

WL-TR-95-2111

DEVELOPMENT OF A BIPOLAR LEAD/ACID
BATTERY FOR THE MORE ELECTRIC AIRCRAFT



JENNIFER L. ROSE

JOHNSON CONTROLS BATTERY GROUP, INC.
5757 NORTH GREEN BAY AVENUE
MILWAUKEE WI 53201-0591

SEPTEMBER 1995

FINAL REPORT FOR 09/01/91-09/30/95

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

19960703 024

AERO PROPULSION AND POWER DIRECTORATE
WRIGHT LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT PATTERSON AFB OH 45433-7650

DTIC QUALITY INSPECTED 1

DISCLAIMER NOTICE



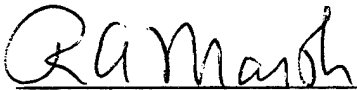
THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

NOTICE

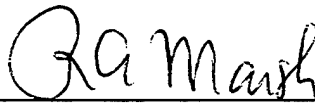
When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.



R.A. MARSH
Project Engineer



R.A. MARSH, Chief
Battery Electrochemistry Section
Power Technology Branch



MICHAEL D. BRAYDICH, Lt Col, USAF
Chief, Aerospace Power Division

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify WL/POOS-2, WPAFB, OH 45433-7251 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE SEPTEMBER 1995	3. REPORT TYPE AND DATES COVERED FINAL REPORT FOR SEP 91 to SEP 95		
4. TITLE AND SUBTITLE DEVELOPMENT OF A BIPOLAR LEAD/ACID BATTERY FOR THE MORE ELECTRIC AIRCRAFT		5. FUNDING NUMBERS CONTR: F33615-91-C-2142 P.E. 62203F PROJ #: 3145 TASK #: 29 WORK UNIT #: L5		
6. AUTHOR(S) JENNIFER L. ROSE				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) JOHNSON CONTROLS BATTERY GROUP, INC. 5757 N. GREEN BAY AVENUE MILWAUKEE, WI 53201-0591		8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AERO PROPULSION AND POWER DIRECTORATE WRIGHT LABORATORY AIR FORCE MATERIEL COMMAND WRIGHT PATTERSON AFB, OH 45433-7650		10. SPONSORING/MONITORING AGENCY REPORT NUMBER WL-TR-95-2111		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report summarizes the development work completed under contract F33615-91-C-2142 for the time period of September 1991 to September 1995. Initial work targeted the development of a filled polymeric composite substrate for use in a true bipolar lead acid battery. Efforts were refocused on metallic substrate technology in Month 33, and concluded with the delivery of battery systems to Wright Laboratory.				
14. SUBJECT TERMS BIPOLAR BATTERY DUPLEX ELECTRODE ELECTRODE SUBSTRATE			15. NUMBER OF PAGES 87	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR	

TABLE OF CONTENTS

1.0 SUMMARY	1
2.0 WORK BREAKDOWN STRUCTURE	2
3.0 COMPOSITE SUBSTRATE DEVELOPMENT	
3.1 WBS 1.0 Program Management	
3.1.1 Subtask 1.1 Managing Strategy	4
3.2 WBS 2.0 Battery Design	
3.2.1 Subtask 2.1 Battery System Design Analysis	4
3.3 WBS 3.0 Bipolar Plate	
3.3.1 Subtask 3.1 Conductive Fillers.....	4
3.3.2 Subtask 3.2 Substrate Fabrication Processes.....	19
3.3.3 Subtask 3.3 Stability Testing.....	21
3.3.4 Subtask 3.4 Proof of Concept Testing.....	21
3.4 WBS 5.0 Battery Fabrication	
3.4.1 Subtask 5.1 Sealing Methods	23
4.0 METALLIC SUBSTRATE DEVELOPMENT	
4.1 WBS 1.0 Program Management	
4.1.1 Subtask 1.1 Managing Strategy	26
4.2 WBS 2.0 Battery Design	
4.2.1 Subtask 2.1 Battery System Design Analysis	26
4.3 WBS 3.0 Bipolar Plate	
4.3.1 Subtask 3.1 Multialloy Substrate Development.....	26
4.3.2 Subtask 3.2 Rolling/Embossing Work	30
4.3.3 Subtask 3.3 Substrate Corrosion Testing	31
4.3.4 Subtask 3.4 Small Scale Characterization	31
4.4 WBS 4.0 Battery Components	
4.4.1 Subtask 4.2 Active Material Development.....	33
4.5 WBS 5.0 Battery Fabrication	
4.5.1 Subtask 5.1 Sealing Methods	33
4.5.2 Subtask 5.2 Formation.....	37
4.6 WBS 6.0 BMET Demonstration	
4.6.1 Subtask 6.1 Deliverables	38
4.6.1.1 24-Volt Injection Molded Containment Trials.....	38
4.6.1.2 Gasketed Containment	41
APPENDICES	
A. Resistivity Testing	44
B. Deliverable Data	78

LIST OF FIGURES

Figure 1	BMET Work Breakdown Schedule	3
Figure 2	Composite Development: Gantt Chart with Milestones	5
Figure 3	Near- and Far-Term BMET Bipolar Battery Projections	6
Figure 4	Near-Term System Performance and Specifications	7
Figure 5	Far-Term System Performance and Specifications	8
Figure 6	Main Engine Starting: Chemset vs F2 Active Materials	9
Figure 7	Main Engine Starting: Performance as a Function of Temperature	10
Figure 8	Ground Power: Chemset vs F2 Active Materials	11
Figure 9	Ground Power: Performance as a Function of Temperature	12
Figure 10	Ground Power: Capacity as a Function of Temperature.....	13
Figure 11	APU Starting: Chemset vs F2 Active Materials	14
Figure 12	APU Starting: Performance as a Function of Temperature	15
Figure 13	Emergency Power: Chemset vs F2 Active Materials	16
Figure 14	Emergency Power: Performance as a Function of Temperature	17
Figure 15	Stability Test Fixture	22
Figure 16	Composite Battery Builds.....	24
Figure 17	No-Cost Time Extension Gantt Chart.....	27
Figure 18	No-Cost Time Extension Deliverable Gantt Chart	28
Figure 19	Constant Power Performance Projections: Metallic Substrate Bipolar	29
Figure 20	Constant Power Performance Normalized to Mass and Volume	32
Figure 21	Small Scale Characterization: Capacity Development	34
Figure 22	Small Scale Characterization: Peukert.....	35
Figure 23	Small Scale Characterization: Ragone.....	35
Figure 24	Small Scale Characterization: Discharge Time vs Power	36
Figure 25	Voltage Drop Across Intermodule Connector Candidate Materials.....	42

1.0 SUMMARY

A 36-month contract was undertaken by Johnson Controls Battery Group, Inc. to develop a highly conductive, non-porous, and lightweight bipolar substrate and deliver a 56-volt prototype module for evaluation for the More Electric Aircraft. Eighteen months into Contract #F33615-91-C-2142, significant accomplishments were reported in the identification of suitable composite materials and in optimizing the compounding parameters of same. Laminated, 8 cm (L) x 8 cm (H) x 0.102 cm (TH) substrates with an overall resistivity of 4-6 Ω -cm were routinely manufactured in-house and used in battery builds. Over 150 cycles were demonstrated to 100% DOD at 0.16 A/cm² in a 4-volt battery configuration. Mass production oriented container molding was also demonstrated, however, process reliability was a major concern. Critical evaluation of the project in Month 33 recognized the difficulties in addressing recurrent substrate and paste adhesion delamination, as well as those to be solved in achieving high power (0.48+ A/cm²) capability from a 400+ cm² electrode. High power capability from a composite substrate was not deemed likely in the remaining contract period. Therefore, given its success in a parallel internally funded bipolar program, JCBGI requested a no-cost time extension to evaluate a new approach in metallic bipolar substrate technology. Five attempts were made at cladding strips of various corrosion resistant alloys, however, resultant materials were never suited to pasting or battery builds. Concurrent efforts to redesign the injection molded container succeeded in eliminating internal distortion of the metallic electrodes, but failed to resolve cell-to-cell leakage around the fill ports. At contract's end, deliverables utilizing a binary lead alloy and an alternative containment design were assembled, formed and delivered to WPAFB for test and evaluation.

Future composite bipolar substrate investigations based upon this body of work should focus on fostering positive paste adhesion. Continued metallic substrate work would benefit most from efforts to increase the substrate strength and corrosion resistance. Both designs require additional development of the injection molded containment concept to eliminate the catastrophic cell-to-cell leakage exhibited at the close of this contract.

2.0. WORK BREAKDOWN SCHEDULE

As with other contract work performed at JCBGI, a Work Breakdown Schedule (WBS) was implemented to plan, execute, and monitor technical progress, costs, and scheduling. Tasks were identified as unitary efforts necessary to complete individual aspects of battery development, and subtasks further delineated each task. Composite plans, shown in Figure 1, were easily translated in August 1994 to more closely describe the efforts necessary to assemble a 24-volt bipolar battery utilizing metallic based substrates. These interpretations are shown in parentheses next to the composite substrate counterparts within Figure 1.

FIGURE 1: BMET WORK BREAKDOWN SCHEDULE

WBS 1.0 PROGRAM MANAGEMENT

- Subtask 1.1 Managing Strategy
- Subtask 1.2 Liaison/Meetings
- Subtask 1.3 Documentation
- Subtask 1.4 Contract Administration
- Subtask 1.5 Operating Supplies

WBS 2.0 BATTERY DESIGN

- Subtask 2.1 Battery System Design Analysis
- Subtask 2.2 Performance Modeling

WBS 3.0 BIPOLAR PLATE

- Subtask 3.1 Conductive Fillers (Multi-Alloy Substrate Development)
- Subtask 3.2 Substrate Fabrication Processes (Rolling/Embossing Work)
- Subtask 3.3 Stability Testing (Corrosion Testing)
- Subtask 3.4 Proof of Concept Testing (Small Scale Characterization)

WBS 4.0 BATTERY COMPONENTS

- Subtask 4.1 Separator Material
- Subtask 4.2 Active Material Development (Freeze/Thaw Work)

WBS 5.0 BATTERY FABRICATION

- Subtask 5.1 Sealing Methods (Lead to Plastic Interface Seal)
- Subtask 5.2 Formation

WBS 6.0 BMET DEMONSTRATION

- Subtask 6.1 Battery Fabrication (Deliverables)
- Subtask 6.2 Testing (Group 34 Cycling)

3.0 COMPOSITE SUBSTRATE DEVELOPMENT

3.1 WBS 1.0 PROGRAM MANAGEMENT

3.1.1 Subtask 1.1 Managing Strategy

Five review meetings were scheduled and attended by WPAFB and JCBGI personnel. These dates, as well as milestones achieved during the composite development phase of the contract, are shown in Gantt chart form in Figure 2.

3.2 WBS 2.0 BATTERY DESIGN

3.2.1 Subtask 2.1 Battery System Design Analysis

Preliminary performance requirements for the More Electric Aircraft (MEA) energy source were given to JCBGI by Richard Flake of WPAFB during the program kickoff meeting on December 12, 1991. The following energy sources were required:

Main Engine Starting:	150 kW, 30 sec
Ground Power:	25-75 kW, 30-45 min
Emergency Power:	75 kW, 10 min
APU Starting:	5-10 kW, 15 sec
Hybrid Emergency:	50-75 kW, 60 sec
Temperature Range:	-65°F to 120°F
Voltage Window:	270 volts (min), 330 volts (max)

Given this, JCBGI proceeded to use its proprietary lead/acid battery mathematical model to design near- and far-term bipolar systems having 5- and 10- year development time frames. Near-term modeling assumed that substrate program goals were reached and conventional active materials were used. The 10-year battery systems were projected assuming a thinner, more conductive substrate and improved active materials. The results, shown in Figures 3 through 14, dramatically illustrate the system configuration's dependence on application. Designs required as little as 0.18 ft³ with a system mass of 33 pounds to as much as 8.13 ft³ and 1349 pounds.

3.3 WBS 3.0 BIPOLAR PLATE

3.3.1 Subtask 3.1 Conductive Fillers

Initial work was focused on identifying an electronically conductive, filled polymeric composite having negligible ionic conduction which could short adjacent cells. The substrate was likewise required to be chemically inert to the electrode reactions, to have high oxygen and hydrogen overpotentials in H₂SO₄, and to be readily manufactured.

FIGURE 2: Composite Development Gantt Chart with Milestones

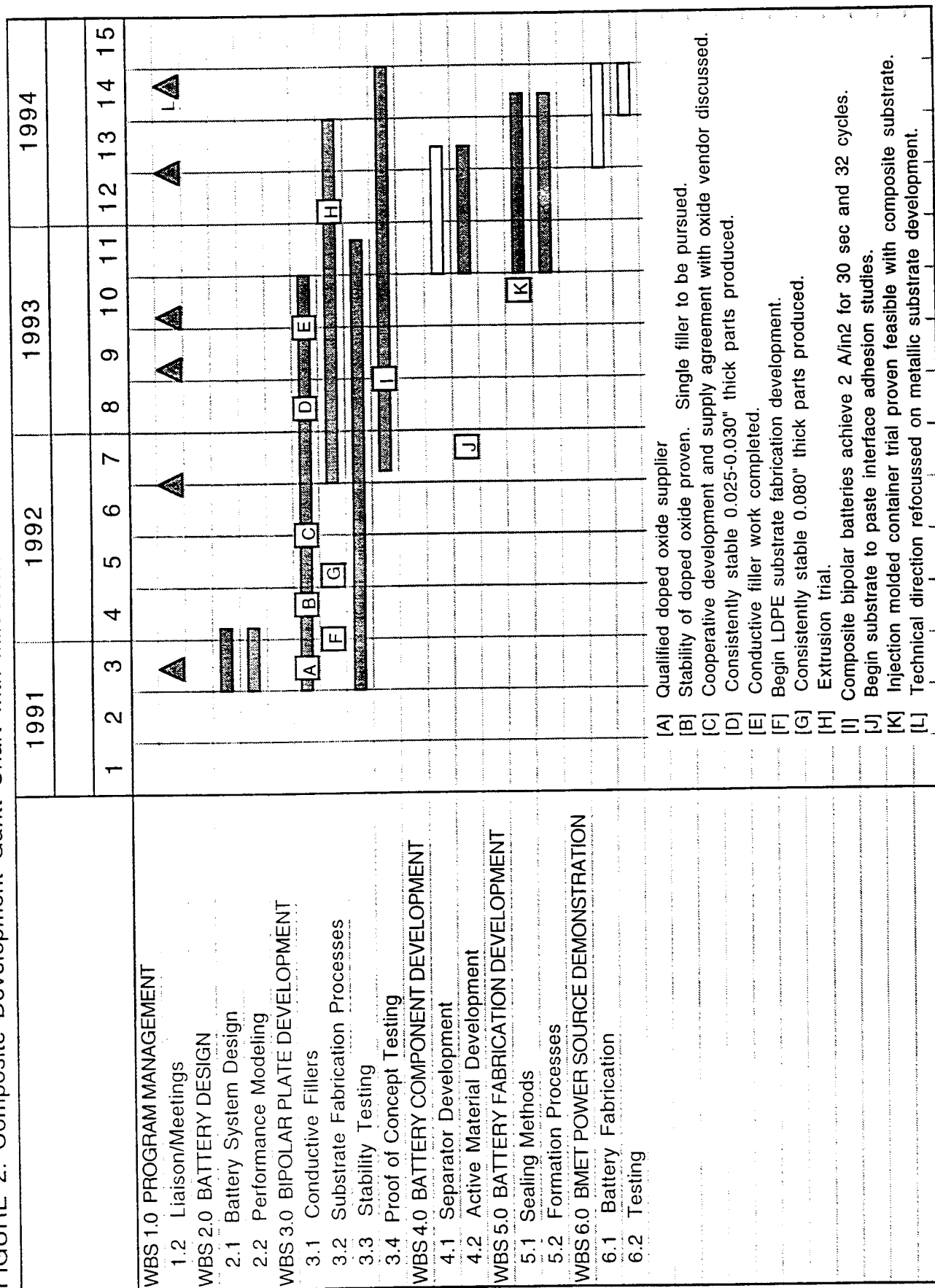


FIGURE 3

NEAR AND FAR TERM BMET BIPOLAR BATTERY SPECIFICATIONS

<u>BATTERY TYPE</u>	<u>NEAR TERM</u>	<u>FAR TERM</u>
Main Engine Starting		
Mass	450 lbs.	389 lbs.
Volume	2.45 ft³	2.00 ft³
Ground Power		
Lower Capacity Unit		
Mass	1000 lbs.	865 lbs.
Volume	6.15 ft³	4.85 ft³
Higher Capacity Unit		
Mass	1349 lbs.	1235 lbs.
Volume	8.13 ft³	6.72 ft³
APU Starting		
Mass Volume	33.4 lbs.	30.6 lbs.
Volume	0.18 ft³	0.16 ft³
Assumptions:		
Substrate Thickness	0.025"	0.010"
Substrate Weight	150 mg/cm²	80 mg/cm²
Substrate Resistivity	2.0 Ω-cm	$\sim$0 Ω-cm

FIGURE 4

**BMET PERFORMANCE REQUIREMENTS
BIPOLAR BATTERY SPECIFICATIONS**
Near Term Projections (within 5 years)
330 Volt Battery Systems

REQUIREMENTS MET	BATTERY DIMENSIONS	BATTERY VOLUME	BATTERY WEIGHT	W/kg	W/cm3	W-hr/kg	W- hr/cm3
Main Engine Starting APV Starting Hybrid Emergency	17.6"x15.5"x15.5"	2.45 ft3	450 lbs	747.9	2.2	12.25	0.036
Main Engine Starting Ground Power Emergency Power APU Starting Hybrid Emergency							
Scenario 1 30 minute ground power capacity	27.4"x19.7"x19.7"	6.15 ft3	1000 lbs	62.2	0.16	31.08	0.081
Scenario 2 45 minute ground power capacity	36.2"x19.7"x19.7"	8.13 ft3	1349 lbs	46.1	0.12	34.56	0.092
APU Starting	16.5"x4.33"x4.33"	0.18 ft3	33 lbs	705.0	2.1	11.75	0.036

FIGURE 5
 BMET PERFORMANCE REQUIREMENTS
 BIPOLAR BATTERY SPECIFICATIONS
 Far Term Projections (10 years)
 330 Volt Battery Systems

REQUIREMENTS MET	BATTERY DIMENSIONS	BATTERY VOLUME	BATTERY WEIGHT	W/kg	W/cm3	W-hr/kg	W- hr/cm3
Main Engine Starting APV Starting Hybrid Emergency	14.4"x15.5"x15.5"	2.00 ft3	389 lbs	895.3	2.8	14.17	0.044
Main Engine Starting Ground Power Emergency Power APU Starting Hybrid Emergency							
Scenario 1 30 minute ground power capacity	21.6"x19.7"x19.7"	4.85 ft3	864 lbs	72.0	0.21	35.97	0.103
Scenario 2 45 minute ground power capacity	29.9"x19.7"x19.7"	6.72 ft3	1235 lbs	50.6	0.15	37.77	0.111
APU Starting	15.2"x4.33"x4.33"	0.16 ft3	31 lbs	772.0	2.3	12.87	0.041

FIGURE 6
Comparison of Chemset and F2 Plates for
Main Engine Starting Battery

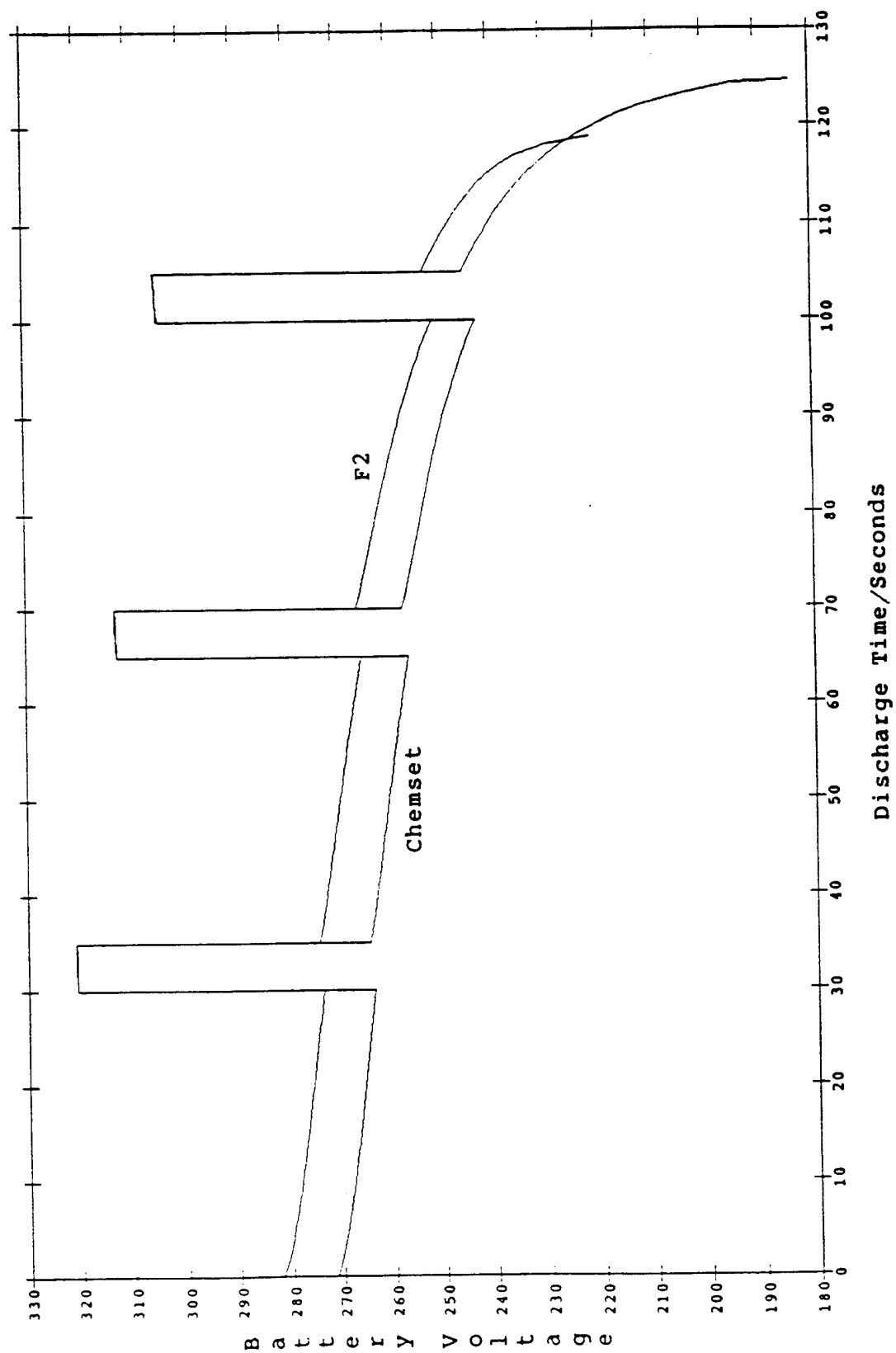


FIGURE 7
Effect of Temperature on Performance
of Main Engine Starting Battery

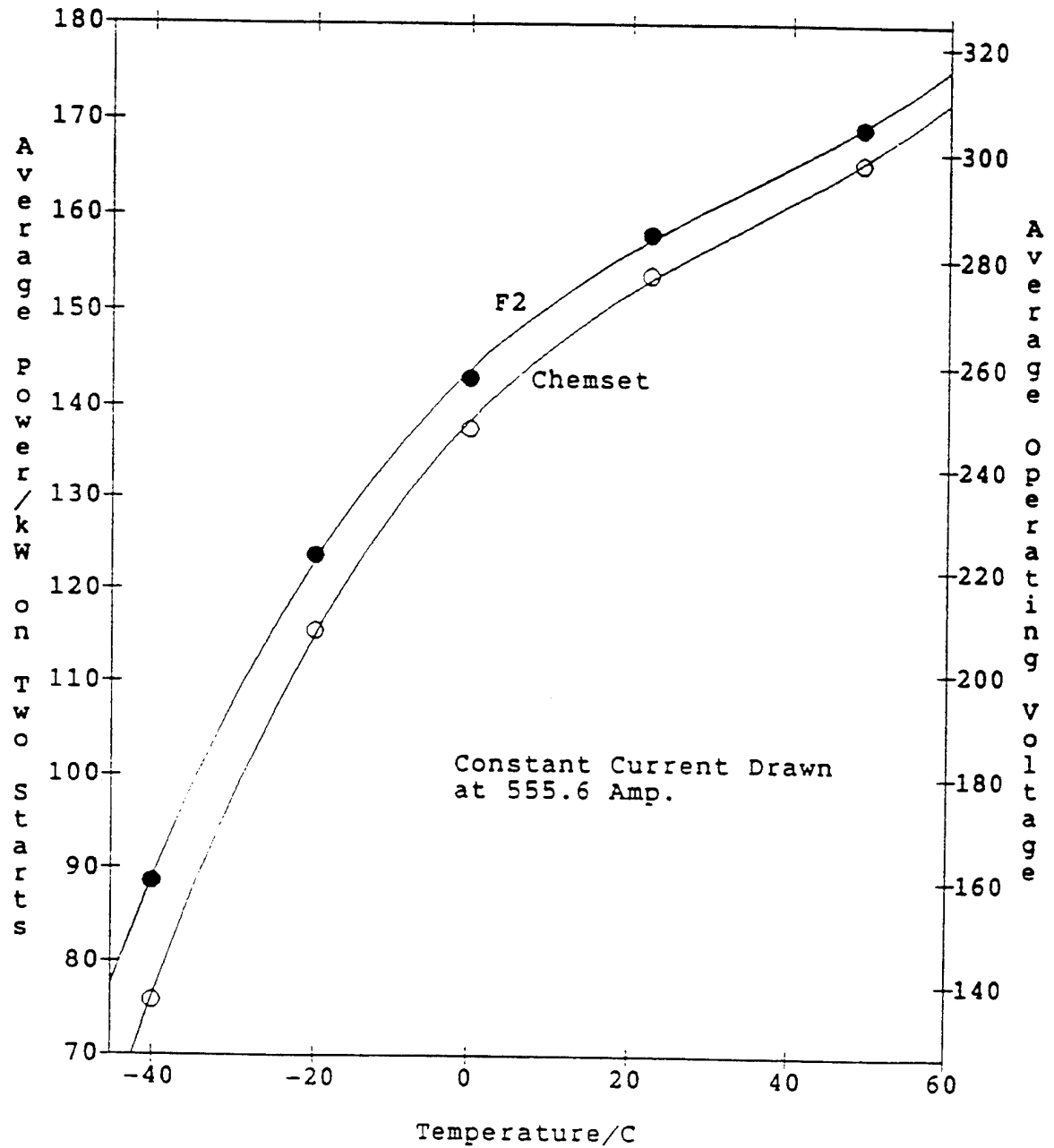


FIGURE 8
Comparison of Chemset and F2 Plates for
Ground Power Units

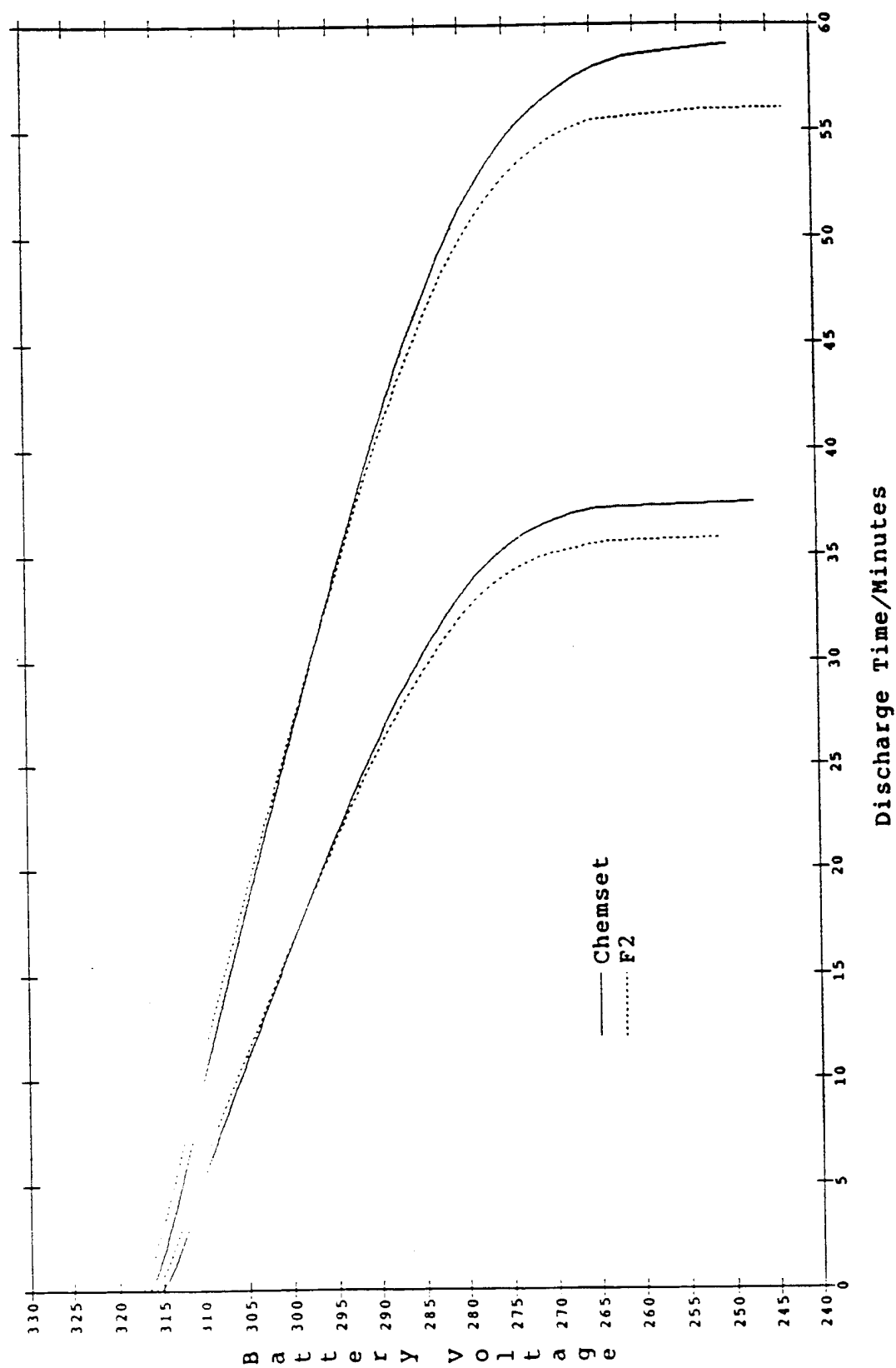


FIGURE 9
Effect of Temperature on Power Output
of the Ground Units

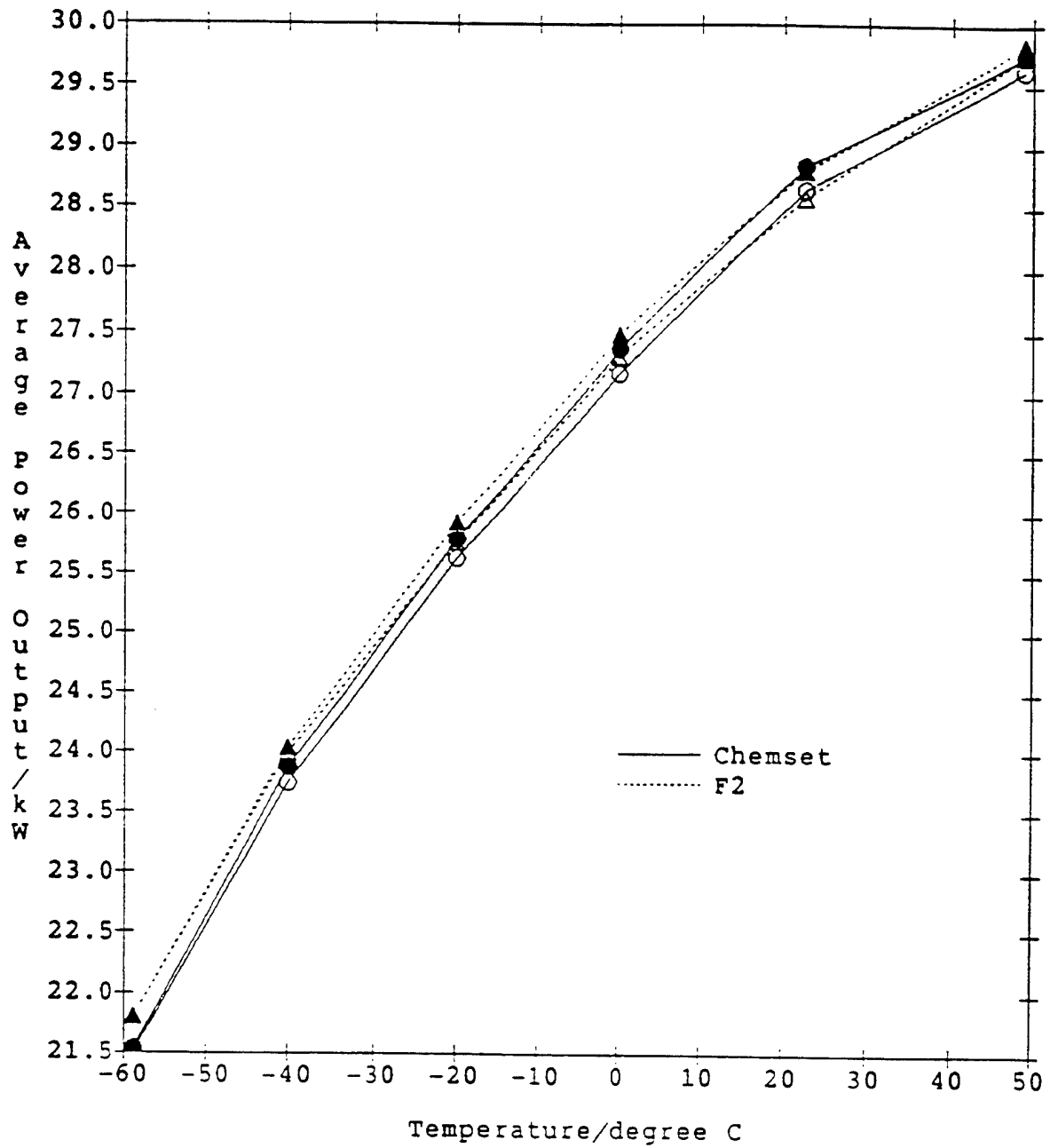


FIGURE 10
Effect of Temperature on Capacity of
the Ground Units

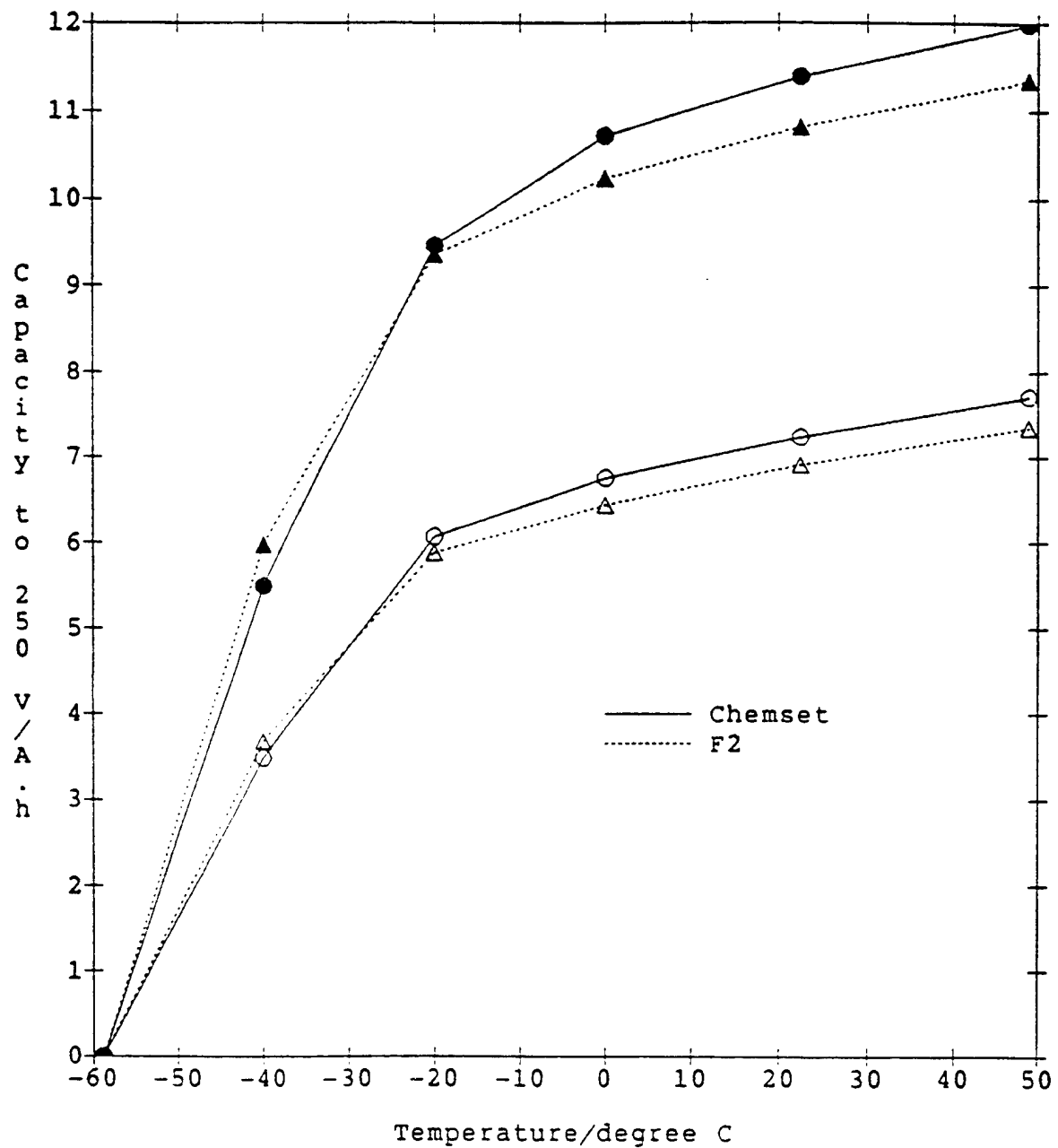


FIGURE 11
Comparison of Chemset and F2 Plates for
APU Starting Battery

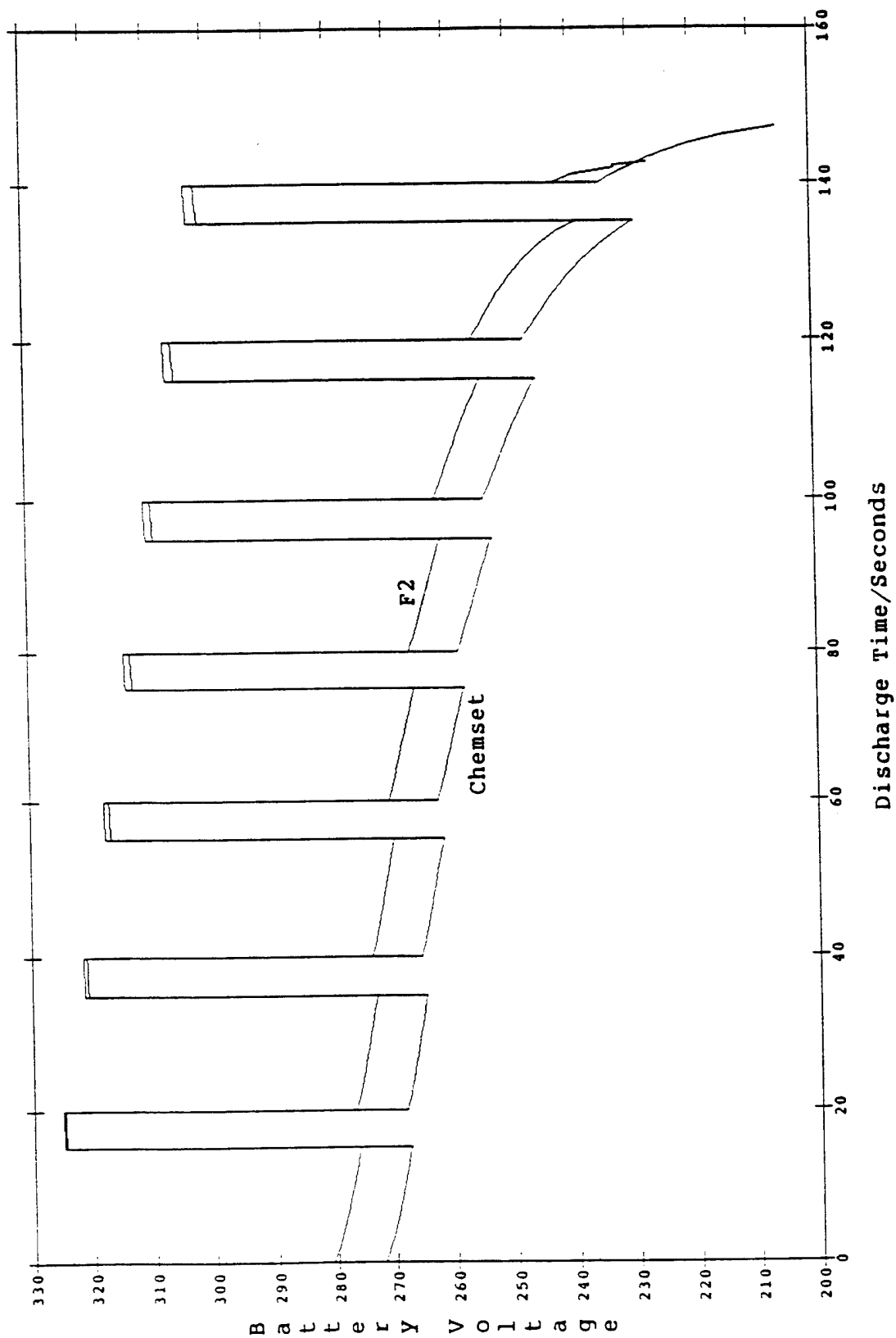


FIGURE 12
Effect of Temperature on Performance
of APU Starting Battery

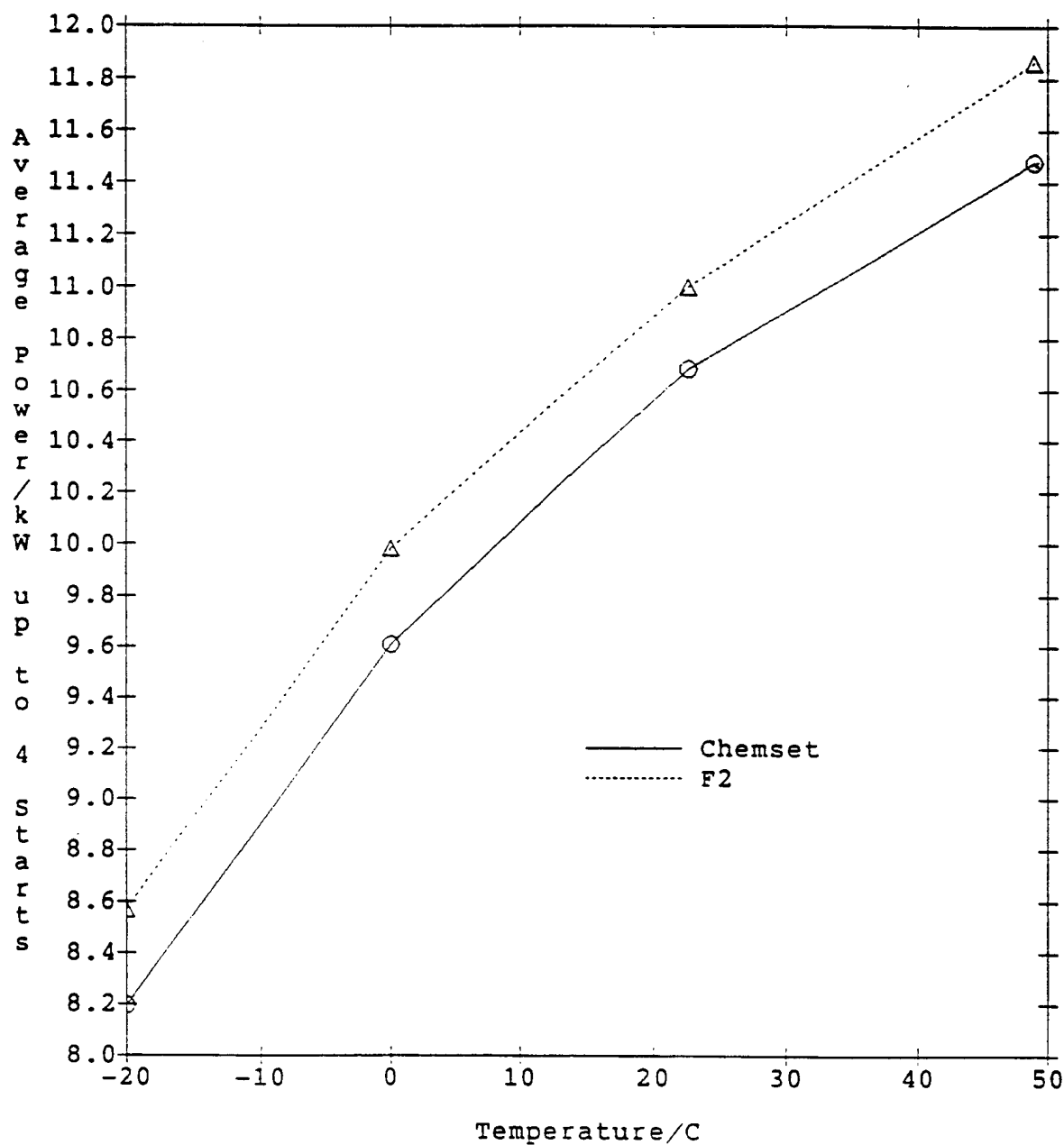


FIGURE 13
Comparison of Chemset and F2 Plates for
Emergency Power Unit

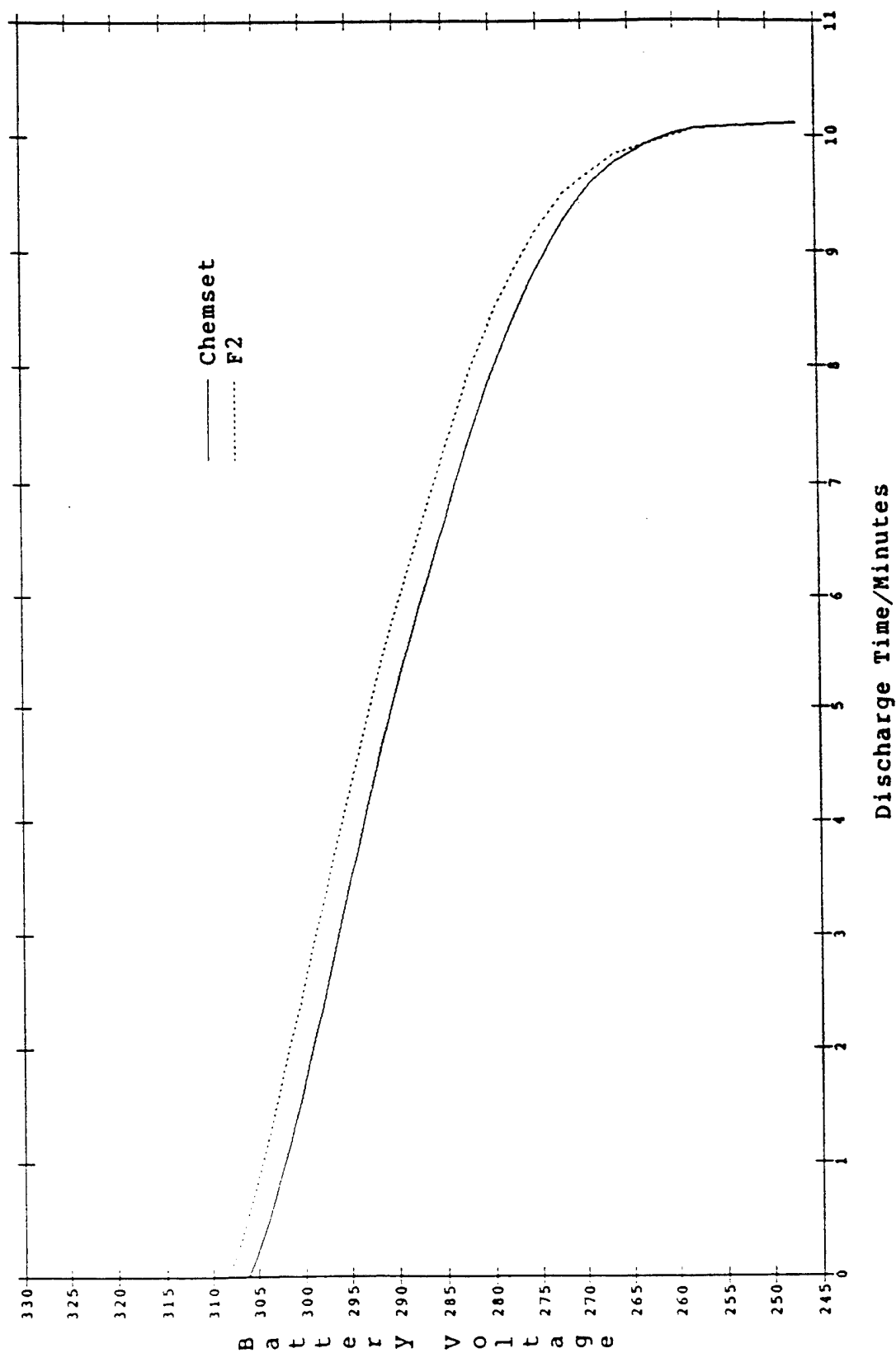
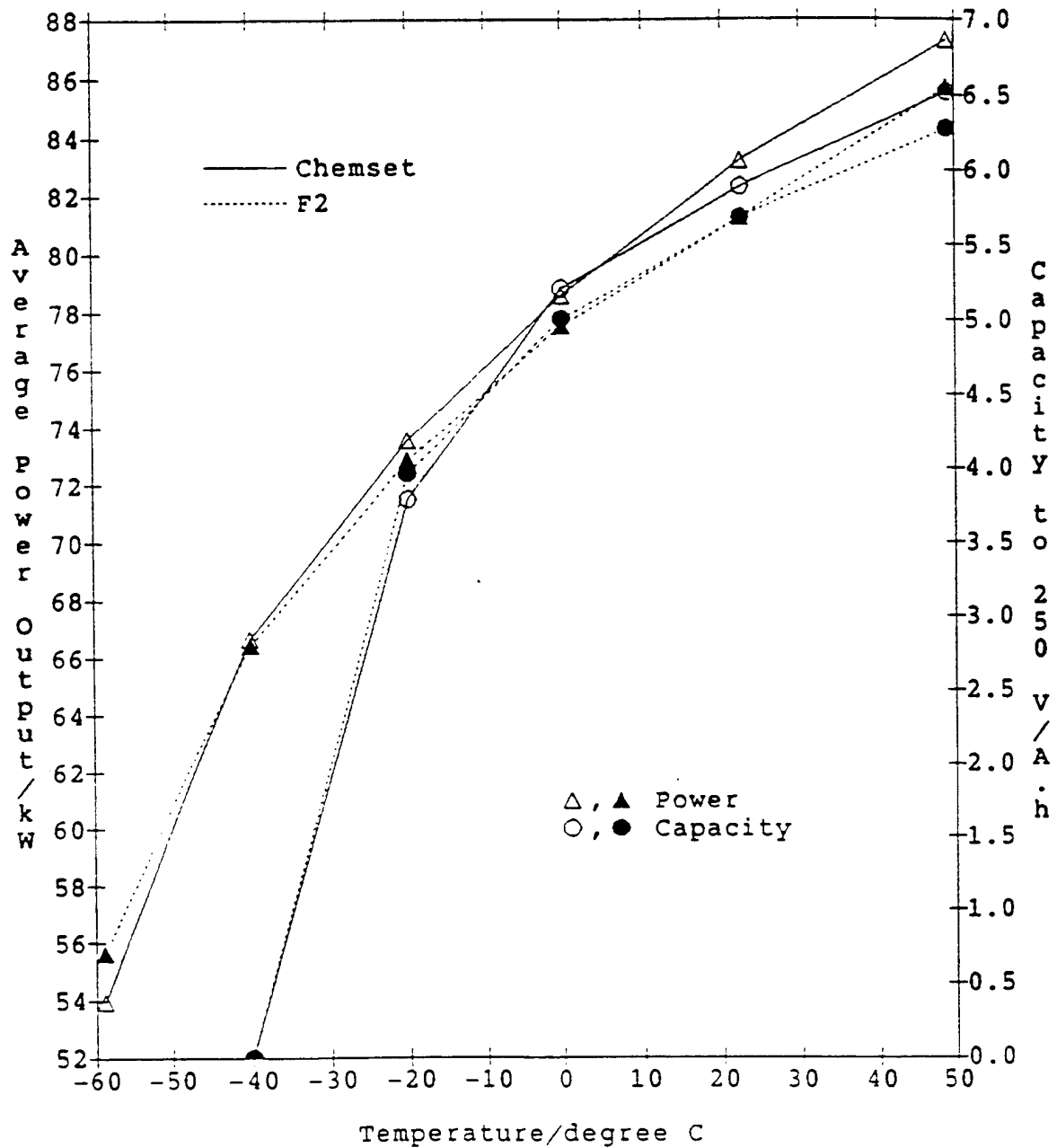


FIGURE 14
Effect of Temperature on Performance
of the Emergency Power Unit



Recognizing the recommendations from previous WPAFB work performed at JCBGI, conductive filler development resumed with further investigation of doped oxide. Coated glass fibers were also studied.

Initial work with Photon Energy Systems (PES) focused on coating doped oxide onto glass fibers. Four separate attempts were made with poor results. The first lot did not withstand the acid environment, and the second lacked uniformity and conductivity. Coated fibers from the third trial possessed no adhesion between the oxide and glass, hence were impossible to handle or compound into plastic. PES ultimately did coat 2-6" long fibers during a fourth trial, but was unable to supply the shorter lengths required for this application. Activity in this area was subsequently discontinued.

Efforts by Materials and Electrochemical Research, Inc. (MER) to produce a dense plaque of doped oxide met with similar difficulties. Prototype samples lost all conductivity and dissolved when put in contact with H_2SO_4 . A carbide compound was also provided, but found too resistive. No further attempts were made.

Two companies were next contacted for samples of doped oxide in powder form. Provided materials were extremely similar in particle size and appearance, and remained stable throughout acid leach testing. Replicate samples of 85% and 90% loaded plastic were then prepared. Measurements showed the oxide from Magnesium Elektron, Inc. (MEI) to be seven to fifteen times more conductive than that obtained from Crystal Research, Inc. (CRI). Throughout ensuing months, MEI recognized the product potential, entered into a joint development (JD) effort with JCBGI, and supplied over \$110,000 worth of oxide to JCBGI at no cost. Leftover material was returned per the appropriate clause in the JD. Additional oxides doped with other elements were prepared by MEI late in the contract, but shown highly resistive and unstable during JCBGI testing. MEI was also instrumental in providing compounding expertise that greatly expedited the development effort.

Particle size optimization was one such area in which MEI provided invaluable help. JCBGI initially believed that a smaller particle size (1 micron) would reduce porosity due to its being more easily wetted by the surrounding plastic resin. Trials using fines screened from the supplied material proved the contrary with regard to both conductivity and porosity. Resistivity readings increased twenty-fold. Discussions with MEI's compounding experts revealed that the use of uniformly shaped, ultrafine particles made it more difficult to achieve the needed particle-to-particle chain of contact through the thickness of the material, i.e. increased resistance. The smaller particle size also increased the available surface area at which pores could and did develop. All contract work was performed using particles roughly 3-5 microns in diameter. Use

of the estimated 10-20 micron optimum particle would have required an entirely different production method. Time and associated costs of the changeover were far beyond the scope of this program.

Subsequent electrical testing of the MEI material showed the doped oxide to lack stability at negative electrode potentials. This finding required doped oxide be used as a laminate in conjunction with a material better able to withstand the environment at the negative plate. Carbon black was immediately proposed as the ideal partner, having been previously identified as highly conductive, lightweight, readily available and stable at negative potentials during the first WPAFB contract. Compounding trials optimized the loading, resulting in highly conductive parts that were also very flexible.

Compounding descriptions and the corresponding conductivity measurements are provided as figures in the text.

3.3.2 Subtask 3.2 Substrate Fabrication Techniques

Given the limited batch size and trial-to-trial variability in hand compounding plastic and filler, resins were carefully chosen for study. These included low-density polyethylene (LDPE), fluoropolymer formulations (Kynar), polytetrafluoroethylene (PTFE), and high-density polyethylene (HDPE).

Given its use in prior WPAFB-sponsored work, initial efforts focused on LDPE and Microthene™ from Quantum Chemical Corporation was purchased. A powdered form was requested and received to facilitate uniform filler dispersion with minimum porosity. Dry mixing of the filler and resin was accomplished by hand using a mortar-and-pestle early on in the contract. This was later replaced by V-blending. The mixture was then melt blended in a twin screw extruder to produce pellets that were compression molded into sheet form. Early samples were thick (0.070") and used exclusively for proving the stability of the filler. After several successful resistivity tests, work was redirected on thinning the part and making it more conductive.

Another resin, PTFE, was investigated concurrently. Loadings from 70-75% produced highly conductive parts, however, these were also very porous. Investigations were undertaken with Imprex, Inc. to impregnate the porous parts under vacuum with a polycarbonate-based liquid resin to reduce the porosity without hindering the conductivity. PTFE development was stopped when samples were shown to have remained porous and become even more resistive following treatment.

Kynar was also explored for use as a base resin. The material showed initial promise, during producing conductive and nonporous material during hand compounding trials. However, the 375°C temperature needed to soften and melt the resin degraded the doped oxide. LDPE and Kynar blends resulted in conductive but highly porous material. Development in this area was discontinued given the successes with LDPE.

Additives were next employed to improve the physical properties of the substrate. Coupling agents, oils, acids, acetates and silicon compounds were each investigated in an attempt to improve part conductivity, reduce porosity, and/or improve manufacturing. Coupling agents, designed to bond the filler and surrounding base resin, offered the only quantifiable advantage. Of particular note was a coupling agent available through Kenrich Chemical, Incorporated. Additions substantially improved the resultant substrate's physical properties. Order of addition was also found critical to the end product. Greatest effectiveness was had in dry mixing with doped oxide prior to adding LDPE powdered resin.

Lastly, JCBGI investigated HDPE resin in an effort to widen the operating temperature range of the battery. Initial stability tests showed high porosity levels. Increasing the melt blend temperature produced stable parts. Development was halted in June 1994 when the program's technical direction was changed (see Section 4.0 - Metallic Substrate Development).

Alternative methods of producing sheet stock were also investigated. Molded Rubber and Plastics (MRP) and JCBGI teamed to design a vacuum compression mold to remove trapped gases and produce pore free parts. Unfortunately, samples exhibited physical properties no better than parts made in the conventional manner. Work was discontinued due to the prohibitive \$75/part cost and the large volume of material needed per trial (10+ pounds).

Skiving was no more successful. Thin rolls of doped oxide in Microthene™ were received from DeWal Industries in May 1993 for laminating and resistivity testing. Resultant laminates were 0.029-0.031" thick with resistivities in the range of 1.7-2.0 Ω-cm. Given the promise of the materials produced by DeWal's skiving process, JCBGI twice supplied additional compounded materials for processing into sheet. Doped oxide samples exhibited low initial porosities that increased as a result of the laminating process; the porosity of the carbon black material was never acceptable. Work with DeWal was subsequently discontinued.

Carbon-black development proceeded more quickly with the aid of JCBGI's zinc-bromine battery development program. Several different types of carbon-black were screened and a Ketjenblack material from Azko Chemical was chosen. Compounding trials identified an optimum carbon-black loading level that afforded parts with a conductivity of 1-1.6 ½-cm and enough flexibility to be used as a bipolar substrate.

Laminating the filled LDPE substrates was next addressed. Early laminates exhibited a resistivity higher than the sum of the constituent pieces due to the "skin" formed on the surface of each sheet when molded. Two methods of removing the "skin" were tried. The addition of carbon black at the interface prior to laminating proved effective, but difficult to perform in a uniform manner. The second and adopted method required gentle sanding of the skinned surfaces with sandpaper. Sanding prior to lamination resulted in a 50-75% reduction in part resistivity and no effect on part stability.

3.3.3 Subtask 3.3 Stability Testing

The procedure and fixture for quantifying a bipolar substrate's stability in acid and under potential were developed at JCBGI over many years. Both three- and four-point tests were required to evaluate a sample's viability.

As shown in Figure 15, a substrate sample was clamped between two hollowed polycarbonate endblocks, exposed to electrolyte, and wired as the working electrode. A potential of 1.5 volts was applied and the current collected at the top of the substrate in the three-point system. After 24 hours on test to establish a baseline current, the leads were rearranged to collect current after passing through the substrate, i.e., the four-point test. The test continued for a minimum of 3 additional days. No change in the current acceptance established the sample to be nonporous. A rising current suggested porosity or filler instability. Detailed stability results are provided in Appendix B.

Conductivity before and after the three- and four-point regimen was also monitored. An increase of 20% or more signalled porosity or filler instability. Since doped oxide had been successfully tested, an increase in resistivity was interpreted as increasing porosity, i.e., carbon-black was exposed to the positive potential as a result of the porosity causing the carbon-black to oxidize and become nonconductive.

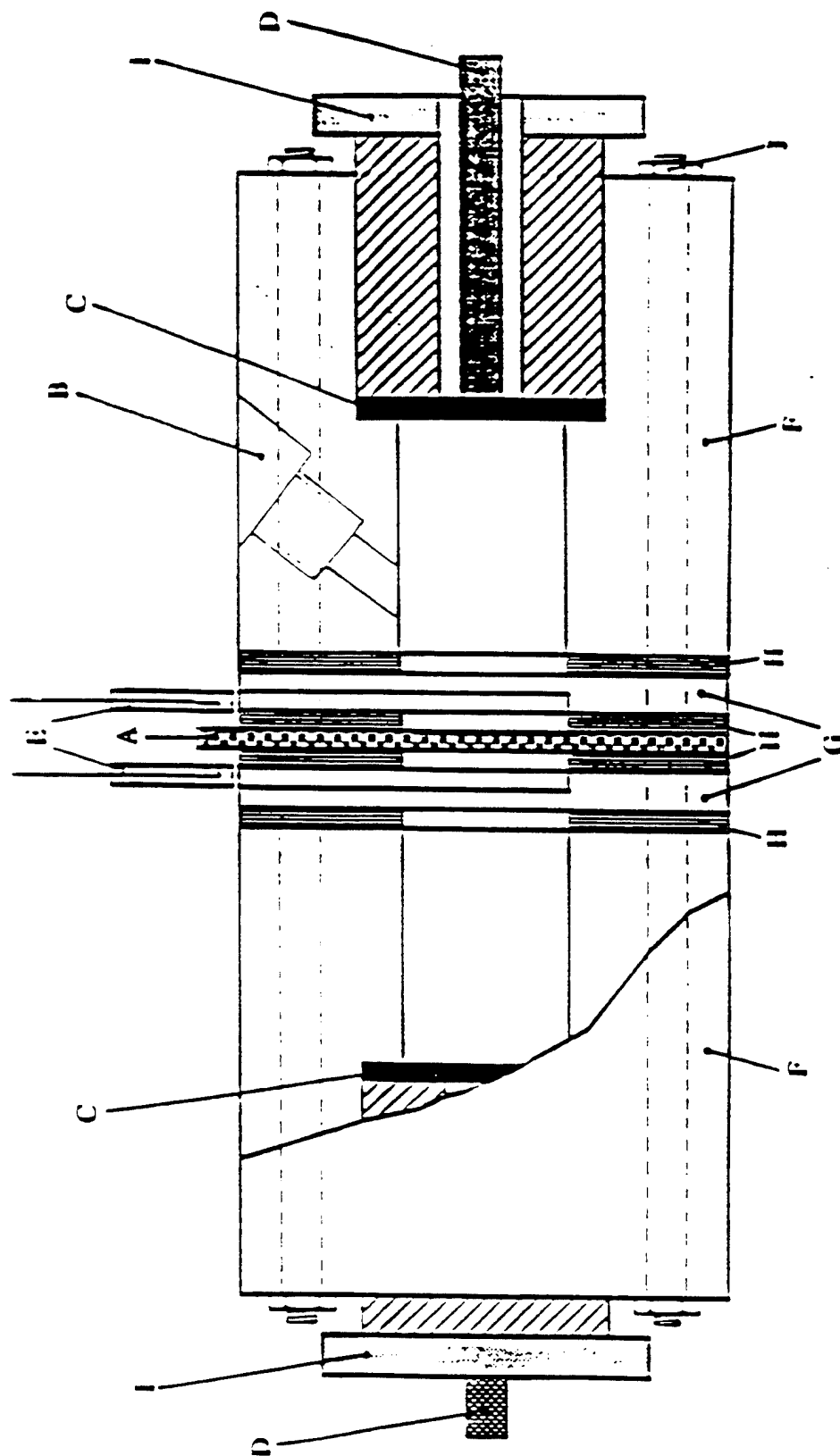
3.3.4 Subtask 3.4 Proof of Concept Testing

Over 60 batteries of various voltages were assembled and tested. Dry, unformed electrodes with 10 in² active areas were alternately stacked with elastomeric spacers and compressed to dimension between 0.5" thick polycarbonate end plates. Insulated bolts positioned around the perimeter of the fixture were easily tightened to compress the gaskets to affect hermetic cell seals. Absorptive glass mat separator was placed between opposing electrodes and filled with electrolyte through channels machined across the upper portion of each

FIGURE 15

Stability Test Fixture

- | | |
|-------------------------------|------------------------------|
| A. Bipolar Substrate | F. Lexan Block |
| B. Reference Electrode Socket | G. Spacer with Sensor Socket |
| C. Counter Electrode | H. Gasket |
| D. Current Collector | I. Counter Electrode Bushing |
| E. Resistance Sensor | J. Clamping Hardware |



gasket. Discharge performance routinely surpassed 5 minutes at 1 A/in², but with limited cycle life.

Laminate and positive paste adhesion were the ultimate issues and numerous approaches were investigated in attempts to foster them. Techniques included roughening the pasted surface with various grit sandpaper, embedding fibers, sintering lead dust or oxide powder onto the active areas, flame spraying lead, pretreating the plastic to increase its wettability. A review of the battery build sequence, documented in Figure 16, quickly shows that any battery formed without the use of lead sheet could not be tested due to high internal resistances caused by poor paste adhesion.

The major breakthrough occurred upon recognizing the special needs of polyolefins. Involved surface pretreatments are recognized as necessary to achieve bonds with wax-like surfaces that are difficult to wet if left alone. Surface treating LDPE prior to attaching a layer of thin lead foil decreased the part resistivity by 50-75%. Over 150 cycles were demonstrated with shorting as the cause of failure. Subsequent builds neared this benchmark, however, lead foil delamination became a recurring problem. Substrate conductivities checked prior to pasting and after cycling showing no change added to the confusion. Treatment parameters were reviewed and found incorrect, resulting in delamination *within* the plastic part. Optimization trials were initiated, along with investigations of HDPE resin. HDPE was proven to bond more strongly to lead sheet, but the resulting cycle life was still unacceptable. Efforts were halted with the change in the program's technical direction.

3.4 WBS 5.0 BATTERY FABRICATION

3.4.1 Subtask 5.1 Sealing Methods

Two 10-volt batteries were produced using an injection molded containment method in October 1993. Electrodes, separators and spacer frames were arranged to form a stack that was inserted into a cavity for molding. Plastic injected into the mold formed a frame around the entire stack to provide the necessary sealing and spacing requirements, as well as provisions for acid fill.

Electrode quality within each 10-volt stack was poor due to the required part size. Length and width exceeded the working area of the press. Pieces were 0.080" thick and highly resistive (10 Ω -cm). Cross sectioning of one dry, unformed (DUF) stack showed complete plastic fill and no electrode distortion. Confirmation of hermetic cell-to-cell sealing was never

FIGURE 16
Composite Battery Builds

ID	Volts	Adhesion Method	Cycles	Cause of Failure
159	4	Lead dust	32	Lack of paste adhesion
159-B	4	Lead dust	15	Lack of paste adhesion
160	4	Lead dust	15	Lack of paste adhesion
182-1	4	Lead dust	5	PbSO ₄ at surface
182-2	4	Sanded surface	5	Lack of paste adhesion
182-3	4	Lead dust	5	PbSO ₄ at surface
182-4	4	Sanded surface	5	Lack of paste adhesion
194-3A	4	Embedded 0.003" glass mat	0	PbSO ₄ at surface
194-4A	4	Embedded 0.003" glass mat	0	PbSO ₄ at surface
194-3A	4	Finely sanded surface	0	PbSO ₄ at surface
194-4A	4	Finely sanded surface	0	PbSO ₄ at surface
205-1	4	0.001" perforated lead foil	18	Lack of paste adhesion
205-2	4	0.001" perforated lead foil	18	Lack of paste adhesion
205-3	4	0.001" lead foil	19	Lack of paste adhesion
205-4	4	0.001" lead foil	14	Lack of paste adhesion
214-1	4	0.010" lead foil over treated surface	18	Leak, cracked substrate
214-4	4	0.010" lead foil	21	Lead foil delamination
214-5	4	0.010" lead foil	45	One very dry cell
214-6V	6	0.010" lead foil over treated surface	47	Lead foil delamination
218-1	4	Carbide fibers	2	Too resistive to cycle
218-2	4	Carbide fibers	2	Too resistive to cycle
224-4	4	0.010" lead foil over treated surface	151	Shed PAM, shorting
224-5	4	0.010" lead foil over treated surface	104	Lead foil delamination
241-2	4	Flame sprayed lead	0	High IR, no AM adhesion
242	12	0.005" lead foil over treated surface	15	Lead foil delamination
242-4	4	Paste over treated surface	0	High IR, no AM adhesion
243-6V	6	0.005" lead foil over treated surface	12	Lead foil delamination
257	12	0.005" lead foil over treated surface	8	Lead foil delamination
259	12	0.005" lead foil over treated surface	0	Lead foil delamination
260-2	4	0.005" lead foil over treated surface	19	Lead foil delamination
263	6	0.005" lead foil over treated surface	9	Lead foil delamination
265	6	0.005" lead foil over treated surface	4	Crack, leak, delamination
267-1C	4	0.005" lead foil over treated surface	15	Lead foil delamination
267-4P	4	0.005" lead foil over treated surface	135	Local lead foil delamination
267-5P	4	0.005" lead foil over treated surface	13	Local lead foil delamination
267-6VP	6	0.005" lead foil over treated surface	33	Local lead foil delamination
267-6P	4	0.005" lead foil over treated surface	18	Local lead foil delamination
267-8C	4	0.005" lead foil over treated surface	20	Local lead foil delamination
267-9P	4	0.005" lead foil over treated surface	20	Local lead foil delamination
267-11C	6	0.005" lead foil over treated surface	11	Local lead foil delamination
268-6VC	6	0.005" lead foil over treated surface	11	Local lead foil delamination
268-8C	4	0.005" lead foil over treated surface	9	Local lead foil delamination
268-10C	4	0.005" lead foil over treated surface	68	Local lead foil delamination
268-11C	4	0.005" lead foil over treated surface	135	Local lead foil delamination
268-12C	12	0.005" lead foil over treated surface	15	Lead foil delamination
277-1C	4	0.005" lead, treated surface, acid dip	2	Local lead foil delamination
277-2C	4	0.005" lead, treated surface, acid dip	4	Local lead foil delamination
277-6VC	6	0.005" lead, treated surface, acid dip	3	Local lead foil delamination
278-1C	4	0.005" lead, treated surface, acid dip	8	Local lead foil delamination
281-1	4	0.005" lead on HDPE, treated surface	6	Local lead foil delamination
282-1	4	0.005" lead on HDPE, sanded, treated surface	23	Lead foil delamination
282-2	4	0.005" lead on HDPE, sanded, treated surface	5	Lead foil delamination
282-6V	6	0.005" lead on HDPE, sanded, treated surface	5	Lead foil delamination
285-1	4	0.005" lead, washed oxide, treated surface	11	Lead foil delamination
286-2	4	0.005" lead, unwashed oxide	0	Short
286-3	4	0.005" lead, unwashed oxide	11	Lead foil delamination
287-2	4	0.005" lead on HDPE, washed, treated surface	1	Cracked substrate
287-3	4	0.005" lead on HDPE, treated surface	10	Lead foil delamination
287-4	4	0.005" lead on HDPE, treated surface	6	Cracked substrate

obtained due to difficulties porting the cells for pressurization tests. The trial did, however, prove that injection molded containment was a viable manufacturing technique.

4.0. METALLIC SUBSTRATE DEVELOPMENT

4.1 WBS 1.0 PROGRAM MANAGEMENT

4.1.1 Subtask 1.1 Managing Strategy

Effective July 28, 1994, Ms. Jennifer Rose assumed the responsibilities of the contract's previous project engineer, Mr. Doug Pierce, due to his departure from JCBGI.

Shortly thereafter, a proposal requesting a no-cost time extension was submitted to the contract negotiator on July 13, 1994. Gantt charts detailing this effort are shown in Figures 17 and 18. This followed a discussion with Mr. Richard Marsh during which it was mutually agreed that, despite significant advances in composite bipolar substrate development, remaining WPAFB contract work should be focussed on the use of a lead substrate with improved corrosion resistance. Through a parallel bipolar program, JCBGI had repeatedly demonstrated 2000+ cycles in a 12-volt configuration utilizing lead substrates, and over 5700 cycles using a 6-volt unit. Laminated metallic substrate work had also been underway for nearly 12 months in an effort to increase corrosion resistance, and hence, cycle life.

4.2 WBS 2.0 BATTERY DESIGN

4.2.1 Subtask 2.1 Battery System Design Analysis

The existing small metallic bipolar battery design was scaled up and modeled to investigate high power performance. Results suggested the use of a thinner cell design to be critical to achieving rates of 500 W/kg and higher. Per these findings, work was redirected to designing a 24-volt module within the volume previously allotted for 12-volts. This effectively aligned the contract deliverable voltage with WPAFB's ultimate application and JCBGI's commercial product target. Constant power performance projections are shown in Figure 19.

4.3 WBS 3.0 BIPOLAR PLATE

4.3.1 Subtask 3.1 Multialloy Substrate Development

Under separate contract, JCBGI began investigations into laminated metal substrates in November 1993. Corrosion testing of three, four and five layer samples and constituent alloys was performed in a bipolar configuration to assess time to breakthrough. Unpasted samples were mounted in the previously described stability test fixtures (Composite Substrate Work, Subtask 3.3) for three-point testing. Only the positive surface was exposed to electrolyte. Working and reference electrodes were also introduced. Initial testing of a new material was

FIGURE 17: No-Cost Time Extension Gantt Chart with Milestones

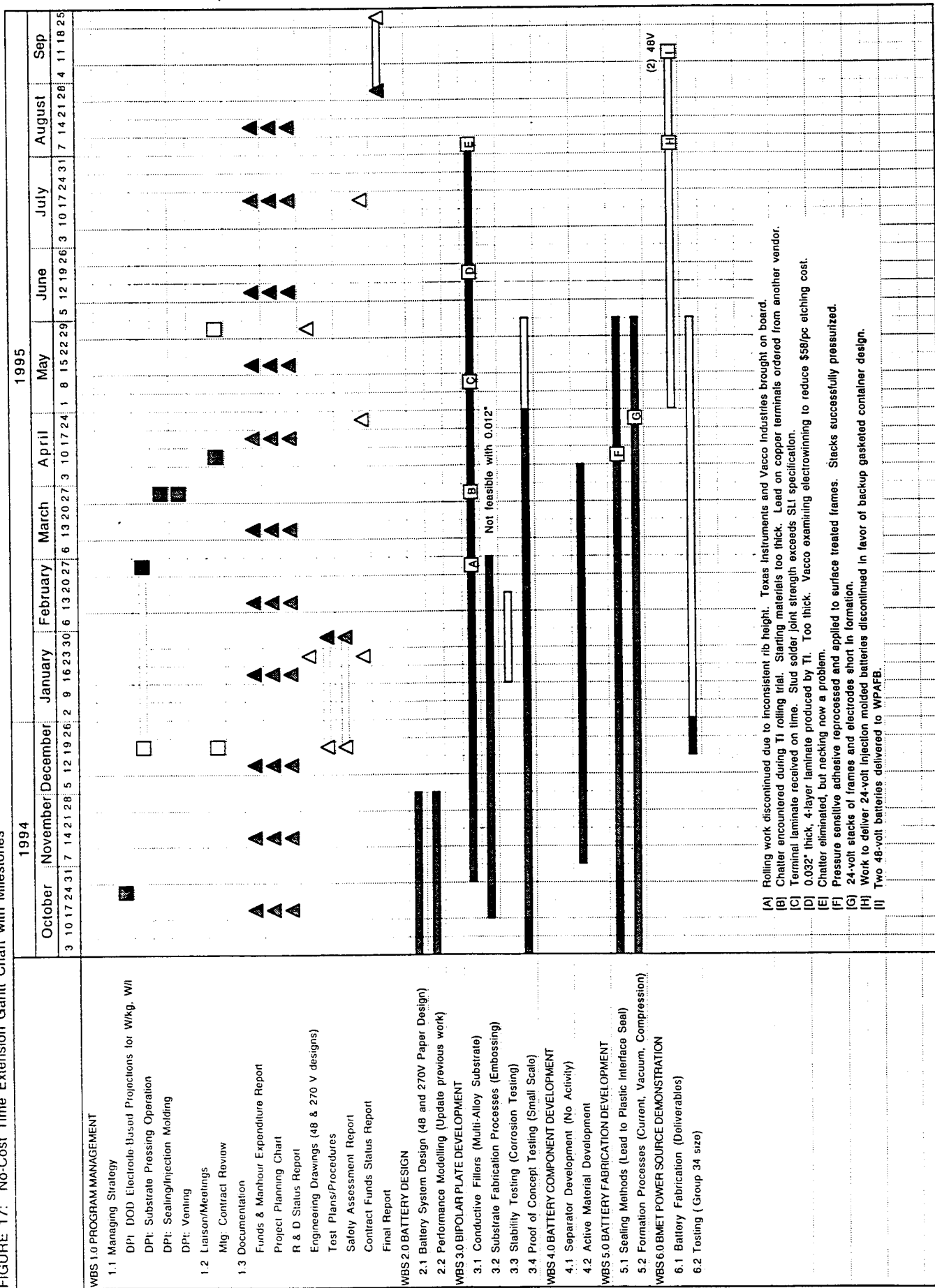


FIGURE 18: WPAFB Bipolar Deliverable Schedule

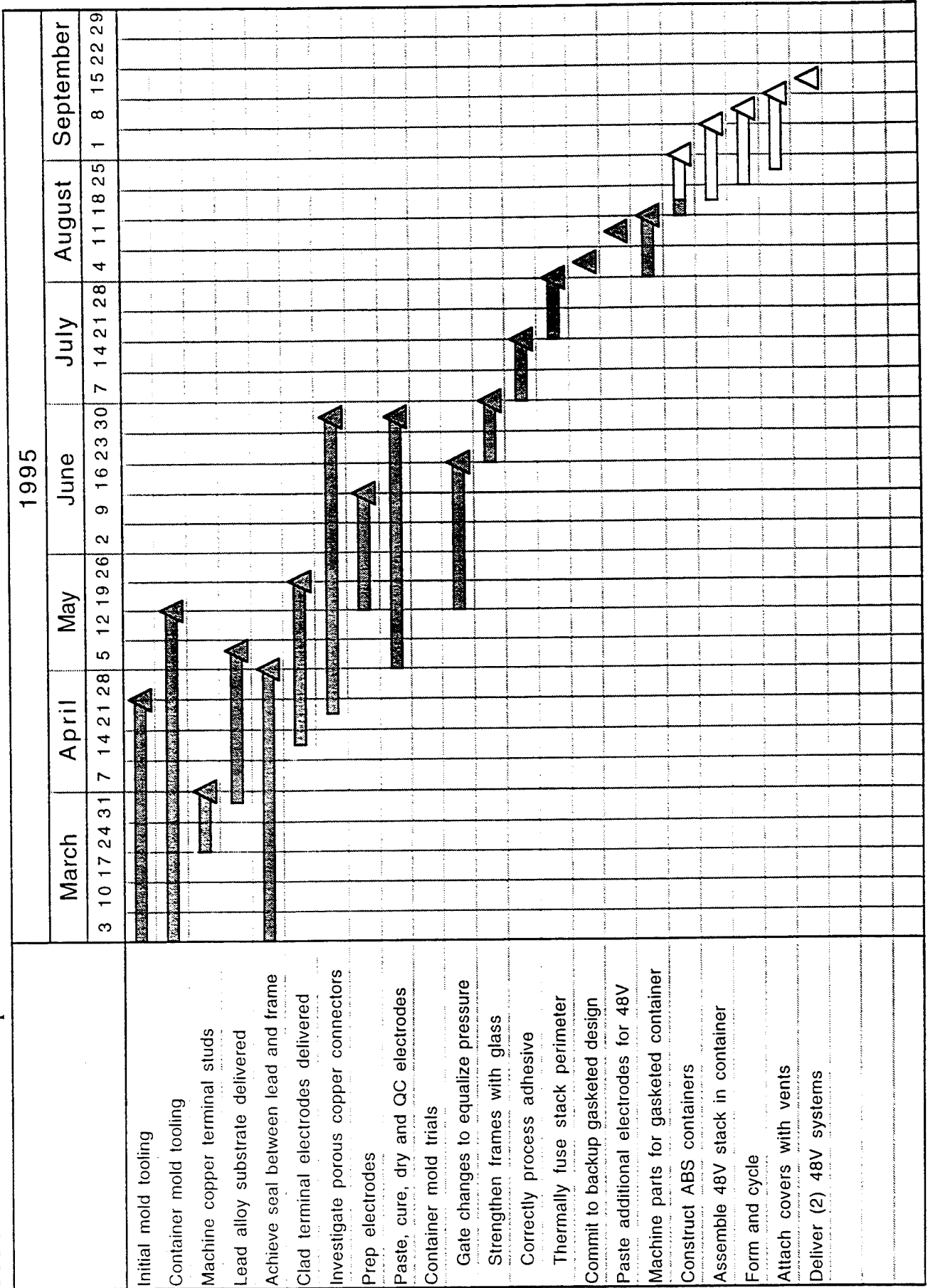
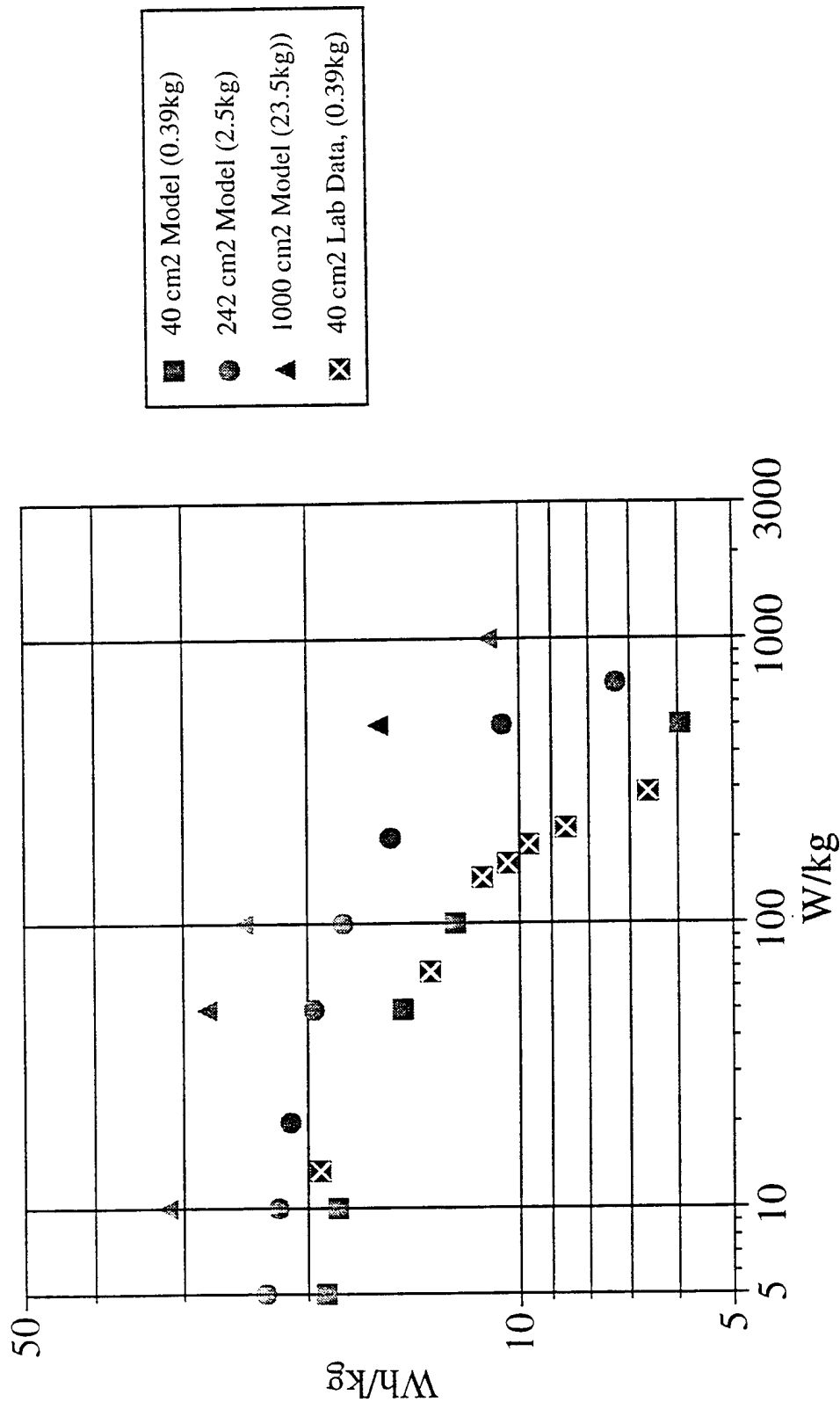


FIGURE 19
Constant Power Performance Projections
Metallic Bipolar Substrate



performed at 70°C and a constant potential of 1.50 V until evidence of pinholes was noted, i.e., liquid in the back chamber or spikes on the current acceptance curve. Replicate samples were then run, pulled at points prior to breakthrough, and submitted for cross sectional photomicrographs to quantify the corrosion rate.

Comparing rates of all samples tested showed the corrosion resistance of laminates to be second only to that of a high silver content alloy. Batteries utilizing the clad material were assembled and tested, but performance was poor. Teardowns showed improper cleaning of the starting materials to have prevented bonding of the dissimilar metals at the molecular level. Delamination resulted in high internal resistance that impeded high rate performance.

In October 1994, assistance was sought from Texas Instruments' Cladding Division (TICD), a leader in the laminating industry. Partnership activities were slow to materialize due to reorganization within TICD, however, two- and three-layer trials cladding lead to a stainless steel core were successful in December 1994. In March 1995, lead clad copper material was received and forwarded to Vacco Industries (see Metallic Substrate Work, Subtask 3.2) for surface etching trials. TI had planned bonding and rolling to facilitate a 65% reduction of the 0.054" thick constituent layers, however, a maximum of 51% was achieved before "chattering" (rippling) was observed. Secondary rolling ruined the bonds achieved in the first pass. New starting materials were requested for the production of 0.013" thick material, but the May delivery date made it unlikely that the laminated material would be available for use as the bipolar substrate in the required deliverables. Four layered, 0.032" thick sample material was received in June, and required reducing the copper core thickness by 50%. The likelihood of having the concept ready for deliverable use then dismissed.

4.3.2 Subtask 3.2 Rolling/Embossing Work

Fostering paste adhesion to metal sheet requires the surface to be roughened in some manner. Small-scale metallic substrates possessed exemplary adhesion when hot pressed in a mold to create ribs protruding from each face. The raised pattern successfully broke up the "single paste pellet" that would otherwise sheet off the lead substrate during handling, and increased the surface area biting into the active material.

Substrate production times were slow and scale up required the use of more tonnage than available on any in-house press. It also lacked promise as a high speed, manufacturing process. A roller die was ordered and five hundred pounds of 0.020", 0.025" and 0.030" thick lead were delivered to MP Metal Products for rolling trials. Without authorization, MP turned to blanking the electrodes from a compression die when the first rolling trial was unsuccessful. Rolled

samples were never provided to JCBGI for evaluation. When informed of the new production direction, JCBGI reiterated their interest in the rolled concept, but conceded to whatever parts could be produced. Time was short. MP continued their effort to produce parts, but quickly found their press tonnage insufficient. Hence, a new vendor was located. Walking 300 tons force across the die produced acceptable parts from 0.020" thick starting material. Efforts to reduce the substrate thickness to the required 0.012" thickness were unsuccessful and the embossing effort abandoned.

Photochemical etching was investigated in conjunction with laminating activities (Metallic Development Work: Subtask 3.3.1). Early trials produced copper pieces that were electroplated with lead, pasted and shown to possess good adhesion. Solid lead sheet was not etched as easily, requiring strong chemicals that made the technique cost prohibitive (\$58/piece).

As backup, plastic screen was used. Pieces were cut to the size of the active material area, pressed to eliminate elevated nodes that could cause shorting through the separator, and were tacked to the lead substrate. This alternative eliminated roughly 240 grams of lead rib mass per battery, but required significantly more labor input than the embossing concept. Despite its facilitating acceptable results, the use of plastic screen is not recommended for manufacturing.

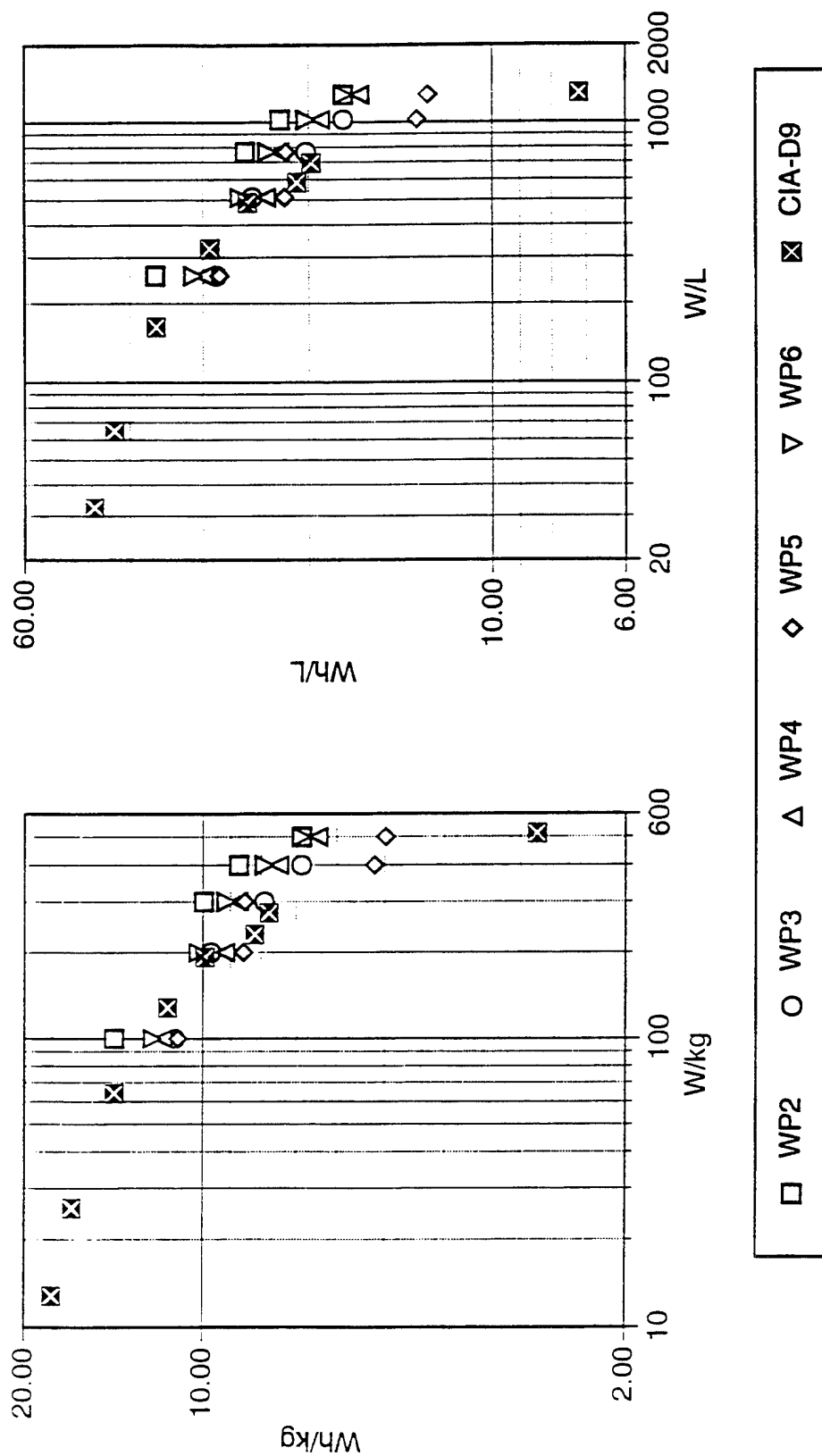
4.3.3 Subtask 3.3 Substrate Corrosion Testing

Laminates received from Texas Instruments were never corrosion tested due to their being too thick.

4.3.4 Subtask 3.4 Small Scale Characterization

Bipolar batteries having 0.012" thick substrates and 0.030" thick pasted layers were assembled, formed and tested in January 1995. Constant power discharge performance plots normalized to battery mass and volume are shown in Figure 20. Performance by WP2 and WP6 represented the best of the lot and greatly exceeded that reported for batteries delivered under the parallel metallic bipolar development contract. This was attributed to the use of 1.265 sg fill/form electrolyte. Reproducibility was an issue and investigated. Teardowns showed sulfated positives and dull negatives. Cured paste analyses reported consistently high levels of free lead that could cause initially poor or rapidly declining performance. A review of pasting procedures showed the starting PbO to be within specification and the paste code to be adequately sulfated

FIGURE 20
Constant Power Performance Normalized to Mass and Volume



and consistent from mix to mix. The dry bulb within the curing chamber was found cracked and was repaired prior to further assembly operations.

Testing of four newly-formed 12-volt units showed 10-15 cycles at 100 W/kg to be necessary to reach full capacity. Discharge times were tightly grouped after formation (Figure 21). WP-12 lagged due to oxygen ingress at cycle 3. A cursory investigation of constant current rates (Figure 22) was performed to give insight into the constant power rates required per the test plan. Constant power performance was plotted along with the modeling prediction in Figure 23, then translated into the time versus power curve shown in Figure 24.

4.4 WBS 4.0 BATTERY COMPONENTS

4.4.1 Subtask 4.2 Active Material Development

Procedures and equipment were reviewed when the free lead content in positive and negative cured plates was reported at 5.5 and 10%, respectively - far above the 4% maximum. Increasing the curing residence time from 16 to 40 hours had little effect. Moisture content was found low (6-7%) as referenced to industry and company standards and, subsequently, paste code and plate handling techniques were reviewed. Efforts to keep plates moist while awaiting transport to the curing chamber only slowed the cure reactions and actually increased the cured free lead content. Lastly, the ABR humidity chamber was diagnosed with a cracked dry bulb, repaired and reset. Cured positive and negative plates from eight subsequent pasting runs displayed acceptable free lead content following a 24 hour residence time in the environmental chamber.

A limited investigation into the effects of freezing and thawing a small 12-volt battery was performed. One unit was tested at room temperature to establish a baseline capacity and then chilled to -60°C. A 5-hour thaw was allowed and the discharge test repeated. Evidence of cell reversal and a 13% capacity loss was documented. Confirmatory work was placed on hold to allow pasting, stacking and debugging of the formation techniques proposed for full-size, 24-volt units.

4.5 WBS 5.0 BATTERY FABRICATION

4.5.1 Subtask 5.1 Sealing Methods

A variety of compounds was evaluated for use in achieving a hermetic cell-to-cell seal. In the end, an engineering sample of hot melt adhesive was pressed between release paper into

FIGURE 21
Small Scale Characterization
Capacity Development, 24 deg C

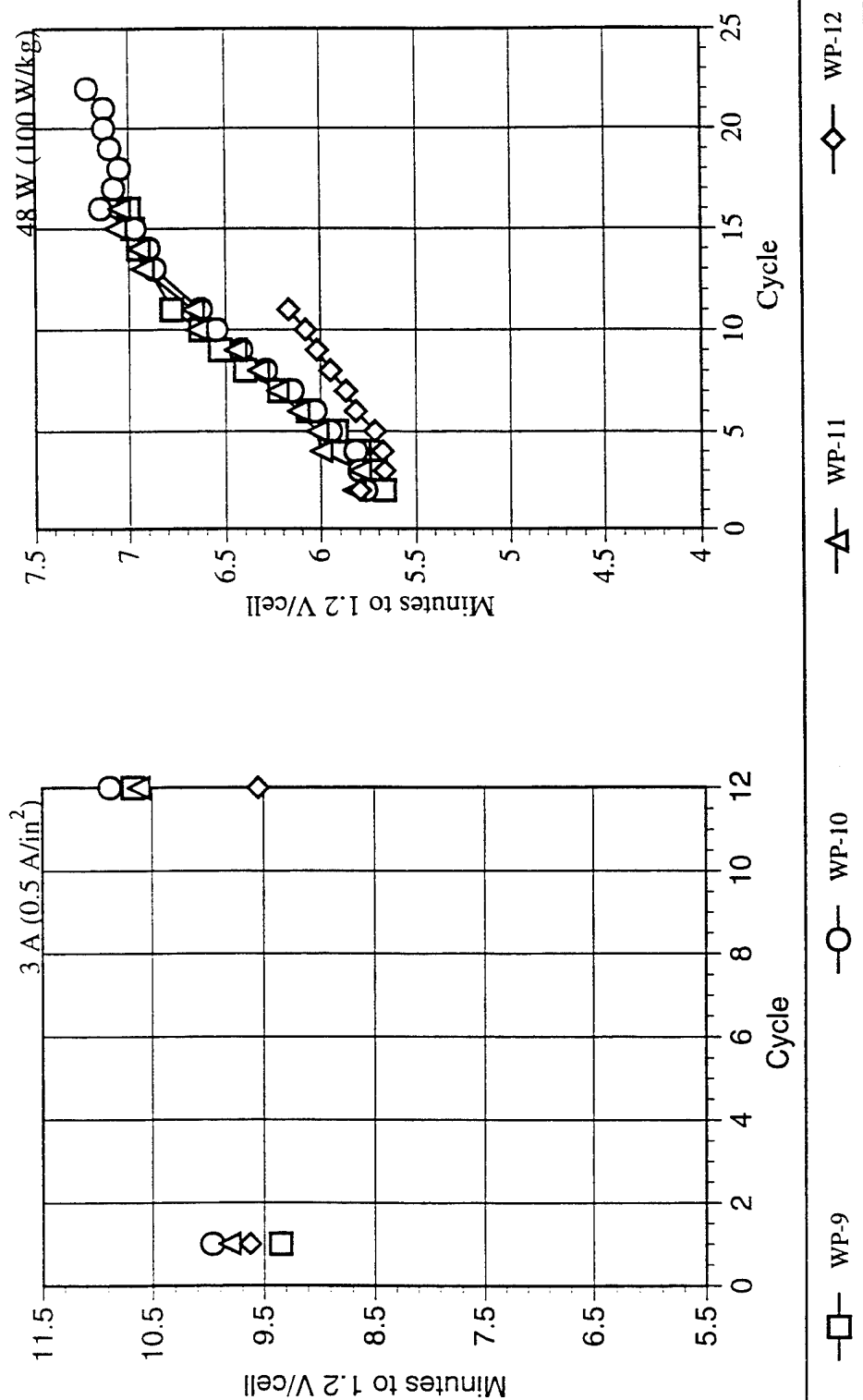


FIGURE 22
Small Scale Characterization
Peukert Relationship, 24 deg C

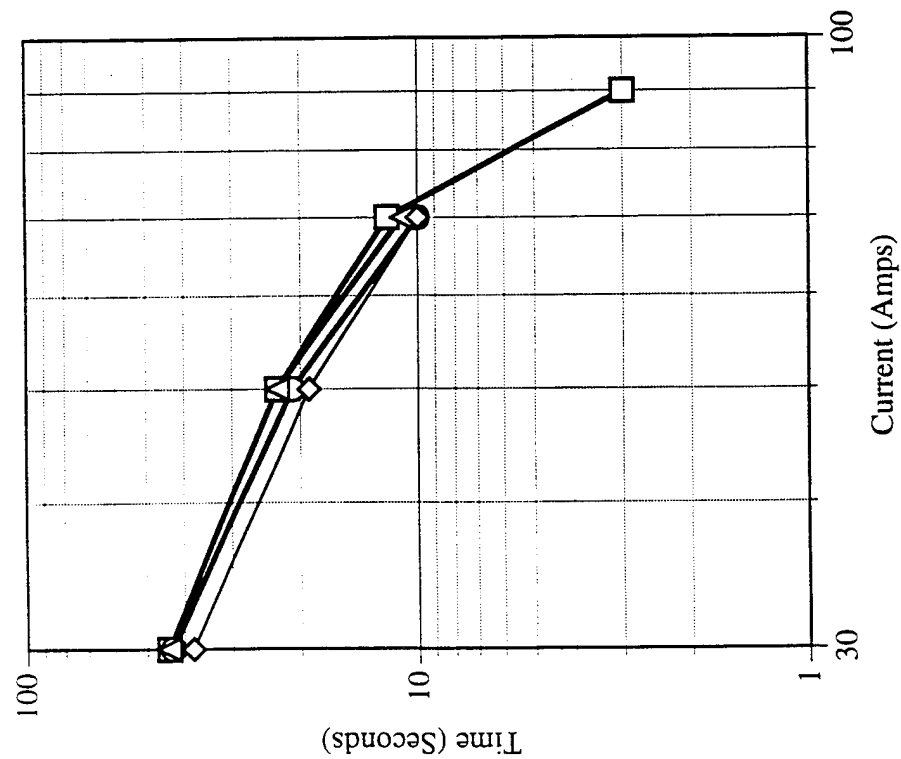
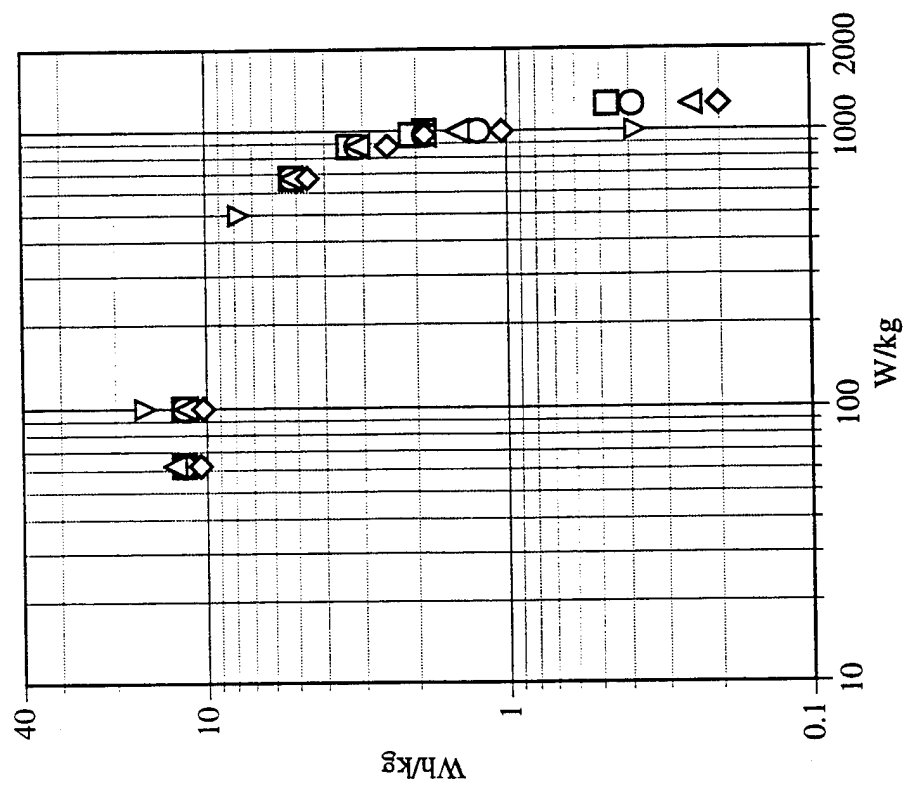


FIGURE 23
Small Scale Characterization
Ragone Relationship, 24 deg C



Model

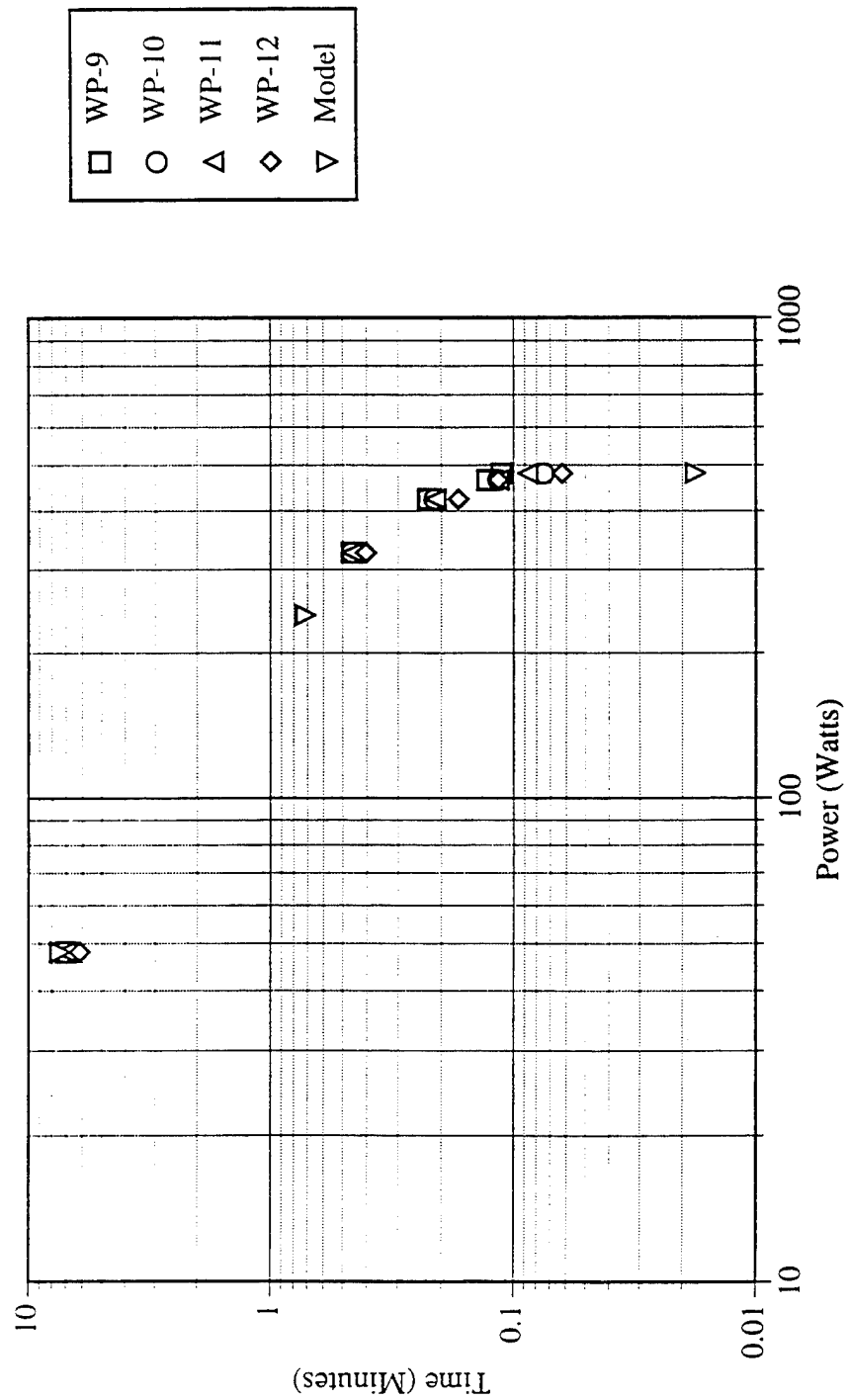
WP-12

WP-11

WP-10

WP-9

FIGURE 24
Small Scale Characterization
Discharge Time vs Power, 24 deg C



sheet, chilled, slit into ribbon, chilled again, and finally laid onto treated plastic spacer frames. Dummy stacks were leak-free to 4 psig, and successfully completed 4 hours of intermittent vacuum pulsing to simulate the fill and form procedure. Cells in 12- and 24-volt stacks were also leak-free when similarly tested.

Sufficient quantities of the engineering sample material resided in-house, but efforts to find a replacement adhesive were initiated when additional material could no longer be obtained. Chemical analyses and physical testing of the original material was requested of H.B. Fuller and resulted in their furnishing two candidate replacement materials. Stack assembly showed one sample to be tackier and both materials able to withstand the level of vacuum required for filling. No further work with these substitutes was carried out since sufficient adhesive existed to complete the contract.

4.5.2 Subtask 5.2 Formation

Two 24-volt batteries were stacked for formation studies. Each was comprised of 13 electrodes, 12 spacer frames, and two copper termination plates bolted between polycarbonate endwalls and outfitted with polycarbonate filling manifolds across each set of top slots.

Air pressurization of the first stack prior to filling showed one of the two fill ports to be leaking. The manifold was removed and the slots closed off after repeated attempts to seal the manifold were unsuccessful. Seventy-five minutes were required to input 300 cc of chilled electrolyte through the remaining manifold. This represented roughly 72% of the available void volume in the stack. Complete (100%) saturation had been targeted, however, small leaks developed around the base of the manifold, decreasing the fill efficiency. Current was applied for 120 minutes when evidence of shorting was apparent. Disassembly showed the majority of cells to have dendritic shorting through the center area of the separator. Failure was attributed to the long fill time (10-15 minutes was targeted to minimize the dissolution and diffusion of lead into the separator) and out-of-spec plate thicknesses. On average, plates were 0.007" over the 0.025" target, resulting in a compressed separator allowance of 0.016". Roughly 0.020" was considered the minimum separator thickness. Paste weights were reduced for the subsequent build.

The second 24-volt battery was assembled into a bolted polycarbonate fixture, filled to 84% saturation with chilled electrolyte, and placed on formation. Further filling risked lead dissolution and dendrite formation in the separator due to the excessive time required. Five cells shorted during formation as a result of a common electrolyte path along the lead exposed within the fill channel. Further formation attempts were placed on hold pending receipt of a molded stack which, by design, better guarded against common electrolyte paths in the fill port area.

4.6 WBS 6.0 BMET DEMONSTRATION

4.6.1 Subtask 6.1 Deliverables

Injection molded containment about metallic substrates was aggressively pursued for the majority of the No-Cost Time Extension. Repeated trials ultimately succeeded in correcting recurrent frame and electrode distortion, however, hermetic cell-to-cell seals were not obtained. Stacks were never available for formation or for trials to attach covers via induction welding. As a result, a backup battery design was implemented to complete the contract's deliverable requirements.

The following section describes the injection molded containment work in more detail, along with the proposed venting and intermodule connector concepts. The subtask is then concluded with a description of the batteries delivered to WPAFB.

4.6.1.2 24-Volt Injection Molded Containment

The use of the injection molded containment concept previously tested with composite electrodes required one design modification to facilitate use with metallic substrates. To prevent distortion of the 0.012" thick metal electrode, the outer edge of the spacer frame was reshaped to wrap around the lead sheet and afford protection against the injection pressure. Glass filler was also added to the spacer resin to promote a melt bond with the outer endwalls. Molded spacers showed that shrinkage of the 0.082" thick parts was less than anticipated (0.003 in/in vs. 0.007 in/in). This was due to the ASTM shrinkage rate reporting basis (0.125"x0.5"x6" sample). As a result, spacers were slightly larger than specified, however, down-the-line assembly problems were not encountered.

The endwall material was also reevaluated and three candidates tested for use in maintaining the compressed stack dimension. Single layers of honeycombed aluminum sheet stock failed deflection testing. Bulk molding compound manufactured by Luvdahl provided the needed strength against a 6 psig load but was incompatible with battery acid. Glass-filled polypropylene was ultimately used after measuring a deflection of 0.013" at 5 psig.

Severely warped endwalls were produced during the first mold trial. Mold gate changes reduced the distortion, but a subsequent heat soak was still necessary to produce a flat part. Limited success was had in adding a blowing agent. Topical sinks located around the outer perimeter and the center termination port were greatly reduced but not eliminated. Slight part warpage also remained. Cross sectioning showed the internal pore size (caused by the blowing agent) to be very small. It also showed a 4-hour heat treatment to cure the warpage with no sign

of reactivating the blowing agent, but at the expense of the recessed terminal electrode cavity dimension. Heat treating was abandoned when measurements showed shrinkage along the length and width centerlines to be so great as to make it impossible to insert the terminal electrode in the recessed cavity.

Endwalls and spacers were then assembled with lead sheet to create dummy stacks for mold trials. Early attempts showed the plastic to distort the 10% glass frames inward toward the pasted portion of the stack, leaving insufficient material to fill the outer frame. Gate modifications were implemented in an effort to equalize the injection pressures at various points within the container mold. Center/side gating achieved complete mold fill and eliminated much of the frame distortion, however, cross-sectioning still showed buckled lead and uneven plastic distribution. The mold clamp location was then widened and additional glass added to the spacer resin for strength.

Strengthened plastic battery components were received and set up parts prepared for a trial in mid-July, 1995. Glass loading in the frame was increased to 30% in order to prevent blowing in and lead distortion, and to reduce part compression when clamped within the mold. The molding trial was nearly successful. Complete mold fill was achieved with slight crowning of the frames. A "clamp only" trial showed the crowning to be a result of the mold closing. Still closer examination revealed the stacks loaded into the mold to be ~0.100" too thick as a result of out-of-spec adhesive. The remaining thick stacks were preheated and easily compressed to the correct 1.454" thick dimension. Disassembly showed no electrode distortion. Laboratory measurements of stacks assembled using 0.003" thick adhesive (a 50% reduction) were similarly flat.

The subsequent molding trial with correctly processed adhesive produced four dummy stacks and one DUF battery for analysis. Electrodes in all four dummy stacks were distorted along the inner frame perimeter. Heat sensitive indicators inserted at two points in each stack recorded the temperature history and showed no indication of having reached the temperature at which the inlaid adhesive would begin to flow.

The distortion was subsequently eliminated in late July by thermally fusing the outer edges of the stack to better resist the high molding pressure. Pressure testing to confirm cell-to-cell seals identified leakage that was traced to the area surrounding the fill channels. Close examination showed a lack of melt bond between the prefused frame and injected containment plastic. Given the cost and time associated with the mold change proposed to eliminate the leakage, the concept was abandoned for use with WPAFB deliverables.

Venting considerations were evaluated concurrently to stack molding. Implementation of a totally sealed design was initially considered, but dismissed. Utilizing a fail-safe panel along

the face representing the endwall would have reduced its functionality as a means of maintaining adequate battery compression. User safety in the event of an abusive overcharge was an even greater concern.

A review of available off-the-shelf vents quickly showed that no battery vent supplier had ever addressed the main issue facing bipolar technology: cell width. Vent designs just 0.060" to 0.080" in width did not exist. Staggering the vents was proposed, but eliminated from further consideration when it became apparent that multiple frame molds would be required.

Having limited data showing success in cycling a small bipolar battery utilizing single point venting, the deliverable venting configuration was drawn. In its final form, a 24-volt battery was to be fitted with a vent over each of the fill slot locations. This duplicity provided a backup venting location to any cell that might incur blockage in one of its ports. Oil applied topically aided in achieving and maintaining the hermetic seal required for recombinant, maintenance-free operation.

Two methods were suggested for attaching the vent/cover to the injection molded battery housing: heat sealing and induction welding.

Heat sealing is used throughout the battery industry. Generally, this involves heating the edges to be joined, bringing them into contact, and allowing them to cool under pressure. Concern was raised over being able to hold the 0.080" thick cover while preheating it with a heat lamp. That and the estimated \$30,000 to build a suitable machine to try the concept made heat sealing a last choice technique.

Induction welding was then investigated. This process was reportedly fast and versatile. Heat induced by a high frequency electrodynamic field in a metallic insert placed at the joint brings the surrounding material to the melt temperature. Pressure maintained as the field is turned off maintains the joint as it solidifies. Welding occurs only in the area immediately adjacent to the metallic insert. As a result, weld strength depends on the size and geometry of the metal insert.

The process was also feasible economically. Purchasing a new laboratory unit required \$10,000. Leasing was also possible at \$750 per month.

Initial induction welded samples prepared by Pillar Industries indicated that a hermetic bond could be easily achieved around the periphery of the vent/cover. A semicircular cavity rimming the upper edge of the battery and the two cross bars spanning the center portion of the upper surface was included in the mold design. Later testing proved that a hermetic bond along the cross bars would not be achieved. Mold changes were ordered to reduce the cross bar height to make them serve only as structural supports. Hermetic seals at these points were not necessary given the remainder of the cover weld met specification. Test welds with stacks and covers were never attempted given the difficulties previously described.

Lastly, NCTE work was performed to efficiently connect two 24-volt units in series to form a higher voltage subassembly. Various porous copper samples were obtained and tested under load. Results showed the porous copper to be less resistive than solid copper sheet wrapped around a foam pad (Figure 25). Twenty pieces of 60 pores per inch (ppi) material were ordered and received on time, but never used in deliverables. The batteries delivered utilized a backup containment design that facilitated direct assembly of higher voltage stacks.

4.6.1.3 Gasketed Containment

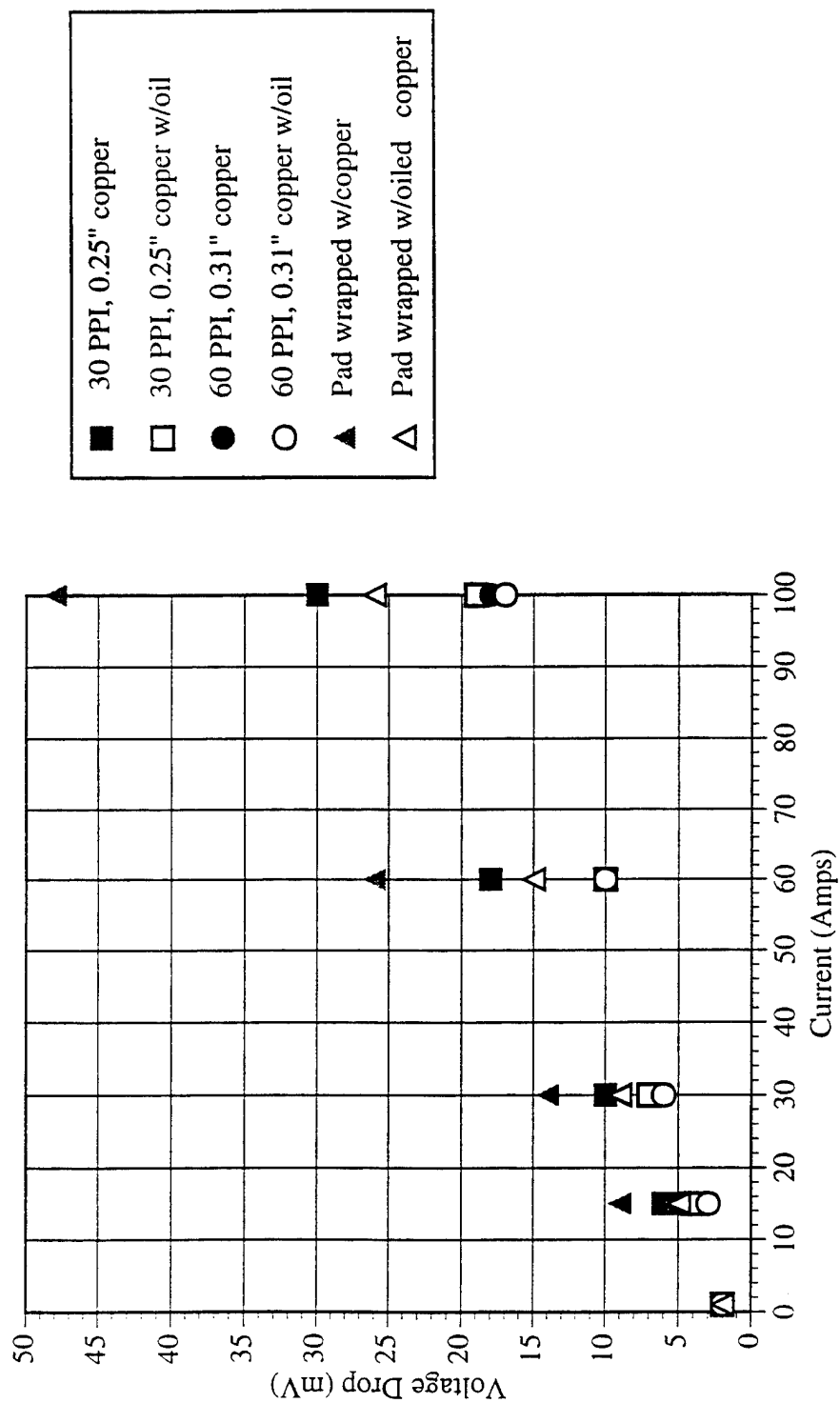
Given the difficulties encountered in achieving hermetic cell-to-cell seals with the injection molded containment concept, WPAFB accepted deliverable batteries assembled using neoprene spacers and machined ABS container components (Appendix B).

Bipolar electrode substrates were die cut from 0.012" thick tin-lead sheet and pasted following the attachment of plastic screen (see Metallic Substrate Development, Subtask 3.3.2). Three paste runs succeeded in pinpointing the wet paste weight needed to achieve the targeted 0.062" electrode thickness. After curing and drying, plates were individually cleaned, weighed, and checked for high spots (thickness). Paste mass and thicknesses of bipolar electrodes used in the deliverable candidates were put at 105.7 ± 2.5 grams and 0.059 ± 0.001 ", respectively.

Terminal electrodes were die cut from laminated sheet stock comprised of 0.008" thick lead and 0.014" thick copper. This design permitted copper terminations to be soldered to the copper face of the electrode with minimal risk of burning a pinhole through the lead face. Each 0.75" long x 0.75" OD stud with a tapped thread was correctly located by first soldering it to an oversized electrode that was then die-cut to achieve the required dead-center location. (This procedure had been critical to injection mold trials since the stack position in the mold was based on the stud location.) Stud welds were shown to withstand an average of 285 in-lb of torque before failing at the solder-to-laminate joint. This compared favorably to the 180 in-lb SLI specification.

Container components were machined from 0.125" and 0.250" (nominal) thick ABS. Solvent bonding was implemented to join the pieces. Endwalls were provided the necessary strength by encapsulating multiple sheets of honeycombed aluminum within a protective ABS cavity. Electrodes were sequentially placed onto neoprene gaskets and absorptive glass mat positioned over the active area to prevent shorting. Separator material was sized to overlap the active area slightly. Starting thickness facilitated the 25% compression deemed critical to supporting high rates of discharge. Fittings were located in channels milled into each gasket to create ports for filling and venting.

FIGURE 25
Voltage Drop Across Intermodule Connector Candidate Materials



Fill and formation were attempted only after confirming each and every cell in a stack to be leak free. Filling was accomplished by evacuating the cells through a column of chilled electrolyte. Returning the system above the electrolyte to atmospheric pressure forced the predetermined volume of acid into each cell quickly and efficiently. Internal stack temperature was monitored constantly and used in controlling the formation current. Current was applied as soon as the fill was completed to minimize the risk of dendritic shorting due to lead dissolution.

Fittings were removed and the cover/vent assembly solvent bonded into place after limited qualification cycling was performed to fully develop the capacity. Details regarding the assembly, formation, and qualification testing of each deliverable are included in Appendix B.

To assist WPAFB in preparing for receipt of these units, three bound copies of safety instructions and operating recommendations were mailed February 29, 1996. One 24-volt and two 12-volt nominal batteries were hand delivered to Wright Laboratory on March 6, 1996 with an additional two copies of the instructions and recommendations. Identification and safety labels were attached to each battery to warn of the potential for explosion, acid burns and electrical shock.

APPENDIX A

RESISTIVITY TESTING

RESISTIVITY TESTING

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
47A	4/2/92	LAMINATED 85% GC23N W/O CA 15% MICROTHENE 4.5 M.I.	0.365	0.365	0.023	0.023	6.248	0.960	0.042	8.999	36.6158656
48A	4/2/92	C-PLASTIC LAMINATED 85% GC23N WITH CA 15% MICROTHENE 4.5 M.I.	0.630	0.570	0.025	0.024	9.921	1.000	0.040	9.843	
52	4/9/92	C-PLASTIC LAMINATED 84% GC23N & 16%PTFE TO C-PLASTIC & Pb FOIL SINGLE APPLICATION OF RESIN	1.180	0.635	0.053	0.024	8.765	19.500	0.062	123.825	1696.53351
53	4/9/92	LAMINATED 84% GC23N & 16%PTFE TO C-PLASTIC & Pb FOIL DOUBLE APPLICATION OF RESIN	3.630	0.661	0.061	0.054	23.428	169.000	0.054	1232.138	
54B	4/14/92	LAMINATED 85% GC23N-1 15% MICROTHENE 4.5 M.I. WITH Pb FOIL	0.195	0.040	0.040	0.040	1.919	0.440	0.040	4.331	138.119658
55B	4/14/92	LAMINATED 85% GC23N-2 15% MICROTHENE 4.5 M.I. W/O Pb FOIL	0.250	0.030	0.030	0.030	3.281	1.730	0.030	22.703	
71A	4/24/92	LAMINATED THICK/THIN GC23N-1 /C-PLASTIC	0.295	0.300	0.206	0.208	0.564	0.390	0.209	0.735	
72A	4/24/92	LAMINATED THIN/THIN GC23N-2 /C-PLASTIC	0.275	0.265	0.208	0.207	0.521	0.410	0.210	0.802	
73A	4/24/92	LAMINATED THICK/THIN GC23N-3 /C-PLASTIC	0.420	0.250	0.031	0.032	5.334	3.800	0.031	48.260	
			0.220	0.220	0.033	0.033	3.678	6.400	0.032	78.740	2083.76933

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
74A	4/24/92	LAMINATED THIN/THIN GC23N-4 /C-PLASTIC	0.380	0.380	0.032	0.032	4.675	4.300	4.300	4.300	0.032	0.032	52.904	52.904	1079.12921
75A	4/24/92	LAMINATED THICK/THIN GC23N-5 /C-PLASTIC	0.440	0.440	0.033	0.033	5.249	5.100	5.100	5.100	0.033	0.033	60.845	60.845	
76A	4/24/92	LAMINATED THIN/THICK GC23N-6 /C-PLASTIC	0.430	0.430	0.031	0.031	5.461	5.500	5.500	5.500	0.032	0.032	67.667	67.667	
77A	5/12/92	LAMINATED GC23N-A-3/92 Pb-FOIL C-PLASTIC	0.350	0.350	0.121	0.121	1.139	0.570	0.570	0.570	0.122	0.122	1.839	1.839	
		LAMINATED GC23N-B-3/92 Pb-FOIL C-PLASTIC	0.580	0.580	0.122	0.122	1.872	0.520	0.520	0.520	0.123	0.123	1.664	1.664	
		LAMINATED GC23N-5 /C-PLASTIC	0.280	0.280	0.123	0.123	0.896	0.320	0.320	0.320	0.123	0.123	1.024	1.024	
		LAMINATED THIN/THICK GC23N-6 /C-PLASTIC	0.285	0.285	0.124	0.124	1.302	2.350	2.350	2.350	0.125	0.125	1.509	1.509	15.9055035
		LAMINATED THIN/THICK GC23N-6 /C-PLASTIC	0.275	0.275	0.126	0.126	0.905	2.580	2.580	2.580	0.124	0.124	7.402	7.402	
		LAMINATED THIN/THICK GC23N-6 /C-PLASTIC	0.270	0.270	0.126	0.126	0.859	2.300	2.300	2.300	0.123	0.123	8.192	8.192	
		LAMINATED THIN/THICK GC23N-6 /C-PLASTIC	0.270	0.270	0.126	0.126	0.844	7.652	7.652	7.652	0.123	0.123	7.362	7.362	780.246688
78A	6/5/92	LAMINATED GC23N,MICROTHENE & C-PLASTIC 1R 2R 3R	0.66	0.66	0.027	0.027	9.624	0.38	0.38	0.38	0.03	0.03	4.987	4.987	66.6666667
		LAMINATED GC23N,MICROTHENE & C-PLASTIC	0.228	0.228	0.03	0.03	2.992	5.8	5.8	5.8	0.03	0.03	76.115	76.115	3035.13514
		LAMINATED GC23N,MICROTHENE & C-PLASTIC	0.185	0.185	0.03	0.03	2.428	0.66	0.66	0.66	0.028	0.028	9.280	9.280	203.061224
		LAMINATED GC23N,MICROTHENE & C-PLASTIC	0.21	0.21	0.027	0.027	3.062								
79A	5/20/92	LAMINATE GC23N-1-85% MICROTHENE/CA GC23N-2-85% MICROTHENE GC23N-3-80.3% KY GC23N-4-80.3%	0.52	0.52	0.046	0.046	4.451	3.7	3.7	3.7	0.046	0.046	31.667	31.667	611.538462
		LAMINATE GC23N-1-85% MICROTHENE/CA	0.335	0.335	0.044	0.044	2.997	2.2	2.2	2.2	0.044	0.044	19.685	19.685	556.716418
		LAMINATE GC23N-2-85% MICROTHENE	0.49	0.49	0.039	0.039	4.946	21	21	21	0.041	0.041	201.652	201.652	3976.65505
		LAMINATE GC23N-3-80.3% KY	0.435	0.435	0.037	0.037	4.629	13.5	13.5	13.5	0.038	0.038	139.867	139.867	2921.77858
		LAMINATE GC23N-4-80.3%													

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
80A	5/27/92 PG. 139/141	KY/CA									
		LAMINATE									
		GC23N-1-85%	0.36	0.445	0.04	0.04	3.543	0.445	0.04	4.380	23.6111111
		MICROTHENE/CA	0.495	0.525	0.039	0.038	4.997	0.525	0.038	5.439	8.85167464
		GC23N-2-85% MICROTHENE	0.223	0.253	0.044	0.044	1.995	0.253	0.044	2.264	13.4529148
81A	6/9/92	GC23N-3-80.3% KY	0.305	0.35	0.042	0.041	2.859	0.35	0.041	3.361	17.5529788
		GC23N-4-80.3% KY/CA									
82A	6/10/92	LAMINATED									
		GC23N,MICROTHENE & C-PLASTIC									
		5/92-1R									
		5/92-2R									
		5/92-3R									
83A	6/10/92	5/92-4R									
		LAMINATED									
84A	6/26/92	DOPED OXIDE/SCW AND C-PLASTIC	0.38	23.3	0.098	0.098	1.527	23.3	0.098	93.604	6031.57895
		LAMINATED									
		DOPED OXIDE-5/92									
		KY 7201 & 711									
		C-PLASTIC									
85A	6/30/92	CA	1.7	26.3	0.031	0.031	21.590	26.3	0.031	334.011	1447.05882
		70%-7201	0.54	220	0.031	0.033	6.858	220	0.033	2624.672	38171.6049
		75%-7201	0.45		0.059		3.003				
		85%-711	0.785	1.75	0.032	0.031	9.658	1.75	0.031	22.225	130.121225
		70%-7201 & CA	0.68	6.4	0.033	0.032	8.113	6.4	0.032	78.740	870.588235
		75%-7201 & CA	0.32		0.062		2.032				
		85%-711 & CA									
		LAMINATES									
		DOPED OXIDE, CA									
		C-PLASTIC, Pb FOIL									
85A	6/30/92	711 KYANR & Pb DUST	3.7	71.5	0.022	0.025	66.213	71.5	0.025	1125.984	22243.75
		70%-W/CA-FOIL	0.6	12	0.022	0.025	10.737	12	0.025	188.976	11776.2887
		70%-W/CA-DUST	2.15		0.022		38.475				
		70%-W/O CA-FOIL	0.32		0.025		5.039				
		70%-W/O CA-DUST	0.097		0.024		1.591				
		75%-W/CA-FOIL	0.43		0.024		7.054				
		75%-W/CA-DUST	1.25		0.024		19.685				
		75%-W/O CA-FOIL			0.025						

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
88A	7/13/92	75%-W/O CA-DUST	0.3		0.026		4.543	70	0.028		984.252		21566.6667
		5/92-DOPED OXIDE KY-711											
		C-PLASTIC											
		.013-C-PLASTIC	0.11		0.013		3.331	0.115	0.012		3.773		13.2575758
		.020-DOPED OXIDE	0.65		0.033		7.755						
92A	7/22/92	.030-DOPED OXIDE	1.15		0.042		10.780	3.85	0.042		36.089		234.782609
		.040-DOPED OXIDE	1.55		0.05		12.205	1.13	0.048		9.268		-24.0591398
		.050-DOPED OXIDE	1.65		0.054		12.030	1.68	0.054		12.248		1.81818182
		LEAD DUST & POLYSULFONE	0.043		0.028		0.505						
		PREMIXED W/1.11 DRIED PRESSED AT 599F 30 TONS 55% BY WT.											
94A	7/28/92	LAMINATE											
		DOPED OXIDE(5/92) KY-711 &											
		KET WITH KY-711	0.305		0.068		1.766	0.48	0.068		2.779		57.3770492
		14%-KET/KYN-.050	0.38		0.061		2.453	0.4	0.061		2.582		5.26315789
		14%-KET/KYN-.040	0.5		0.051		3.860	0.74	0.051		5.713	48	
95A	7/30/92	14%-KET/KYN-.030	0.066		0.025		1.039	0.57	0.025		8.976		763.636364
		PI/POLYSULFONE											
		LAMINATE											
		DOPED OXIDE(5/92) KY-7201 &											
		KET WITH KY-7201	0.305		0.066		1.819	0.345	0.066		2.058		13.1147541
96A	8/10/92	14%-KET/KYN-.050	0.295		0.061		1.904	0.4	0.061		2.582		35.5932203
		14%-KET/KYN-.040	0.27		0.052		2.044	1.15	0.052		8.707		325.925926
		14%-KET/KYN-.030	0.255		0.043		2.335	4.2	0.043		38.454		1547.05882
		14%-KET/KYN-.020	0.243		0.047		2.036	SAMPLE	FOR		SHOW		
		14%-KET/KYN-.026											
96A	8/10/92	LAMINATES											
		DOPED OXIDE W/MICROTHENE											
		KET & MICROTHENE											
		80%-DOPED OXIDE-96A-1	0.62		0.071		3.438	0.64	0.071		3.549		3.22580645
		80%-DOPED OXIDE-96A-2	0.46		0.063		2.875	0.44	0.063		2.750		-4.34782609

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)	RESISTANCE (OHM)	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
97A	8/18/92	LAMINATES									
		DOPED OXIDE/KY(8/92)									
		KET/KY(8/92)									
		75%-DOPED OXIDE-97A-1	0.21	0.052	1.590	1.65	0.052	12.492	685.714286		
99A	8/21/92	75%-DOPED OXIDE-97A-2	0.23	0.063	1.437	0.43	0.063	2.687	86.9565217		
		75%-DOPED OXIDE-97A-3	0.218	0.067	1.281	0.29	0.067	1.704	33.0275229		
		LAMINATES									
		DOPED OXIDE/KY									
102A	9/16/92	75%-DOPED OXIDE-99A-1	0.25	0.074	1.330	0.31	0.074	1.649	24		
		75%-DOPED OXIDE-99A-2	0.22	0.076	1.140	0.32	0.076	1.658	45.4545455		
		75%-DOPED OXIDE-99A-3	0.225	0.06	1.476	0.51	0.06	3.346	126.666667		
		75%-DOPED OXIDE-99A-4	0.185	0.06	1.214	0.33	0.06	2.165	78.3783784		
103A	9/23/92	LAMINATES									
		DOPED OXIDE/MICROTHENE									
		KET/MICROTHENE									
		80%-DOPED OXIDE-102A-1	1.55	0.061	10.004	2.4	0.062	15.240	52.3413111		
104A	9/29/92	80%-DOPED OXIDE-102A-2	1.15	0.073	6.202	1.63	0.077	8.334	34.3760587		
		80%-DOPED OXIDE-102A-3	1.75	0.049	14.061	3.4	0.049	27.318	94.2857143		
		80%-DOPED OXIDE-102A-4	1.13	0.046	9.671	1.83	0.048	15.010	55.199115		
		LAMINATES									
105A	10/9/92	WASHED DOPED OXIDE									
		PRECOMPOUNDED									
		C-PLASTIC									
		103A-1	0.58	0.08	2.854	1.5	0.08	7.382	158.62069		
103A	9/23/92	103A-2	0.595	0.063	3.718	6	0.063	37.495	908.403361		
		103A-3	0.375	0.05	2.953	2.8	0.05	22.047	646.666667		
		103A-4	0.355	0.04	3.494	12.5	0.04	123.031	3421.12676		
		LAMINATES									
104A	9/29/92	WASHED DOPED OXIDE									
		PRECOMPOUNDED									
		C-PLASTIC									
		104A-1	0.33	0.047	2.764	8.5	0.047	71.201	2475.75758		
105A	10/9/92	104A-2	0.44	0.058	2.987	3.2	0.058	21.721	627.272727		
		104A-3	0.31	0.064	1.907	5.2	0.064	31.988	1577.41935		
		104A-4	0.355	0.073	1.915	2.9	0.073	15.640	716.901408		
		104A-5	0.72	0.048	5.906	10.3	0.048	84.482	1330.55556		
105A	10/9/92	104A-6	0.7	0.062	4.445	5.5	0.062	34.925	685.714286		
		104A-7	0.455	0.066	2.714	5.5	0.066	32.808	1108.79121		
		104A-8	0.54	0.066	3.221	4.3	0.066	25.650	696.296296		
		KY (7/92) & MICROTHENE (5/92)									

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM) BEFORE	THICKNESS (INCH) BEFORE	RESISTIVITY (OHM-CM) BEFORE	RESISTANCE (OHM) AFTER	THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
109A		80%-LOADING							
		DOPED OXIDE (5/92)							
		10%KY/90%MIC.-105A-1	0.17	0.056	1.195	0.45	0.056	3.164	164.705882
		20%KY/80%MIC.-105A-2	0.185	0.053	1.374	0.78	0.053	5.794	321.621622
		30%KY/70%MIC.-105A-3	0.173	0.053	1.285	1.85	0.053	13.742	969.364162
109A		40%KY/60%MIC.-105A-4	0.165	0.05	1.299	2.8	0.05	22.047	1596.9697
		KY (7/92) & MICROTHENE (5/92)							
		80%-LOADING							
		DOPED OXIDE (5/92)							
		109A-1	0.29	0.041	2.785	0.87	0.04	8.563	141.666667
110A	10-26-92	109A-2	0.36	0.04	3.543	44	0.042	412.448	12915.873
		109A-3	0.33	0.041	3.169	0.85	0.041	8.162	83.7583149
		109A-4	0.44	0.039	4.442				
		LAMINATES							
		80% DOPED OXIDE(5/92) & MICRO.(5/92) & KY(7/92)							
111A	10/29/92	110A-1	0.225	0.038	2.331	4.9	0.038	50.767	2077.77778
		110A-2	0.35	0.039	3.533	4.8	0.039	48.455	1271.42857
		110A-3	0.22	0.042	2.062	1.75	0.042	16.404	695.454545
		110A-4	0.33	0.041	3.169	0.57	0.041	5.473	72.7272727
		LAMINATES							
111A	5MIN SOAK/3MIN CYC.	PRECOMPOUNDED MICRO/DOPED OXIDE							
		85%-LOADING							
		111A-1	1	0.042	9.374	1.95	0.042	18.279	95
		111A-2	2.1	0.043	19.227	3	0.043	27.467	42.8571429
		111A-3	0.8	0.053	5.943	1.2	0.053	8.914	50
112A	11/5/92	75%-LOADING							
		MICRO/DOPED OXIDE							
		80%-LOADING							
		111A-4	1.8	0.036	19.685	2	0.036	21.872	11.1111111
		LAMINATES							
112A	400F/3 TONS	75% LOADING							
		DOPED OXIDE(7/92)							
		KY(7/92)							
		14%KET(9/92)							
		KY(7/92)							
112A	400F/3 TONS	112A-1	0.15	0.089	0.664	0.089	0.089	0.000	-100
		112A-2	0.165	0.088	0.738	0.088	0.088	0.000	-100
		400F/3 TONS							
		400F/3 TONS							
		400F/3 TONS							

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
113A	325F/3 TONS 11/10/92	LAMINATES 80% LOADING											
		DOPED OXIDE(7/92) MICROTHENE(5/92) PRECOMPOUNDED C-PLASTIC											
		112A-3	0.46		0.069		2.625		0.069		0.000		-100
		112A-4	0.58		0.075		3.045		0.075		0.000		-100
		LAMINATES											
		80% DOPED OXIDE(7/92) MICROTHENE(5/92) CA											
		PRECOMPOUNDED C-PLASTIC											
		113A-1	0.49		0.064		3.014		0.064		28.912		859.183673
		113A-2	0.37		0.066		2.207		0.066		27.440		1143.24324
		113A-3	0.36		0.074		1.915		0.074		4.522		136.111111
114A	325F/3 TONS 11/10/92	113A-4	0.41		0.068		2.374		0.068		4.111		73.1707317
		LAMINATES											
		80% DOPED OXIDE(7/92) MICROTHENE(5/92) CA											
		PRECOMPOUNDED C-PLASTIC											
		114A-1	0.43		0.062		2.731		0.062		11.113		306.976744
		114A-2	0.42		0.069		2.396		0.069		7.760		223.809524
		114A-3	0.46		0.068		2.663		0.068		5.616		110.869565
		114A-4	0.64		0.076		3.315		0.076		5.439		64.0625
		LAMINATES											
		80% LOADING DOPED OXIDE											
115A	325F/3 TONS 11/24/92	20% MICROTHENE											
		WASHING TECH. PRECOMPOUNDED C-PLASTIC .2%/07GMS CA											
		325F/3 TONS											
		115A-1 COARSE-X	0.38		0.073		2.049		0.072		2.843		38.7426901

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
116A	325F/3 TONS	115A-2 COARSE-X	0.35		0.072	1.914		0.52		0.072		2.843		48.5714286
	325F/3 TONS	115A-3 MEDIUM-X	0.46		0.062	2.921		0.96		0.062		6.096		108.695652
	325F/3 TONS	115A-4 MEDIUM-X	0.58		0.067	3.408		1.18		0.067		6.934		103.448276
	11/25/92	LAMINATES												
80% LOADING DOPED OXIDE														
20% MICROTHENE														
PRECOMPOUNDED														
C-PLASTIC														
2%/07GMS CA														
117A	325F/3 TONS	116A-1 COARSE	0.37		0.077	1.892								
	325F/3 TONS	116A-2 COARSE	0.3		0.071	1.664								
	325F/3 TONS	116A-3 MEDIUM	0.88		0.067	5.171								
	325F/3 TONS	116A-4 MEDIUM	0.61		0.066	3.639								
117A	12/03/92	LAMINATES												
		80% LOADING DOPED OXIDE												
		20% MICROTHENE												
		PRECOMPOUNDED												
C-PLASTIC														
.15% TO .45% CA														
118A	325F/3 TONS	117-1A (.15%)	0.38		0.071	2.107		0.98		0.071		5.434		157.894737
	325F/3 TONS	117-2A (.20%)	0.51		0.071	2.828		1.15		0.071		6.377		125.490196
	325F/3 TONS	117-3A (.25%)	0.42		0.068	2.432		0.7		0.066		4.176		71.7171717
	325F/3 TONS	117-4A (.30%)	0.56		0.068	3.242		0.98		0.068		5.674		75
118A	12/07/92	LAMINATES												
		80% LOADING DOPED OXIDE												
		20% MICROTHENE												
		PRECOMPOUNDED												
C-PLASTIC														
.15% TO .45% CA														
118	325F/3 TONS	118-1A (.15%)	0.4		0.068	2.316								

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
119A	12/04/92 119A	118-2A (.20%)	0.4		0.071		2.218								
		118-3A (.25%)	0.38		0.068		2.200								
		118-4A (.30%)	0.33		0.068		1.911		0.4		0.069		2.282		19.4554238
		118-5A (.35%)	0.3		0.068		1.737		0.4		0.067		2.350		35.323831
		118-6A (.40%)	0.4		0.069		2.282		0.46		0.069		2.625		15
		118-7A (.45%)	0.36		0.068		2.084		0.45		0.068		2.605		25
120A	12/16/92	THIN LAMINATES													
		80% LOADING DOPED OXIDE													
		20% MICROTHENE PRECOMPOUNDED													
		C-PLASTIC													
		.25% CA													
		325F/3 TONS													
		119-1A	0.5		0.038		5.180								
		119-2A	0.34		0.038		3.523								
		119-3A	0.225		0.033		2.684								
		119-4A	0.42		0.03		5.512								
121	12/17/92	HAND COMPOUNDED													
		CARBON PLASTIC													
		120-1A 350F	0.43		0.058		2.919								
		120-2A 350F	0.51		0.061		3.292								
		120-3A 375F	0.38		0.059		2.536		0.52		0.059		3.470		36.8421053
		120-4A 375F	0.44		0.062		2.794		0.56		0.062		3.556		27.2727273
121A	12/17/92	PRECOMPOUNDED													
		CARBON PLASTIC													
		120-5A	1.3		0.056		9.139		1.95		0.056		13.709		50
		120-6A	2.05		0.058		13.915		2.95		0.058		20.024		43.902439
		LAMINATES													
		80% LOADING DOPED OXIDE													
121A	12/17/92	MICROTHENE (5/92)													
		.25% CA													
		HANDCOMPOUNDED													
		CARBON PLASTIC													
		121-1A	0.43		0.075		2.257								
		121-2A	0.43		0.07		2.418								
122A	12/17/92	LAMINATES													
		2.60G KETBLACK													
		10.37G MICRO (5/92)													
		325F/15 TONS													
122A	12/17/92	0.060" SHIM													

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)	RESISTIVITY (OHM-CM)	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER			
125A	125A 01/12/93	124-4A (30%)	0.66		0.077		3.375				
		LAMINATES									
		TEMP 230F TO 400F									
		85% DOPED OXIDE PELLETS									
		HANDCOMPOUNDED									
		C-PLASTIC									
		125-1A (300F)	0.41		0.057		2.832				
		125-2A (300F)	0.73		0.057		5.042				
		125-3A (350F)	0.42		0.05		3.307				
		125-4A (350F)	0.59		0.051		4.555				
		125-5A (375F)	0.45		0.051		3.474				
		125-6A (375F)	0.44		0.052		3.331				
		125-7A (400F)	0.39		0.051		3.011				
		125-8A (400F)	0.39		0.051		3.011				
126	126A 01/14/93	125-11A (275F)	0.58		0.057		4.006				
		125-12A (275F)	0.38		0.057		2.625				
		LAMINATES									
		80% TO 90% LOADING									
		DOPED OXIDE(7/92)									
		.35% CA									
		SAMPLES 1&2									
		.30% CA									
		SAMPLES 3-7									
		HANDCOMPOUNDED									
		C-PLASTIC									
		MICROTHENE (5/92)									
		325F/3 TONS									
		126-1A (80%)	1.45		0.061		9.358				
129A	01/15/93	126-2A (80%)	2.85		0.061		18.394				
		126-3A (85%)	0.32		0.08		1.575	0.4	0.08	1.969	25
		126-4A (85%)	0.27		0.076		1.399	0.33	0.076	1.709	22.2222222
		275F/3 TONS									
		126-6A (82.5%)	1.4		0.073		7.550	1.45	0.073	7.820	3.57142857
		126-7A (82.5%)	0.52		0.062		3.302	0.53	0.062	3.366	1.92307692
		LAMINATES									
		85% DOPED OXIDE PELLETS									
		14% TO 22%									
		KET (9/92)									
		325F/3 TONS									
		129-1A (15%)	0.54		0.05		4.252				
		129-2A (15%)	0.64		0.048		5.249				
		129-3A (16%)	0.55		0.049		4.419				
		129-4A (16%)	0.56		0.049		4.499				

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
130A	130A 01/19/93	129-5A (16%)	0.75		0.05		5.906								
		129-6A (18%)	0.66		0.049		5.303								
		129-7A (22%)	0.63		0.051		4.863								
		129-8A (22%)	0.38		0.05		2.992								
		LAMINATE 325F/3 TONS													
130A	130A 01/19/93	130-1A (18%)	0.46		0.049		3.696		0.71		0.049		5.705		54.3478261
		130-2A (18%)	0.46		0.044		4.116		0.76		0.045		6.649		61.5458937
		130-3A (16%)	0.43		0.044		3.848		0.53		0.044		4.742		23.255814
		130-4A (16%)	0.49		0.043		4.486		0.64		0.044		5.727		27.6437848
131A	131A 01/27/93	LAMINATE 325F/3 TONS													
		131-1A(3 TONS)	0.58		0.061		3.743								
		131-3A(15 TONS)	0.74		0.055		5.297								
		131-4A(15 TONS)	0.51		0.052		3.861								
		131-5A(3 TONS)	0.78		0.076		4.041								
132A	132A 01/28/93	LAMINATE 325F/3 TONS													
		132-1A(3 TONS)	1.3		0.057		8.979								
		132-2A(3 TONS)	1.5		0.048		12.303								
		132-3A(15 TONS)	0.96		0.05		7.559								
		132-4A(15 TONS)	0.79		0.051		6.099								
133A	133A 01/28/93	LAMINATE 325F/3 TONS													
		133-1A(3 TONS)	0.36		0.069		2.054								
		133-2A(3 TONS)	0.32		0.065		1.938								
		133-3A(15 TONS)	0.44		0.051		3.397								
		133-4A(15 TONS)	0.5		0.052		3.786								
134A	134A 01/28/93	LAMINATE 325F/3 TONS													
		134-1A(3 TONS)	0.76		0.058		5.159		0.83		0.058		5.634		9.21052632
		134-2A(3 TONS)	0.63		0.057		4.351		0.69		0.058		4.684		7.63546798
		134-3A(15 TONS)	0.85		0.049		6.830		0.72		0.049		5.785		-15.2941176
		134-4A(15 TONS)	0.76		0.051		5.867		0.68		0.05		5.354		-8.73684211
135A	01/28/93	LAMINATE 325F/3 TONS													
		135-1A(.010")	0.65		0.029		8.824		0.61		0.03		8.005		-9.28205128
		135-2A(.010")	0.6		0.034		6.948		0.57		0.034		6.600		-5
		135-3A(.006")	0.56		0.029		7.602		0.51		0.029		6.924		-8.92857143
		135-4A(.006")	0.62		0.029		8.417		0.72		0.029		9.775		16.1290323
136A	02/01/93	LAMINATE 325F/3 TONS													
		136-1A(22%)	0.39		0.034		4.516								

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
137A	02/03/93	LAMINATE 325F/3 TONS 137-1A 137-2A 137-3A 137-4A	0.57	0.033	6.800										
			0.34	0.035	3.825										
			0.39	0.034	4.516										
MRP	02/03/93	LAMINATE 325F/3 TONS MRP-1 MRP-2 MRP-3 MRP-4	0.48	0.056	3.375	0.59	0.056	4.148	22.9166667						
			0.41	0.061	2.646	0.48	0.06	3.150	19.0243902						
			0.49	0.054	3.572	0.89	0.054	6.489	81.6326531						
			0.43	0.058	2.919	0.47	0.058	3.190	9.30232558						
138A	02/04/93	LAMINATE 325F/3 TONS 138-1A 138-2A 138-3A 138-4A	0.34	0.03	4.462										
			0.6	0.032	7.382										
			0.43	0.036	4.703										
			0.35	0.035	3.937										
139A	02/05/93	LAMINATE 325F/3 TONS 139-1A(18%) 139-2A(18%) 139-3A(22%) 139-4A(22%)	0.39	0.022	6.979										
			0.36	0.025	5.669										
			0.33	0.026	4.997										
			0.4	0.027	4.997										
BR AND R3	02/05/93	LAMINATE 325F/3 TONS BR-1 BR-2 R3-1 R3-2	0.76	0.039	7.672										
			0.85	0.039	8.581										
			0.47	0.042	4.406										
			0.51	0.049	4.098										
EXTRUDED 3/24/93		168-1A 100/115/120/125 168-2A 100/110/120/125 168-3A LAMINATION STOPPED.	1.2												
169A	03/25/93	LAMINATE 325F/3 TONS 169-1A	0.89	0.041	8.5461878	>100									

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
		169-2A	0.52	0.041	4.9932783	>100									
170A	03/26/93	LAMINATE 325F/3 TONS													
		170-1A	0.68	0.041	6.5296716	0.66	0.041	6.337622431	-2.94117647						
		170-2A	0.9	0.041	8.6422124	0.86	0.041	8.258114077	-4.44444444						
171A	03/30/93	LAMINATE 325F/3 TONS													
		171-1A	0.35	0.035	3.9370079	0.74	0.035	8.323959505	111.428571						
		171-2A	0.68	0.035	7.6490439	1.05	0.036	11.48293963	50.122549						
		171-3A	0.52	0.039	5.2493438										
		171-4A	0.55	0.038	5.6983009										
173A	04/2/93	LAMINATE 325F/3 TONS													
		173-1A	0.34	0.039	3.4322633	0.36	0.04	3.543307087	3.23529412						
		173-2A	0.41	0.039	4.1389057	0.48	0.041	4.60917995	11.3622844						
175A	04/05/93	LAMINATE 325F/3 TONS													
		175-1A(160)	0.55	0.041	5.281352	0.79	0.041	7.585942001	43.6363636						
		175-2A(160)	0.39	0.042	3.655793	0.53	0.042	4.968128984	35.8974359						
		175-3A(180)	0.47	0.043	4.3032412	0.68	0.043	6.22596594	44.6808511						
		175-4A(180)	0.44	0.042	4.1244844	0.58	0.043	5.310382714	28.7526427						
176A	04/06/93	LAMINATE 325F/3 TONS													
		176-1A(160)	0.42	0.04	4.1338583	0.43	0.04	4.232283465	2.38095238						
		176-2A(160)	0.49	0.04	4.8228346	0.49	0.041	4.705204532	-2.43902439						
		176-3A(180)	0.38	0.039	3.836059	0.39	0.039	3.937007874	2.63157895						
		176-4A(180)	0.35	0.038	3.6261915	0.36	0.04	3.543307087	-2.28571429						
		176-1A	0.42	0.04	4.1338583	0.67	0.04	6.594488189	59.5238095						
		176-3A	0.38	0.039	3.836059	0.59	0.04	5.807086614	51.3815789						
		176-4A	0.35	0.038	3.6261915	0.5	0.04	4.921259843	35.7142857						

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
177A	04/12/93	*176-3A	0.38	0.38	0.039	0.04	4.134	0.9	0.04	8.858267717	114.278368			
		*SAMPLE TESTED FOR 30 DAYS												
		176-3A	0.38	0.38	0.039	0.039	4.134	0.64	0.039	6.46073087	56.282798			
		READING TAKEN AFTER 1 DAY												
		176-3A	0.38	0.38	0.039	0.04	4.134	0.833	0.04	8.198818898	98.3265336			
177A	04/12/93	READING TAKEN AFTER 2 DAYS												
		LAMINATE 325F/3 TONS												
		177-1A(160)	0.61	0.61	0.041	0.041	5.8574995	0.53	0.041	5.089302862	-13.1147541			
		177-2A(160)	0.81	0.81	0.044	0.042	7.2476736	0.74	0.042	6.936632921	-4.29159318			
		177-3A(180)	1.05	1.05	0.043	0.042	9.6136239	0.77	0.042	7.217847769	-24.9206349			
178A	04/14/93	177-4A(180)	0.84	0.84	0.044	0.043	7.5161059	0.65	0.043	5.951290972	-20.8194906			
		LAMINATE 325F/3 TONS												
		178-1A(160)	0.54	0.54	0.046	0.046	4.6217049	0.58	0.046	4.964053406	7.40740741			
		178-2A(160)	0.64	0.64	0.047	0.045	5.361032	0.68	0.045	5.949256343	10.9722222			
		178-3A(180)	0.53	0.53	0.045	0.045	4.6369204	0.48	0.045	4.199475066	-9.43396226			
179A	04/15/93	178-4A(180)	0.45	0.45	0.041	0.041	4.3211062	0.48	0.041	4.60917995	6.66666667			
		LAMINATE 325F/3 TONS												
		179-1A(160)	0.39	0.39	0.045	0.045	3.4120735	0.46	0.045	4.024496938	17.9487179			
		179-2A(160)	0.31	0.31	0.043	0.043	2.838308	0.39	0.043	3.570774583	25.8064516			
		179-3A(180)	0.28	0.28	0.043	0.043	2.563633	0.34	0.043	3.11298297	21.4285714			
181A	04/28/93	179-4A(180)	0.31	0.31	0.043	0.043	2.838308	0.38	0.043	3.479216261	22.5806452			
		LAMINATE 325F/3 TONS												
		181-1A(200)	0.47	0.47	0.063	0.062	2.9371329	0.58	0.062	3.683007366	25.3946465			
		181-2A(200)	0.4	0.4	0.059	0.057	2.6691579	0.56	0.057	3.86793756	44.9122807			
		181-3A(180)	0.54	0.54	0.064	0.064	3.3218504	0.61	0.064	3.75246063	12.962963			

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM) BEFORE	THICKNESS (INCH) BEFORE	RESISTIVITY (OHM-CM) BEFORE	RESISTANCE (OHM) AFTER	THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
182A	04/28/93	LAMINATE 325F/3 TONS	0.55	0.064	3.3833661	0.58	0.064	3.567913386	5.45454545
4V BATTERIES FOR PASTE ADHESION									
		182-1A(200) SANDED	0.68	0.073	3.6673498				
		182-2A(200)	0.7	0.06	4.5931759				
		Pb THEN SANDED							
		182-3A(180) SANDED	0.68	0.071	3.7706554				
		182-4A(180)	0.6	0.058	4.0727668				
		Pb THEN SANDED							
183A	04/29/93	LAMINATE 325F/3 TONS	IR at corner.						
		183-1A	0.38	0.043	3.4792163	0.54	0.044	4.831782391	38.8755981
		183-2A	0.38	0.043	3.4792163	0.55	0.048	4.511154856	29.6600877
		183-3A	0.38	0.059	2.5357	0.55	0.059	3.670092086	44.7368421
		183-4A	0.38	0.057	2.6246719	0.58	0.059	3.870278927	47.4576271
184A	05/04/93	LAMINATE 325F/3 TONS							
		184-1A	0.58	0.046	4.9640534	0.78	0.046	6.67579596	34.4827586
		184-2A	0.5	0.046	4.2793564	0.8	0.047	6.701289998	56.5957447
		184-3A	0.58	0.05	4.5669291	0.76	0.051	5.866913695	28.4651792
185A	05/05/93	LAMINATE 325F/3 TONS							
		185-1A	0.38	0.055	2.7201145	0.58	0.055	4.151753758	52.6315789
		185-2A	0.29	0.048	2.3786089	0.41	0.05	3.228346457	35.7241379
		THICK SUBSTRATE							
186A	05/05/93	LAMINATE 325F/3 TONS							
		186-1A	1	0.041	9.6024582	1.55	0.042	14.52943382	51.3095238
		186-2A	0.82	0.041	7.8740157	1.3	0.043	11.90258194	51.1627907
187A		LAMINATE 330F/2 TONS							
		187-1A	0.155	0.03	2.0341207	10.5	0.03	137.7952756	6674.19355

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
188A		LAMINATE 330F/2 TONS	0.135	0.135	0.029	0.029	1.832745	1.832745	20	20	0.029	0.029	271.5177844	271.5177844	14714.8148
			0.135	0.135	0.029	0.029	1.832745	1.832745	6.2	6.2	0.029	0.029	84.17051317	84.17051317	4492.59259
			0.155	0.155	0.03	0.03	2.0341207	2.0341207	8.1	8.1	0.03	0.03	106.2992126	106.2992126	5125.80645
189A	06/14/93	LAMINATE 295F/3 TONS	0.14	0.14	0.028	0.028	1.9685039	1.9685039	6	6	0.03	0.03	78.74015748	78.74015748	3900
			0.14	0.14	0.031	0.031	1.7780036	1.7780036	9	9	0.03	0.03	118.1102362	118.1102362	6542.85714
			0.135	0.135	0.031	0.031	1.7145034	1.7145034	8.1	8.1	0.031	0.031	102.8702057	102.8702057	5900
			0.155	0.155	0.031	0.031	1.9685039	1.9685039	9.6	9.6	0.031	0.031	121.9202438	121.9202438	6093.54839
189A	06/14/93	LAMINATE 295F/3 TONS	0.97	0.97	0.045	0.045	8.486	8.486							
190A	06/16/93	LAMINATE 295F/3 TONS	0.47	0.47	0.051	0.051	3.6282229	3.6282229	0.7	0.7	0.051	0.051	5.403736298	5.403736298	48.9361702
			0.54	0.54	0.045	0.045	4.7244094	4.7244094	0.83	0.83	0.045	0.045	7.261592301	7.261592301	53.7037037
			0.74	0.74	0.086	0.086	3.3876579	3.3876579							
			0.78	0.78	0.092	0.092	3.337898	3.337898							
191A	06/18/93	LAMINATE 295F/3 TONS	0.73	0.73	0.086	0.086	3.3418788	3.3418788							
			0.66	0.66	0.086	0.086	3.0214246	3.0214246							
191A	06/18/93	LAMINATE 295F/3 TONS	0.25	0.25	0.044	0.044	2.2369363	2.2369363	1.6	1.6	0.044	0.044	14.31639227	14.31639227	540
			0.255	0.255	0.045	0.045	2.2309711	2.2309711	0.97	0.97	0.044	0.044	8.679312813	8.679312813	289.037433
			0.255	0.255	0.045	0.045	2.2309711	2.2309711	0.38	0.38	0.044	0.044	3.400143164	3.400143164	52.4064171
192A	06/18/93	LAMINATE 295F/3 TONS	0.23	0.23	0.043	0.043	2.1058414	2.1058414	0.48	0.48	0.044	0.044	4.294917681	4.294917681	103.952569
			0.29	0.29	0.044	0.044	2.5948461	2.5948461	0.58	0.58	0.044	0.044	5.189692198	5.189692198	100
			1.3	1.3	0.051	0.051	10.03551	10.03551	3.5	3.5	0.049	0.049	28.12148481	28.12148481	180.21978
			1.9	1.9	0.049	0.049	15.265949	15.265949	4.4	4.4	0.05	0.05	34.64566929	34.64566929	126.947368
193A	06/18/93	LAMINATE 295F/3 TONS													
193A	06/18/93	LAMINATE 295F/3 TONS	0.19	0.19	0.062	0.062	1.2065024	1.2065024	0.82	0.82	0.062	0.062	5.207010414	5.207010414	331.578947
			0.26	0.26	0.058	0.058	1.7648656	1.7648656	2.2	2.2	0.059	0.059	14.68036834	14.68036834	731.812256

IR OF SAMPLE WAS TOO HIGH, NEW SAMPLES WILL BE MADE AND TESTED

READING TAKEN AFTER BEING STORED FOR 2.5 MONTHS

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
194A	06/24/93	LAMINATE 295F/3 TONS 194-1A(.008") 194-2A(.008") 194-3A(.010") 194-4A(.010")	0.265		0.031		3.3655067		8.5		0.032		104.5767717		3007.31132
			0.32		0.042		2.999625		>100		0.043				
			0.29		0.04		2.8543307		>100		0.04				
			0.31		0.034		3.5896248		44		0.034		509.4951366		14093.5484
195A	06/28/93	LAMINATE 295F/3 TONS 195-1A 195-2A	0.46		0.046		3.9370079		0.65		0.046		5.5631633		41.3043478
			0.58		0.046		4.9640534		0.72		0.046		6.162273194		24.137931
196A	06/28/93	LAMINATE 295F/3 TONS 196-1A 196-2A	1.15		0.044		10.289907		1.15		0.045		10.06124234		-2.22222222
			1.05		0.045		9.1863517		1.3		0.045		11.3735783		23.8095238
197A	06/29/93	LAMINATE 295F/3 TONS 197-1A(315F) 197-2A(315F) 197-3A(335F) 197-4A(335F) 197-5A(355F) 197-6A(355F) 197-7A(375F) 197-8A(375F) 197-9A(400F) 197-10A(400F)	0.24		0.044		2.1474588		0.7		0.045		6.124234471		185.185185
			0.275		0.045		2.4059493		0.65		0.045		5.686789151		136.363636
			0.225		0.045		1.9685039		0.73		0.045		6.386701662		224.444444
			0.36		0.051		2.7790644		0.81		0.051		6.252894859		125
			0.24		0.044		2.1474588		0.37		0.045		3.237095363		50.7407407
			0.22		0.045		1.9247594		0.275		0.045		2.405949256		25
			0.235		0.045		2.055993		0.29		0.045		2.537182852		23.4042553
			0.215		0.045		1.8810149		0.3		0.045		2.624671916		39.5348837
			0.205		0.045		1.7935258		0.275		0.045		2.405949256		34.1463415
			0.2		0.046		1.7117426		0.275		0.045		2.405949256		40.5555556
198A	06/29/93	LAMINATE 295F/3 TONS 198-1A(315F) 198-2A(315F) 198-3A(335F) 198-4A(335F) 198-5A(355F) 198-6A(355F) 198-7A(375F) 198-8A(375F) 198-9A(400F)	0.43		0.049		3.4549253		0.86		0.049		6.909850554		100
			0.41		0.05		3.2283465		1.25		0.05		9.842519685		204.878049
			0.295		0.047		2.4711007		0.82		0.047		6.86822248		177.966102
			0.32		0.052		2.4227741		0.54		0.052		4.088431254		68.75
			0.28		0.046		2.3964396		1.75		0.044		15.65855404		553.409091
			0.23		0.046		1.9685039		4		0.044		35.79098067		1718.18182
			0.21		0.047		1.7590886		1.95		0.046		16.6894899		848.757764
			0.36		0.049		2.8924956		0.65		0.048		5.331364829		84.3171296
			0.245		0.048		2.0095144		1.2		0.046		10.27045532		411.091393

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
199A	07/21/93	198-10A(400F)	0.24	0.045	2.0997375	1.3	0.045	11.3735783	441.666667
		STABILITY TESTING WAS SHORTENED BY ONE DAY ON SAMPLES 1-4 PROBLEM WITH POWER SUPPLY ON SAMPLES 5A-8A							
		LAMINATE 295F/3 TONS							
		199-1A(NOT SANDED)	0.66	0.044	5.9055118				
200A	07/23/93	199-2A(NOT SANDED)	0.62	0.043	5.676616				
		199-3A(SANDED)	0.31	0.044	2.773801	0.5	0.045	4.374453193	57.7060932
		199-4A(SANDED)	0.37	0.043	3.3876579	0.54	0.044	4.831782391	42.6289926
		LAMINATE 295F/3 TONS							
201A	07/23/93	200-1(SANDED)	0.45	0.043	4.1201245	0.58	0.044	5.189692198	25.959596
		200-2(SANDED)	0.47	0.045	4.111986	0.66	0.044	5.905511811	43.6170213
		LAMINATE 295F/3 TONS							
		201-1(325)	0.32	0.046	2.7387881	0.4	0.043	3.662332906	33.7209302
202A	07/23/93	201-2(350)	0.295	0.043	2.7009705	0.4	0.043	3.662332906	35.5932203
		201-3(375)	0.34	0.044	3.0422334	0.45	0.045	3.937007874	29.4117647
		201-4(400)	0.31	0.044	2.773801	0.58	0.044	5.189692198	87.0967742
		201-5(425)	0.31	0.044	2.773801	1.4	0.044	12.52684324	351.612903
203A	07/23/93	LAMINATE 295F/3 TONS							
		202-1(325)	0.41	0.043	3.7538912	0.71	0.043	6.500640908	73.1707317
		202-2(350)	0.31	0.043	2.838308	0.48	0.043	4.394799487	54.8387097
		202-3(375)	0.35	0.044	3.1317108	0.54	0.044	4.831782391	54.2857143
204A	07/27/93	202-4(400)	0.38	0.043	3.4792163	0.54	0.044	4.831782391	38.8755981
		202-5(425)	0.295	0.044	2.6395848	0.98	0.044	8.768790265	232.20339
		LAMINATE 295F/3 TONS							
		203-1(325)	0.34	0.044	3.0422334	3.1	0.042	29.05886764	855.182073
205A	07/27/93	203-2(350)	0.42	0.044	3.758053	2.2	0.044	19.68503937	423.809524
		203-3(375)	0.36	0.044	3.2211883	5	0.042	46.86914136	1355.02646
		203-4(400)	0.5	0.044	4.4738726	3	0.043	27.4674968	513.953488
		LAMINATE 300F/3 TONS							
206A	07/27/93	204-1A(250)	0.62	0.046	5.3064019	1.6	0.046	13.69394043	158.064516
		204-2A(275)	0.45	0.044	4.0264853	0.83	0.044	7.42662849	84.444444
		204-3A(300)	0.51	0.045	4.4619423	0.68	0.045	5.949256343	33.3333333
		204-4A(325)	0.51	0.045	4.4619423	0.98	0.045	8.573928259	92.1588627
207A	07/27/93	204-5A(350)	0.47	0.044	4.2054402	2.9	0.044	25.94846099	517.021277
		204-6A(375)	0.46	0.044	4.1159628	2.35	0.045	20.55993001	399.516908

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
205A													
SEE BATTERY													
BUILD													
206A	8/10/93	LAMINATE 300F/3 TONS 206-1A(SP006) 206-2A(SP006)	0.275	0.053	2.0427871	0.34	0.053	2.52527693	23.6363636	0.053	2.52527693	23.6363636	
			0.25	0.052	1.8927922	0.31	0.053	2.30277819	21.6603774	0.053	2.30277819	21.6603774	
		206-3A(SP007) 206-4A(SP007)	0.36	0.052	2.7256208	0.48	0.052	3.63416114	33.3333333	0.052	3.63416114	33.3333333	
			0.23	0.053	1.7085129	0.34	0.052	2.574197456	50.6688963	0.052	2.574197456	50.6688963	
207A	8/10/93	LAMINATE 300F/3 TONS 207-1A(SP006) 207-2A(SP006)	0.83	0.043	7.5993408	1.65	0.042	15.46681665	103.528399	0.042	15.46681665	103.528399	
			0.48	0.041	4.60918	0.64	0.042	5.999250094	30.1587302	0.042	5.999250094	30.1587302	
		207-3A(SP007) 207-4A(SP007)	0.96	0.043	8.789599	1	0.044	8.947745168	1.79924242	0.044	8.947745168	1.79924242	
			0.89	0.042	8.3427072	0.86	0.041	8.258114077	-1.01397643	0.041	8.258114077	-1.01397643	
208A	8/11/93	LAMINATE 300F/3 TONS 208-1A 208-2A 208-3A 208-4A	0.4	0.037	4.2562247	0.6	0.039	6.056935191	42.3076923	0.039	6.056935191	42.3076923	
			0.5	0.038	5.1802735	0.7	0.038	7.252382926	40	0.038	7.252382926	40	
			0.3	0.036	3.2808399	0.54	0.037	5.745903384	75.1351351	0.037	5.745903384	75.1351351	
			0.32	0.038	3.3153751	0.73	0.039	7.369271149	122.275641	0.039	7.369271149	122.275641	
209A	8/16/93	LAMINATE 300F/3 TONS 209-1A(SANDED) 209-2A	0.96	0.051	7.4108384	3.4	0.051	26.24671916	254.166667	0.051	26.24671916	254.166667	
			1.35	0.053	10.028228	4.3	0.053	31.941762	218.518519	0.053	31.941762	218.518519	
210A	8/24/93	LAMINATE 300F/3 TONS 210-1A 210-2A 210-3A 210-4A	0.28	0.033	3.3404915	13.75	0.033	164.0419948	4810.71429	0.033	164.0419948	4810.71429	
			0.23	0.033	2.7439752	11	0.034	127.3737842	4541.94373	0.034	127.3737842	4541.94373	
			0.41	0.041	3.9370079	2.4	0.043	21.97399744	458.139535	0.043	21.97399744	458.139535	
			0.56	0.042	5.2493438	24	0.043	219.7399744	4086.04651	0.043	219.7399744	4086.04651	
211A	9/2/93	LAMINATE 300F/3 TONS											

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
212A	9/8/93	LAMINATE 300F/3 TONS	0.56	0.69	0.032	0.03	6.8897638	9.05511811	0.69	0.03	0.03	0.03	7.874015748	9.05511811	31.4285714
			0.41	0.62	0.031	0.031	5.2070104	7.874015748	0.62	0.031	0.031	0.031	9.186351706	7.874015748	51.2195122
			0.32	0.56	0.024	0.024	5.2493438	9.186351706	0.56	0.024	0.024	0.024	13.12335958	9.186351706	75
			0.33	0.8	0.023	0.024	5.6487504	13.12335958	0.8	0.024	0.024	0.024		13.12335958	132.323232
213A	9/16/93	LAMINATE 350F/3 TONS	0.86	1.25	0.044	0.044	7.6950608	11.18468146	1.25	0.044	0.044	0.044	39.37007874	11.18468146	45.3488372
			0.99	4.4	0.044	0.044	8.8582677	39.37007874	4.4	0.044	0.044	0.044	21.05841421	39.37007874	344.444444
			0.64	2.3	0.043	0.043	5.8597326	21.05841421	2.3	0.043	0.043	0.043	17.3960813	21.05841421	259.375
			0.72	1.9	0.043	0.043	6.5921992	17.3960813	1.9	0.043	0.043	0.043		17.3960813	163.888889
214A	9/20/93	LAMINATE 350F/3 TONS	2.6	0.035	0.035	0.035	29.246344								
			3.4	0.036	0.036	0.036	37.182852								
			3.8	0.035	0.035	0.035	42.744657								
			2.8	0.036	0.036	0.036	30.621172								
			2.5	0.04	0.04	0.04	24.606299								
			3	0.036	0.036	0.036	32.808399								
215A	9/22/93	LAMINATE 350F/3 TONS	0.5	0.067	0.067	0.067	2.9380656								
			0.6	0.082	0.082	0.082	2.8807375								
			0.84	0.081	0.081	0.081	4.082823								
			0.82	0.081	0.081	0.081	3.9856129								
			0.86	0.081	0.081	0.081	4.1800331								
216A	9/27/93	LAMINATE 350F/3 TONS	0.45	0.022	0.022	0.022	8.0529707								
			0.3	0.021	0.021	0.021	5.624297								
			0.34	0.022	0.022	0.022	6.0844667								
			0.36	0.022	0.022	0.022	6.4423765								
216A	9/27/93	LAMINATE 350F/30 TONS	0.37	0.024	0.024	0.024	6.0695538								
			0.285	0.022	0.022	0.022	5.1002147								
			0.34	0.021	0.021	0.021	6.3742032								
			0.37	0.02	0.02	0.02	7.2834646								

*SAMPLES NOT SURFACE TREATED

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
217A	9/29/93	LAMINATE 300F/3 TONS													
			0.48	0.052	3.6341611	0.66	0.052	4.996971532							37.5
			0.43	0.05	3.3858268	0.5	0.05	3.937007874							16.2790698
			0.47	0.052	3.5584494	0.51	0.052	3.861296184							8.5106383
		217-4A	0.46	0.05	3.6220472	0.6	0.05	4.724409449							30.4347826
218A	9/29/93	LAMINATE 300F/3 TONS													
			0.9	0.051	6.947661										
			1	0.051	7.7196233										
			0.7	0.051	5.4037363										
		218-4A	0.73	0.051	5.635325										
219A	10/4/93	LAMINATE 350F/3 TONS													
			0.46	0.038	4.7658516	0.73	0.038	7.563199337							58.6956522
			0.4	0.038	4.1442188	0.74	0.038	7.666804807							85
			0.37	0.039	3.73511	0.8	0.04	7.874015748							110.810811
		219-4A(3 TONS)	0.43	0.04	4.2322835	0.77	0.04	7.578740157							79.0697674
220A	10/6/93	LAMINATE 300F/3 TONS													
			0.34	0.021	6.3742032	0.88	0.022	15.7480315							147.058824
			0.3	0.019	6.2163282	0.69	0.019	14.29755491							130
			0.28	0.02	5.511811	0.54	0.02	10.62992126							92.8571429
		220-4A	0.34	0.019	7.045172	0.7	0.019	14.50476585							105.882353
221A	10/11/93	LAMINATE 300F/3 TONS													
			0.83	0.045	7.2615923	1.15	0.045	10.06124234							38.5542169
			0.81	0.044	7.2476736	1.1	0.044	9.842519685							35.8024691
			0.85	0.045	7.4365704	1	0.045	8.748906387							17.6470588
		221-4A	0.92	0.044	8.2319256	1.3	0.044	11.63206872							41.3043478
222A	10/15/93	LAMINATE 300F/3 TONS													
			0.8	0.026	12.11387	1.15	0.026	17.41368867							43.75
			1.2	0.025	18.897638	1.1	0.025	17.32283465							-8.33333333
			0.78	0.025	12.283465	1.15	0.025	18.11023622							47.4358974
		222-4A	0.91	0.025	14.330709	0.82	0.025	12.91338583							-9.89010989
223A	10/18/93	LAMINATE 300F/3 TONS													
			0.54	0.044	4.8317824	0.55	0.045	4.811898513							-0.41152263
			0.49	0.044	4.3843951	0.7	0.044	6.263421618							42.8571429
			.470/.620	0.044	5.54	1.15	0.045	10.06124234							81.6108726
		223-4A(WI)	.440/.450	0.045	3.93	1	0.044	8.947745168							127.677994
FIRST WITHOUT SCW, SECOND WITH															
224A	10/19/93	LAMINATE 350F/3 TONS													
		224-1A	1.7	0.08	8.3661417										

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)	
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
225A	10/20/93	LAMINATE 300F/3 TONS (TTS)225-1A (TTS)225-2A (138S)225-3A (138S)225-4A	1.65		0.08		8.1200787									
			1.7		0.08		8.3661417									
			1.65		0.08		8.1200787									
			1.6		0.081		7.7768057									
			1.75		0.08		8.6122047									
			1.85		0.08		9.1043307									
			1.8		0.08		8.8582677									
			2		0.081		9.7210071									
			1.8		0.081		8.7489064									
			*SAMPLES SURFACE TREATED													
226A	10/21/93	LAMINATE 300F/3 TONS (TTS)226-1A (TTS)226-2A (138S)226-3A (138S)226-4A (30 DAYS)226-3A	0.175		0.046		1.4977747		0.36		0.045		3.149606299		110.285714	
			0.195		0.045		1.7060367		0.46		0.044		4.115962777		141.258741	
			0.235		0.046		2.0112975		0.285		0.045		2.49343832		23.9716312	
			0.21		0.045		1.8372703		0.245		0.046		2.096884629		14.1304348	
227A	10/22/93	LAMINATE 300F/3 TONS 227-1A 227-2A 227-3A 227-4A	0.14		0.028		1.9685039		100		0.028		1406.074241		71328.5714	
			0.16		0.028		2.2497188		100		0.028		1406.074241		62400	
			0.23		0.028		3.2339708		0.23		0.028		3.233970754		0	
			0.28		0.027		4.082823		0.34		0.029		4.615802335		13.0541872	
			0.23		0.028		3.2339708		0.28		0.028		3.937007874		21.7391304	
228A	10/25/93	LAMINATE 300F/3 TONS 228-1A(TTS) 228-1A(TTS) 228-3A(138S) 228-4A(138S)	0.84		0.044		7.5161059		0.9		0.044		8.052970651		7.14285714	
			0.96		0.043		8.789599		1.15		0.043		10.5292071		19.7916667	
			0.94		0.044		8.4108805		1.1		0.044		9.842519685		17.0212766	
			0.94		0.043		8.6064823		1		0.045		8.748906387		1.65484634	
229A	10/26/93	LAMINATE 300F/3 TONS 229-1A(TTS) 229-1A(TTS) 229-3A(138S) 229-4A(138S)	0.35		0.046		2.9955495		0.73		0.046		6.247860322		108.571429	
			0.3		0.045		2.6246719		0.67		0.045		5.861767279		123.333333	
			0.47		0.045		4.111986		0.62		0.045		5.42432196		31.9148936	
			0.44		0.045		3.8495188		0.54		0.045		4.724409449		22.7272727	

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
230A	10/29/93	LAMINATE 300F/3 TONS													
		230-1A(TTS)	0.29	0.044	0.044	0.044	2.5948461	0.68	0.68	0.044	0.044	6.084466714	134.482759		
		230-1A(TTS)	0.31	0.043	0.043	0.044	2.838308	0.59	0.59	0.044	0.044	5.279169649	85.9970674		
		230-3A(138S)	0.45	0.043	0.043	0.044	4.1201245	0.52	0.52	0.044	0.044	4.652827487	12.9292929		
		230-4A(138S)	0.34	0.044	0.044	0.044	3.0422334	0.42	0.42	0.044	0.044	3.758052971	23.5294118		
138S															
231A	10/29/93	LAMINATE 300F/3 TONS													
		231-1A(TTS)	0.41	0.044	0.044	0.044	3.6685755	1.3	1.3	0.044	0.044	11.63206872	217.073171		
		231-1A(TTS)	0.32	0.044	0.044	0.044	2.8632785	2.2	2.2	0.045	0.045	19.24759405	572.222222		
		231-3A(138S)	0.49	0.044	0.044	0.044	4.3843951	0.68	0.68	0.044	0.044	6.084466714	38.7755102		
		231-4A(138S)	0.52	0.044	0.044	0.044	4.6528275	0.65	0.65	0.044	0.044	5.816034359	25		
232A	10/29/93	LAMINATE 300F/3 TONS													
		232-1A(TTS)	0.34	0.044	0.044	0.044	3.0422334								
		232-1A(TTS)	0.36	0.044	0.044	0.044	3.2211883								
		232-3A(138S)	0.57	0.044	0.044	0.044	5.1002147	0.71	0.71	0.044	0.044	6.352899069	24.5614035		
		232-4A(138S)	0.58	0.044	0.044	0.044	5.1896922	0.62	0.62	0.044	0.044	5.547602004	6.89655172		
233A	10/29/93	LAMINATE 300F/3 TONS													
		233-1A(TTS)	0.22	0.045	0.045	0.045	1.9247594								
		233-1A(TTS)	0.23	0.044	0.044	0.044	2.0579814								
		233-3A(138S)	0.28	0.044	0.044	0.044	2.5053686	2.25	2.25	0.044	0.044	20.13242663	703.571429		
		233-4A(138S)	0.35	0.045	0.045	0.045	3.0621172	1.2	1.2	0.044	0.044	10.7372942	250.649351		
234A	11/7/93	LAMINATE 300F/3 TONS													
		234-1A(TTS)	0.45	0.044	0.044	0.044	4.0264853								
		234-1A(TTS)	0.46	0.044	0.044	0.044	4.1159628								
		234-3A(138S)	0.5	0.044	0.044	0.044	4.4738726	1.05	1.05	0.044	0.044	9.395132427	110		
		234-4A(138S)	0.64	0.044	0.044	0.044	5.7265569	1.35	1.35	0.043	0.043	12.36037356	115.843023		
235A	11/7/93	LAMINATE 300F/3 TONS													
		235-1A(TTS)	0.46	0.044	0.044	0.044	4.1159628								
		235-1A(TTS)	0.44	0.044	0.044	0.044	3.9370079								
		235-3A(138S)	0.76	0.044	0.044	0.044	6.8002863	0.66	0.66	0.044	0.044	5.905511811	-13.1578947		
		235-4A(138S)	0.68	0.044	0.044	0.044	6.0844667	0.7	0.7	0.044	0.044	6.263421618	2.94117647		
236A	11/7/93	LAMINATE 300F/3 TONS													
		236-1A(TTS)	0.68	0.033	0.033	0.033	8.1126223								

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
237A	11/7/93	LAMINATE 300F/3 TONS 237-1A(TTS) 237-1A(TTS) 237-3A(138S) 237-4A(138S)	0.8	0.031	10.16002				1.3	0.043	11.90258194				23.8095238
			1.05	0.043	9.6136239				1.2	0.044	10.7372942				20.5741627
			0.95	0.042	8.9051369										
238A	11/7/93	LAMINATE 300F/3 TONS 238-1A 238-2A 238-3A 238-4A	0.67	0.043	6.1344076										
			0.8	0.044	7.1581961				0.96	0.044	8.589835361				40.027137
			0.67	0.043	6.1344076				1.2	0.044	10.7372942				144.897959
			0.49	0.044	4.3843951										
239A	11/10/93	LAMINATE 300F/3 TONS 239-1A 239-2A 239-3A 239-4A	0.42	0.044	3.758053				0.55	0.044	4.921259843				30.952381
			0.38	0.045	3.3245844				0.4	0.045	3.499562555				5.26315789
			0.36	0.044	3.2211883				0.48	0.044	4.294917681				33.3333333
			0.34	0.045	2.9746282				0.5	0.045	4.374453193				47.0588235
240A	11/16/93	LAMINATE 300F/3 TONS 240-1A 240-2A 240-3A 240-4A	0.459	0.045	4.015748				0.64	0.045	5.599300087				39.4335512
			0.39	0.045	3.4120735				0.45	0.045	3.937007874				15.3846154
			0.45	0.045	3.9370079				0.79	0.045	6.911636045				75.5555556
			0.44	0.044	3.9370079				0.58	0.044	5.189692198				31.8181818
241A	11/15/93	LAMINATE 300F/3 TONS 241-1A 241-2A 241-3A	0.54	0.045	4.7244094				0.64	0.045	5.599300087				18.5185185
			0.66	0.044	5.9055118										
			0.6	0.045	5.2493438				0.84	0.044	7.516105941				43.1818182
			0.77	0.044	6.8897638										
242A	11/18/93	LAMINATE 300F/3 TONS 242-1A 242-2A 242-3A 242-4A(NO PB)	0.72	0.077	3.681358										
			0.78	0.077	3.9881378										
			0.79	0.076	4.0924161										
243A	11/18/93	LAMINATE 300F/3 TONS 243-1A	0.59	0.066	3.5194464										
			0.64	0.066	3.8177046										
			0.67	0.067	3.9370079										
			0.72	0.066	4.2949177										

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE		THICKNESS		RESISTIVITY		RESISTANCE		THICKNESS		RESISTIVITY		PERCENT CHANGE
			(OHM) BEFORE	(OHM) AFTER	(INCH) BEFORE	(INCH) AFTER	(OHM-CM) BEFORE	(OHM-CM) AFTER	(OHM) BEFORE	(OHM) AFTER	(INCH) BEFORE	(INCH) AFTER	(OHM-CM) BEFORE	(OHM-CM) AFTER	
244A	11/18/93	LAMINATE 300F/3 TONS 243-2A 243-3A 242-4A(NO PB)	0.42	2.4679751	0.067	0.067	2.4679751	2.4679751	FOR BATTERY BUILD						
			0.41	2.445717	0.066	0.066	2.445717								
			0.41	2.4092138	0.067	0.067	2.4092138								
			0.56	3.3404915	0.066	0.066	3.3404915		FOR BATTERY BUILD						
245A	12/11/93	LAMINATE 300F/3 TONS 244-1A 244-2A 244-3A 244-4A(NO PB)	0.49	2.9229301	0.066	0.066	2.9229301		ACTIVE SIDE WITH NEG PASTE						
			0.5	2.9825817	0.066	0.066	2.9825817								
			0.49	2.9229301	0.066	0.066	2.9229301								
			0.59	5.6654504	0.041	0.041	5.6654504	0.62	0.041	5.953524102	0.041	5.953524102	5.08474576	5.08474576	
			0.55	5.1556055	0.042	0.042	5.1556055	0.71	0.041	6.817745343	0.041	6.817745343	32.2394678	32.2394678	
246A	12/13/93	LAMINATE 300F/3 TONS 245-1A 245-2A 245-3A 245-4A	0.66	6.3376224	0.041	0.041	6.3376224	0.77	0.041	7.393892837	0.041	7.393892837	16.8666667	16.8666667	
			0.7	6.7217208	0.041	0.041	6.7217208	1	0.04	9.842519685	0.04	9.842519685	46.4285714	46.4285714	
			0.6	12.432656	0.019	0.019	12.432656	SAMPLE BROKE							
			0.42	9.1863517	0.018	0.018	9.1863517	0.5	0.018	10.93613298	0.018	10.93613298	19.047619	19.047619	
247A	12/13/93	LAMINATE 300F/3 TONS 246-1A 246-2A 246-3A 246-4A	0.54	11.189391	0.019	0.019	11.189391	0.52	0.019	10.77496892	0.019	10.77496892	-3.7037037	-3.7037037	
			0.42	8.7028595	0.019	0.019	8.7028595	0.52	0.019	10.77496892	0.019	10.77496892	23.8095238	23.8095238	
			0.285	5.6102362	0.02	0.02	5.6102362	0.39	0.02	7.677165354	0.02	7.677165354	36.8421053	36.8421053	
			0.34	6.6929134	0.02	0.02	6.6929134	0.38	0.021	7.124109486	0.021	7.124109486	6.44257703	6.44257703	
248A	12/27/93	LAMINATE 300F/3 TONS 247-1A 247-2A 247-3A 247-4A	0.36	7.0866142	0.02	0.02	7.0866142	0.52	0.02	10.23622047	0.02	10.23622047	44.444444	44.444444	
			0.31	6.1023622	0.02	0.02	6.1023622	0.45	0.02	8.858267717	0.02	8.858267717	45.1612903	45.1612903	
			0.52	10.774969	0.019	0.019	10.774969	1	0.019	20.72109407	0.019	20.72109407	92.3076923	92.3076923	
			0.4	8.7489064	0.018	0.018	8.7489064	0.66	0.018	14.43569554	0.018	14.43569554	65	65	
249A	1/5/94	LAMINATE 300F/3 TONS *249-1A 249-2A 249-3A 249-4A	0.48	9.4488189	0.02	0.02	9.4488189	1	0.02	19.68503937	0.02	19.68503937	108.333333	108.333333	
			0.46	10.061242	0.018	0.018	10.061242	0.66	0.019	13.67592209	0.019	13.67592209	35.9267735	35.9267735	
			0.88	17.322835	0.02	0.02	17.322835	0.8	0.02	15.7480315	0.02	15.7480315	-9.09090909	-9.09090909	
			0.38	7.8740157	0.019	0.019	7.8740157	0.34	0.019	7.045171985	0.019	7.045171985	-10.5263158	-10.5263158	
250A	1/5/94	LAMINATE 300F/3 TONS 250-1A 250-2A	0.38	7.8740157	0.019	0.019	7.8740157	0.42	0.019	8.702859511	0.019	8.702859511	10.5263158	10.5263158	
			0.4	7.8740157	0.02	0.02	7.8740157	0.44	0.02	8.661417323	0.02	8.661417323	10	10	
			*SAMPLE NOT SANDED PRIOR TO LAMINATION												
			0.88	8.4501632	0.041	0.041	8.4501632	0.84	0.041	8.066064913	0.041	8.066064913	-4.54545455	-4.54545455	
250A	1/5/94	LAMINATE 300F/3 TONS 250-1A 250-2A	0.5	4.8012291	0.041	0.041	4.8012291	0.46	0.041	4.417130785	0.041	4.417130785	-8	-8	

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
251A	1/5/94	LAMINATE 300F/3 TONS 251-1A 251-2A	0.19 0.225		0.041 0.041		1.8244671 2.1605531		0.24 0.23		0.041 0.041		2.304589975 2.208565393		26.3157895 2.22222222
252A	1/7/94	LAMINATE 300F/3 TONS 252-1A 252-2A	0.15 0.125		0.041 0.042		1.4403687 1.1717285		0.195 0.18		0.041 0.042		1.872479355 1.687289089		30 44
253A	1/7/94	LAMINATE 300F/3 TONS 253-1A 253-2A(30 TONS)	0.15 0.155		0.019 0.011		3.1081641 5.547602		0.245 0.11		0.02 0.01		4.822834646 4.330708661		55.1666667 -21.9354839
254A	1/12/94	LAMINATE 300F/3 TONS 254-1A 254-2A 254-3A 254-4A	0.38 0.4 0.46 0.5		0.021 0.021 0.02 0.021		7.1241095 7.4990626 9.0551181 9.3738283		0.32 0.48 0.64 0.6		0.021 0.021 0.02 0.021		5.999250094 8.998875141 12.5984252 11.24859393		-15.7894737 20 39.1304348 20
255A	1/20/94	LAMINATE 300F 3 TONS/30 TONS 255-1A(3 TONS) 255-2A(3 TONS) 255-3A(30 TONS) 255-4A(30 TONS)	0.3 0.29 0.28 0.235		0.016 0.019 0.011 0.011		7.3818898 6.0091173 10.021475 8.4108805		0.265 0.28 0.32 0.295		0.016 0.019 0.011 0.011		6.520669291 5.801906341 11.45311382 10.5583393		-11.6666667 -3.44827586 14.2857143 25.5319149
256A	1/20/94	LAMINATE 300F/3 TONS NO SHIM 256-1A 256-2A 256-3A 256-4A	0.44 0.62 0.41 0.45		0.018 0.019 0.019 0.019		9.623797 12.847078 8.4956486 9.3244923		0.79 1.3 0.78 0.9		0.018 0.019 0.019 0.019		17.27909011 26.9374223 16.16245338 18.64898467		79.5454545 109.677419 90.2439024 100
257A	1/24/94	LAMINATE 300F/3 TONS .045" .031" SHIM 257-1A 257-2A 257-3A 257-4A 257-5A	0.76 0.74 0.8 0.9 0.77		0.04 0.04 0.04 0.041 0.04		7.480315 7.2834646 7.8740157 8.6422124 7.5787402								

1AKE BATTERY #257 (12V)
FULL PB SHEET

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
258A	1/25/94	STABILITY TESTING													
		257-6A	0.73		0.028		10.264342		0.91		0.028		12.79527559		24.6575342
		257-7A	0.79		0.028		11.107987		1.2		0.029		16.29106706		46.6608468
		LAMINATE 300F/3 TONS													
		.045" .031" SHIM													
		258-1A	0.36		0.041		3.456885		OR BATTERY #258 4V						
		258-2A	0.4		0.042		3.7495313		CRACKED DURING ASSEMBLY						
		258-3A	0.34		0.034		3.9370079		OR BATTERY #258 4V						
		STABILITY TESTING													
		258-4A	0.295		0.029		4.0048873		0.36		0.029		4.887320119		22.0338983
259A	1/26/94	258-5A	0.33		0.029		4.4800434		0.4		0.029		5.430355688		21.2121212
		LAMINATE 300F/3 TONS													
		.045" .031" SHIM													
		259-1A	0.71		0.041		6.8177453								
		259-2A	0.78		0.043		7.1415492								
		259-3A	0.6		0.041		5.7614749		N UPON PRESSING IN THE PB SHEET						
		259-4A	0.69		0.04		6.7913386								
		259-5A	0.7		0.042		6.5616798								
		259-6A	0.7		0.029		9.5031225								
		STABILITY TESTING													
260A	2/4/94	259-7A	0.51		0.026		7.7225924		0.48		0.026		7.268322229		-5.88235294
		259-8A	0.51		0.027		7.4365704		0.54		0.027		7.874015748		5.88235294
		LAMINATE 300F/3 TONS													
		.045" .031" SHIM													
		260-1A	0.56		0.041		5.3773766		DOUG-						
		260-2A	0.49		0.042		4.5931759		TO MAKE 4V BATTERY						
		260-3A	0.35		0.03		4.5931759		AMINATE BROKE						
		STABILITY TESTING													
		260-4A	0.46		0.028		6.4679415		0.54		0.027		7.874015748		21.7391304
		260-5A	0.34		0.026		5.1483949		0.49		0.026		7.419745609		44.1176471
261A	2/4/94	LAMINATE 300F/3 TONS													
		.045" .031" SHIM													
		261-1A	0.41		0.042		3.8432696		ULD NOT STICK TO LAMINATE						
		261-2A	0.42		0.042		3.9370079		" " "						
		261-3A	0.42		0.03		5.511811		" " "						
		STABILITY TESTING													
		261-4A	0.43		0.026		6.5112053		0.38		0.026		5.754088431		-11.627907
		261-5A	0.44		0.026		6.6626287		0.46		0.025		7.244094488		8.72727273
		LAMINATE 375F/3 TONS													
		NO SHIM													
262A	2/4/94	262-1A	0.52		0.017		12.042612		0.74		0.016		18.20866142		51.2019231
		262-2A	0.6		0.017		13.895322		0.72		0.016		17.71653543		27.5
		262-3A	0.53		0.017		12.274201		0.69		0.016		16.97834646		38.3254717
		262-4A	0.51		0.017		11.811024		0.63		0.016		15.5019685		31.25

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		THICKNESS (INCH)	RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		BEFORE	AFTER	
263A	2/1/94	LAMINATE 300F/3 TONS 0.045" SHIM 263-1A 263-2A	0.5		0.043		4.5779161	ATTY #263 6V-FULL PB SHEET				
			0.49		0.043		4.4863578	"				
264A	2/4/94	LAMINATE 300F/3 TONS 0.031" SHIM 264-1A 264-2A	0.46		0.034		5.3265401	MAKE BATTERY #264 4V				
			0.41		0.034		4.7475683	3STRATE CRACKED				
265A	2/4/94	LAMINATE 300F/3 TONS 0.031" SHIM 265-1A 265-2A 265-3A 265-4A 265-5A	0.3		0.033		3.5790981	MAKE BATTERY #265-6V				
			0.28		0.033		3.3404915	"				
			0.33		0.032		4.0600394	DELAMINATED AT CORNER				
			0.33		0.032		4.0600394	MAKE BATTERY #265-4V				
			0.33		0.032		4.0600394	MINATE CRACKED				
266A	2/18/94	LAMINATE 300F/3 TONS 0.051" SHIM 266-1A 266-2A 266-3A 266-4A	0.36		0.046		3.0811366	0.37	0.045	3.237095363	5.0617284	
			0.38		0.045		3.3245844	0.48	0.044	4.294917681	29.1866029	
			0.41		0.046		3.5090722	0.84	0.045	7.349081365	109.430894	
			0.4		0.045		3.4995626	0.46	0.045	4.024496938	15	
267A	3-3-94	LAMINATE 300F/3 TONS 267-1A(C) 267-2A(P) 267-3A(P) 267-4A(P) 267-5A(P) 267-6A(P) 267-7A(P) 267-8A(C) 267-9A(C) 267-10A(C) 267-11A(C) 267-12A 267-13A	0.52		0.039		5.2493438	0.73	0.044	6.531853973	W/PB SHEET	
			0.61		0.037		6.4907427	0.6	0.041	5.761474938	"	
			0.63		0.038		6.5271446	0.55	0.041	5.281352026	"	
			0.45		0.036		4.9212598	0.56	0.041	5.377376608	"	
			0.43		0.036		4.7025372	0.56	0.039	5.653139511	"	
								0.54	0.04	5.31496063	MINATED, PB SHEET	
								0.5	0.04	4.921259843	"	
								0.4	0.04	3.937007874	"	
								0.37	0.04	3.641732283	"	
								0.53	0.041	5.089302862	"	
								0.56	0.041	5.377376608	"	
			0.45		0.036		4.9212598	0.44	0.037	4.681847202	-4.86486486	
			0.43		0.036		4.7025372	0.46	0.036	5.030621172	6.97674419	
268A	3-3-94	LAMINATE 300F/3 TONS 268-1A	0.57		0.042		5.3430821	0.66	0.045	5.774278215	W/PB SHEET	

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)	
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
269A	3/3/94	LAMINATE 300F/3 TONS	0.6		0.045	0.046	5.2493438	5.5631633	0.65		0.046	0.046	5.5631633		"	
			0.53		0.044	0.046	4.7423049	4.964053406	0.58		0.046	0.046	4.964053406		"	
			0.49		0.044	0.044	4.3843951	4.878466279	0.57		0.046	0.046	4.878466279		"	
			0.54		0.04	0.047	5.3149606	5.193499749	0.62		0.047	0.047	5.193499749		"	
						0.048	4.019028871	4.019028871	0.49		0.048	0.048	4.019028871		INATED, PB SHE	
						0.048	3.772965879	3.772965879	0.46		0.048	0.048	3.772965879		"	
						0.049	4.017354973	4.017354973	0.5		0.049	0.049	4.017354973		"	
						0.048	3.772965879	3.772965879	0.46		0.048	0.048	3.772965879		"	
						0.045	8.23972003	8.23972003	0.94		0.045	0.045	8.23972003		"	
			0.52		0.043	0.044	4.7610328	4.831782391	0.54		0.044	0.044	4.831782391		1.48601399	
			0.48		0.043	0.044	4.3947995	5.010737294	0.56		0.044	0.044	5.010737294		14.0151515	
270A	3/4/94	LAMINATE 300F/3 TONS	0.6		0.025	0.027	9.4488189	11.81102362	0.81		0.027	0.027	11.81102362		25	
			0.44		0.028	0.028	6.1867267	8.436445444	0.6		0.028	0.028	8.436445444		36.3636364	
			0.55		0.028	0.028	7.7334083	9.561304837	0.68		0.028	0.028	9.561304837		23.6363636	
			0.36		0.021	0.021	6.7491564	11.24859393	0.6		0.021	0.021	11.24859393		66.6666667	
			0.94		0.018	0.018	20.55993	7.655293088	0.35		0.018	0.018	7.655293088		-62.7659574	
			0.824		0.022	0.022	14.745884	17.53758053	0.98		0.022	0.022	17.53758053		18.9320388	
			0.745		0.02	0.02	14.665354	PLASTIC CRACKED								
			0.4		0.018	0.018	8.7489064	9.623797025	0.44		0.018	0.018	9.623797025		10	
			0.59		0.022	0.021	10.558339	13.87326584	0.74		0.021	0.021	13.87326584		31.3962873	
			0.37		0.02	0.02	7.2834646	7.677165354	0.39		0.02	0.02	7.677165354		5.40540541	
271A	3/10/94	LAMINATE 300F/3 TONS	0.34		0.02	0.02	6.6929134	6.102362205	0.31		0.02	0.02	6.102362205		-8.82352941	
			0.245		0.019	0.02	5.076668	8.464566929	0.43		0.02	0.02	8.464566929		66.7346939	
			0.345		0.02	0.022	6.7913386	6.263421618	0.35		0.022	0.022	6.263421618		-7.77338603	
			0.3		0.028	0.027	4.2182227	8.457276174	0.58		0.027	0.027	8.457276174		100.493827	
			0.33		0.028	0.028	4.640045	9.139482565	0.65		0.028	0.028	9.139482565		96.969697	
			0.36		0.028	0.028	5.0618673	6.046119235	0.43		0.028	0.028	6.046119235		19.4444444	
			0.36		0.028	0.028	5.0618673	5.764904387	0.41		0.028	0.028	5.764904387		13.8888889	
			0.38		0.04	0.041	3.7401575	9.026310736	0.94		0.041	0.041	9.026310736		141.335045	
			0.34		0.04	0.04	3.3464567	7.086614173	0.72		0.04	0.04	7.086614173		111.764706	
			0.39		0.041	0.041	3.7449587	6.241597849	0.65		0.041	0.041	6.241597849		66.6666667	
272A	3/17/94	LAMINATE 300F/3 TONS	0.37		0.042	0.041	3.4683165	4.993278279	0.52		0.041	0.041	4.993278279		43.9683596	
273A	3/17/94	LAMINATE 300F/3 TONS														
274A	4/28/94	LAMINATE 300F/3 TONS														

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
275A	4/28/94	LAMINATE 300F/3 TONS 275-1A 275-2A	2.65		0.044	0.044	23.711525		24.5		0.044	0.044	219.2197566		824.528302
			1.95		0.042		18.278965		50		0.044		447.3872584		2347.55245
276A	4/28/94	LAMINATE 300F/3 TONS 276-1A 276-2A	3.2		0.06		20.997375		6.8		0.064		41.83070866		99.21875
			3.8		0.06		24.934383		5		0.062		31.7500635		27.3344652
277A	5/2/94	LAMINATE 300F/3 TONS 277-1A 277-2A 277-3A 277-4A	0.58		0.047		4.8584352		OR 4V BATTERY		277-1 C				
			NA		0.041		NA		OR 4V BATTERY		277-2 C				
			NA		0.042		NA		OR 6V BATTERY		277-6V C				
			NA		0.042		NA		"		"				
278A	5/2/94	LAMINATE 300F/3 TONS 278-1A 278-2A 278-3A	NA		0.04		NA		OR 4V BATTERY		278-1 C				
			NA		0.039		NA		OR 6V BATTERY		278-6V C				
			NA		0.04		NA		"		"				
279A	5/2/94	LAMINATE 300F/3 TONS 279-1A 279-2A 279-3A 279-4A	NA		0.042		NA		OR 4V BATTERY		279-1 C				
			NA		0.039		NA		OR 4V BATTERY		279-2 C				
			NA		0.04		NA		OR 6V BATTERY		279-6V C				
			NA		0.039		NA		"		"				
280A	5/9/94	LAMINATE 300F/3 TONS 280-1A 280-2A 280-3A 280-4A	0.38		0.035		4.2744657		2.75		0.037		29.26154501		584.566145
			0.31		0.039		3.1294165		8.1		0.04		79.72440945		2447.58065
			0.28		0.035		3.1496063		3		0.037		31.92168546		913.513514
			0.3		0.035		3.3745782		2.3		0.037		24.47329219		625.225225
281A	5/12/94	LAMINATE 300F/3 TONS 281-1A 281-2A	0.43		0.033		5.1300406		OR 4V BATTERY		281-1 C				
			0.41		0.035		4.6119235		OR 4V BATTERY		281-2 C				

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM) BEFORE	THICKNESS (INCH) BEFORE	RESISTIVITY (OHM-CM) BEFORE	RESISTANCE (OHM) AFTER	THICKNESS (INCH) AFTER	RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
282A	5/13/94	LAMINATE 300F/3 TONS 281-3A 281-4A	0.3 0.36	0.034 0.034	3.4738305 4.1685966	R 6V BATTERY 281-6V C " " "			
283A	5/13/94	LAMINATE 300F/3 TONS 282-1A 282-2A 282-3A 282-4A	0.4 0.42 0.38 0.4	0.035 0.037 0.036 0.036	4.4994376 4.469036 4.1557305 4.3744532	3R 4V BATTERY 282-1 C 3R 4V BATTERY 282-2 C R 6V BATTERY 282-6V C " " "			
284A	5/25/94	LAMINATE 300F/3 TONS 283-1A 283-2A 283-3A 283-4A	0.52 0.5 0.45 0.36	0.025 0.025 0.025 0.024	8.1889764 7.8740157 7.0866142 5.9055118	2.85 2.35 3.3 2.5	0.025 0.025 0.025 0.024	44.88188976 37.00787402 51.96850394 41.01049869	448.076923 370 633.333333 594.444444
285A	6/2/94	LAMINATE 300F/3 TONS 284-1A 284-2A 284-3A 284-4A	0.5 0.54 0.55 0.7	0.041 0.041 0.041 0.04	4.8012291 5.1853274 5.281352 6.8897638	1.1 1.4 1.6 1.6	0.041 0.041 0.041 0.041	10.56270405 13.44344152 15.36393317 15.36393317	120 159.259259 190.909091 122.996516
286A	6/2/94	LAMINATE 300F/3 TONS 285-1A 285-2A 285-3A 285-4A	0.89 1.15 1.25 1.35	0.045 0.046 0.048 0.047	7.7865267 9.8425197 10.252625 11.308427	OR 4V BATTERY 285-1 DONT USE OR 4V BATTERY 286-2 DONT USE			
287A	6/3/94	LAMINATE 300F/3 TONS 286-1A 286-2A 286-3A 286-4A	1.1 1.25 1.05 1.25	0.047 0.049 0.05 0.051	9.2142737 10.043387 8.2677165 9.6495291	DONT USE OR 4V BATTERY 286-2 DONT USE			
288A	6/15/94	LAMINATE 300F/3 TONS 287-1A 287-2A 287-3A 287-4A	0.9 0.6 0.595 0.53	0.047 0.043 0.044 0.043	7.5389512 5.4934994 5.3239084 4.8525911	DONT USE OR 4V BATTERY 287-2 OR 4V BATTERY 287-3 E. SUBSTRATE CRACKED			

SAMPLE NUMBER	TEST DATE	MATERIAL COMPOSITION	RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM)		RESISTANCE (OHM)		THICKNESS (INCH)		RESISTIVITY (OHM-CM) AFTER	PERCENT CHANGE (%)
			BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER		
289A	6/16/94	LAMINATE 300F/3 TONS	288-2A	0.8	0.042	0.042	7.4990626	OR 4V BATTERY 288-2						
			288-3A	0.54	0.041	0.041	5.1853274							
			288-4A	0.92	0.042	0.042	8.623922							
290A	6/23/94	LAMINATE 300F/3 TONS	289-1A	0.56	0.04	0.04	5.511811	OR 4V BATTERY 289-1						
			289-2A	0.52	0.04	0.04	5.1181102							
			289-3A	0.53	0.041	0.041	5.0893029							
			289-4A	0.55	0.04	0.04	5.4133858							
290A	6/23/94	LAMINATE 300F/3 TONS	290-1A	0.68	0.018	0.018	14.873141	OR 4V BATTERY 290-1						
			290-2A	0.7	0.019	0.019	14.504766	OR 4V BATTERY 290-6V						
			290-3A	0.62	0.019	0.019	12.847078	" " "						
			290-4A	0.66	0.02	0.02	12.992126							
			290-5A	0.52	0.02	0.02	10.23622							
			290-6A	0.49	0.02	0.02	9.6456693							
			290-7A	0.44	0.019	0.019	9.1172814							
			290-8A	0.5	0.019	0.019	10.360547							
			290-9A	0.5	0.021	0.021	9.3738283							
			290-10A	0.5	0.021	0.021	9.3738283							
			290-11A	0.52	0.021	0.021	9.7487814							
			290-12A	0.54	0.021	0.021	10.123735							

APPENDIX B

DELIVERABLE DATA

BUILD ID

WPG-6

Description

12 V Bipolar Battery

ASSEMBLY

Substrate Type 5.9375" X 9.1875" X 0.012" tin-lead alloy sheet

Grid Type 0.016" thick metallic screen soldered to the substrate

Separator Type, Dimensions 5.125" X 8.562" X 0.029"

Positive Paste Density 3.35 g/cc

Negative Paste Density 3.75 g/cc

Plate ID	PTE D2	D5		D7		D8		D9		D10		NTE D4
Pb Mass (g.)	260.90	158.80		160.20		162.60		158.10		161.60		261.90
AM Mass (g.)	51.70	104.30		104.20		106.00		103.50		104.80		53.40
Dry AM (g.)	51.70	52.19	52.11	52.52	51.68	52.92	53.08	52.26	51.24	51.94	52.86	53.40
Sep. Mass (g.)	Cell 1	3.54	Cell 2	3.52	Cell 3	3.53	Cell 4	3.53	Cell 5	3.52	Cell 6	3.51

Termination Copper stud soldered to terminal electrode

Containment Type Solvent bonded ABS. Container core thickness = 0.668"

Completed Mass 3.5121 kg

FORMATION

Acid Gravity Chilled 1.265

% Sodium Sulfate 1.5

Method of Fill Vacuum

Time 27H:55M:04S

Amps 1.0

Voltage Limit 16.32

Amp Hours 20.62

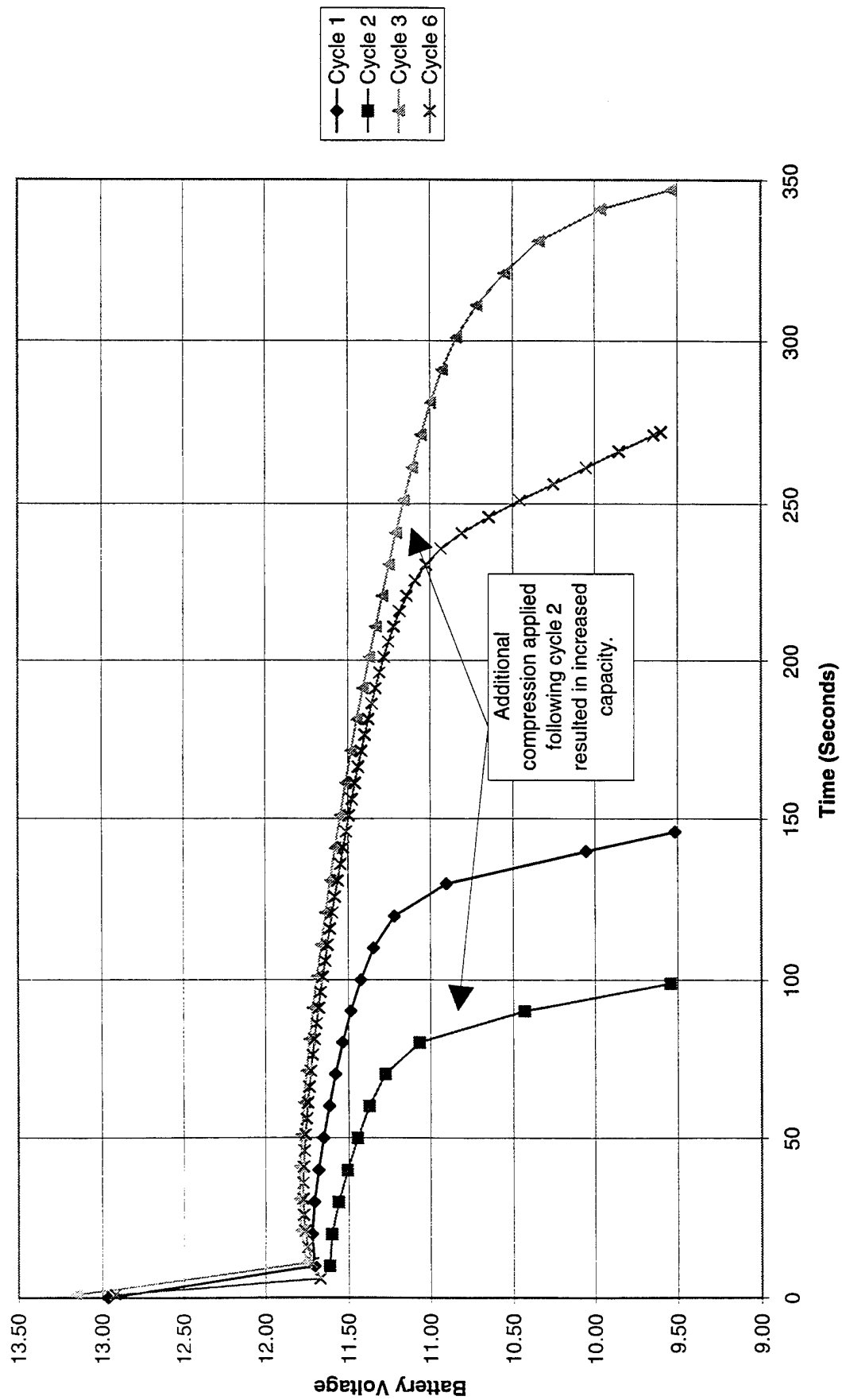
Watt Hours 311.8

Internal Resistance 13.5 mΩ

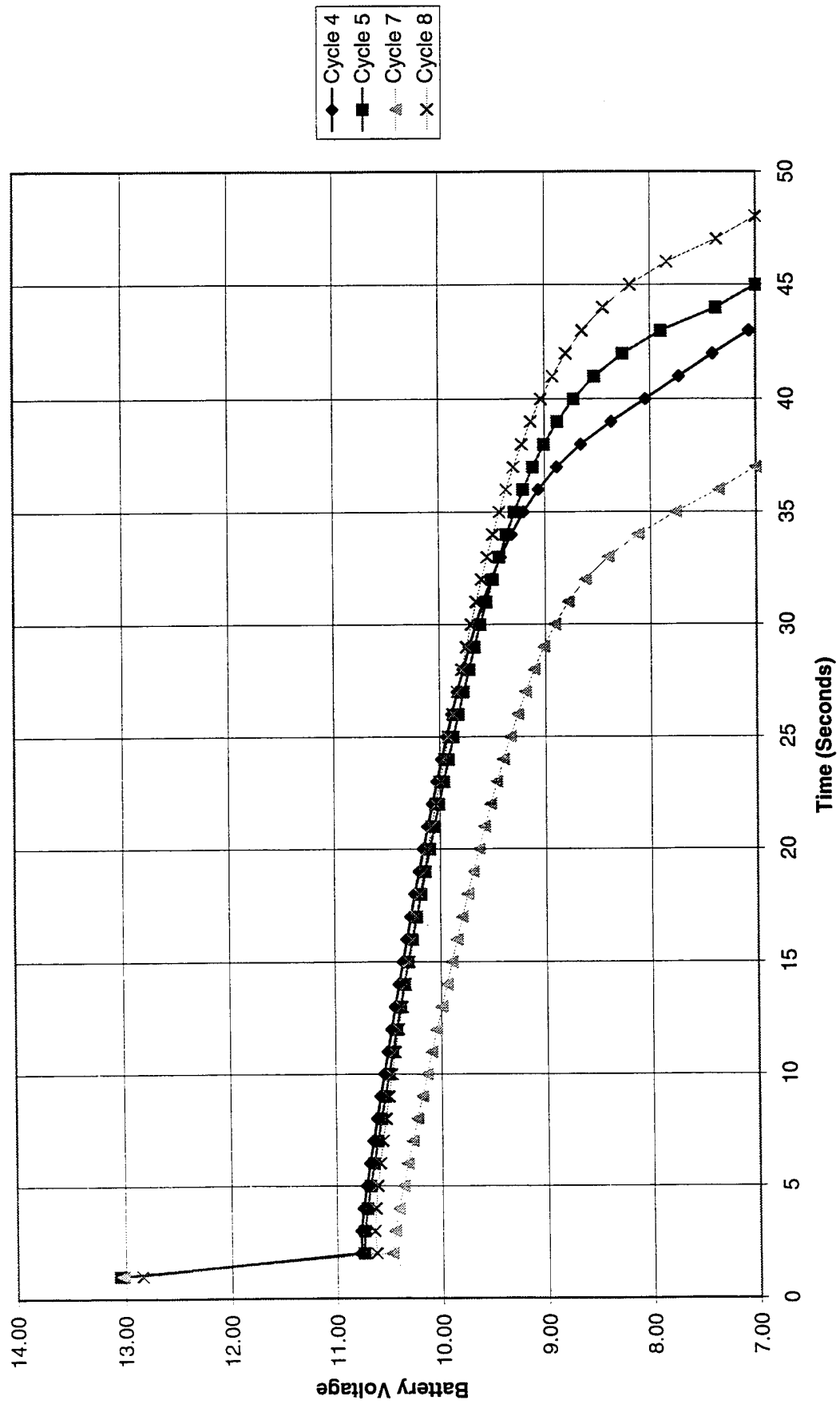
CYCLING HISTORY

Cycle	Date	IR (mΩ)	OCV	Discharge				Recharge				
				Amps	EODV	Ah	Wh	Amps	Vlimit	Ah	Wh	% Rchg
1	11/15/95	13.5	12.966	21	9.6	0.85	9.6	0.5	15.30	0.935	12.92	110
2	11/16/95	16.5	NA	21	9.6	0.57	6.4	0.1	14.40	NA	NA	NA
3	11/20/95	10.5	13.158	21	9.6	2.01	22.8	0.5	14.40	2.211	29.48	110
4	11/21/95	8.2	13.019	124	7.2	1.44	14.1	0.5	14.40	1.584	21.22	110
5	11/22/95	8.6	13.05	124	7.2	1.51	14.7	0.5	14.40	1.661	22.24	110
6	11/30/95	10.0	12.922	21	9.6	1.58	17.9	0.5	14.40	1.738	23.20	110
7	12/1/95	9.8	13.017	124	7.2	1.23	11.7	0.5	14.40	1.353	18.12	110
8	12/11/95	8.8	12.84	124	7.2	1.61	15.6	0.5	14.40	1.771	23.42	110

WPG-6 21 Amp Discharge Curves



WPG-6
124 Amp Discharge Curves



BUILD ID

WPG-8

Description

24 V Bipolar Battery

ASSEMBLY

Substrate Type 5.9375" X 9.1875" X 0.012" tin-lead alloy sheet

Grid Type 0.016" thick metallic screen soldered to the substrate

Separator Type, Dimensions 5.125" X 8.562" X 0.029"

Positive Paste Density 3.51 g/cc

Negative Paste Density 3.83 g/cc

Plate ID	PTE D54	D14		D15		D17		D18		D20		D21	
Pb Mass	258.70	162.90		162.20		161.90		162.80		163.10		162.00	
AM Mass	52.10	106.00		105.30		104.70		104.80		105.40		103.60	
Dry AM	52.10	52.71	53.29	52.41	52.89	52.65	52.05	52.33	52.47	52.37	53.03	51.85	51.75
Sep. Mass	Cell 1	3.52	Cell 2	3.53	Cell 3	3.48	Cell 4	3.52	Cell 5	3.48	Cell 6	3.47	Cell 7

Plate ID	D22		D23		D25		D26		D27		NTE D57
Pb Mass	160.40		163.10		160.90		161.90		162.80		258.50
AM Mass	103.20		102.00		106.00		101.70		103.30		54.00
Dry AM	52.05	51.15	51.24	50.76	51.22	54.78	50.75	50.95	51.51	51.79	54.00
Sep. Mass	3.49	Cell 8	3.46	Cell 9	3.49	Cell 10	3.50	Cell 11	3.51	Cell 12	3.50

Termination Copper stud soldered to terminal electrodes

Containment Type Solvent bonded ABS. Container core thickness = 1.153".

Containment Mass 5.5360 kg

FORMATION

Acid Gravity Chilled 1.265

% Sodium Sulfate 1.5

Method of Fill Vacuum

Time 20H:37M:03S

Amps 1.0

Voltage Limit 32.64

Amp Hours 20.62

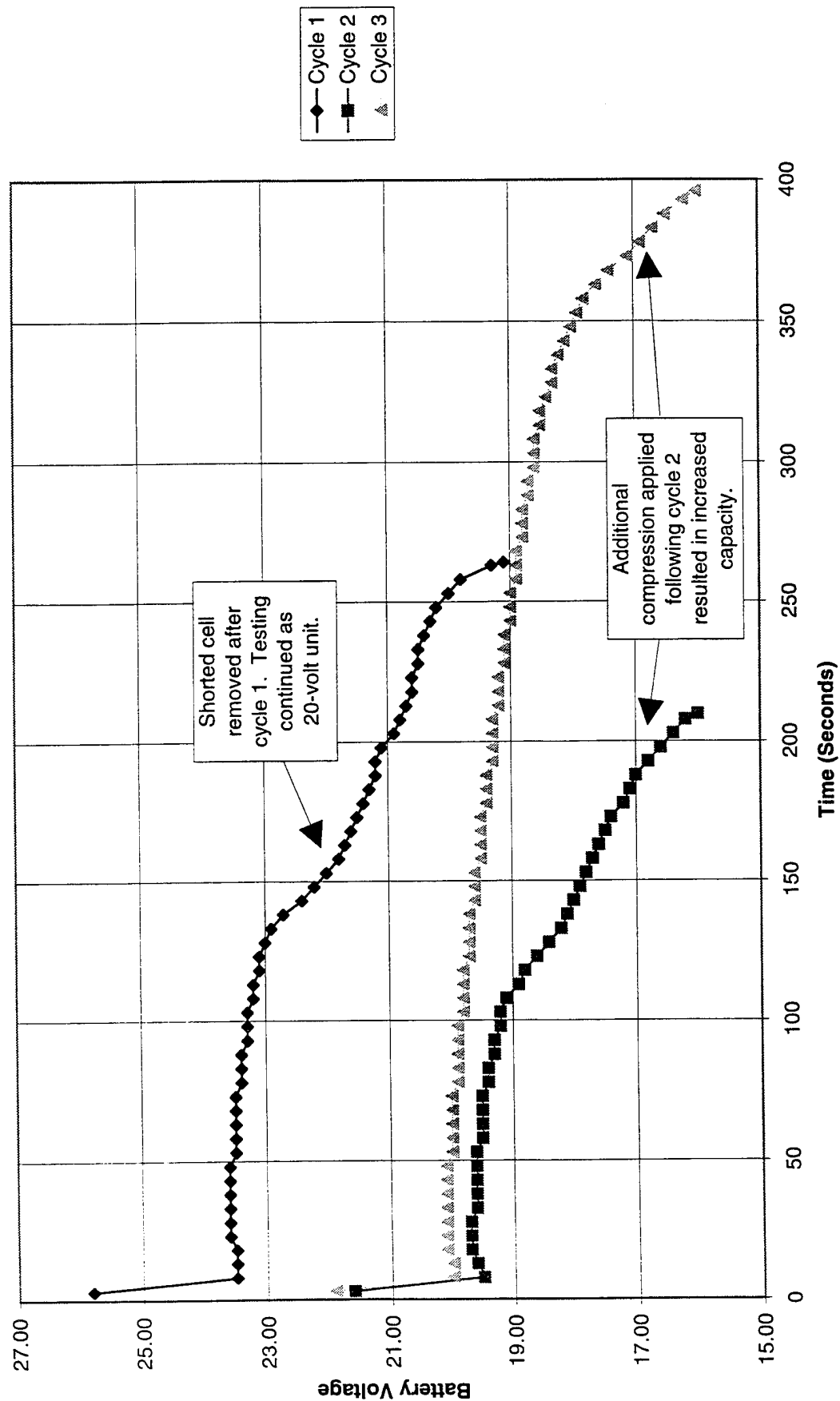
Watt Hours 594.0

Internal Resistance 14.0 mΩ

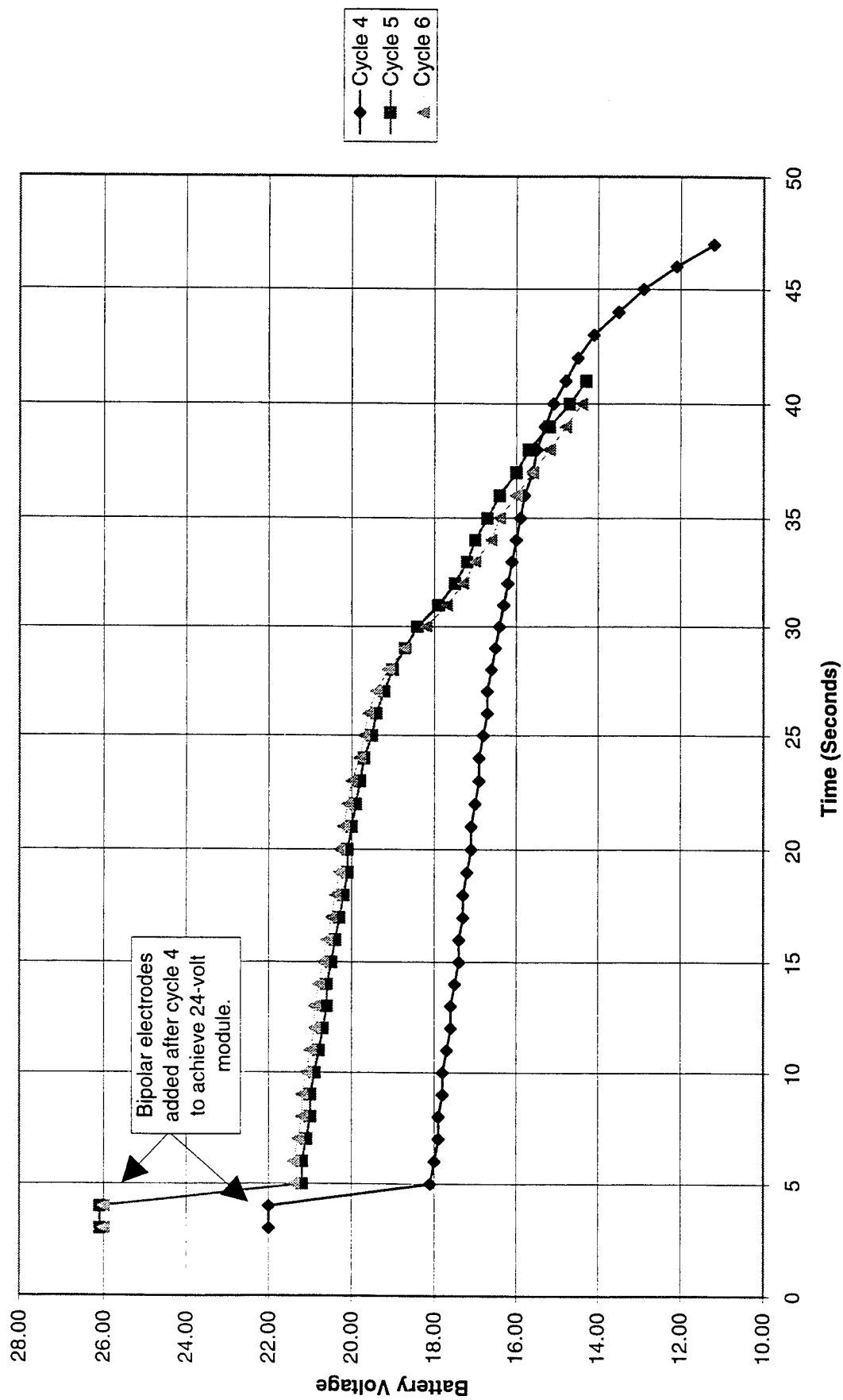
CYCLING HISTORY

Cycle	Date	IR (mW)	OCV	Discharge				Recharge				
				Amps	EODV	Ah	Wh	Amps	Vlimit	Ah	Wh	% Rchg
1	1/16/96	14.5	25.80	21	19.2	1.50	31	0.5	30.60	1.65	44	110
	1/16/96	Two shorted bipolar electrodes removed. Continue cycling as 20-volt nominal battery.										
2	1/18/96	17.5	21.60	21	16.0	1.20	20	1.0	25.50	1.32	29	110
3	1/18/96	12.5	21.90	21	16.0	2.29	41	0.1	25.50	2.51	50	110
4	1/19/96	12.5	22.00	124	12.0	1.48	23	0.1	25.50	1.62	32	110
	1/23/96	Two good bipolar electrodes added to stack to achieve 24-volt module.										
5	1/24/96	17.0	26.10	124	14.4	1.27	23	0.1	30.60	1.39	28	110
6	1/26/96	16.0	26.00	124	14.4	1.24	23	0.1	30.60	1.36	27	110

WPG-8 21 Amp Discharge Curves



WPG-8 124 Amp Discharge Curves



BUILD ID

WPG-11

Description

12 V Bipolar Battery

ASSEMBLY

Substrate Type 5.9375" X 9.1875" X 0.012" tin-lead alloy sheet

Grid Type 0.016" thick metallic screen soldered to the substrate

Separator Type, Dimensions 5.125" X 8.562" X 0.029"

Positive Paste Density 3.40 g/cc

Negative Paste Density 3.75 g/cc

Plate ID	PTE D72	D66		D67		D69		D64		D65		NTE D74
Pb Mass (g.)	261.03	160.07		160.71		163.42		163.13		164.39		258.98
AM Mass (g.)	50.97	102.23		102.49		102.98		101.27		101.91		54.32
Dry AM (g.)	50.97	51.03	51.20	50.97	51.52	51.23	51.75	50.40	50.87	50.57	51.34	54.32
Sep. Mass (g.)	Cell 1	3.53	Cell 2	3.45	Cell 3	3.48	Cell 4	3.52	Cell 5	3.50	Cell 6	3.48

Termination Copper stud soldered to terminal electrode

Containment Type Solvent bonded ABS. Container core thickness = 0.671".

Containment Mass 3.4908 kg

FORMATION

Acid Gravity Chilled 1.265

% Sodium Sulfate 1.5

Method of Fill Vacuum

Time

Amps 1

Voltage Limit 16.32

Amp Hours 20.62

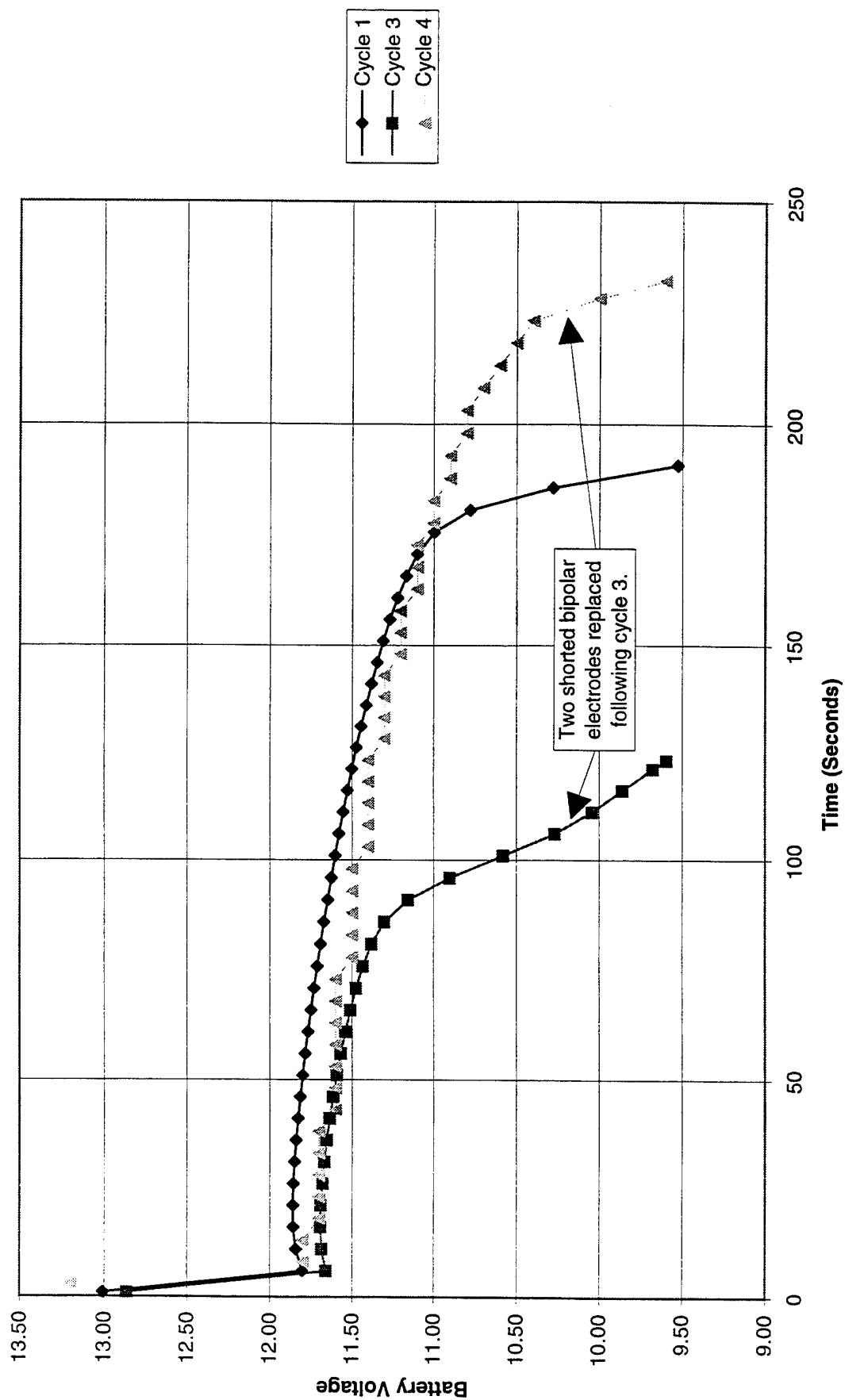
Watt Hours NA

Internal Resistance 12 mΩ

CYCLING HISTORY

Cycle	Date	IR (mW)	OCV	Discharge				Recharge				
				Amps	EODV	Ah	Wh	Amps	Vlimit	Ah	Wh	% Rchg
1	2/16/96	10.5	13.009	21	9.6	1.1	12.7	0.5	15.30	1.21	16.4	110
2	2/16/96	11.0	13.137	124	7.2	0.72	6.6	0.5	15.30	0.79	10.8	110
3	2/19/96	12.0	12.866	21	9.6	0.71	7.9	0.5	15.30	0.78	10.5	110
2/26/96 Replaced two shorted bipolar electrodes.												
4	2/27/96	11.5	13.200	21	9.6	1.33	12.0	0.5	14.40	1.46	17.0	110
5	2/28/96	11.0	13.005	124	7.2	0.82	7.0	0.5	14.40	0.90	10.0	110

WPG-11 21 Amp Discharge Curves



WPG-11
124 Amp Discharge Curves

