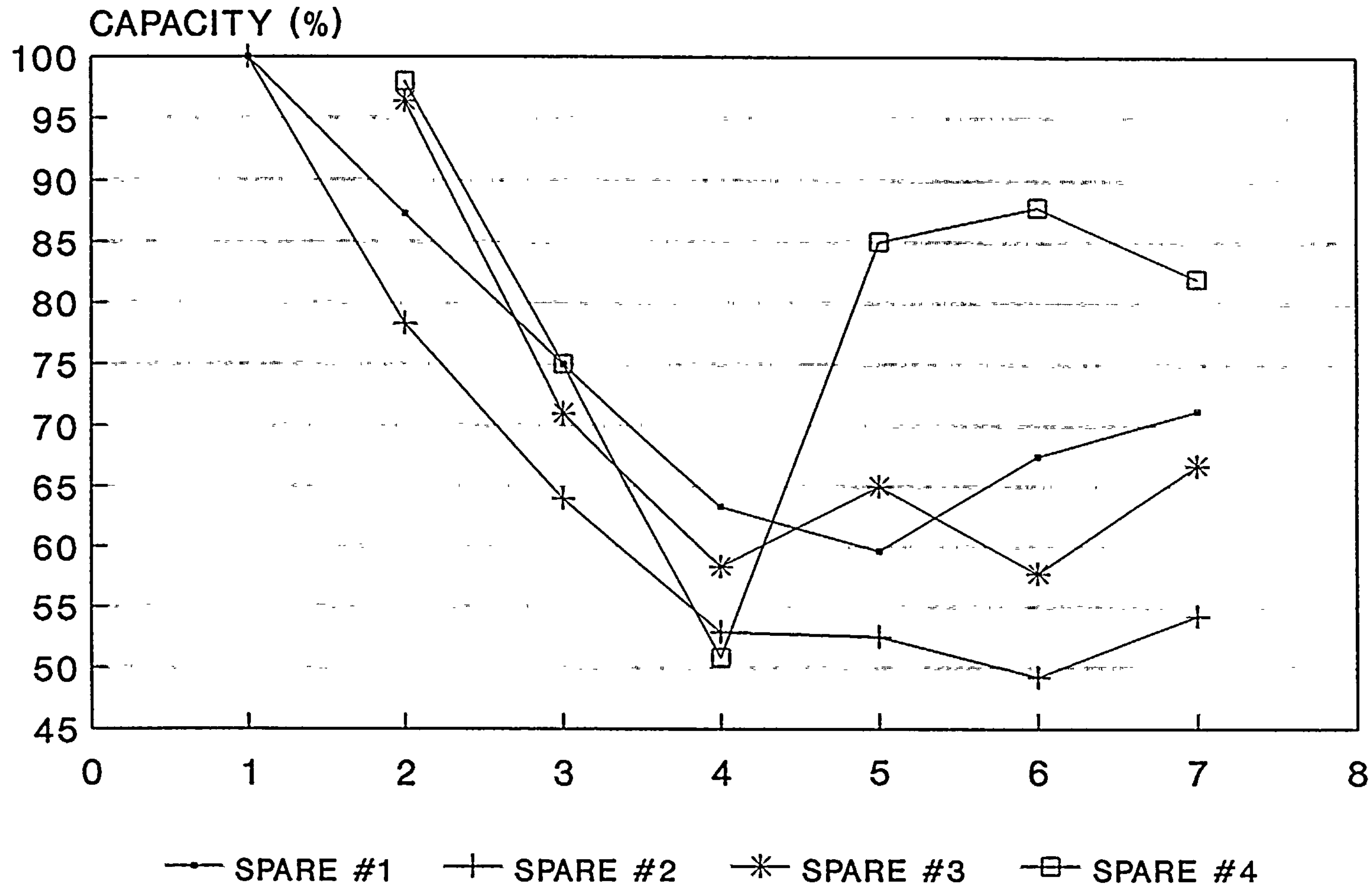
INDIVIDUAL CELL CAPACITIES FOR BATTERY 2C

S/N	STRING	CELL		FACTORY	DELTA	09/94	DELTA	PROJECTED-1	PROJECTED-2	PROJECTED-3	PROJECTED-4	PROJECTED-5
83484	3-6-93-37	9		111.5		110.3	1.2	109.10	109.10	109.10	109.10	109.10
83590	3-9-93-63	58		110.5		107.8	2.7	105.10	105.10	105.10	105.10	105.10
83541	3-6-93-24	8		112.9		108.4	4.5	103.90	103.90	103.90	103.90	103.90
83469	3-9-93-65	35		110.2		106.3	3.9	102.40	102.40	102.40	102.40	102.40
83567	3-6-93-20	3		115.0		107.7	7.3	100.40	100.40	100.40	100.40	100.40
83474	3-6-93-3	21		107.6		103.7	3.9	99.80	99.80	99.80	99.80	99.80
83477	3-9-93-64	59		112.7		106.0	6.7	99.30	99.30	99.30	99.30	99.30
83577	3-9-93-28	31		110.5		103.1	7.4	95.70	95.70	95.70	95.70	95.70
83523	3-9-93-12	43		110.5		102.7	7.8	94.90	94.90	94.90	94.90	94.90
83486	3-9-93-8	41		108.8		101.5	7.3	94.20	94.20	94.20	94.20	94.20
83448	3-9-93-59	17		110.5		102.3	8.2	94.10	94.10	94.10	94.10	94.10
83473	3-6-93-10	39		108.6		100.9	7.7	93.20	93.20	93.20	93.20	93.20
83505	3-6-93-41	7		111.7		102.2	9.5	92.70	92.70	92.70	92.70	92.70
83386	3-6-93-48	24		105.7		98.4	7.3	91.10	91.10	91.10	91.10	91.10
83512	3-9-93-56	36		103.2		96.6	6.6	90.00	90.00	90.00	90.00	90.00
83468	3-9-93-58	15		109.3		99.5	9.8	89.70	89.70	89.70	89.70	89.70
83348	3-6-93-13	53		103.7		95.6	8.1	87.50	87.50	87.50	87.50	87.50
83514	3-9-93-60	18		111.8		99.3	12.5	86.80	86.80	86.80	86.80	86.80
83542	3-6-93-44	1		110.1		98.2	11.9	86.30	86.30	86.30	86.30	86.30
83288	3-6-93-58	25		105.2		95.4	9.8	85.60	85.60	85.60	85.60	85.60
83520	3-6-93-11	38		109.2		97.2	12.0	85.20	85.20	85.20	85.20	85.20
83462	3-9-93-5	42		111.3		98.0	13.3	84.70	84.70	84.70	84.70	84.70
83329	3-6-93-67	40		108.9		96.8	12.1	84.70	84.70	84.70	84.70	84.70
83344	3-6-93-53	37		103.6		94.1	9.5	84.60	84.60	84.60	84.60	84.60
83547	3-9-93-1	16		107.8		96.0	11.8	84.20	84.20	84.20	84.20	84.20
83487	3-6-93-16	10		109.6		96.6	13.0	83.60	83.60	83.60	83.60	83.60
83532	3-6-93-42	6		106.6		94.8	11.8	83.00	83.00	83.00	83.00	83.00
83554	3-6-93-38	49		109.1		94.7	14.4	80.30	80.30	80.30	80.30	80.30
83378	3-6-93-28	46		107.6		93.7	13.9	79.80	79.80	79.80	79.80	79.80
83566	3-9-93-21	45		105.7		92.4	13.3	79.10	79.10	79.10	79.10	79.10
83303	3-9-93-15	60		103.8		90.8	13.0	77.80	77.80	77.80	77.80	77.80
83470	3-6-93-61	56		108.2		92.9	15.3	77.60	77.60	77.60	77.60	77.60
83259	3-6-93-40	4		108.7		93.1	15.6	77.50	77.50	77.50	77.50	77.50
83564	3-6-93-2	19		107.6		92.3	15.3	77.00	77.00	77.00	77.00	77.00
83460	3-6-93-4	22		106.6		90.7	15.9	74.80	74.80	74.80	74.80	74.80
83370	3-6-93-22	50		106.6		90.4	16.2	74.20	74.20	74.20	74.20	74.20
83457	3-9-93-23	28		108.3		90.7	17.6	73.10	73.10	73.10	73.10	73.10
83281	3-9-93-29	30		104.3		88.4	15.9	72.50	72.50	72.50	72.50	72.50
83306	3-6-93-39	52		105.6		88.6	17.0	71.60	71.60	71.60	71.60	71.60
83394	3-6-93-1	20		111.7		89.9	21.8	68.10	68.10	68.10	68.10	68.10
83356	3-6-93-47	23		103.7		85.8	17.9	67.90	67.90	67.90	67.90	67.90
83335	3-6-93-17	2		108.6		88.1	20.5	67.60	67.60	67.60	67.60	67.60
83389	3-6-93-26	13		108.1		87.7	20.4	67.30	67.30	67.30	67.30	67.30
83395	3-6-93-35	54		101.7		83.9	17.8	66.10	66.10	66.10	66.10	66.10
83568	3-9-93-53	34		109.0		87.4	21.6	65.80	65.80	65.80	65.80	65.80
83585	3-9-93-54	33		104.8		84.9	19.9	65.00	65.00	65.00	65.00	65.00
83390	3-6-93-49	48		107.6		86.3	21.3	65.00	65.00	65.00	65.00	65.00
83515	3-9-93-22	26		105.7		85.1	20.6	64.50	64.50	64.50	64.50	64.50
83357	3-6-93-23	51		108.1		85.3	22.8	62.50	94.18	86.18	78.70	50.00
83301	3-6-93-21	5		106.0		83.3	22.7	60.60	94.18	86.18	78.70	50.00
83307	3-9-93-24	27		103.8		81.8	22.0	59.80	94.68	86.68	79.20	50.00
83351	3-9-93-31	29		104.8		82.1	22.7	59.40	95.53	87.53	80.05	50.00
83498	3-6-93-57	14		110.2		82.5	27.7	54.80	95.44	87.44	79.96	50.00
83287	3-6-93-50	47		103.6		78.7	24.9	53.80	95.44	87.44	79.96	50.00
83582	3-9-93-7	44		109.0		80.8	28.2	52.60	98.01	90.01	82.53	50.00
83293	3-6-93-36	55		104.5		77.6	26.9	50.70	97.51	89.51	82.03	50.00
83282	3-9-93-30	32		105.8		77.2	28.6	48.60	94.28	86.28	78.80	50.00
83376	3-6-93-25	11		107.1		75.5	31.6	43.90	94.67	86.67	79.19	50.00
83510	3-6-93-15	12		103.6		67.9	35.7	32.20	96.68	88.68	81.20	50.00
83443	3-9-93-16	57		105.2		62.9	42.3	20.60	95.06	87.06	79.58	50.00
AVERAGE:			0.00	107.70		92.21	15.48	76.73	85.83	84.23	82.74	76.74

ATTACHMENT

ATTACHMENT 4

CAPACITY VERSUS DISCHARGE

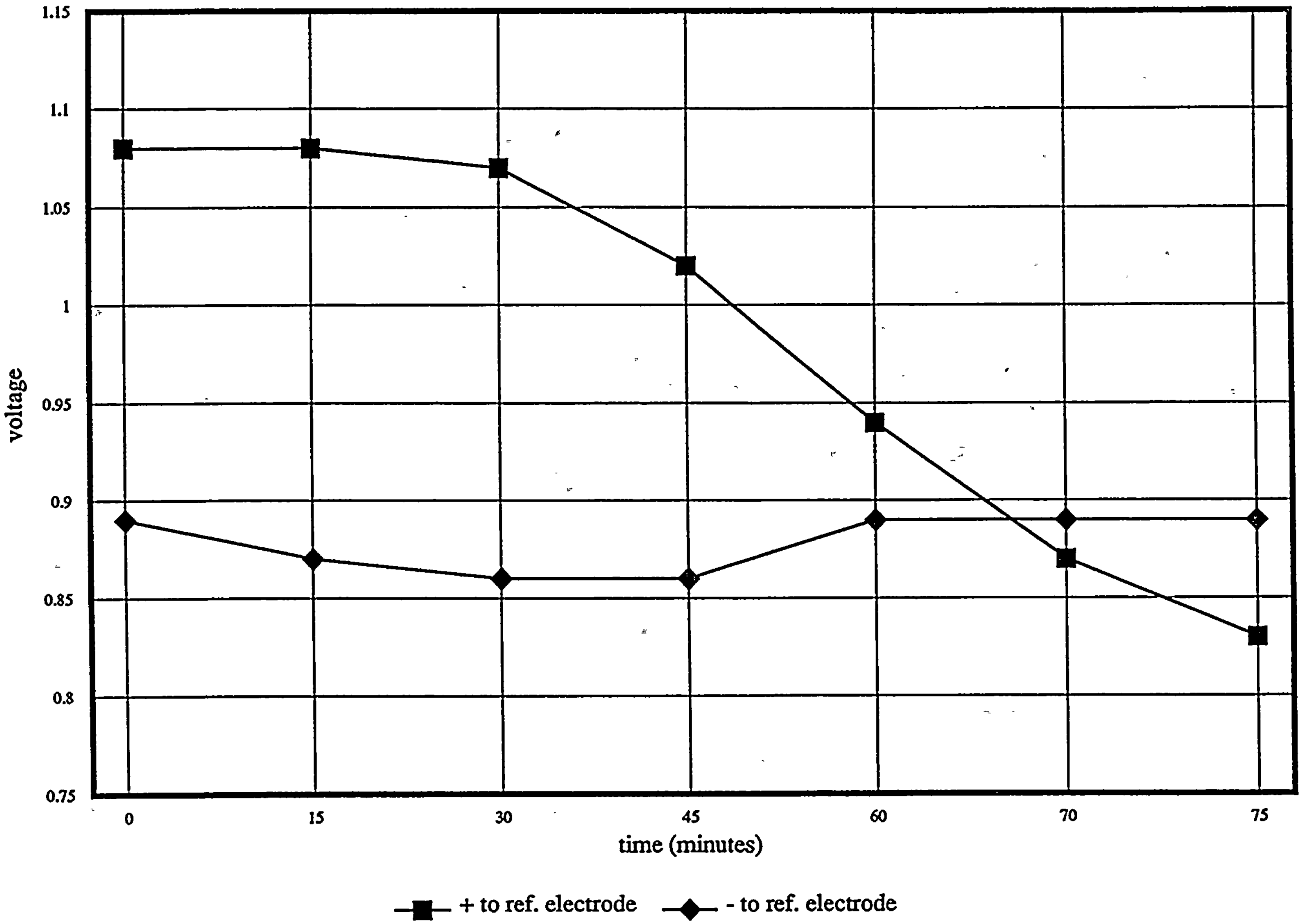


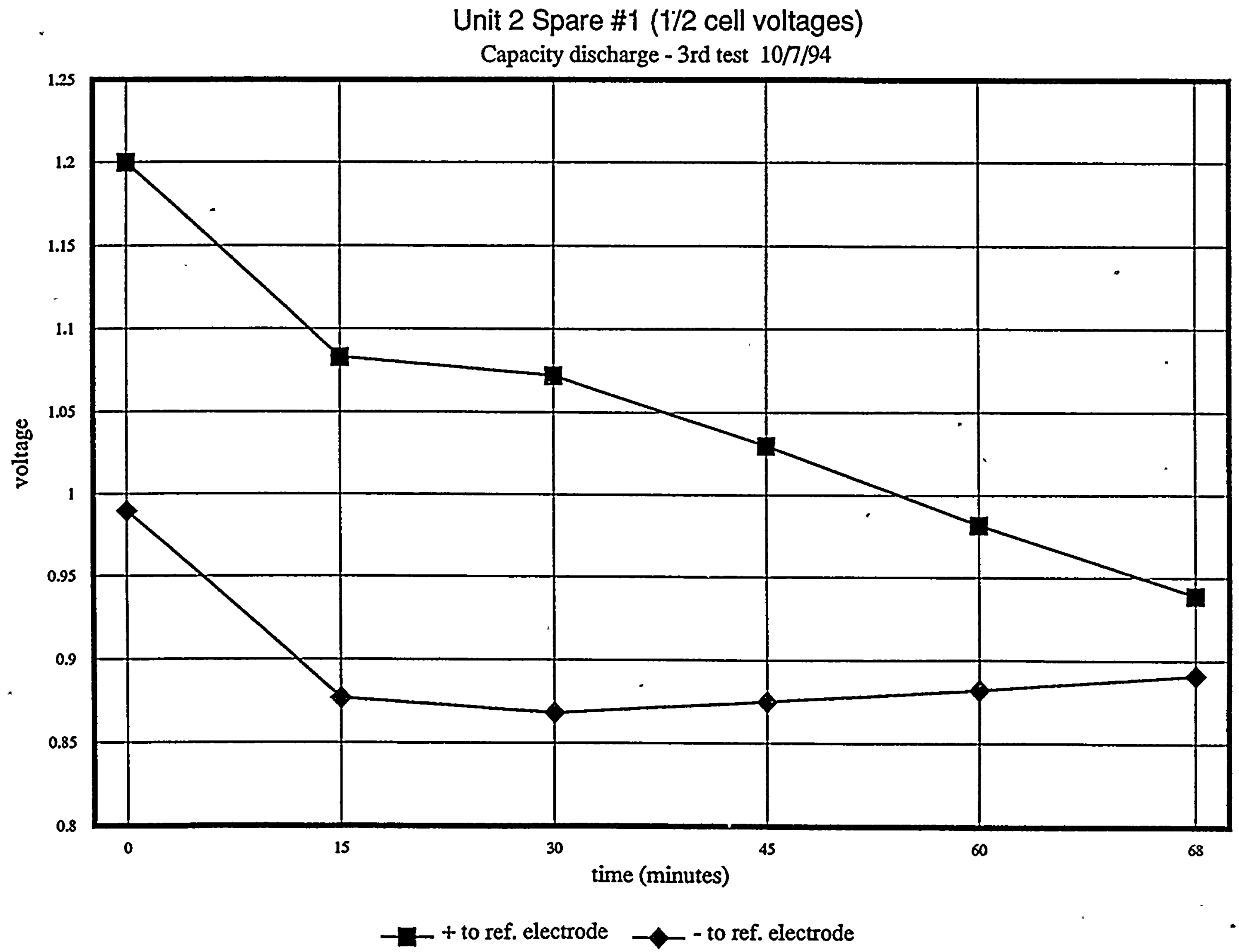
SP1 & 2 TESTED 3/15, 9/23, 9/29, 10/5-8
SP3 & 4 TESTED 9/23, 9/29, 10/5-8

ATTACHMENT 6

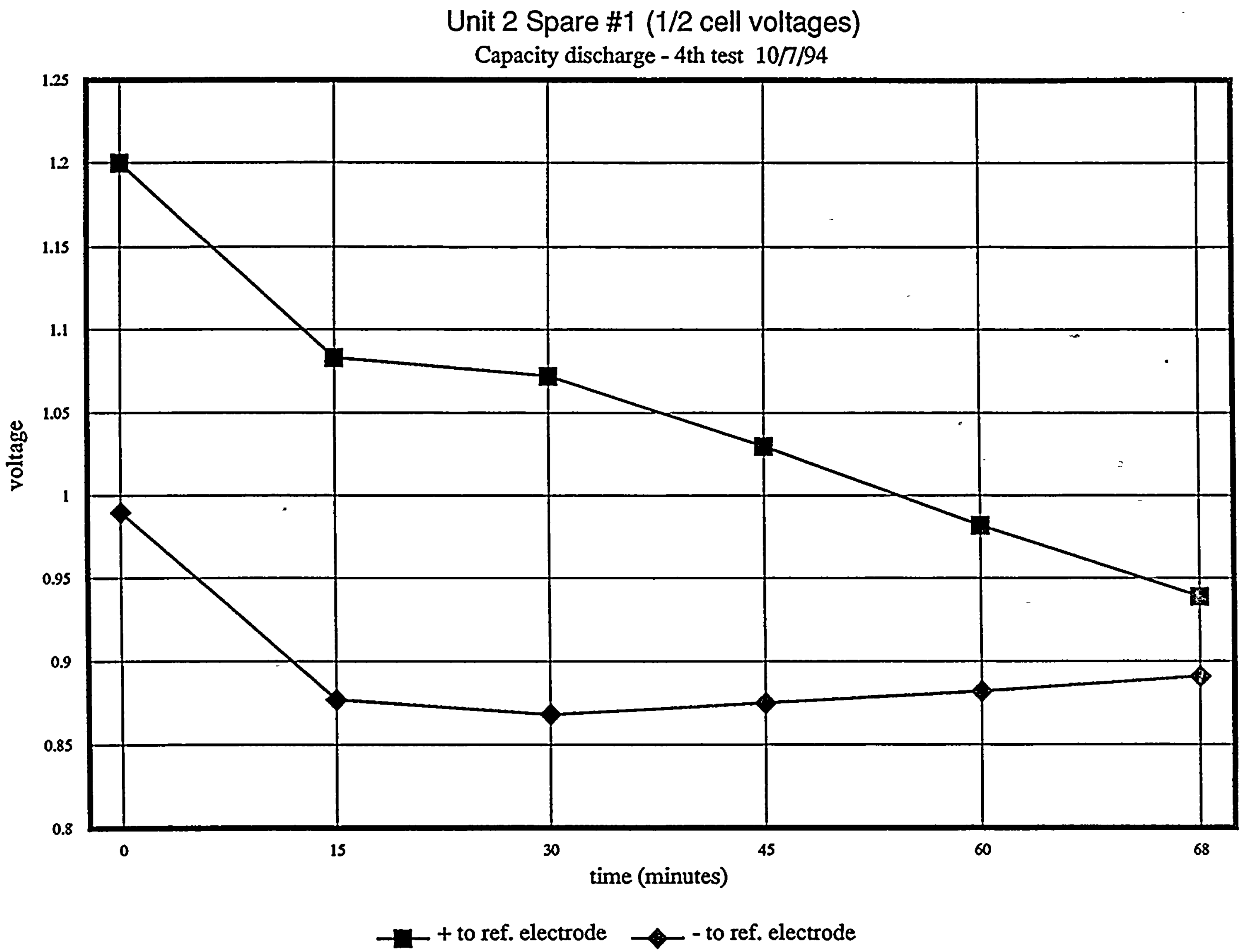
Unit 2 Spare #1 (1/2 cell voltages)

Capacity discharge - 2nd test 10/6/94

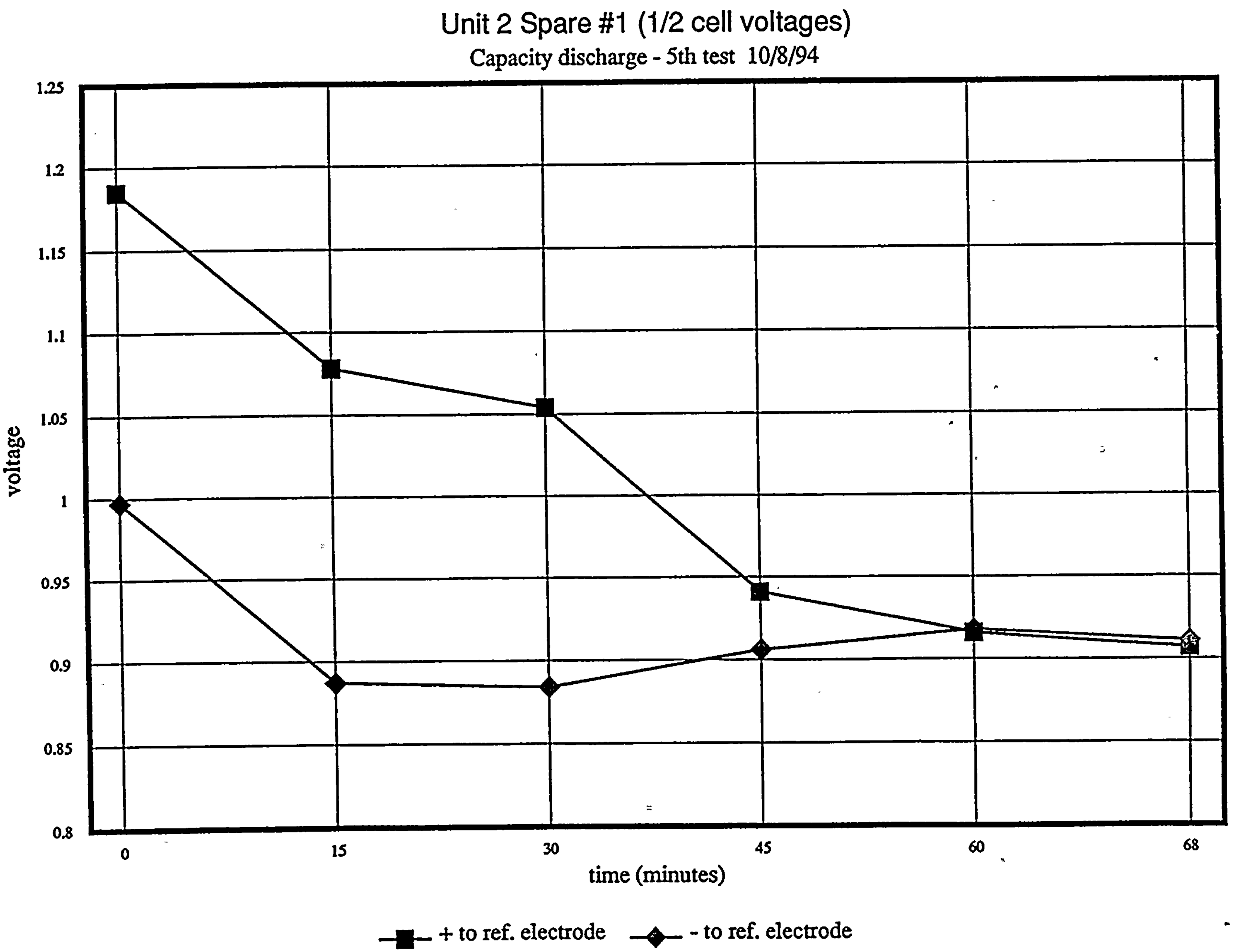


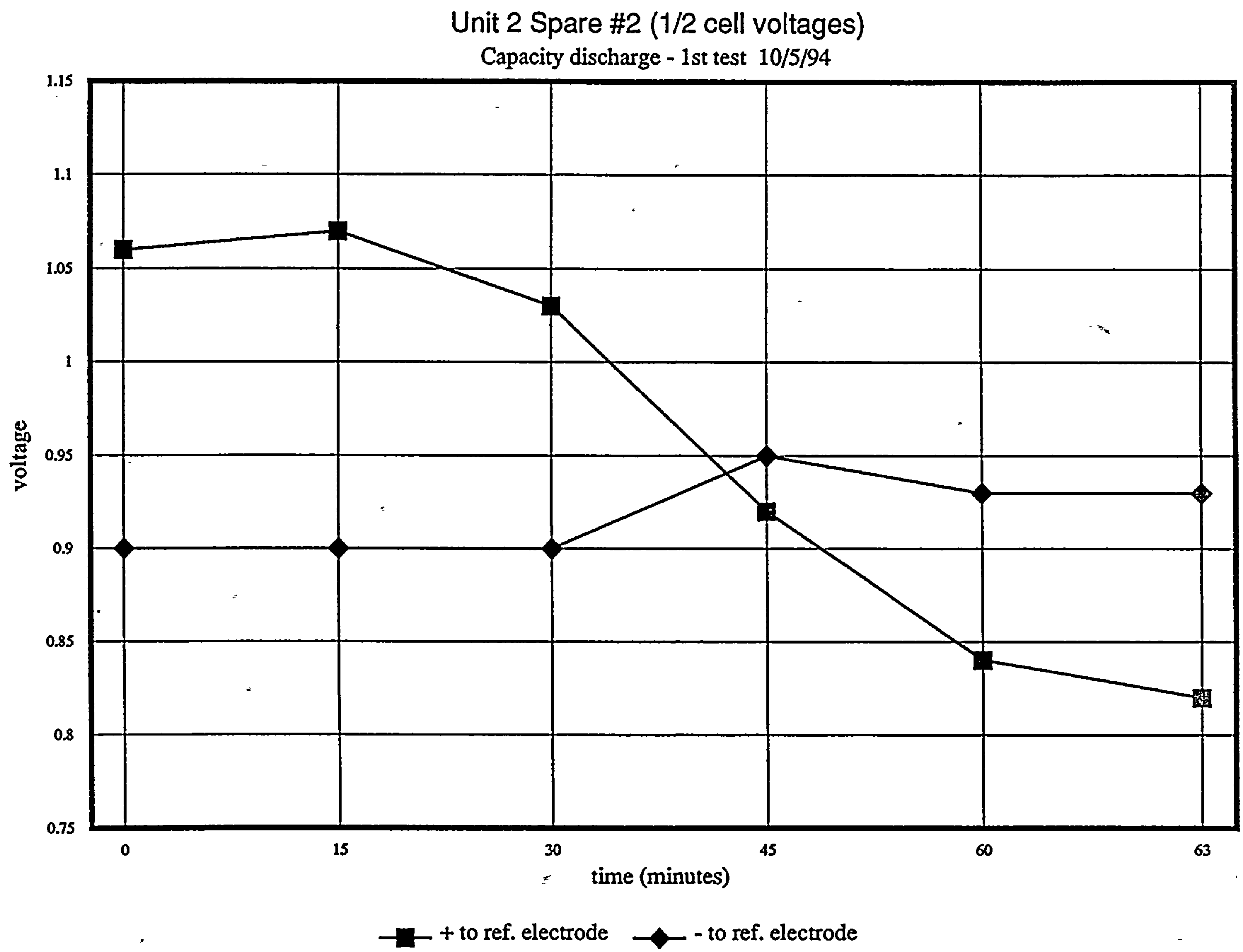


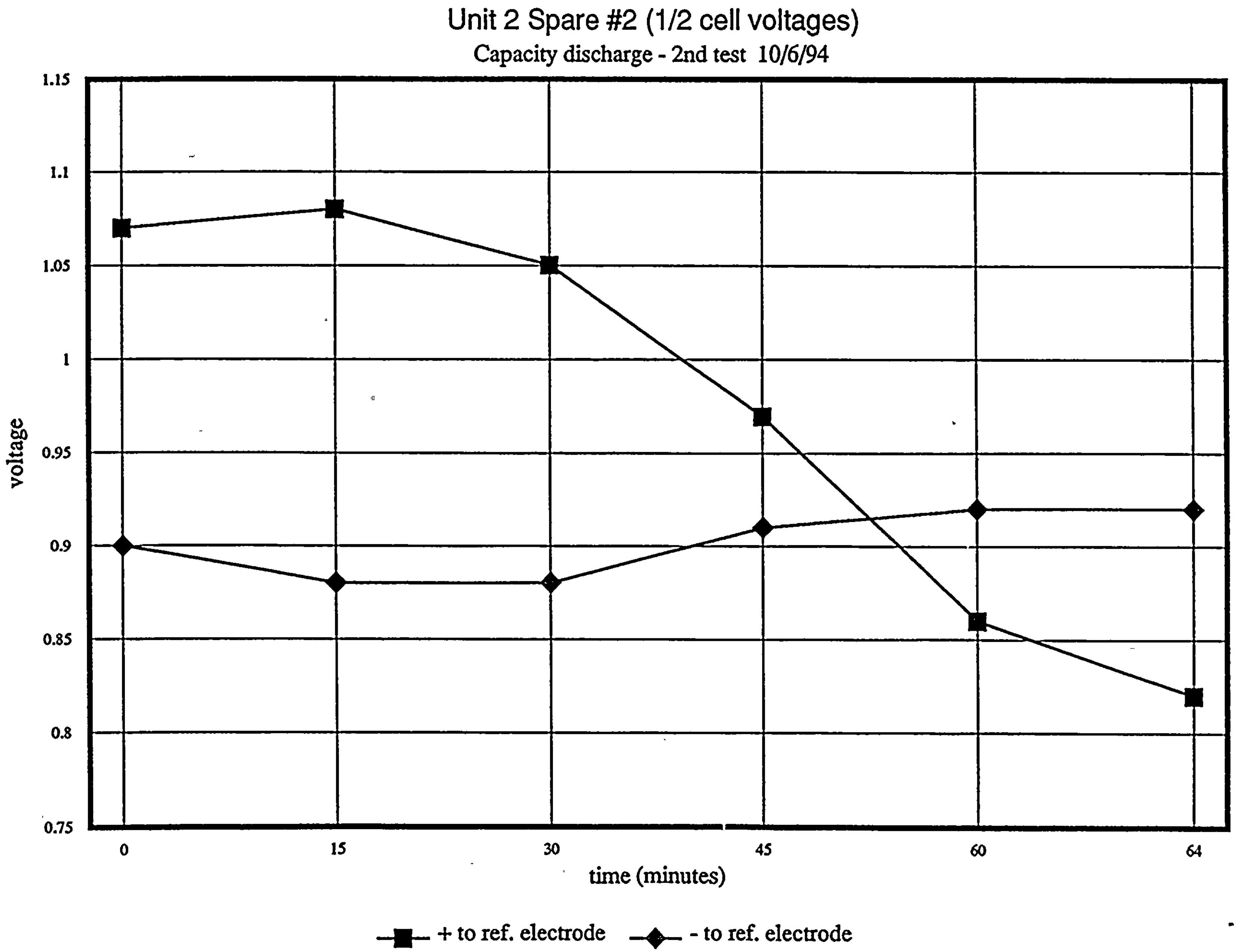
Unit 2 Spare #1 (1/2 cell voltages)
Capacity discharge - 3rd test 10/7/94
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
voltage
0
15
30
45
60
68
time (minutes)
+ to ref. electrode
- to ref. electrode



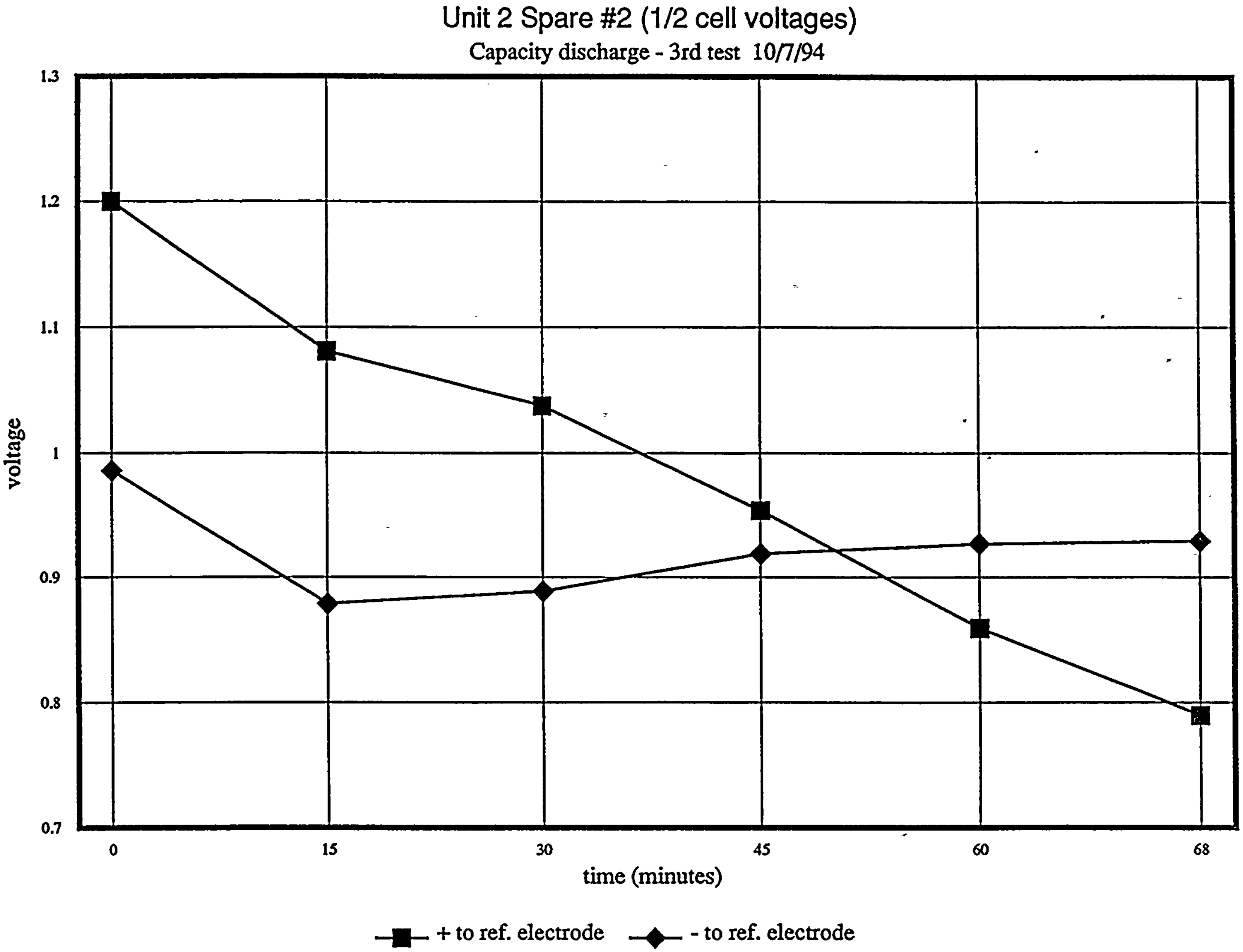
Unit 2 Spare #1 (1/2 cell voltages)
Capacity discharge - 4th test 10/7/94
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
voltage
0
15
30
45
60
68
time (minutes)
+ to ref. electrode
- to ref. electrode

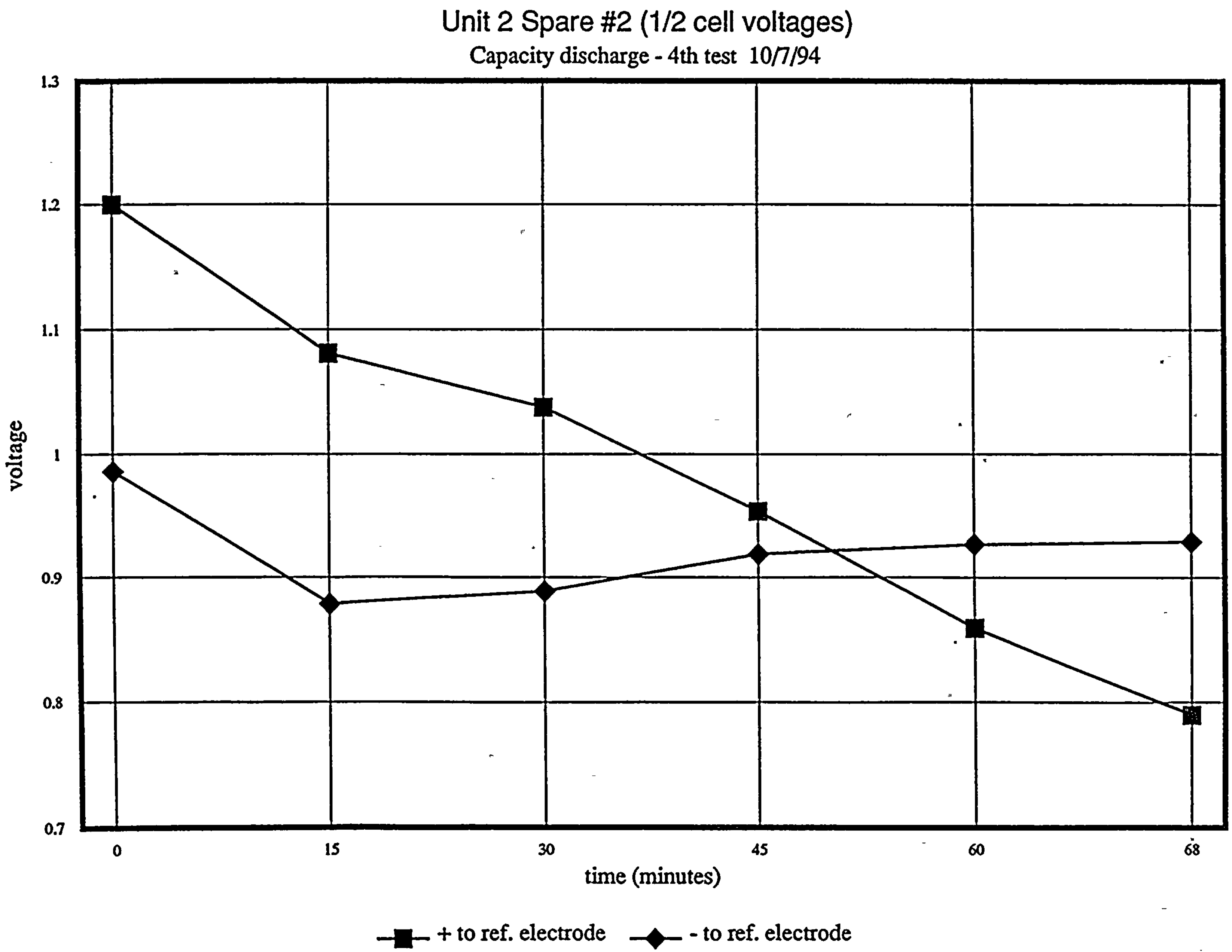

Unit 2 Spare #1 (1/2 cell voltages)
Capacity discharge - 5th test 10/8/94
voltage
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0
15
30
45
60
68
time (minutes)
+ to ref. electrode
- to ref. electrode


Unit 2 Spare #2 (1/2 cell voltages)
Capacity discharge - 1st test 10/5/94
voltage
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0
15
30
45
60
63
time (minutes)
+ to ref. electrode
- to ref. electrode

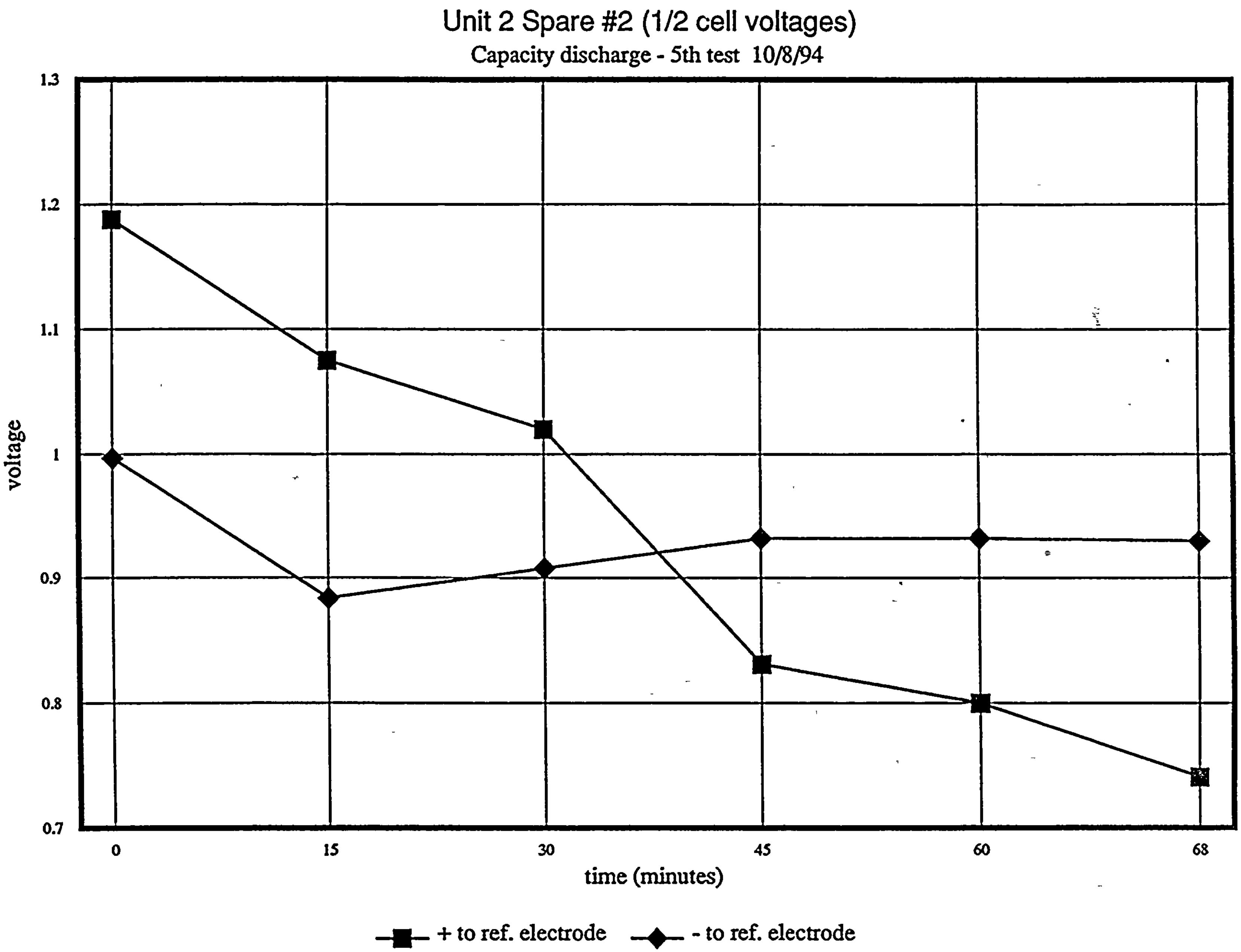


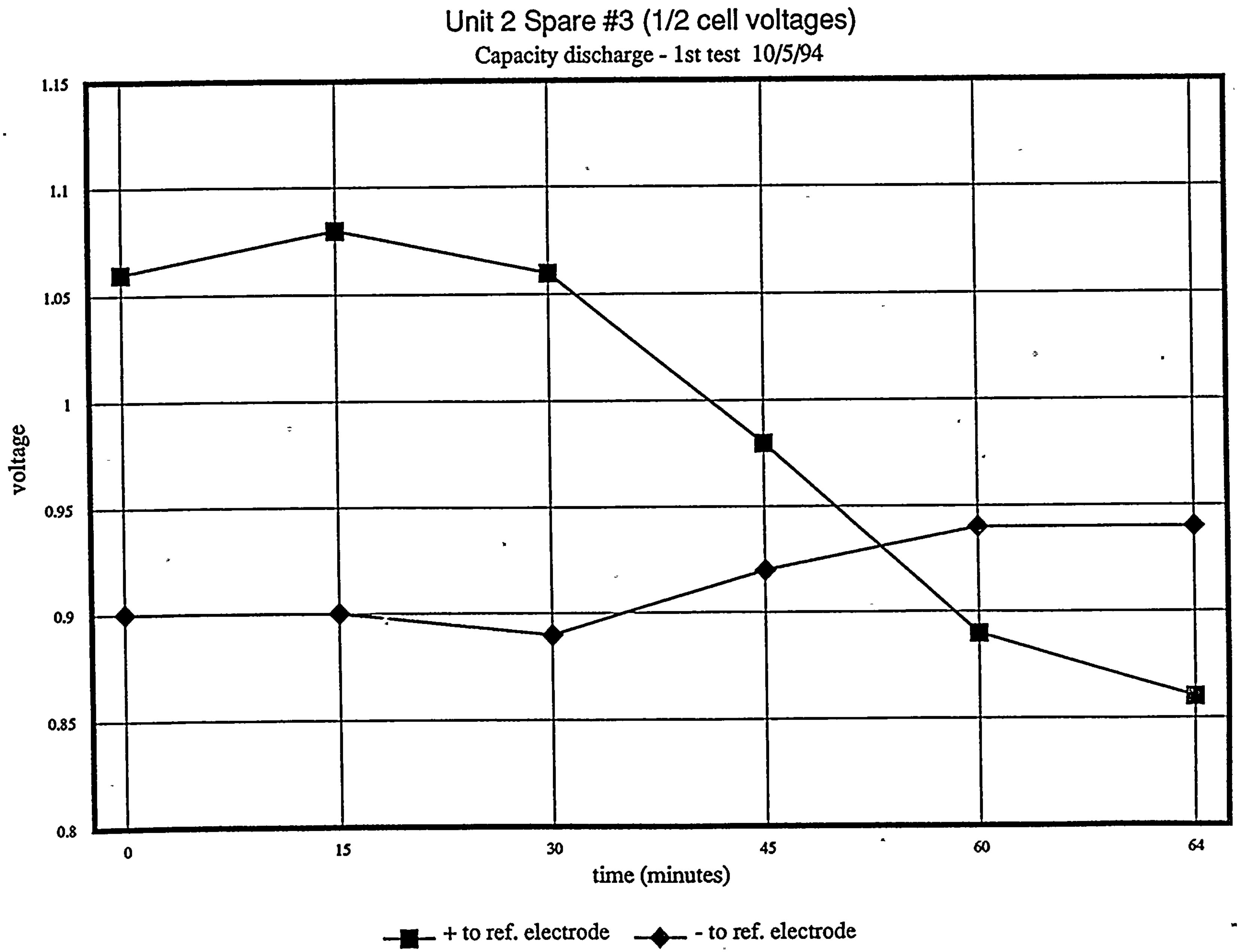
Unit 2 Spare #2 (1/2 cell voltages)
Capacity discharge - 2nd test 10/6/94
voltage
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0
15
30
45
60
64
time (minutes)
+ to ref. electrode
- to ref. electrode


Unit 2 Spare #2 (1/2 cell voltages)
Capacity discharge - 3rd test 10/7/94
1.3
1.2
1.1
1
0.9
0.8
0.7
voltage
0
15
30
45
60
68
time (minutes)
+ to ref. electrode
- to ref. electrode

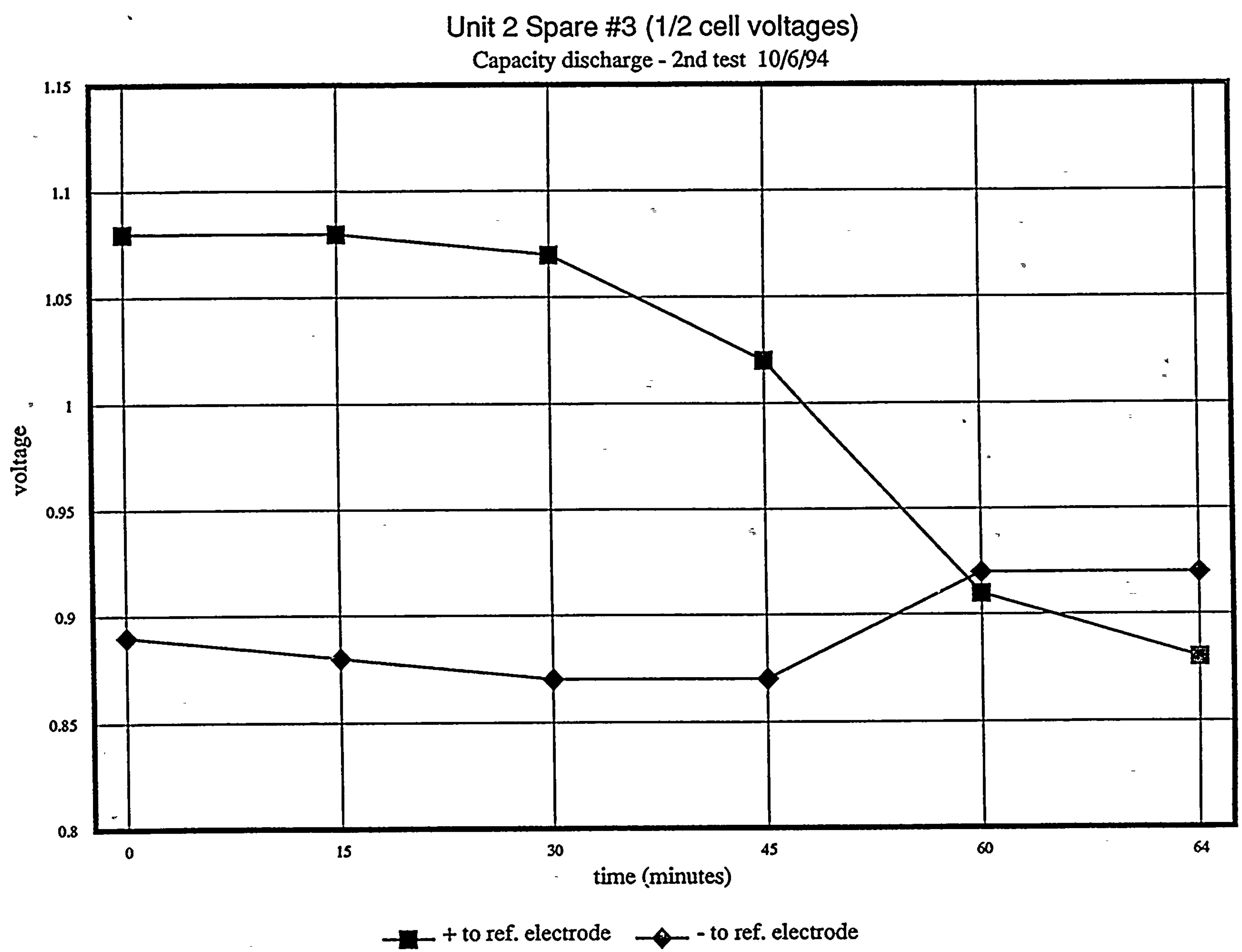


Unit 2 Spare #2 (1/2 cell voltages)
Capacity discharge - 4th test 10/7/94
1.3
1.2
1.1
1
0.9
0.8
0.7
voltage
0
15
30
45
60
68
time (minutes)
+ to ref. electrode
- to ref. electrode

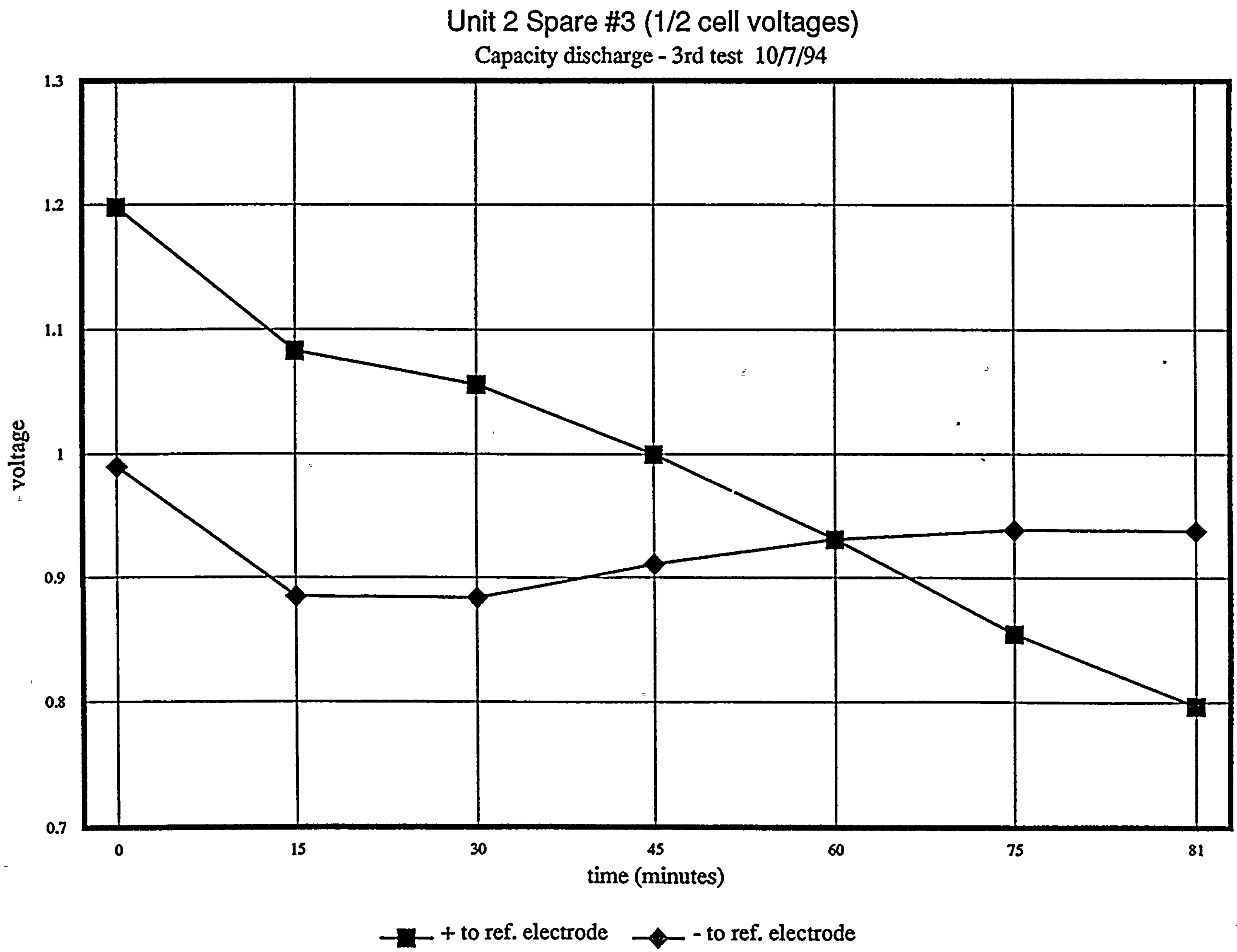

Unit 2 Spare #2 (1/2 cell voltages)
Capacity discharge - 5th test 10/8/94
1.3
1.2
1.1
1
0.9
0.8
0.7
voltage
0
15
30
45
60
68
time (minutes)
+ to ref. electrode
- to ref. electrode

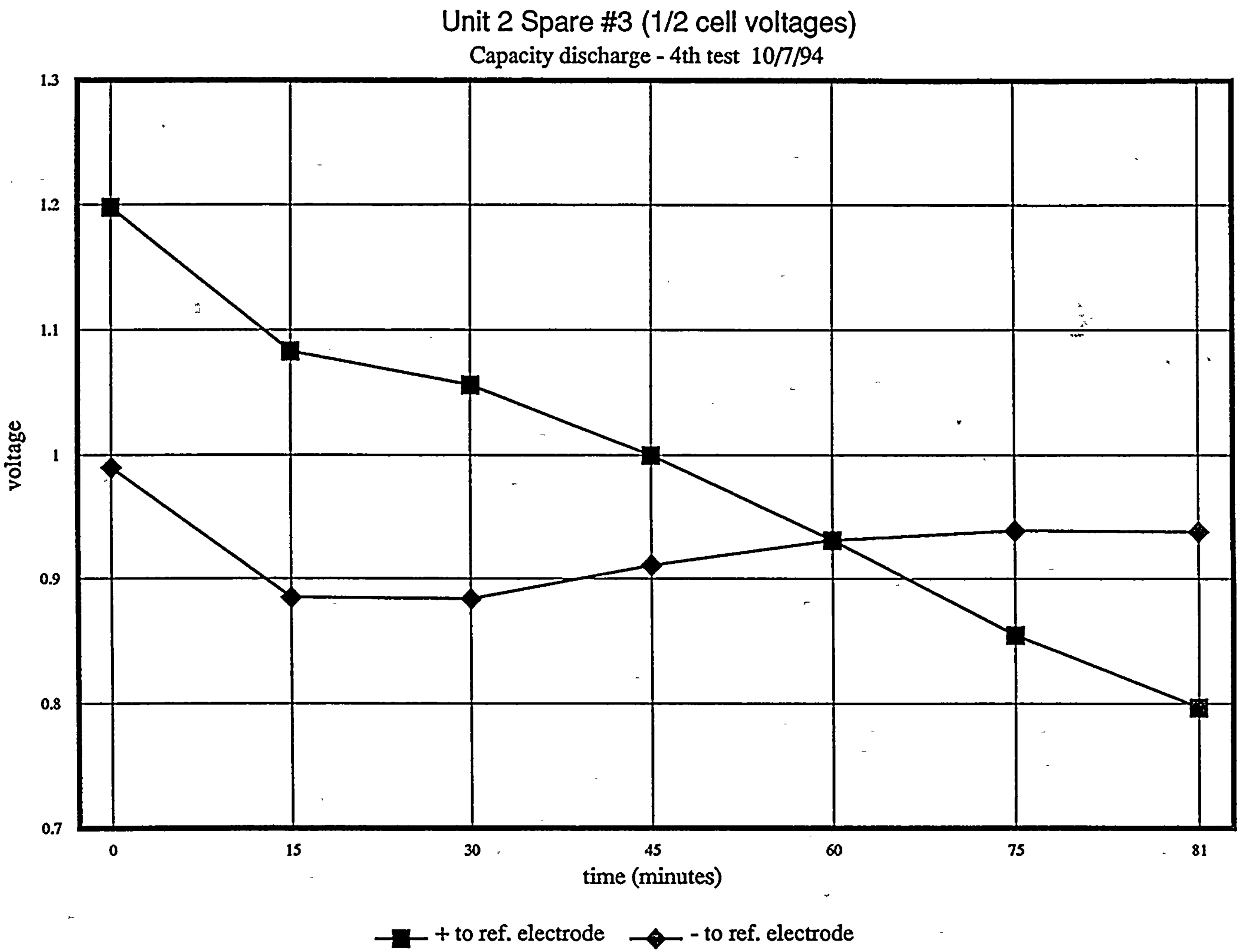


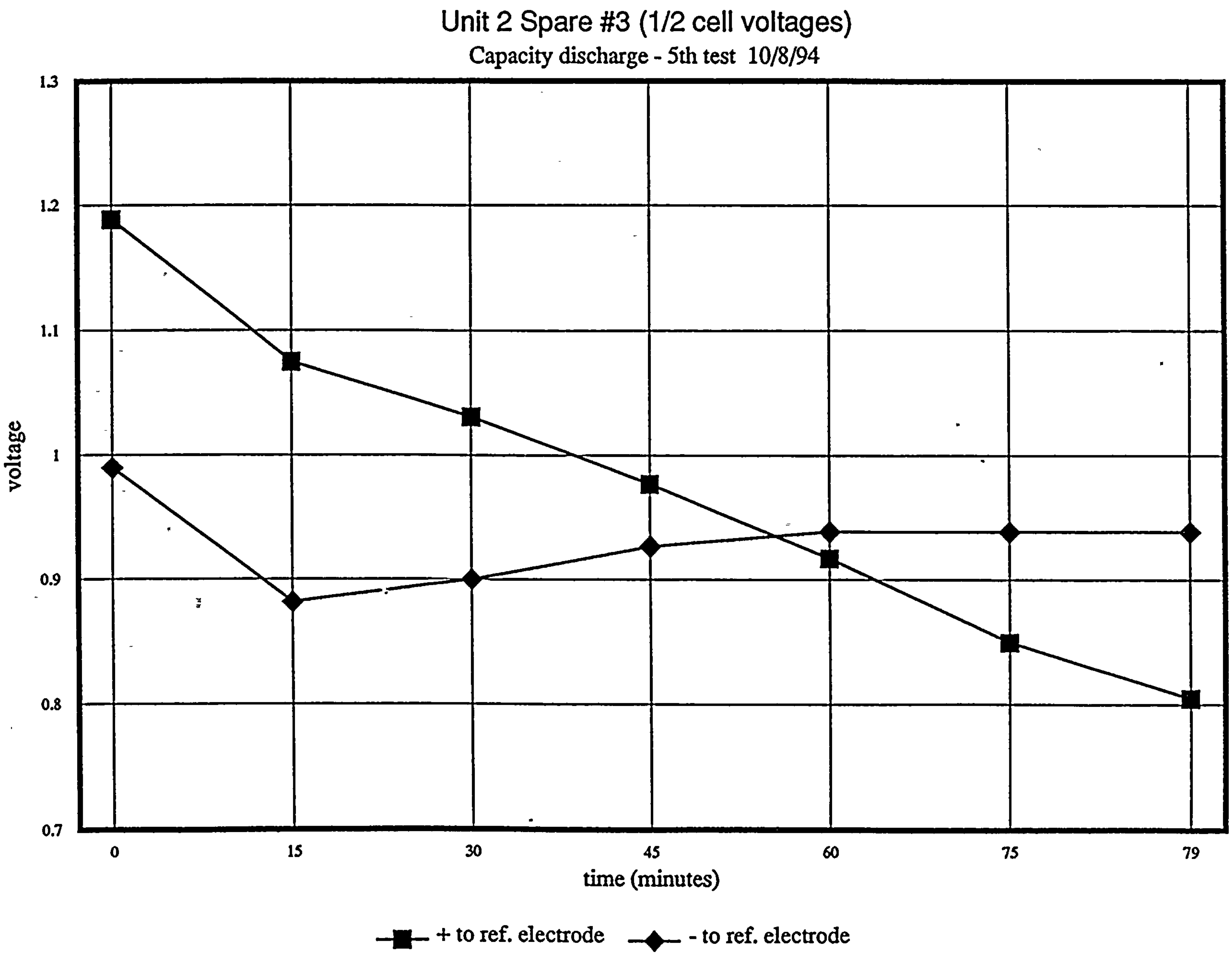
Unit 2 Spare #3 (1/2 cell voltages)
Capacity discharge - 1st test 10/5/94
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
voltage
0
15
30
45
60
64
time (minutes)
+ to ref. electrode
- to ref. electrode



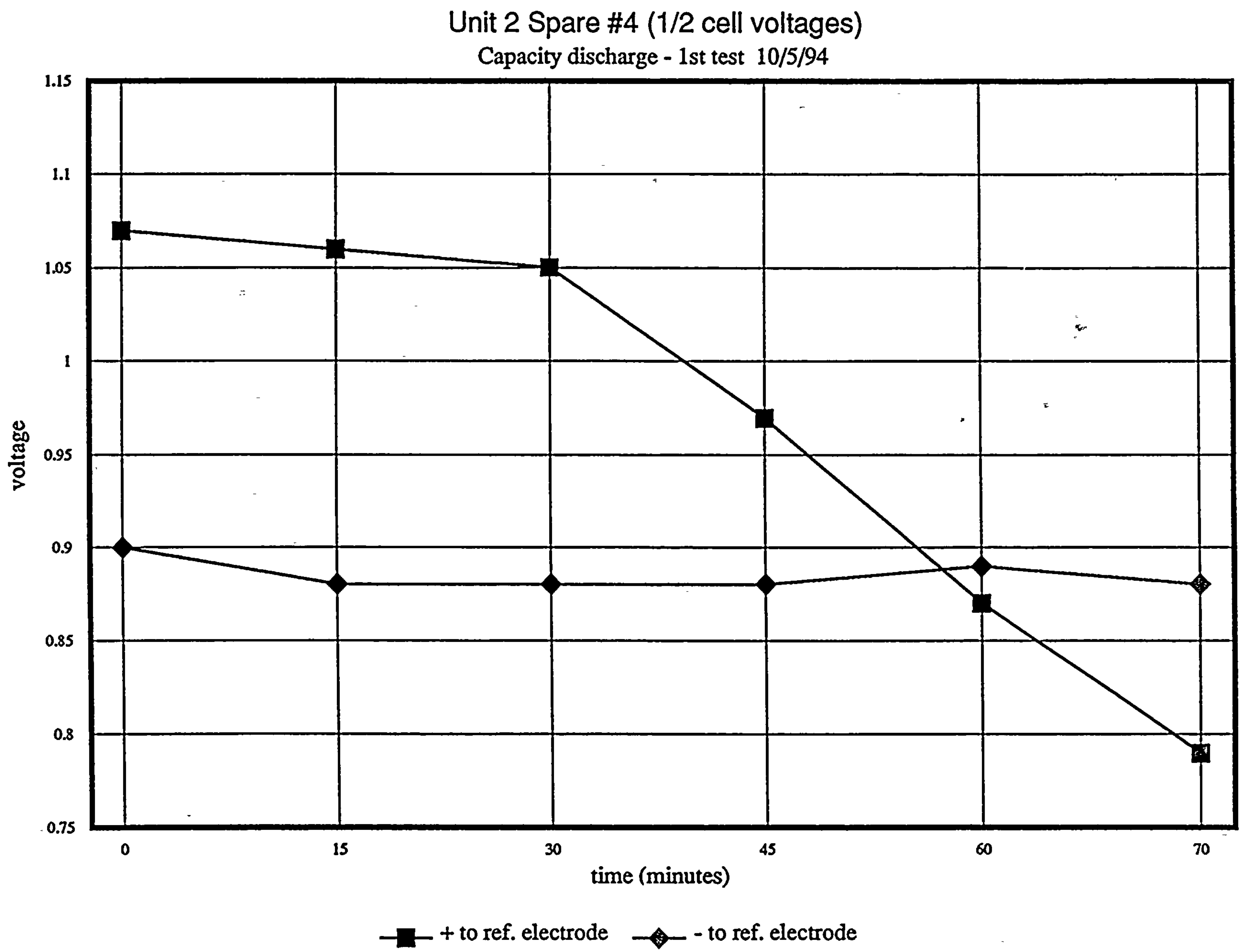
Unit 2 Spare #3 (1/2 cell voltages)
Capacity discharge - 2nd test 10/6/94
voltage
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0
15
30
45
60
64
time (minutes)
+ to ref. electrode
- to ref. electrode


Unit 2 Spare #3 (1/2 cell voltages)
Capacity discharge - 3rd test 10/7/94
voltage
1.3
1.2
1.1
1
0.9
0.8
0.7
0
15
30
45
60
75
81
time (minutes)
+ to ref. electrode
- to ref. electrode


Unit 2 Spare #3 (1/2 cell voltages)
Capacity discharge - 4th test 10/7/94
voltage
1.3
1.2
1.1
1
0.9
0.8
0.7
0
15
30
45
60
75
81
time (minutes)
+ to ref. electrode
- to ref. electrode

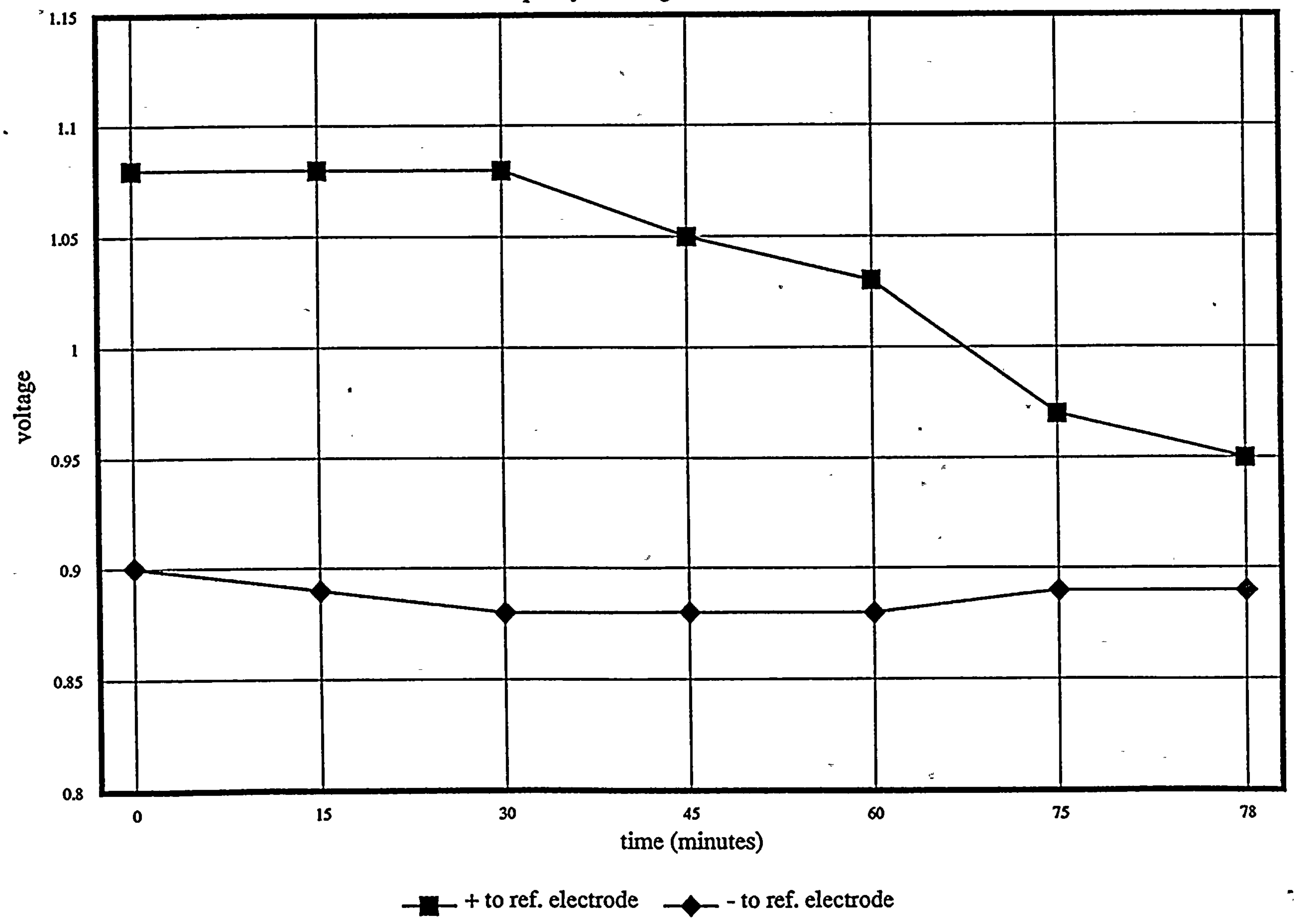


Unit 2 Spare #3 (1/2 cell voltages)
Capacity discharge - 5th test 10/8/94
voltage
1.3
1.2
1.1
1
0.9
0.8
0.7
0
15
30
45
60
75
79
time (minutes)
+ to ref. electrode
- to ref. electrode


Unit 2 Spare #4 (1/2 cell voltages)
Capacity discharge - 1st test 10/5/94
voltage
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0
15
30
45
60
70
time (minutes)
+ to ref. electrode
- to ref. electrode

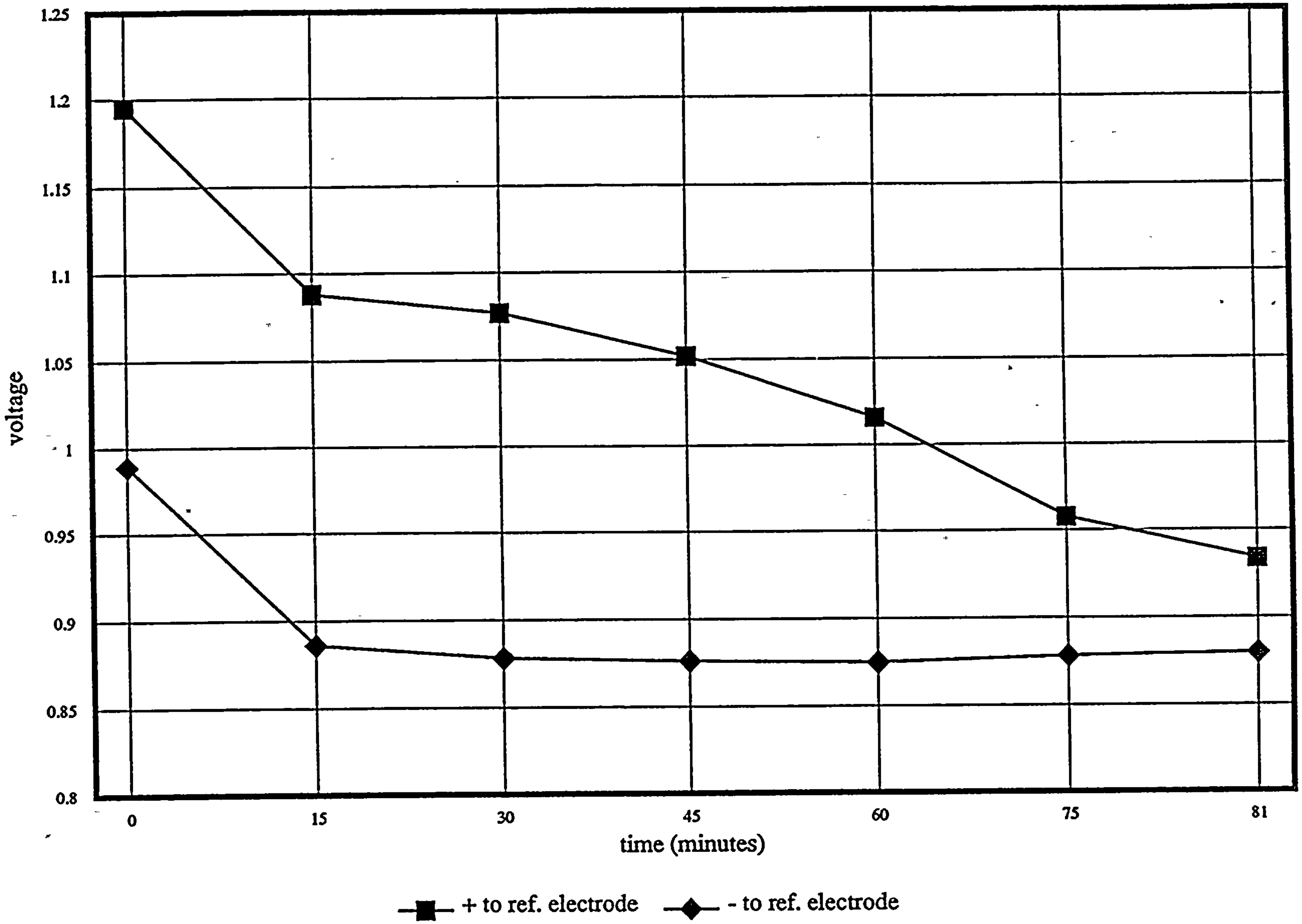
Unit 2 Spare #4 (1/2 cell voltages)

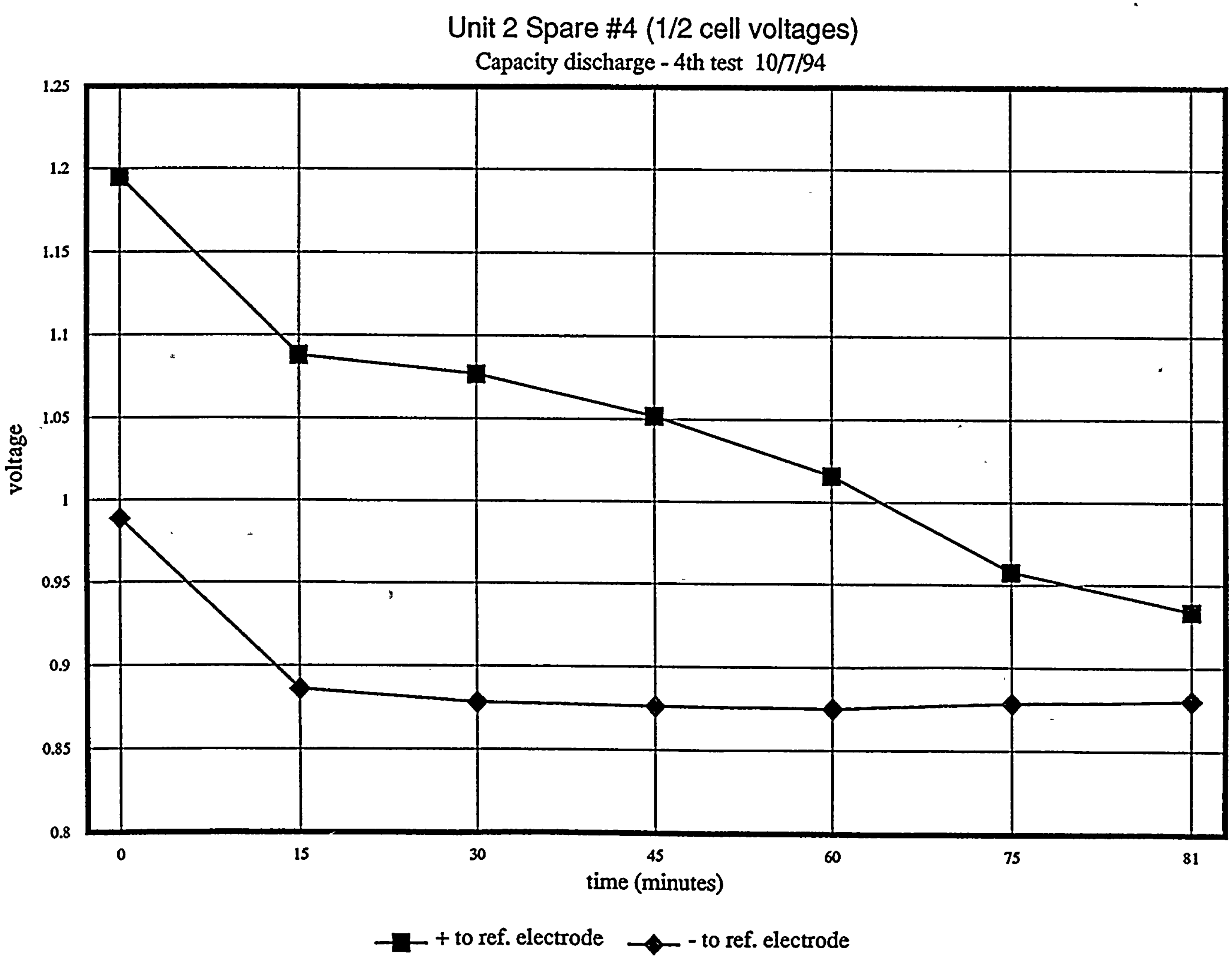
Capacity discharge - 2nd test 10/6/94



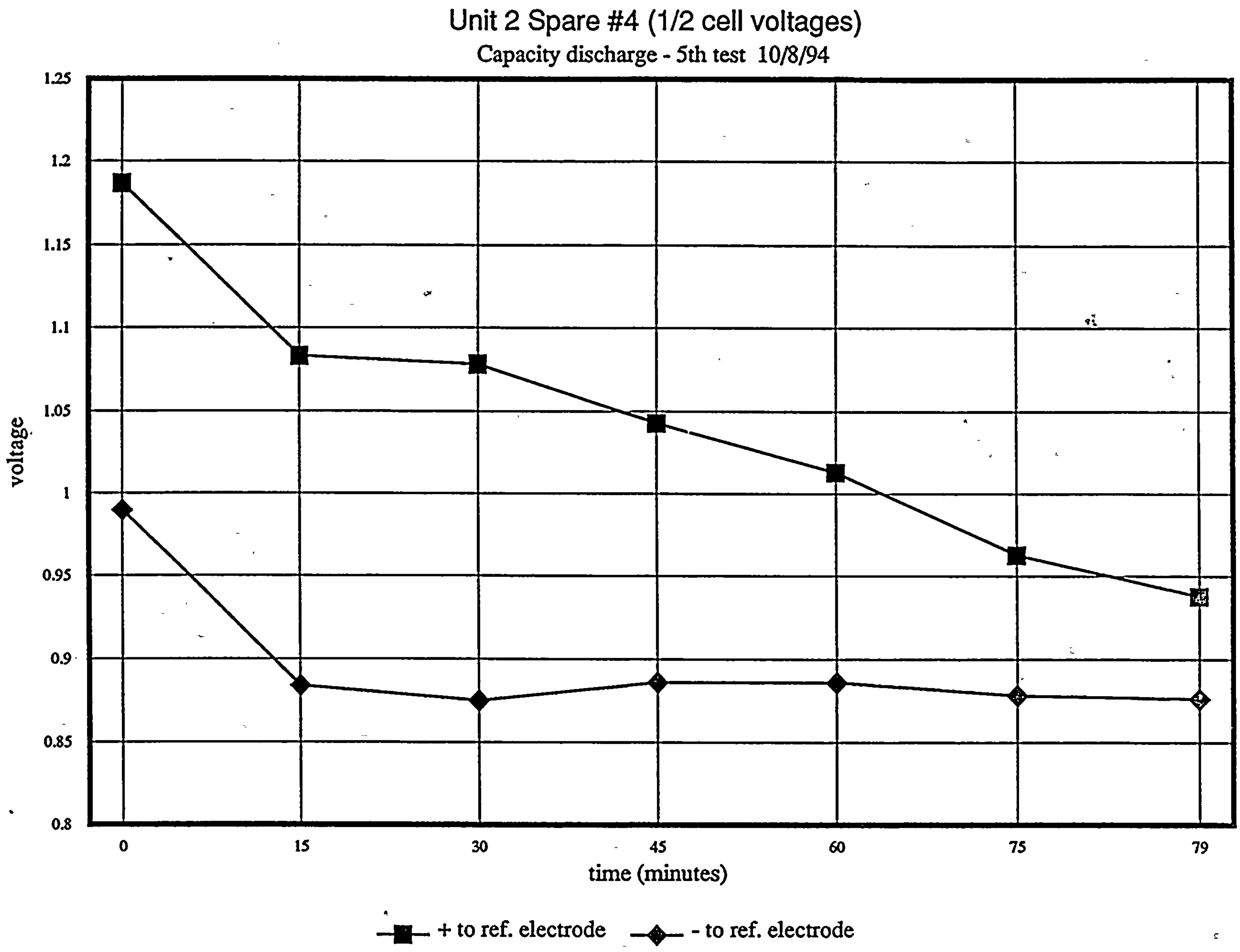
Unit 2 Spare #4 (1/2 cell voltages)

Capacity discharge - 3rd test 10/7/94



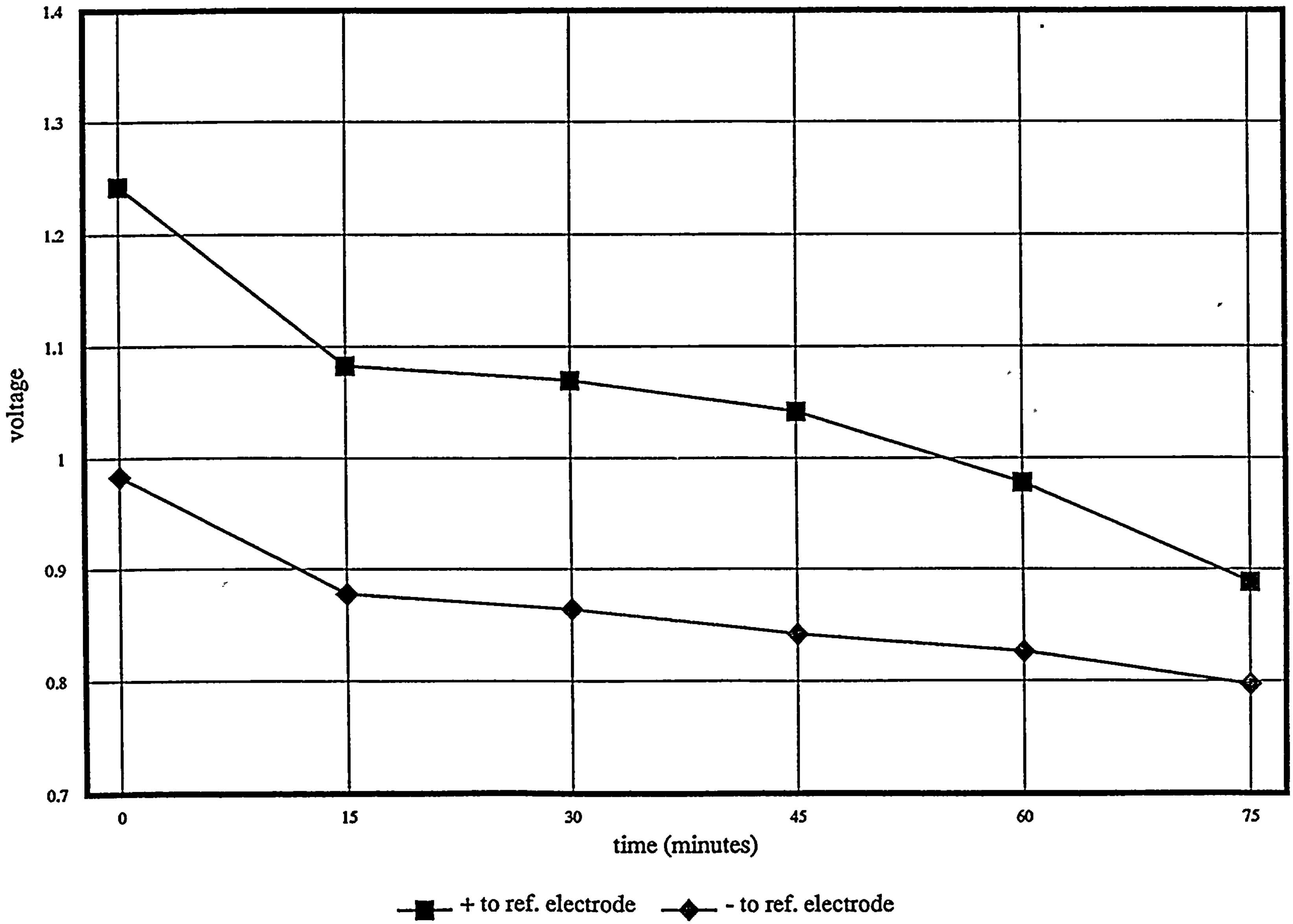


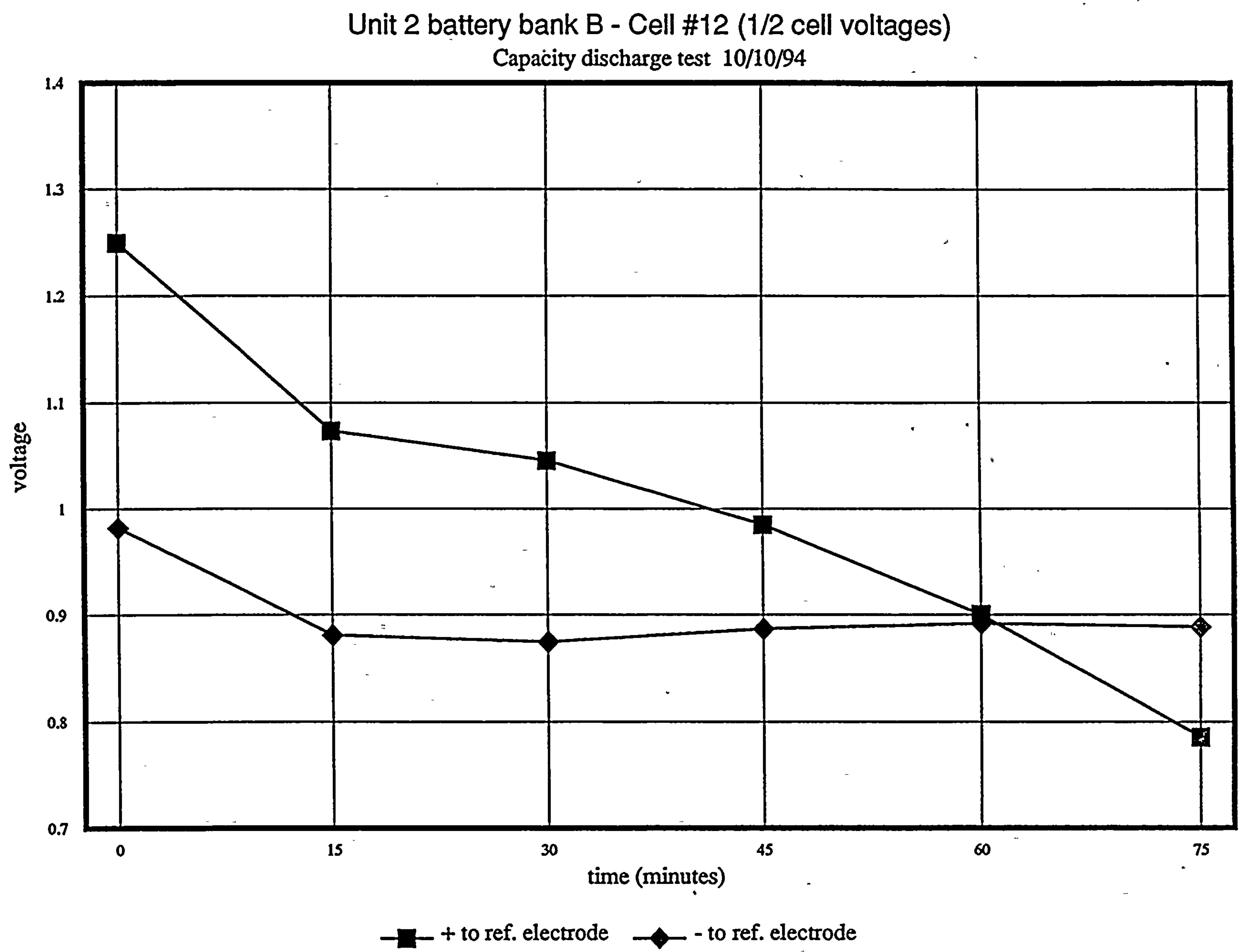
Unit 2 Spare #4 (1/2 cell voltages)
Capacity discharge - 4th test 10/7/94
voltage
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0
15
30
45
60
75
81
time (minutes)
+ to ref. electrode
- to ref. electrode

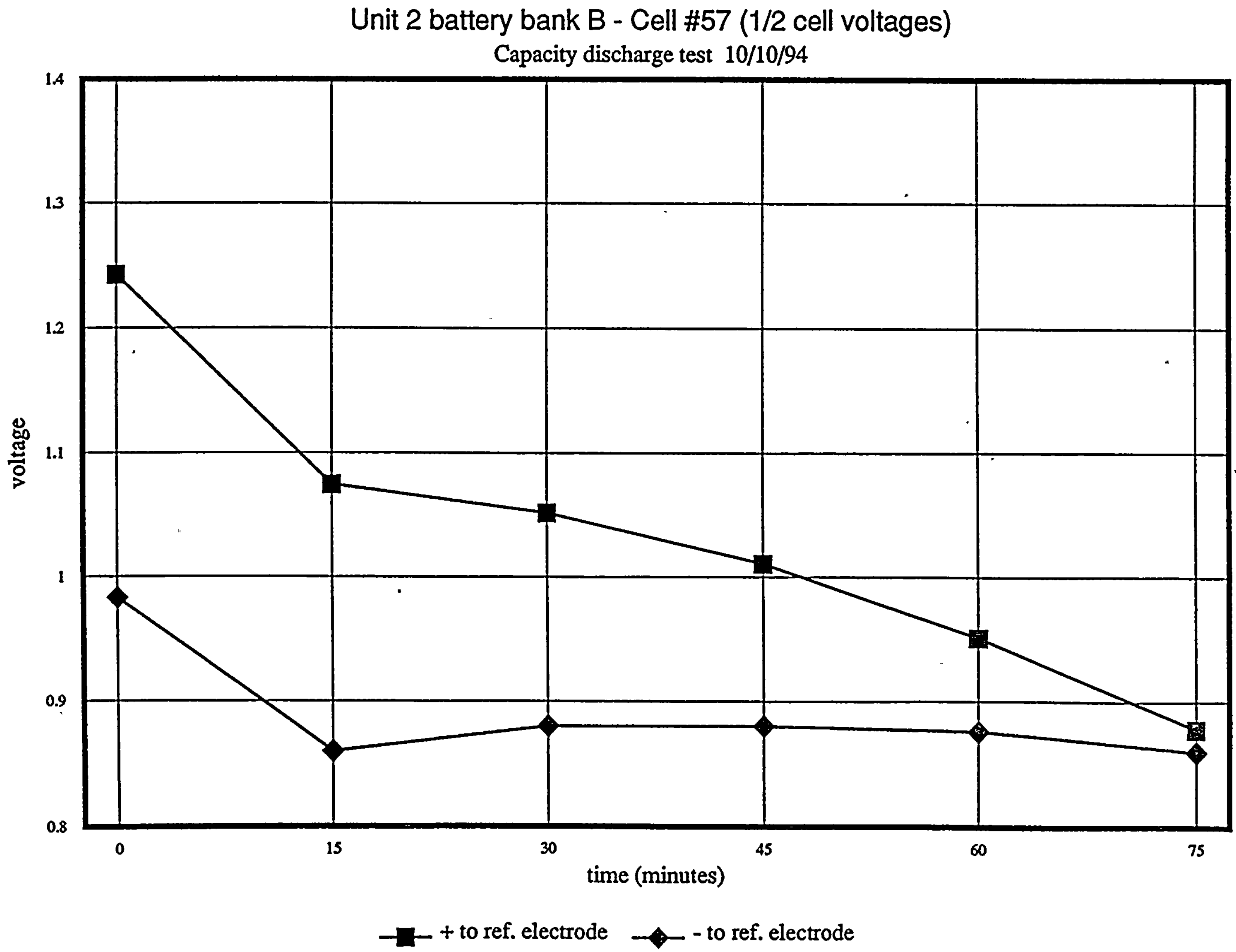

Unit 2 Spare #4 (1/2 cell voltages)
Capacity discharge - 5th test 10/8/94
voltage
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0
15
30
45
60
75
79
time (minutes)
+ to ref. electrode
- to ref. electrode

Unit 2 battery bank B - Cell #10 (1/2 cell voltages)

Capacity discharge test 10/10/94



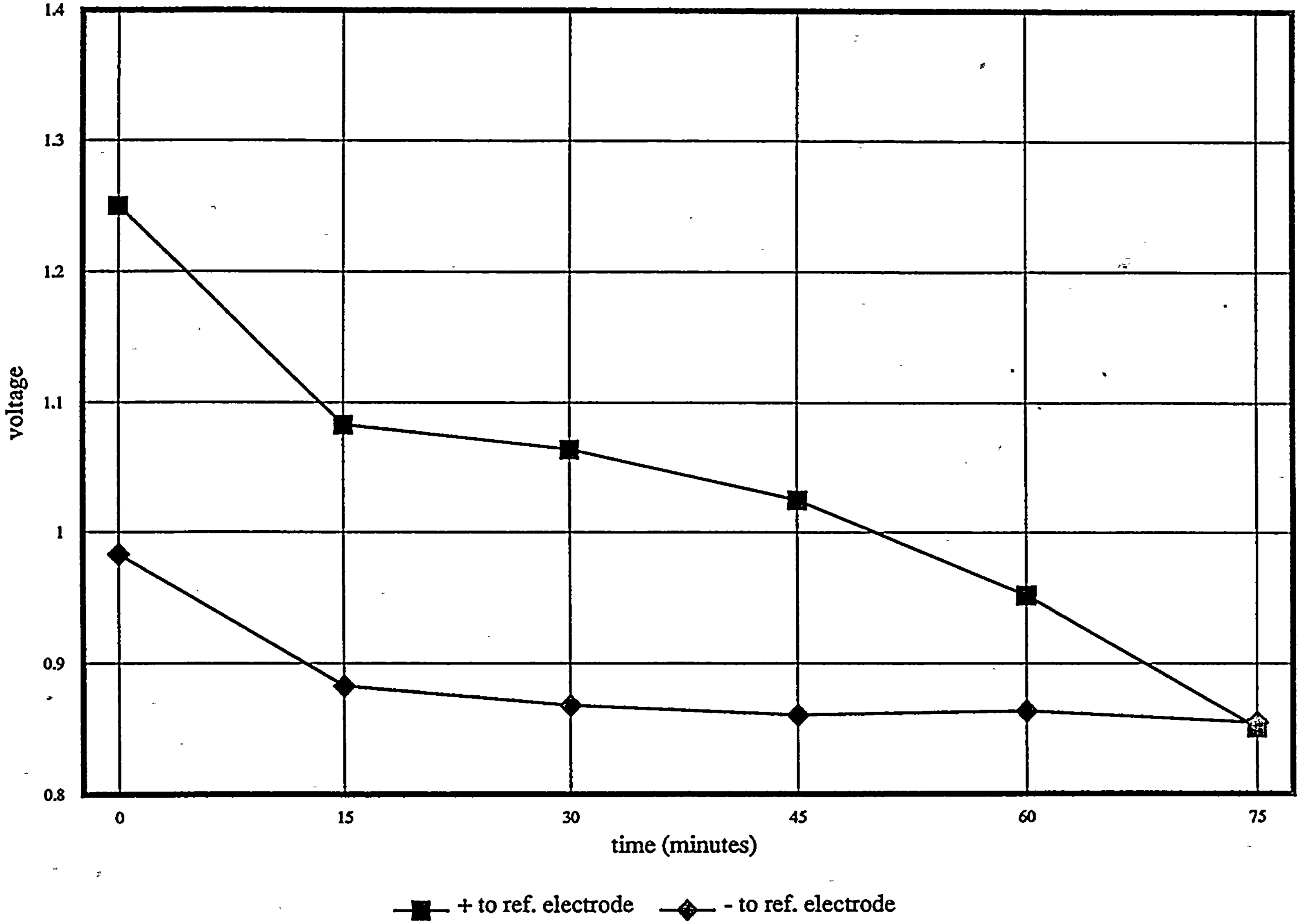

Unit 2 battery bank B - Cell #12 (1/2 cell voltages)
Capacity discharge test 10/10/94
voltage
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
15
30
45
60
75
time (minutes)
+ to ref. electrode
- to ref. electrode

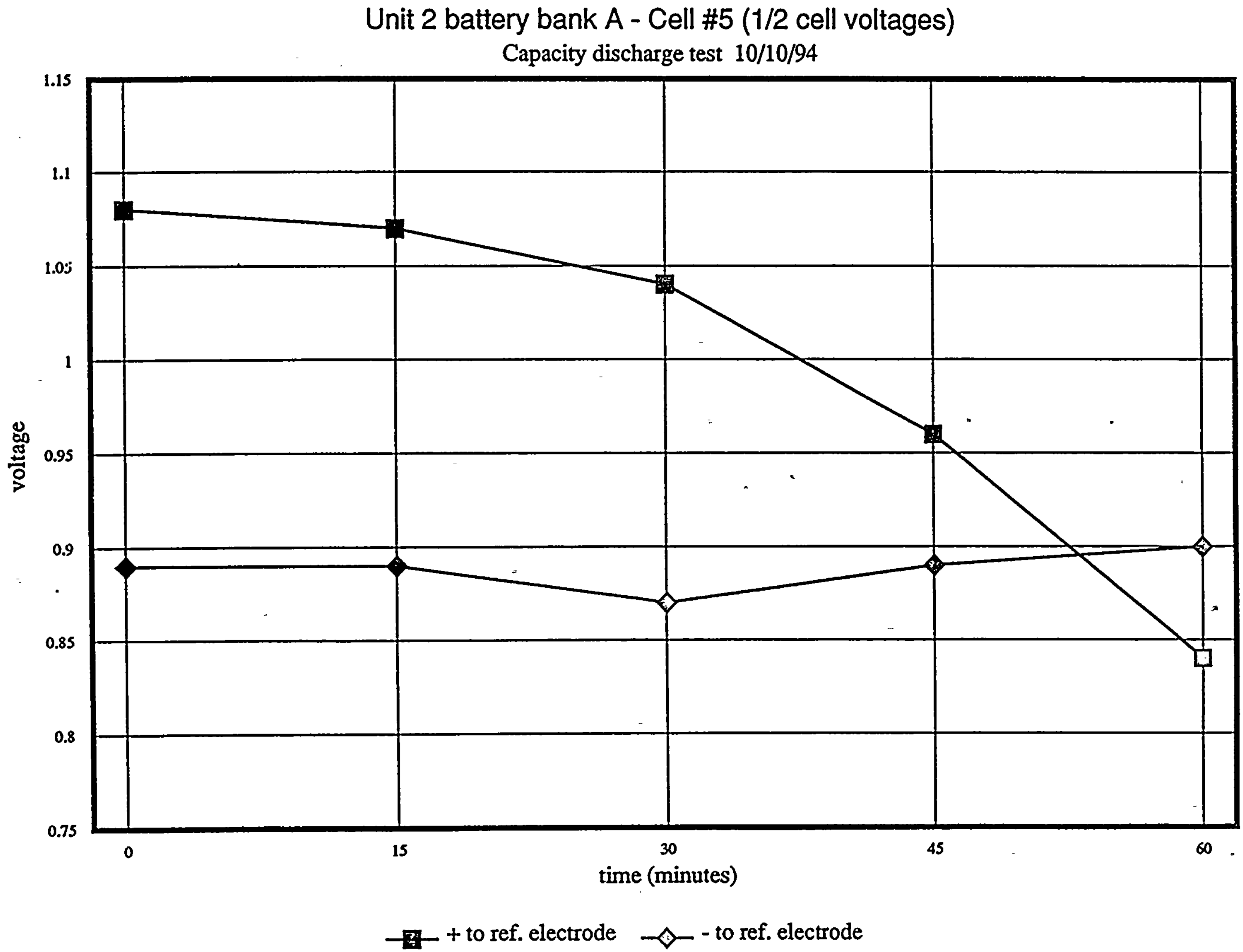


Unit 2 battery bank B - Cell #57 (1/2 cell voltages)
Capacity discharge test 10/10/94
voltage
1.4
1.3
1.2
1.1
1
0.9
0.8
0
15
30
45
60
75
time (minutes)
+ to ref. electrode
- to ref. electrode

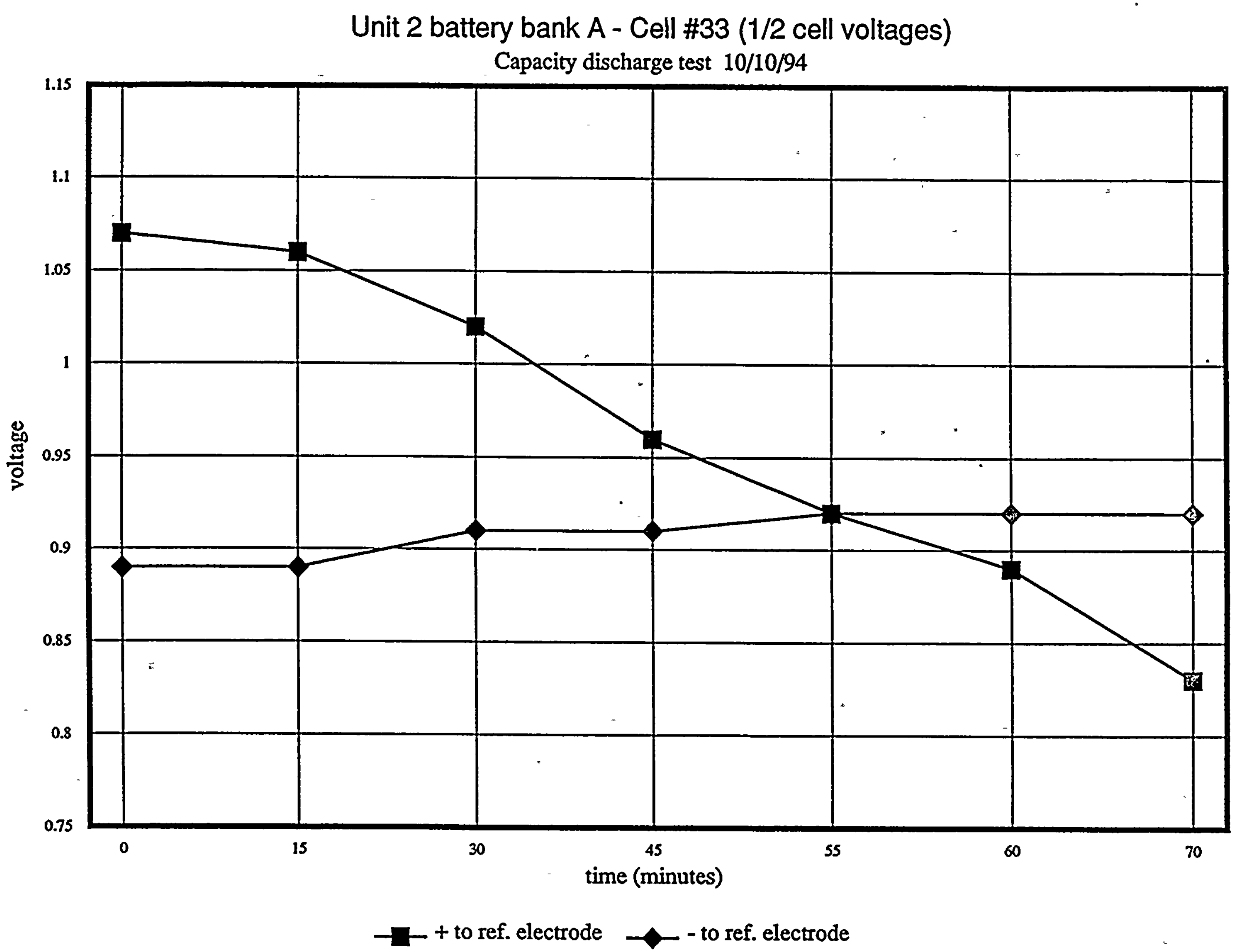
Unit 2 battery bank B - Cell #60 (1/2 cell voltages)

Capacity discharge test 10/10/94

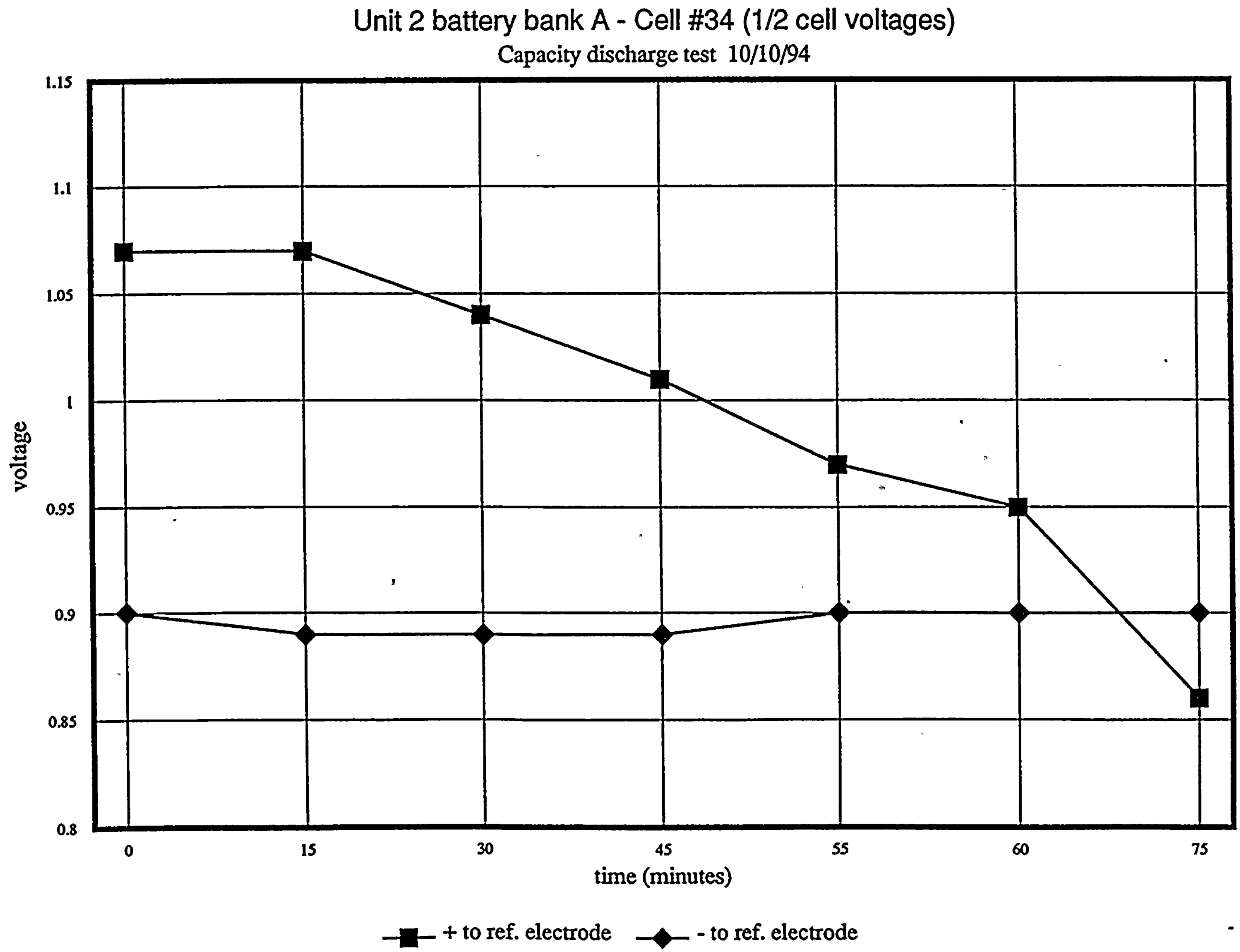




Unit 2 battery bank A - Cell #5 (1/2 cell voltages)
Capacity discharge test 10/10/94
voltage
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0
15
30
45
60
time (minutes)
+ to ref. electrode
- to ref. electrode



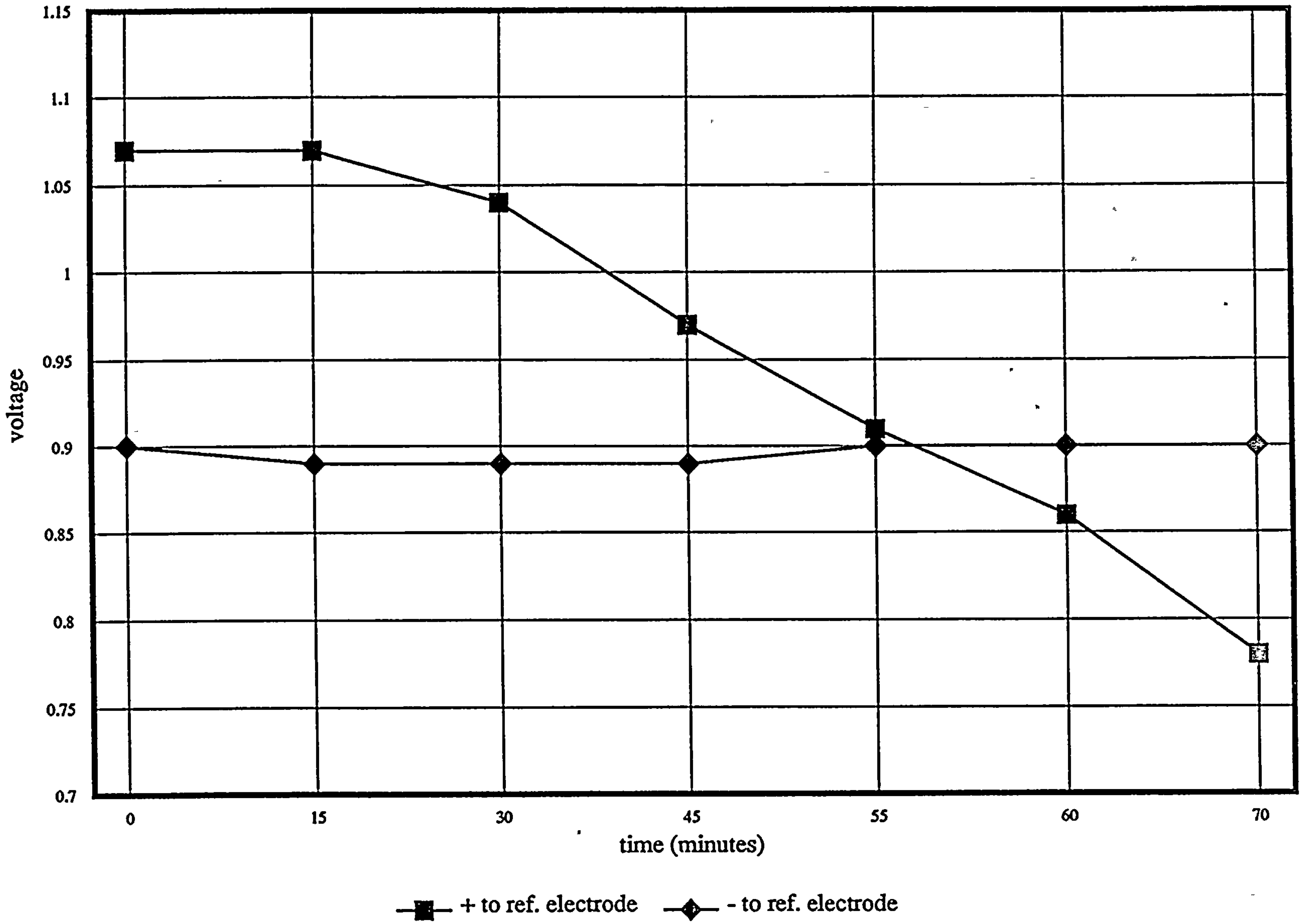
Unit 2 battery bank A - Cell #33 (1/2 cell voltages)
Capacity discharge test 10/10/94
voltage
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0
15
30
45
55
60
70
time (minutes)
+ to ref. electrode
- to ref. electrode

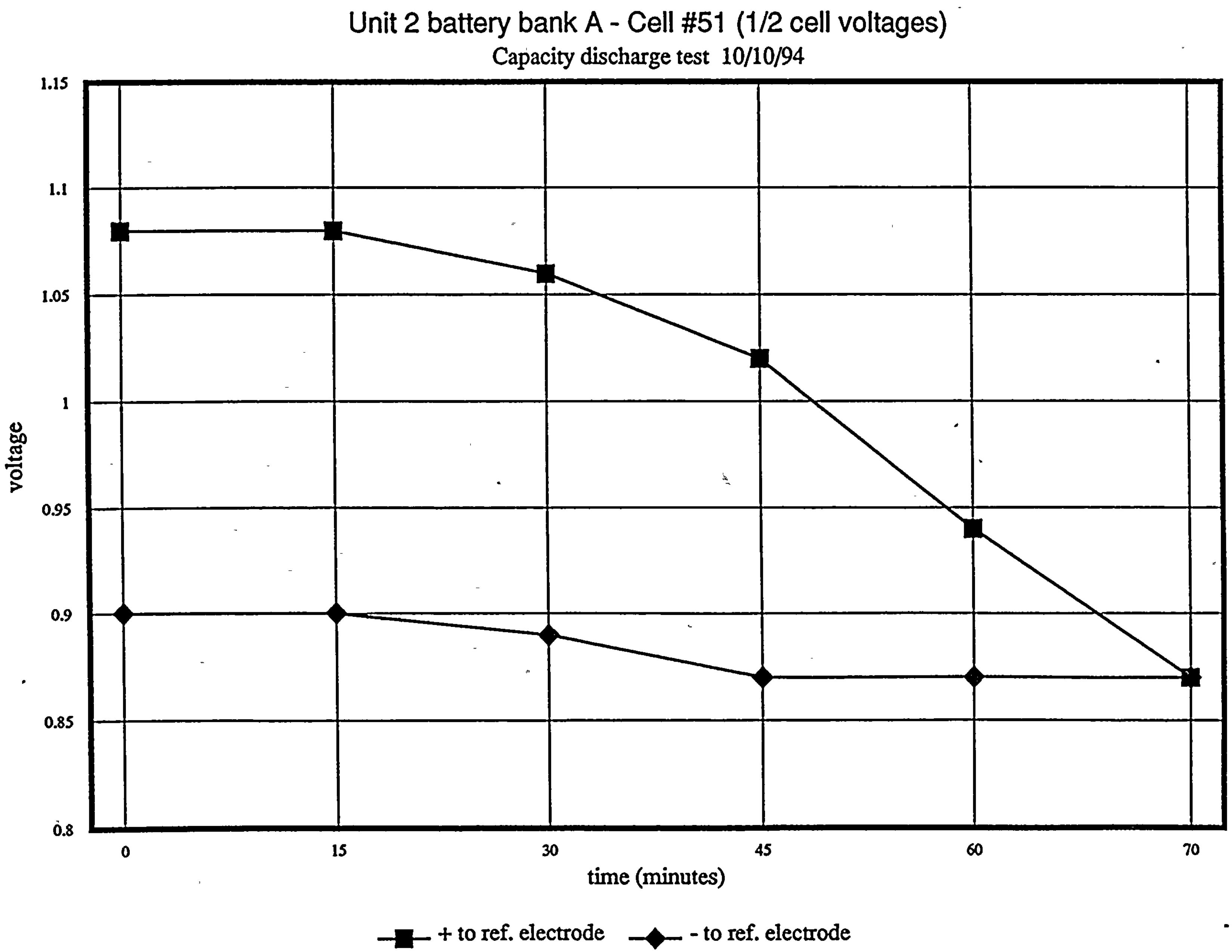


Unit 2 battery bank A - Cell #34 (1/2 cell voltages)
Capacity discharge test 10/10/94
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
voltage
0
15
30
45
55
60
75
time (minutes)
+ to ref. electrode
- to ref. electrode

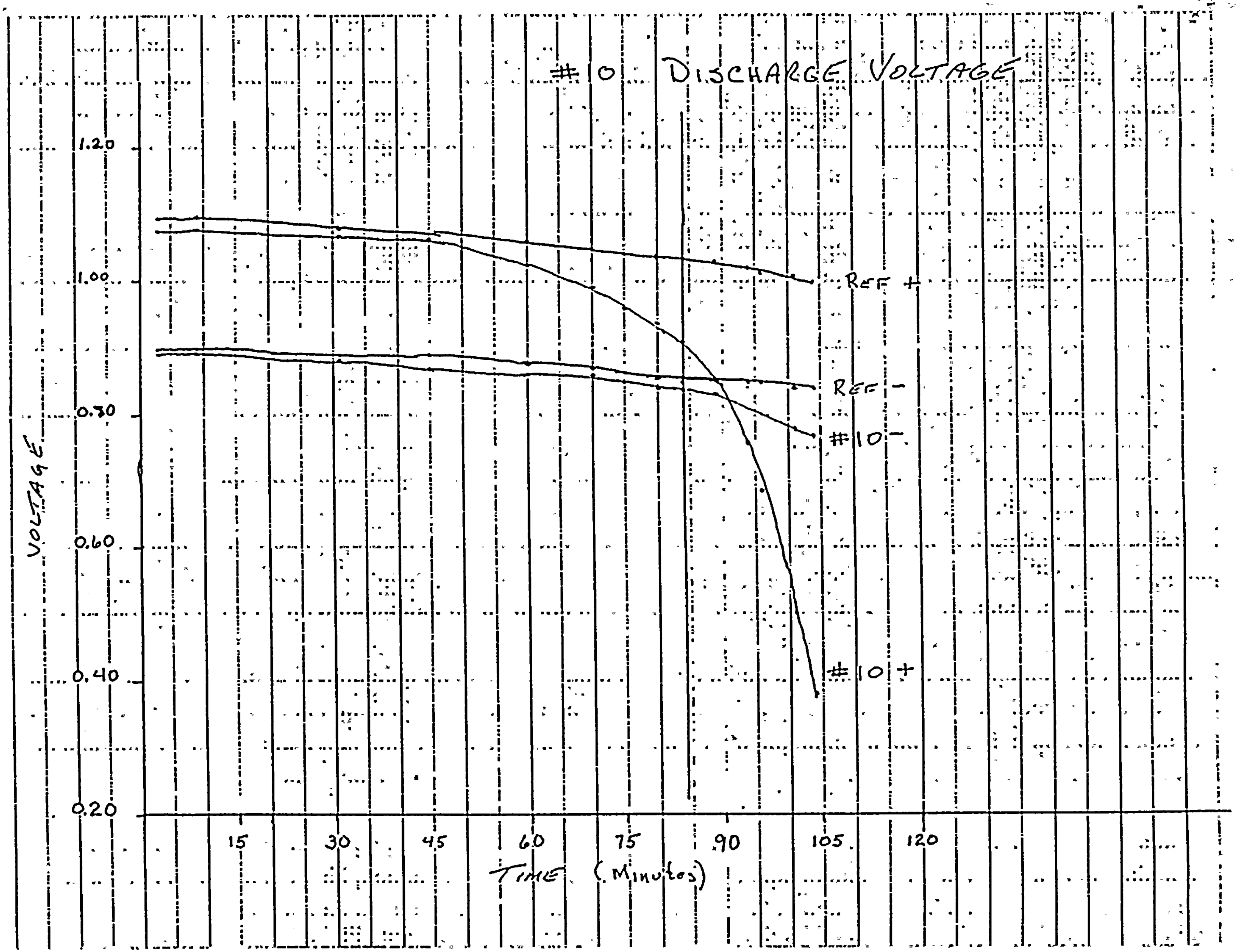
Unit 2 battery bank A - Cell #35 (1/2 cell voltages)

Capacity discharge test 10/10/94




Unit 2 battery bank A - Cell #51 (1/2 cell voltages)
Capacity discharge test 10/10/94
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
voltage
0
15
30
45
60
70
time (minutes)
+ to ref. electrode
- to ref. electrode

VERNON McMILLAN, INC., ELIZABETH N... No. 19 0020 (R 2470 20) 20 Squares to the inch



SP/G	0	86.5m
#6:	1303 (72°)	1270 (78)
#36:	1302 (68°)	1270 (77)

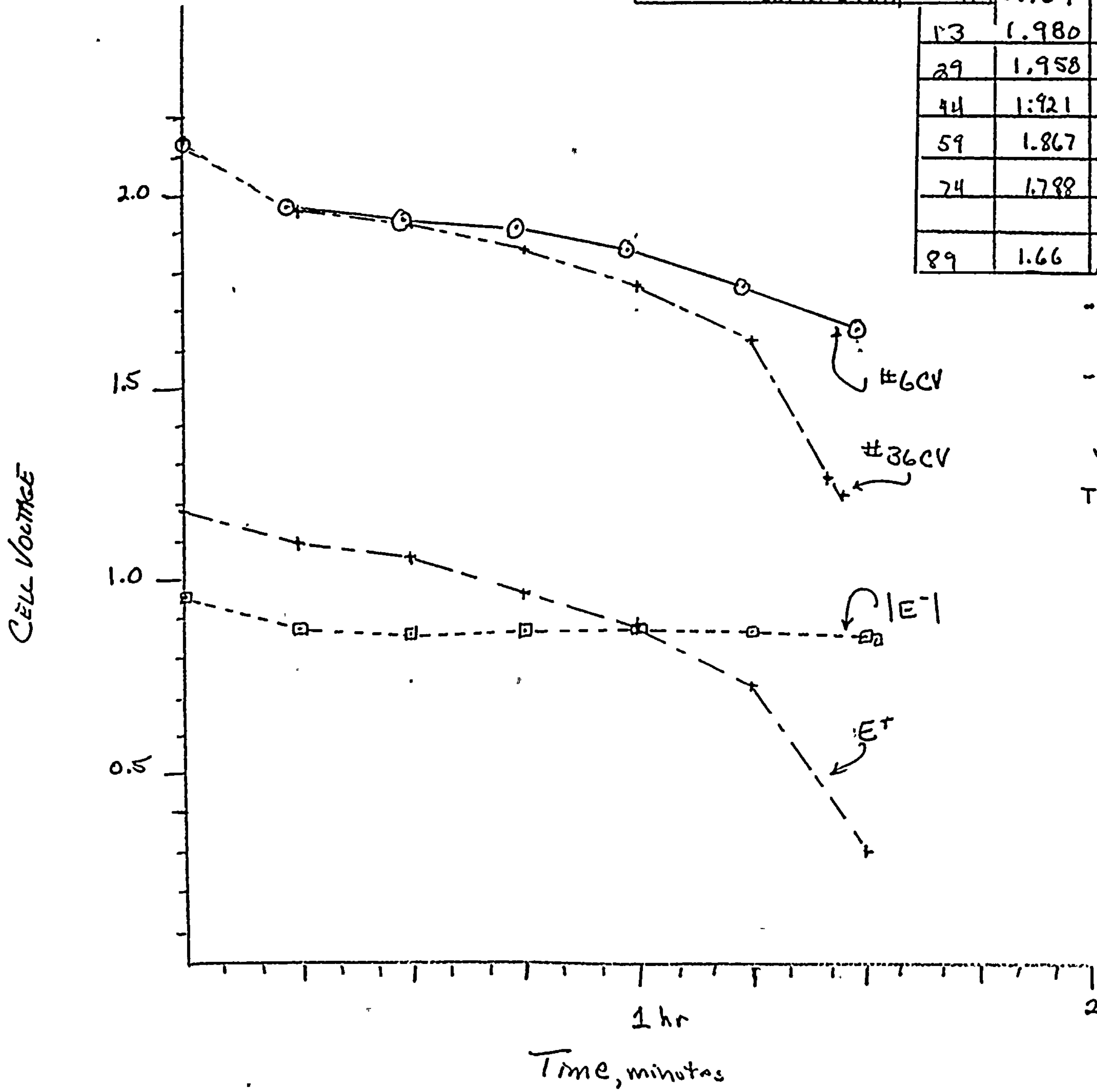
CELL 6		CELL 36 (Ref. Electrode)			
	CV	Time	CV	E+	E-
	2.164	0	2.168	1.191	-0.976
13	1.980	15	1.973	1.100	-0.875
29	1.958	30*	1.932	1.057	-0.873
44	1:921	45	1.864	0.982	-0.882
59	1.867	60	1.784	0.893	-0.890
74	1.788	75	1.614	0.727	-0.886
		85	1.276	0.400	-0.871
89	1.66	86.5	1.22	0.347	-0.860

- discharge Current was 511 #1a during test
- Before Discharge acid level was at "Low-Level"

* Electrode moved accidently

TOTAL Elapsed time: 1:26:34.

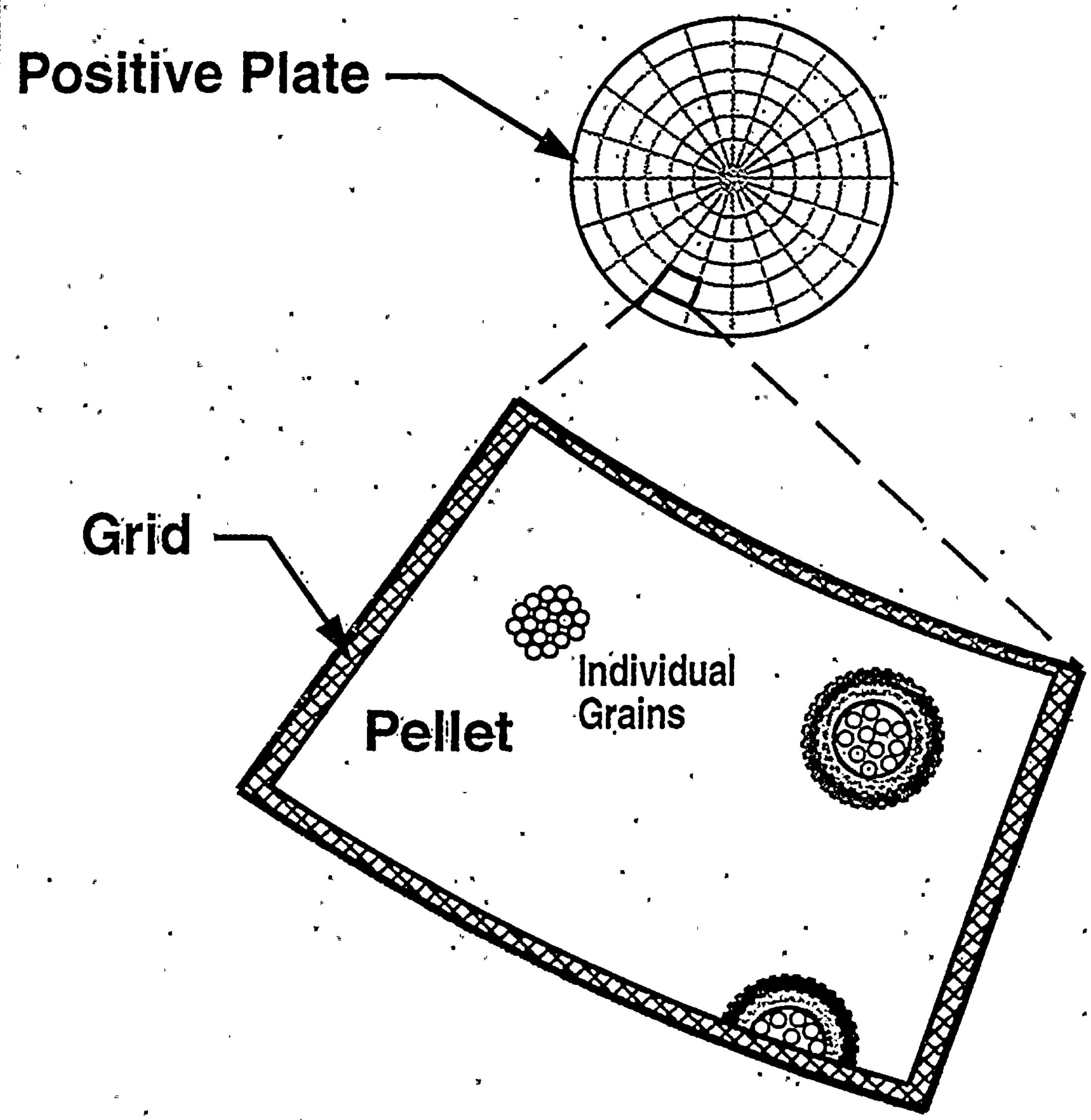
Data taken by Herb Smith et-al.



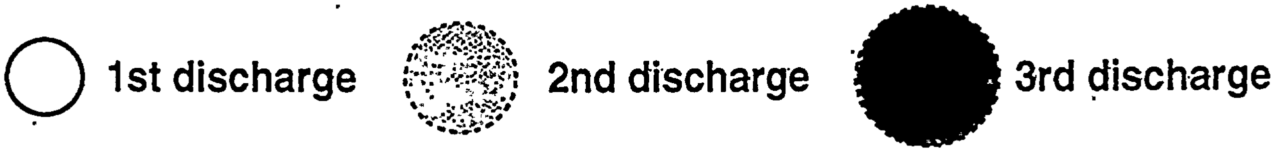
M.R. Oren
10/11/94

ATTACHMENT 10

Pellets with "Electrically Isolated" Grains

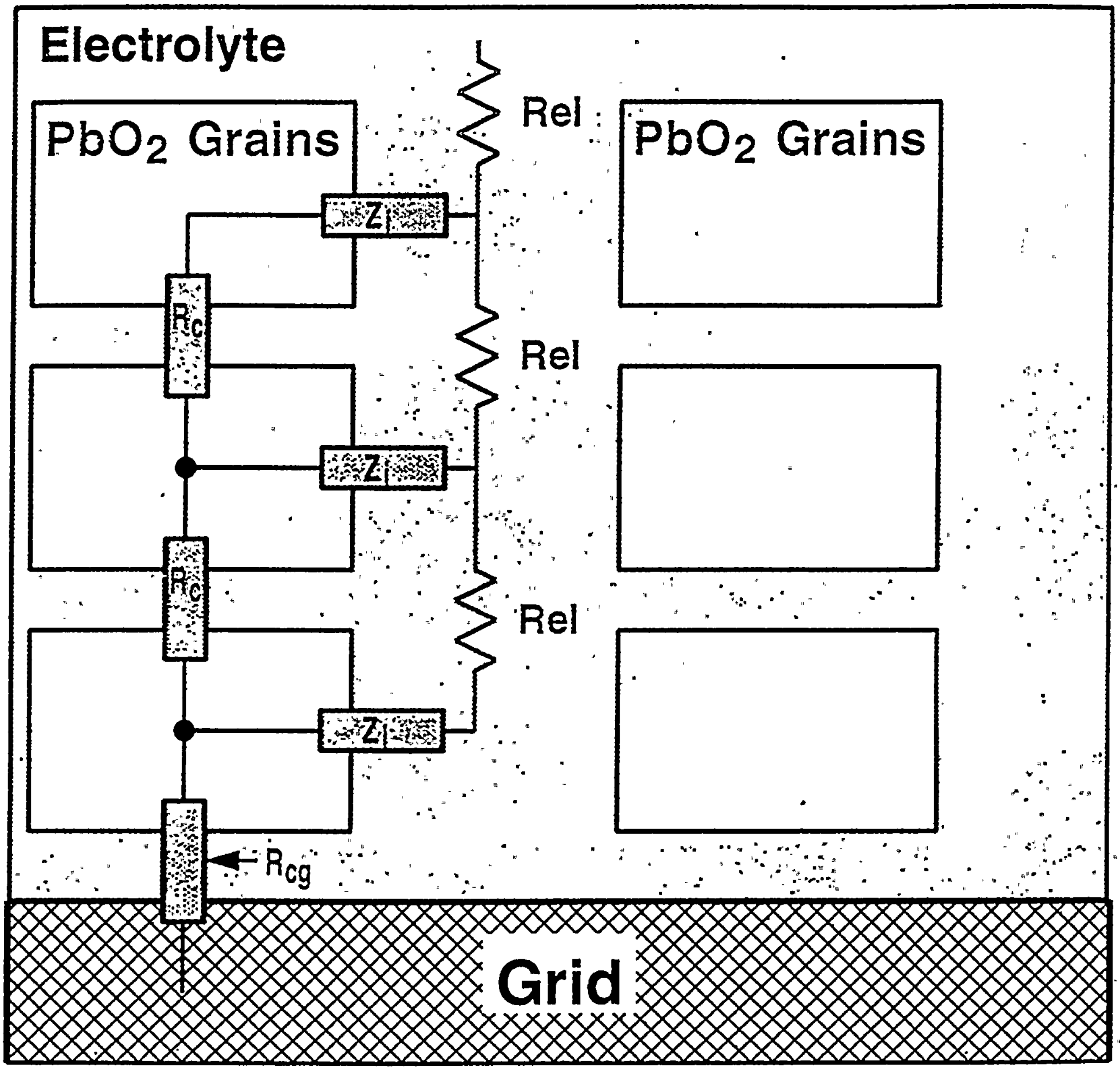


"Electrically Isolated Areas" Legend:



ATTACHMENT 11

Internal Resistance of Porous Electrode



Rel = Electrolyte Resistance
R_c = Contact Resistance
Z_i = Interface Impedance
R_{cg} = Grid/Positive Grain Resistance

ATTACHMENT 12

Appendix A

Failure Mechanism of Round Cell Batteries

Based on the tests of the degraded batteries, the following symptoms were observed:

- The discharge voltage degraded after a discharge-charge cycle (capacity loss)
- The specific gravity of the sulfuric acid remained normal after re-charge.

Also, it was found that all degraded batteries were manufactured during a certain time period. Based on the SEM examination of 7 positive plates in 7 batteries, the 5 positive plates in degraded batteries were found excessive calcium crystals (covering 10 to 20% of the interface surface) at the interface between the positive grids and the active material.

No calcium were found at the positive grid interfaces on those good batteries that were manufactured in different time frames than that for those degraded batteries.

Calcium Passivation Failure Model

Despite their wide use in many industries, many unexpected premature capacity losses of lead acid batteries with lead-calcium grids were reported and studied when the batteries were subject to deep discharge and charge cycles (References A.1 to A.5). Figure 1 shows the premature capacity loss phenomenon of lead-calcium positive grid batteries. The pioneer research performed in Reference A.4 found that calcium tended to help form large lead sulfate crystals (Figure 2) after discharge versus more disperse, fine crystalline formed with positive grids containing other alloys (Figure 3) (such Sn, As, Cu, or Bi). It was believed by the authors (A.1 to A.6) that the premature capacity loss was due to formation of large lead sulfate (non-conductive) crystals that "passivated" the lead dioxide active material by breaking its conductivity path in the matrix.

The calcium content in the positive grid used in the tests (A.4) was 0.08 to 0.09%, greater than 0.02% solubility of calcium in

lead. As such, it was logical to say that a small quantify of free calcium (only 0.05% of free calcium in the experiments conducted in Reference A.4) present on the positive grid surface was able to create the lead sulfate insulating network during discharge, which later blocking the transformation of lead dioxide into lead sulfate during successive discharges. It is reasonable to assume that this calcium passivation effect (called by Mr. H. Dietz, Reference A.6) could become more pronounced if more free calcium is present at the interface between the grid and the active material.

In additional to the insulating lead sulfate crystals formed due to the presence of the calcium, some authors also found alpha-lead-oxide (an insulating material) at the interface between the positive grid and the active material. It was believed that alpha-lead-oxide might have the same insulating effect as the large crystals of lead sulfate (A.7).

Based on the findings of the effects of calcium on forming insulating lead sulfate crystals, we can hypothesize a failure scenario as follows:

> During fabrication of the positive plates over a period of time, calcium contamination of the surface of the positive grids occurred.
>
> The calcium helped to form lead sulfate in large-size crystals, which were less conductive than small crystalline crystals, during discharge. During the succesive discharge, some of the large crystals would block the conversion of the lead dioxide to sulfate lead, thus losing the discharge capacity.

Supporting Evidence

The supporting evidences of this calcium passivation mode are described below:

(1) The measured voltage drop versus time behavior of those degraded batteries were consistent with that caused by the failure mode suggested by the calcium passivation model. During discharge, after an initial stage of good performance, voltage dropped off rapidly. The delay for the voltage drop was explained in Reference A.8 as a phenomenon of diffusion of the sulfuric acid into the deep part of the active material and the late reaction of the inactive material after all the active material was used up.

Note that the conductive active material will react with the sulfuric acid first. As it reacts and is used up, the inactive material becomes important to control the discharge current. As suggested by the model, some of the insulating

lead sulfate crystals are embedded deep in the active material and is in a matrix form. As a result, its negative effects in controlling the discharge will come in later after an initial stage of good performance.

(2) Out of the 7 positive plates FPI examined, 5 were in degraded batteries and 2 were in good performance batteries. 5 "degraded" positive plates have excessive calcium contamination, and all 2 "good performance" positive plates have no calcium contamination.

(3) A negative plate in one of the degraded batteries was also examined under SEM. The pores in the active material of the negative plate were plugged extensively by calcium crystals. This fact suggests that the calcium contamination did exist and was very extensive in the degraded batteries.

(4) The capacity loss was not observed in batteries manufactured before and after the unit 2 batteries. This fact suggests that the root causes of the problem is not generic to all batteries (such as higher sulfuric concentration, battery design, etc).

References

(A.1) J. Burbank (1964), Journal of Electrochemical Society, Vol (III), page 1112

(A.2) S. Tudor, et al, Electrochemistry Technology, Vol (5), 21 (1967)

(A.3) Abdul Azim et al, Corrosion Science, Vol (12) 371 (1972)

(A.4) I. K. Gibson, et al, in Power Sources, (8), edited by Thompson, page 565 (1981)

(A.5) A. Komaki, et al, Progess in Batteries and Solar Cells, Vol (4) (1982)

(A.6) H. Dietz, et al, "Premature Capacity Loss in Lead Acid Batteries With Antimony Free Grids During Cycling Under Constant Voltage Charging Conditions," Elsevier, Sequoia (1993)

(A.7) J. Yamashita, et al, Power Source 11, Letherhead Surrey, UK (1986)

(A.8) J. Bouet, et al, Electrochemica Acta., Vol (26), No.10 (1981)

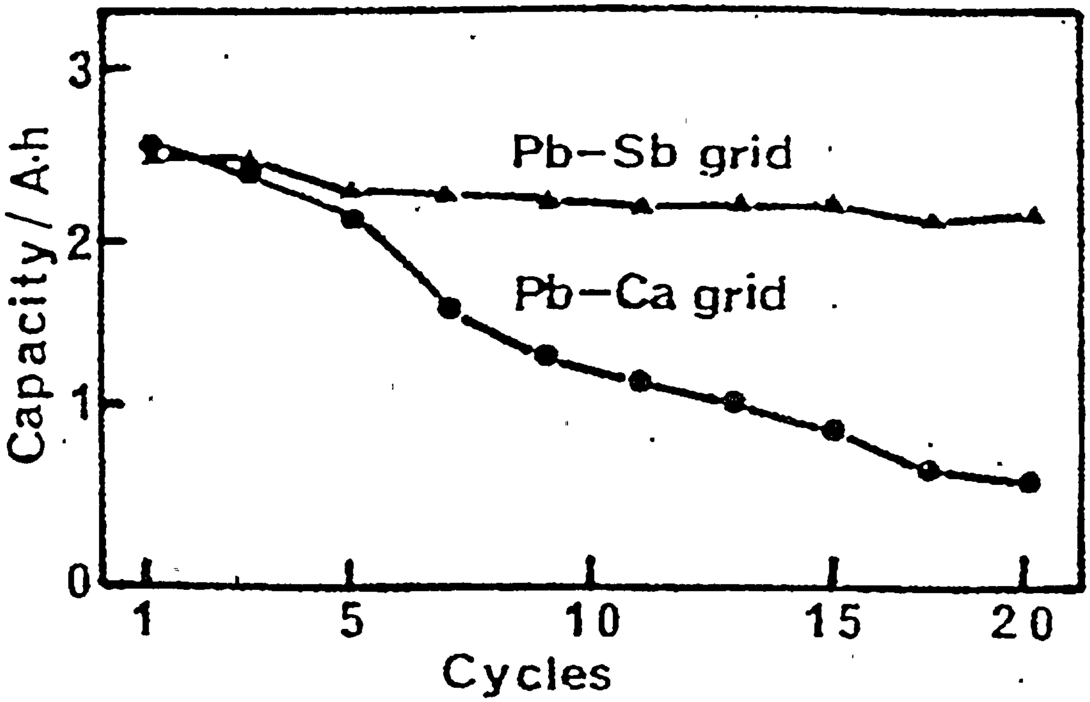


Figure A.1 Capacity Loss of Lead-Calcium Grid Due to Large Lead Sulfate Crystals

Figure A.2 Large Lead Sulfate Crystals After Discharge Due To Presence of Calcium (1600x)

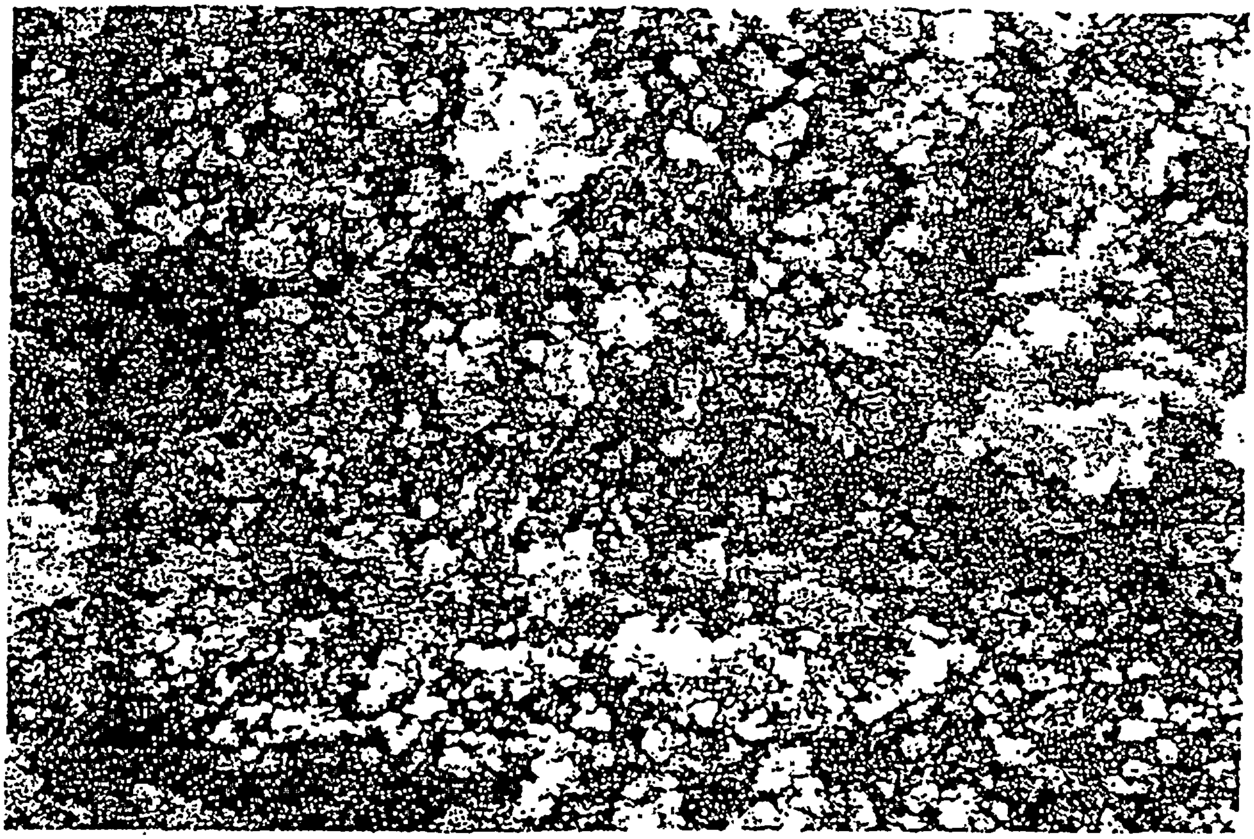


Figure A.3 Small Crystalline Lead Sulfate Without Calcium (with a small amount of tin) (1600x)

ATTACHMENT 16

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

October 13, 1994

Mr. William L. Stewart
Executive Vice President, Nuclear
Arizona Public Service Company
Post Office Box 53999
Phoenix, Arizona 85072-3999

SUBJECT: ISSUANCE OF EMERGENCY AMENDMENT FOR THE PALO VERDE NUCLEAR GENERATING STATION UNIT NO. 2 (TAC NO. M90581)

Dear Mr. Stewart:

The Commission has issued the enclosed Amendment No. 71 to Facility Operating License No. NPF-51 for the Palo Verde Nuclear Generating Station (PVNGS), Unit No. 2. The amendment consists of changes to the Technical Specifications (TS) in response to your application dated October 9, 1994, as supplemented by letter dated October 12, 1994.

The amendment modifies TS 4.8.2.1.e, "DC Sources - Operating," to specify that the provisions of TS 4.0.1 and 4.0.4 are not applicable to the battery capacity requirements until entry into Mode 4 coming out of the fifth refueling outage or upon any deep discharge cycle of the battery. You requested the change on an emergency basis when you discovered that the 125V DC batteries do not meet the TS requirement for minimum battery capacity, thereby precluding PVNGS Unit 2 from changing modes.

A copy of the related safety evaluation is also enclosed. A Notice of Issuance and Final Determination of No Significant Hazards Consideration and Opportunity for Hearing will be included in the Commission's next regular biweekly Federal Register notice.

Sincerely,

B. E. H

Brian E. Holian, Senior Project Manager
Project Directorate IV-2
Division of Reactor Projects III/IV
Office of Nuclear Reactor Regulation

Docket No. STN 50-529

Enclosures: 1. Amendment No. 71 to NPF-51
2. Safety Evaluation

cc w/encls: See next page

cc:

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111 South Third Avenue
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

ARIZONA PUBLIC SERVICE COMPANY, ET AL.

DOCKET NO. STN 50-529

PALO VERDE NUCLEAR GENERATING STATION, UNIT NO. 2

AMENDMENT TO FACILITY OPERATING LICENSE

Amendment No. 71

License No. NPF-51

1. The Nuclear Regulatory Commission (the Commission) has found that:

   A. The application for amendment by the Arizona Public Service Company (APS or the licensee) on behalf of itself and the Salt River Project Agricultural Improvement and Power District, El Paso Electric Company, Southern California Edison Company, Public Service Company of New Mexico, Los Angeles Department of Water and Power, and Southern California Public Power Authority dated October 9, 1994, as supplemented by letter dated October 12, 1994, complies with the standards and requirements of the Atomic Energy Act of 1954, as amended (the Act) and the Commission's regulations set forth in 10 CFR Chapter I;

   B. The facility will operate in conformity with the application, the provisions of the Act, and the rules and regulations of the Commission;

   C. There is reasonable assurance (i) that the activities authorized by this amendment can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations;

   D. The issuance of this amendment will not be inimical to the common defense and security or to the health and safety of the public; and

   E. The issuance of this amendment is in accordance with 10 CFR Part 51 of the Commission's regulations and all applicable requirements have been satisfied.

2. Accordingly, the license is amended by changes to the Technical Specifications as indicated in the attachment to this license amendment; and paragraph 2.C(2) of Facility Operating License No. NPF-51 is hereby amended to read as follows:

(2) Technical Specifications and Environmental Protection Plan

The Technical Specifications contained in Appendix A, as revised through Amendment No. 71, and the Environmental Protection Plan contained in Appendix B, are hereby incorporated into this license. APS shall operate the facility in accordance with the Technical Specifications and the Environmental Protection Plan, except where otherwise stated in specific license conditions.

3. This license amendment is effective as of the date of issuance and must be fully implemented prior to entry into Mode 4 from the current midcycle outage.

FOR THE NUCLEAR REGULATORY COMMISSION

Elinor G. Adensam

Elinor G. Adensam, Deputy Director
Division of Reactor Projects III/IV
Office of Nuclear Reactor Regulation

Attachment:
Changes to the Technical Specifications

Date of Issuance: October 13, 1994

ATTACHMENT TO LICENSE AMENDMENT

AMENDMENT NO. 71 TO FACILITY OPERATING LICENSE NO. NPF-51

DOCKET NO. STN 50-529

Replace the following page of the Appendix A Technical Specifications with the enclosed page. The revised page is identified by amendment number and contains vertical lines indicating the areas of change.

Remove	Insert
3/4 8-10	3/4 8-10

SURVEILLANCE REQUIREMENTS (Continued)

b. At least once per 92 days and within 7 days after a battery discharge with battery terminal voltage below 105 volts, or battery overcharge with battery terminal voltage above 150 volts, by verifying that:

1. The parameters in Table 4.8-2 meet the Category B limits,

2. There is no visible corrosion at either terminals or connectors, or the connection resistance of these items is less than 150×10^{-6} ohms, and

3. The average electrolyte temperature of six connected cells is above 60°F.

c. At least once per 18 months by verifying that:

1. The cells, cell plates, and battery racks show no visual indication of physical damage or abnormal deterioration,

2. The cell-to-cell and terminal connections are clean, tight, and coated with anticorrosion material,

3. The resistance of each cell-to-cell and terminal connection is less than or equal to 150×10^{-6} ohms, and

4. The battery charger will supply at least 400 amperes for batteries A and B and 300 amperes for batteries C and D at 125 volts for at least 8 hours.

d. At least once per 18 months, during shutdown, by verifying that the battery capacity is adequate to supply and maintain in OPERABLE status all of the actual or simulated emergency loads for the design duty cycle when the battery is subjected to a battery service test.

e. At least once per 60 months, during shutdown, by verifying that the battery capacity is at least 80% (Exide) or 90% (AT&T) of the manufacturer's rating when subjected to a performance discharge test. This performance discharge test may be performed in lieu of the battery service test required by Surveillance Requirement 4.8.2.1d.*

f. Annual performance discharge tests of battery capacity shall be given to any battery that shows signs of degradation or has reached 85% of the service life expected for the application. Degradation is indicated when the battery capacity drops more than 10% (Exide) or 5% (AT&T) of rated capacity from its average on previous performance tests, or is below 90% (Exide) or 95% (AT&T) of the manufacturer's rating.

*The provisions of Specification 4.0.1 and 4.0.4 are not applicable. This provision expires upon entry into Mode 4 coming out of the fifth refueling outage or upon any deep discharge of the battery.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO AMENDMENT NO. 71 TO FACILITY OPERATING LICENSE NO. NPF-51,

ARIZONA PUBLIC SERVICE COMPANY, ET AL.

PALO VERDE NUCLEAR GENERATING STATION, UNIT NO. 2

DOCKET NOS. STN 50-529

1.0 INTRODUCTION

By letter dated October 9, 1994, as supplemented by letter dated October 12, 1994, the Arizona Public Service Company (APS or the licensee) submitted a request for changes to the Technical Specifications (TS) for the Palo Verde Nuclear Generating Station, Unit 2 (Appendix A to Facility Operating License No. NPF-51). The Arizona Public Service Company submitted this request on behalf of itself, the Salt River Project Agricultural Improvement and Power District, Southern California Edison Company, El Paso Electric Company, Public Service Company of New Mexico, Los Angeles Department of Water and Power, and Southern California Public Power Authority. The proposed amendment would modify TS 4.8.2.1.e, DC Sources - Operating, to specify that the provisions of TSs 4.0.1 and 4.0.4 are not applicable to the battery capacity requirements until entry into Mode 4 coming out of the fifth refueling outage or upon any deep discharge cycle of the battery.

The licensee requested an emergency TS change in order to declare the Unit 2 batteries operable based upon the current capacities of the batteries without having to satisfy the surveillance requirement of TS 4.8.2.1.e., and thereby change modes and start-up from the current mid-cycle steam generator inspection outage.

2.0 BACKGROUND

TS 3.8.2.1, DC Sources - Operating, requires the operability of two trains of DC power sources to ensure that sufficient power will be available to supply the safety-related equipment required for 1) the safe shutdown of the facility and 2) the mitigation and control of accident conditions within the facility.

Palo Verde Nuclear Generating Station Units 1, 2, and 3 have AT&T LINEAGE 2000 Round Cell batteries installed in the safety-related 125V DC battery banks. The AT&T LINEAGE 2000 Round Cell battery, although relatively new in nuclear applications, has been available for almost twenty years, and there are more than 500,000 in service today. The Round Cell battery is similar in design to other lead-acid batteries in that it uses a conventional pasted plate construction. However, the Round Cell battery is unique in that the positive grid is of pure lead and is of circular construction which creates a slow,

uniform growth rate of ≈ 2% over 70 years compared with a growth rate of ≈ 4% over 15 years in conventional rectangular lead calcium batteries. Because each concentric ring of the positive grid in the Round Cell grows at the same rate, good contact with the active material (or paste) is maintained over the life of the battery and capacity is predicted to increase over the life of the battery.

Four Class 1E DC power banks designated A, B, C, and D are provided in each unit. The DC banks A and B provide control power for alternating current (AC) load groups 1 and 2, respectively. These banks also provide vital instrumentation and control power for channels A and B, respectively, of the reactor protection and Engineered Safety Features (ESF) systems and diesel generators A and B, respectively. The DC banks C and D provide vital instrumentation and control power for channels C and D, respectively, of the reactor protection and ESF systems, and other safety-related loads as referenced in Table 8.3-6, Class 1E DC System Loads, of the Updated Final Safety Analysis Report (FSAR). Each Class 1E DC power bank consists of one 125V DC battery composed of 60 cells, one battery charger, one distribution panel, and is supplied with 480V AC power from a separate motor control center (MCC). Four inverters, supplied from the DC banks, provide four independent 120V AC vital instrumentation and control power supplies for the banks of reactor protection and ESF systems.

During normal operation, the normal battery charger supplies DC power at a float voltage of 135V DC. In addition to carrying the DC loads, the normal battery charger provides a float (trickle) charge to the battery to keep the battery fully charged. The battery is available as a standby DC source to carry the loads automatically in case of loss of the charger. In case of complete loss of AC power, each DC control center will be fed by its battery for at least 2 hours. Upon restoration of AC power, the battery charger is operated in the equalize mode to supply all the steady state loads and the charging current required to restore the battery from the design minimum charge state to the fully-charged state within 12 hours. In case of loss of AC power to the normal battery charger or nonavailability of the normal battery charger due to maintenance or testing, a backup battery charger is available in each train which can be manually connected to supply the loads and trickle charge for one battery.

3.0 DISCUSSION

To date Units 1 and 3 have experienced the expected capacity from the 125V DC batteries. This has been confirmed by recent tests of the four spare cells in each of these units. The 125V DC batteries installed in Unit 2, however, are exhibiting degraded capacity. Capacity discharge tests run in September 1994 (during the mid-cycle outage) indicated capacities of 91.6% for bank A, 89.0% for bank B, 90.6% for bank C, and 88.3% for bank D. The licensee has concluded that the failure mechanism causes the batteries to degrade during the discharge/recharge cycle and that the projected capacities of the banks following the last capacity discharge test are: (1) bank A, 78.82%; (2) bank B, 82.49%; (3) bank C, 76.73%; and (4) bank D, 81.75%. As such, all banks are below the 90% limit of Specification 4.8.2.1.e. All banks have currently been

declared inoperable. The proposed TS amendment would allow operation of the Unit 2 safety-related 125V DC battery banks at less than the required 90% capacity in Specification 4.8.2.1.e. This proposed change is necessary to allow the Unit to change modes and to operate approximately three and one-half months (until the fifth refueling outage currently scheduled to begin on February 4, 1995). At that time all cells from the original AT&T lot in the four Class 1E batteries of Unit 2 will be replaced.

Each of the Class 1E batteries has sufficient capacity to independently supply the required loads as shown in Table 8.3-6 of the Updated FSAR for 2 hours. The sizing of the batteries is based on a minimum temperature of 60° F in the battery room for the 2-hour service period. The PVNGS design exceeds the IEEE Standard 450-1980 requirement for 25% design margin. For example, battery bank B has a design profile requiring 69.06% of the manufacturer's rated capacity of this battery bank (and recent recalculations by the licensee have resulted in additional margin for this particular battery). The current TS requires the as-found capacity to equal or exceed 90% of manufacturer's rated capacity and was conservatively selected based upon the expectation that the AT&T LINEAGE 2000 Round Cell battery capacity would increase for the rest of plant life.

Unit 2 Testing and Degradation Predictions

During the current outage to perform eddy current testing in Unit 2, the licensee conducted performance discharge capacity testing of the Class 1E batteries to satisfy the requirement of IEEE Standard 450-1980 to capacity test new batteries within the first two years in service. The test revealed that the battery capacities for the B and D battery banks were less than the 90% capacity required by TS 4.8.2.1.e (i.e., 89% and 88.3% respectively) while banks A and C were 91.6% and 90.6%, respectively. These results indicated unexpected degradation has occurred in battery capacity. The licensee performed an individual cell and battery capacity evaluation on previous tests of banks A, B, C, & D, factory tests, and additional testing on spare cells. The projections for battery capacity from this evaluation indicated that all four battery banks in Unit 2 were inoperable.

Each cell was evaluated for capacity using actual test data from the factory and Palo Verde capacity discharge testing. During these tests, individual cell voltages were recorded on a periodic basis throughout the testing. From this data, actual cell capacities could be determined directly or, in some cases, by extrapolation. Data was recorded (time and voltage) until overall battery terminal voltage reached 105.0V DC or an average of 1.75V DC per cell for a 60 cell bank.

After each individual cell capacity was calculated, a projection was made on cell capacity after the last test. Known cell degradation was calculated between discharge tests by subtracting the difference between tests. A linear regression analysis was performed on the data for battery banks B and D since there were three data points for these banks. The analysis showed that 117 of the 120 cells passed the goodness of fit test (correlation coefficient greater than 0.85). These results indicated that a linear degradation model

(averaging approximately 12% per capacity discharge test) adequately described the observed degradation process based on the data accumulated to date. Hence, using the known degradations from previous testing, a degradation was calculated for projection purposes.

After the calculated capacities were obtained for each cell, the total battery capacity was calculated. The actual capacities from Palo Verde test results for the four battery banks were compared to the analysis method to verify the results of the analysis and determine the magnitude of error. The analysis results were shown to be within 1 to 4% of actual test results. Part of this error is due to rounding up on calculated individual cell capacities.

Using the same methodology described above, a plan was formulated to make use of the spare cells from Units 1 and 3, and 23 new cells received from the manufacturer. It was determined to replace the four weakest cells in each of banks B and D with the spares from Units 1 and 3, and to replace the weakest 11 cells in bank A and the weakest 12 cells in bank C with the 23 new cells. As a result of this replacement, the capacities of the banks using the method discussed above are projected to be slightly above 85%. These capacities provide adequate margin to the required capacity for the most limiting battery bank (Battery A at approximately 56%) and ensure that the safety-related function of the batteries can be performed without cell reversal.

Compensatory Actions

The licensee has replaced the four weakest cells in battery banks B and D. Also prior to entering Mode 4, 11 of the weakest cells will be replaced in bank A and 12 in bank C. These replacements will increase projected battery capacities so that there will be adequate margin above that required for safety-related loads. Projected battery capacities prior to entering Mode 4 are expected to be slightly above 85% for each bank. Testing of the replacement cells and subsequent calculation of the resulting battery bank capacities prior to entry into Mode 4 will demonstrate that the battery banks will have sufficient capacity to perform their safety-related functions.

The licensee has replaced a combined total of 23 cells in the bank A and C batteries. The replaced cells will be used to form four control groups of 4 cells each. Testing of these four groups will be performed at approximately 30-day intervals as follows:

Time From Present and Type of Test

Control Group #	October	November	December	January
1	S	N/A	N/A	N/A
2	N/A	S	N/A	N/A
3	N/A	N/A	S	N/A
4	N/A	N/A	N/A	S

Legend: S = Battery Service Test (performed to the bank A battery load profile)

This testing is being performed to provide assurance that the degradation mechanism is primarily related to discharge/recharge cycling of the batteries (in lieu of aging) and to demonstrate that the batteries in the unit are capable of meeting the design duty cycle. After each test, an evaluation of the performance of each group will be performed using the following acceptance criteria:

(1) the control group results meet the bank A battery service load profile and

(2) no individual cell reversal occurs (<1.0 volts).

If the above criteria are not met, the unit will enter the action statement for Specification 3.8.2.1 and will take appropriate actions. During the meeting with the staff on October 12, 1994, the licensee additionally committed to verify the validity of their degradation model following each test and to provide the NRC staff with the results of each test.

In addition to the above testing, the licensee has committed to perform additional monitoring and measurements on the installed battery trains. The monitoring and measurements will be performed every other week for all cells, on a staggered basis between trains (so that one train is monitored each week) with limits and required action as shown below:

Parameter	Limits/Allowable	Actions to be Taken if Outside Limits
Float Voltage	≥ 2.18 Volts	Battery Inoperable
Float Current	≤500 ma	Battery Inoperable
Specific Gravity	≥ 1.280	Restore within limits within 7 days
	Avg of all connected cells >1.290	Restore within limits within 7 days
	Not more than 0.020 below average of all connected cells	Battery Inoperable
	Avg of all connected cells ≥ 1.280	Battery Inoperable

The licensee has also committed to the following additional controls and limitations on maintenance on important equipment:

PRA will be used to review all 125V DC system and related auxiliaries corrective/preventive maintenance work. The need to perform long-term maintenance and achieve long-term availability of important-to-safety equipment will be balanced.

PVNGS will issue a night order to the Unit 1 Control Room stating that Unit 2 offsite power supplies and associated 13.8 kV buses should not be interrupted.

Access to the switchyard will be limited. All emergent switchyard work will be reviewed by the Unit I Shift Supervisor.

Manual operation of the Auxiliary Feedwater Pump Turbine and Atmospheric Dump Valves will be reviewed with the Unit 2 operators.

Margin Calculation and Additional Testing

As discussed in the October 12, 1994, meeting with the staff, the licensee committed to complete the electrical load calculation for bank B battery by October 14, 1994. This action ensures that the bank A load profile is the worst-case profile.

Also, the licensee reported that additional capacity tests were performed on five cells removed from Battery 2A. The average of the results from these five cells supported the licensee's projections on battery capacity degradation during testing.

Root Cause

The three worst cells from bank D have been shipped to the manufacturer for a root cause determination. This root cause effort is being overseen by APS with the participation of , AT&T (the cell designer) and Failure Prevention International. The cells arrived October 6, 1994; and one cell has undergone preliminary examination to exclude sudden loss of capacity as the potential cause of failure. The three sudden failure modes are (1) open or near open circuit, (2) low impedance short circuit, and (3) passivation of electrode active material. Teardown inspection of one cell revealed some signs of poor workmanship, but did not reveal the reason for diminished capacity. The cell examination ruled out sudden loss of capacity as a failure mode for this particular cell. It was, therefore, concluded for this cell that the failure mode would be a gradual decline in capacity due to an active material utilization problem. Further examination and testing will be performed until a final determination of the cause of failure is made. Disassembly and inspection of the remaining 2 cells at the Facility will be performed. The licensee has committed to promptly report to the NRC staff any significant findings that invalidate their conclusion(s) from surveillance testing, root cause determination, or any other source. Also, the licensee committed to provide the NRC staff with results from their root cause determination efforts.

An NRC staff member toured the manufacturer's facility on October 9, 1994, and observed the root cause determination effort. A visual inspection of the three cells (including the internal parts from the teardown) was performed and a walkdown of the different manufacturing stages was conducted.

Conclusions

The initial conditions of the Design Basis Accident and transient analyses in the Updated FSAR, Chapter 6 and Chapter 15, assumes that Engineered Safety Feature systems are operable. The DC electric power system provides normal and emergency DC electrical power for the Emergency Diesel Generators, emergency auxiliaries, and control and switching during all modes of operation. The operability of the DC sources is consistent with the initial assumptions of the accident analyses and is based upon meeting the design basis of the unit. This includes maintaining the DC sources operable during accident conditions in the event of (1) an assumed loss of all offsite AC power or all onsite AC power and (2) a worst case single failure.

The degradation experienced by the Unit 2 batteries has resulted in capacities which are still in excess of that required for the batteries to perform their safety-related function. The licensee has performed calculations that demonstrate that the maximum required capacity necessary for the most limiting bank (Battery bank A, at approximately 56%) is maintained with adequate margin. Additionally, the licensee has performed adequate testing on the spare cells and cells removed from Battery 2A to support their degradation model, and has proposed acceptable compensatory actions to ensure continued battery operability. Therefore, the staff concludes that projected available capacity for each battery (greater than 85%), although a reduction from the current TS margin based on a minimum of 90% capacity, is acceptable.

4.0 EMERGENCY CIRCUMSTANCES

During the current Unit 2 outage to conduct steam generator eddy current testing, APS performed capacity testing on the Class 1E batteries. Battery Banks A and C were capacity discharge tested to satisfy the requirements of IEEE Standard 450-1980 to capacity test new batteries within the first two years of service. While test results met TS requirements, the capacity of the battery banks were below that expected. As a result, the B and D banks were capacity tested. On September 29, 1994, the B and D battery banks were declared inoperable because the measured capacity was less than the required 90% capacity stated in Specification 4.8.2.1.e. Although preliminary test results indicated that battery Banks A and C were satisfactory, on October 6, 1994, they were also declared inoperable because a projection of the test results based upon anticipated degradation indicated that they did not meet the 90% criteria of Specification 4.8.2.1.e. Currently, Unit 2 is complying with Action a. of Specification 3.8.2.2, "DC Sources - Shutdown."

The emergency circumstances exist because the four Class 1E batteries do not meet the 90% requirement; therefore, PVNGS Unit 2 cannot change modes per TSs 4.0.1 and 4.0.4. TS 4.0.1 states that Surveillance Requirements shall be applicable during the OPERATIONAL MODES or other conditions specified for individual Limiting Conditions for Operation unless otherwise stated in an individual Surveillance Requirement. TS 4.0.4 states that entry into an OPERATION MODE or other specified condition shall not be made unless the Surveillance Requirement(s) associated with the Limiting Condition for Operation have been performed within the stated surveillance interval or as

otherwise specified. This provision shall not prevent passage through or to operational MODES as required to comply with ACTION requirements. The proposed one-time TS states that the provisions of Specifications 4.0.1 and 4.0.4 are not applicable only to the battery performance discharge test of SR 4.8.1.2.e until the batteries are replaced during the upcoming refueling outage or upon any deep discharge of the battery. This change permits resumed plant operation, while maintaining the current TS action statements and limiting conditions for operation.

APS has eight spare cells on hand, and 23 cells have been received from the vendor. A replacement plan has been developed so that the four battery banks will all have capacities which exceed 85% as determined by engineering analysis. It has been determined that this capacity is sufficient for the battery banks to perform their safety-related function until entry into Mode 4 following the Unit 2 shutdown for refueling in February 1995. Calculations performed by the licensee, and documented in their letter dated October 12, 1994, show greater than 25% capacity margin on all batteries.

The emergency circumstances could not be avoided because the degradation in battery capacity was unexpected. The batteries were installed in Unit 2 in May 1993 and were expected to have a useful life of at least 40 years. Therefore, APS was not prepared to replace the batteries at this time. An insufficient number of cells exist to replace all four battery banks (a total of 244 cells) at this time. Successful manufacture, testing, delivery and installation cannot be accomplished for several weeks.

5.0 FINAL NO SIGNIFICANT HAZARDS CONSIDERATION DETERMINATION

The Commission's regulations in 10 CFR 50.92 state that the Commission may make a final determination that a license amendment involves no significant hazards consideration if operation of the facility in accordance with the amendment would not (1) involve a significant increase in the probability or consequences of an accident previously evaluated; or (2) create the possibility of a new or different kind of accident from any accident previously evaluated; or (3) involve a significant reduction in a margin of safety. The licensee has evaluated the proposed changes against these standards and has concluded that:

a. The change does not involve a significant increase in the probability or consequences of an accident previously evaluated:

The DC power sources are required to ensure that sufficient power is available to supply safety-related equipment required for safe plant shutdown and the mitigation and control of accident conditions. Therefore, a change in battery capacity requirements does not involve a significant increase in on [sic] the probability of an accident previously evaluated.

APS has determined, through calculation and test, that the most highly loaded battery bank can continue to perform safety-related

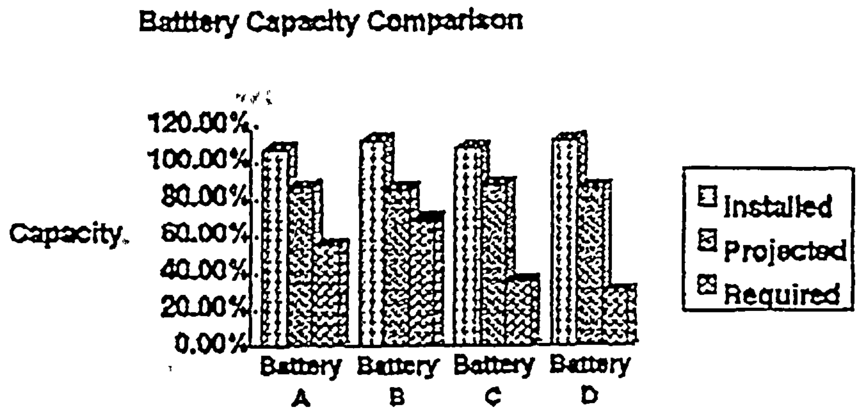
function with its capacity reduced to 69.06% of the original installed capacity. With the replacement of 11 cells in bank A, 4 cells in bank B, 12 cells in bank C and 4 cells in bank D, analysis shows that the projected capacities of the banks, will provide at least 15% margin above that required for the safety-related loads. The projected capacities are expected to be in excess of 85% for each bank. As such, the battery banks have sufficient capacity for the safety-related loads following a design basis event. In addition, the majority of the degradation of the battery cells occurs during discharge testing of the batteries. Therefore, since no discharge testing of the batteries will be performed between now and the next refueling outage, the battery capacity will remain above that needed to fulfill the required safety function. Should any deep discharge of any battery occur, the battery will be declared inoperable. Therefore, the proposed change to the battery capacity requirement does not involve a significant reduction in the consequences of an accident previously evaluated.

b. The change does not create the possibility of a new or different kind of accident from any accident previously evaluated:

Calculations and testing have demonstrated that the most highly loaded battery bank (bank B) will continue to perform its safety-related function even if degraded to 69.06% of its original installed capacity. Conservative projections indicate that battery capacity will remain well above this value. Therefore, the proposed change will not create the possibility of a new or different kind of accident from any previously evaluated.

c. The change does not involve a significant reduction in a margin of safety:

Although battery capacity is less than required by Specification 4.8.2.1.e, sufficient capacity remains for the batteries to perform their intended function. The following graph demonstrates the margin in capacity based on projected capacity after the replacement of 31 cells as described above.



- In the most limiting case, the B battery still has greater than 15% margin between the projected and required capacities. Therefore, the proposed change to battery capacity requirements does not involve a significant reduction in a margin of safety.

The NRC staff notes that by letter dated October 12, 1994, the licensee stated that the electrical load calculation for bank B battery has been completed, thereby ensuring that the bank A load profile is the worst-case profile. This recalculation provides additional margin between the worst-case projected and required capacities (Battery A has greater than 25% margin). The NRC staff agrees that the above standards are satisfied and, therefore, determines that the amendment request involves no significant hazards consideration.

6.0 STATE CONSULTATION

In accordance with the Commission's regulations, the Arizona State official was notified of the proposed issuance of the amendment. The State official had no comments.

7.0 ENVIRONMENTAL CONSIDERATION

The amendment changes a requirement with respect to installation or use of a facility component located within the restricted area as defined in 10 CFR Part 20 and changes surveillance requirements. The NRC staff has determined that the amendment involves no significant increase in the amounts, and no significant change in the types, of any effluents that may be released offsite, and that there is no significant increase in individual or cumulative occupational radiation exposure. The Commission made a final no significant hazards consideration finding with respect to this amendment. Accordingly, the amendment meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the issuance of the amendment.

8.0 CONCLUSION

The Commission has concluded, based on the considerations discussed above, that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

Principal Contributors: F. Burrows
B. Holian

Date: October 13, 1994

ATTACHMENT 17

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94-056-026

RECORDS ... UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 3, 1994

Mr. William L. Stewart
Executive Vice President, Nuclear
Arizona Public Service Company
Post Office Box 53999
Phoenix, Arizona 85072-3999

SUBJECT: REVISION TO COMPENSATORY ACTIONS REGARDING 125V DC BATTERIES AT PALO VERDE NUCLEAR GENERATING STATION UNIT NO. 2 (TAC NO. M90581)

Dear Mr. Stewart:

The Commission issued Amendment No. 71 to Facility Operating License No. NPF-51 for the Palo Verde Nuclear Generating Station (PVNGS), Unit No. 2, on October 13, 1994. The amendment consist of changes to the Technical Specifications (TS) in response to your application dated October 9, 1994, as supplemented by letter dated October 12, 1994. The amendment modified TS 4.8.2.1.e, "DC Sources - Operating," to specify that the provisions of TS 4.0.1 and 4.0.4 are not applicable to the battery capacity requirements until entry into Mode 4 coming out of the fifth refueling outage or upon any deep discharge cycle of the battery. The amendment was issued on an emergency basis when you discovered that the 125V DC batteries do not meet the TS requirement for minimum battery capacity, thereby precluding PVNGS Unit 2 from changing modes.

The safety evaluation for the amendment defined the compensatory actions to be implemented while the amendment is in effect. One of the defined compensatory actions was that float current of the installed battery trains must be measured on one train each week and the value found to be less than or equal to 500 mA or the batteries were to be declared inoperable. Your testing conducted during the week of October 24, 1994, has determined that accurate float current readings can not be taken on the installed battery trains in accordance with this compensatory action.

Based upon a telephone conversation with NRC staff on October 28, 1994, Arizona Public Service Company (APS) provided supplemental information, dated October 29, 1994, to support a modification of the compensatory actions. The staff has reviewed the revised compensatory actions and finds them acceptable for monitoring battery performance. The enclosure to this letter revises a

portion of the compensatory action section of the staff's safety evaluation dated October 13, 1994.

Sincerely,

Brian E. Holian, Senior Project Manager
Project Directorate IV-2
Division of Reactor Projects III/IV
Office of Nuclear Reactor Regulation

Docket No. STN 50-529

Enclosure: Revision to October 13, 1994, Safety Evaluation

cc w/encl: See next page

Mr. William L. Stewart
Arizona Public Service Company

Palo Verde

cc:

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

REVISION TO SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO AMENDMENT NO. 71 TO FACILITY OPERATING LICENSE NO. NPF-51,

ARIZONA PUBLIC SERVICE COMPANY, ET AL.

PALO VERDE NUCLEAR GENERATING STATION, UNIT NO. 2

DOCKET NO. STN 50-529

On October 13, 1994, Amendment No. 71 to Facility Operating License No. NPF-51 for the Palo Verde Nuclear Generating Station (PVNGS) was issued. The safety evaluation for the amendment defined the compensatory actions to be implemented while the amendment is in effect. One of the defined compensatory actions was that float current of the installed battery trains must be measured on one train each week and the value found to be less than or equal to 500 mA or the batteries were to be declared inoperable. Licensee-performed testing conducted during the week of October 24, 1994, determined that accurate float current readings cannot be taken on the installed battery trains in accordance with this compensatory action. The licensee discussed the test results with the staff on October 28, 1994, and described proposed revised compensatory actions in a letter dated October 29, 1994.

The licensee reported that, because of the configuration of the safety-related 125V DC system at PVNGS, the float current reading taken on the installed Unit 2 batteries contains noise from the battery chargers, which supply power to plant loads under normal operation. The readings are taken using an existing shunt in the battery circuit and a digital volt meter. The voltage value is then converted to amperage based on the known resistance value of the shunt. The installed shunt is sized to read the much higher currents experienced during battery discharge rather than to read the float current. As a result, the float current readings taken at the shunt are masked by noise of a magnitude equal to or greater than the float current, preventing an accurate reading. The licensee cannot modify the installed instrumentation without removing the batteries from service. In response to staff questions regarding Units 1 and 3 measurements, the licensee stated that similar float current results were obtained.

The licensee has stated that, since the battery banks contain both degraded cells and new cells (the 23 new replacement cells and the combined 8 spare cells from Units 1 and 3), the individual cell voltages of the new cells would increase if the degraded cells were drawing an increased float current. This effect is experienced because all cells are connected in series and the new cells would experience the same increased float current as the degraded cells, thereby driving up their individual voltage. The staff agrees that, in lieu of an accurate float current, the individual cell voltage of the new cells will provide a measure of the state of the degraded cells.

Based upon the above information, the licensee proposed to modify the identified compensatory actions for float voltage and float current as follows:

Parameter	Limits/Allowable	Actions to be Taken if Outside Limits
Float Voltage		
All cells	≥ 2.18 volts	Battery inoperable
New cells	≤ 2.35 volts	Battery inoperable
Float Current		
Control cells	≤ 500 mA	Battery inoperable
Installed cells	< 2 amps averaged value	Battery inoperable

The licensee noted in its October 29, 1994, letter that the control cells will consist of cells that have not been subjected to a battery service test. Additionally, the battery service test for the first control group has been deferred until the end of the first week of November, when more testing equipment will arrive. The second service test will be performed in late November in accordance with the staff's safety evaluation for the license amendment.

In effect, three changes have been made to the original compensatory actions: (1) Because of the difficulty of reading ≤ 500 mA on the installed battery cells, the limit was changed to < 2 amps (averaged value); (2) a requirement was added to place a maximum cell float voltage on the new cells (≤ 2.35 volts); and (3) a requirement was added to measure the float current on the control cells. An accurate control cell float current can be taken by the licensee and will provide an indicator that the cells are not experiencing significant time-related degradation. These changes are acceptable to the staff since monitoring will continue to be in place to detect potential battery degradation. The requirement for a 2-amp float current maximum on the installed cells, coupled with a maximum cell voltage reading on the new cells, provides the necessary controls to ensure that battery performance is adequately monitored. These minor revisions to the compensatory actions of the October 13, 1994, safety evaluation do not change the conclusions or no significant hazards determination of the original evaluation.

Principal Contributor: B. Holian

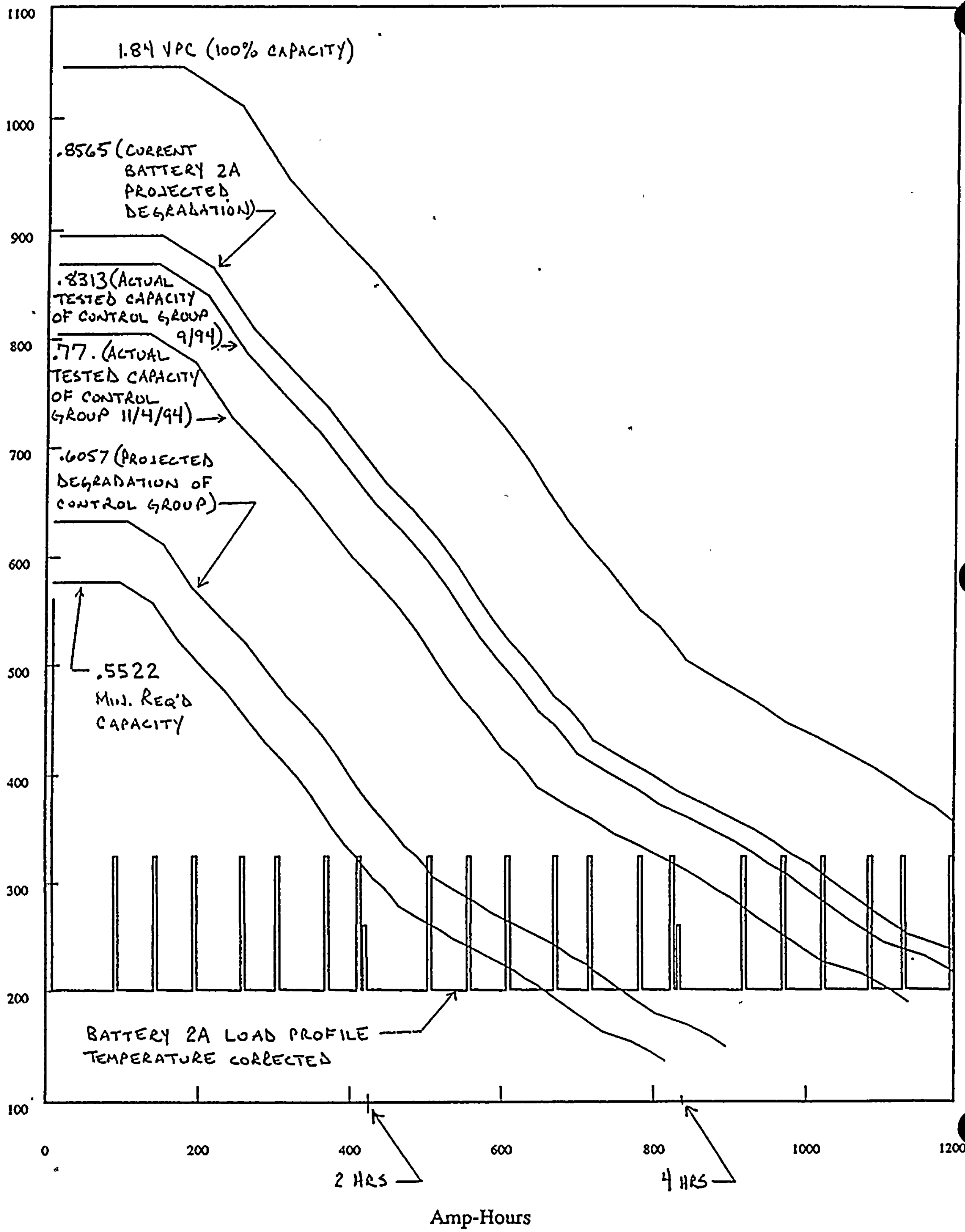
Date: November 3, 1994

ATTACHMENT 18

Projected Battery Degradation vs. Load Req.

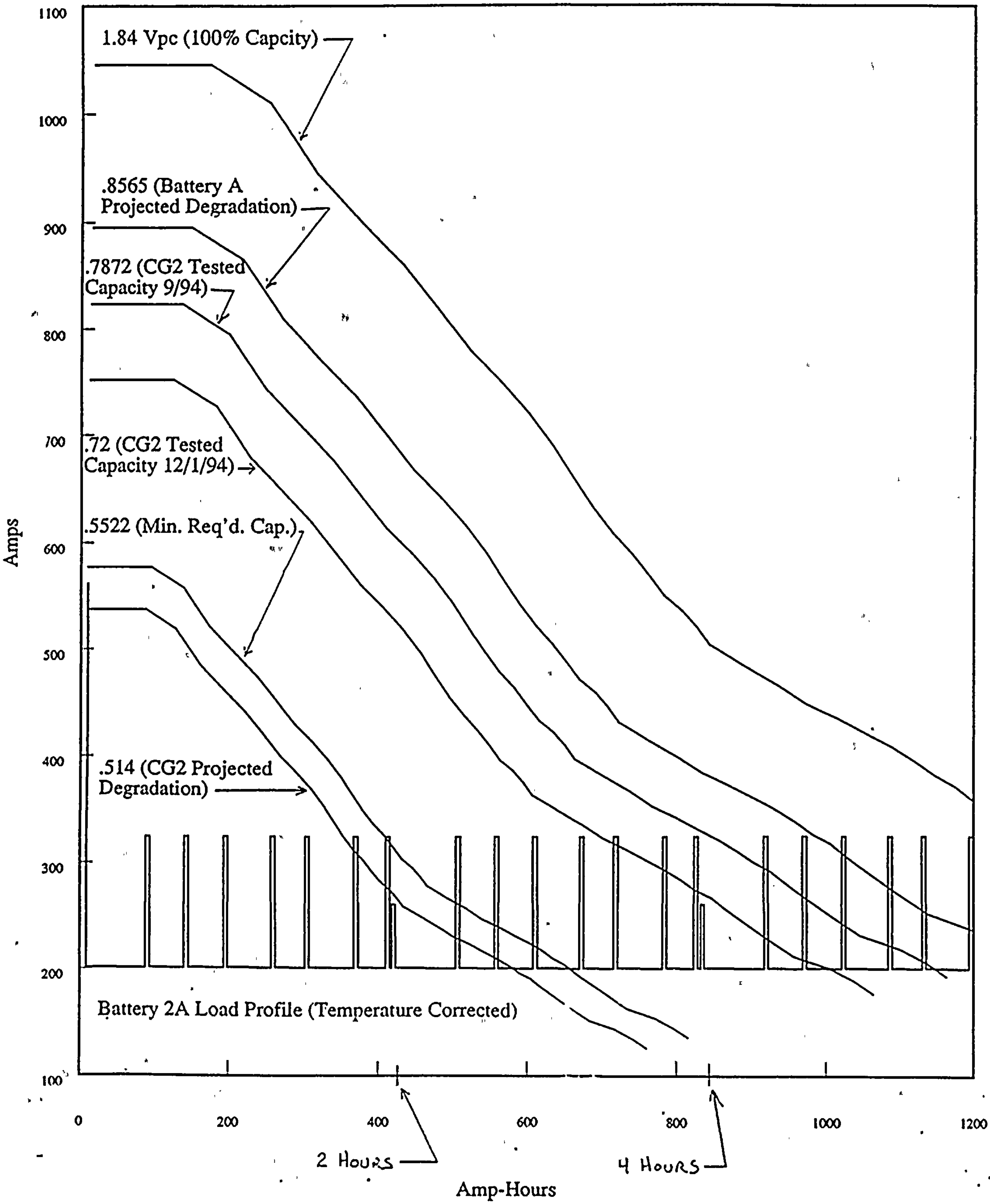
Actual Test Results vs. Load Requirements

Group 1



Projected Battery Degradation vs. Load Req.

Control Group 2 Test Results vs. Load Requirements



Projected Battery Degradation vs. Load Req.

Control Group 3 Test Results vs. Load Requirements