WL-TR-95-2111

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

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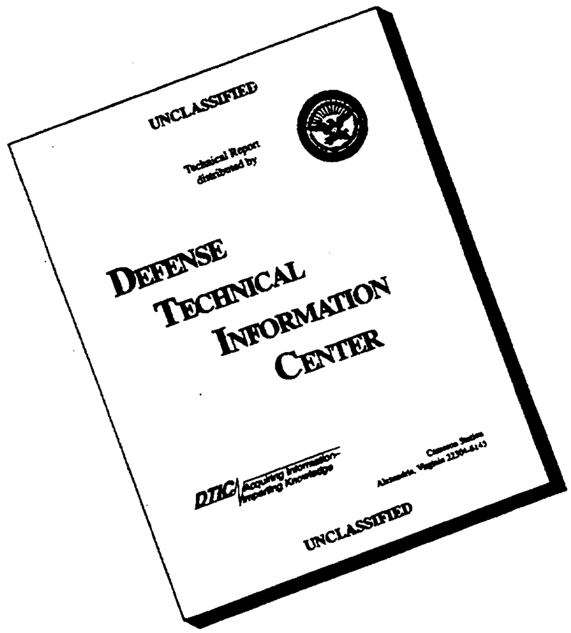


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This report summarizes the development work completed under contract F33615-91-C-2142 for the time period of September 1991 to September 1995. Initial work targeted the development of a filled polymeric composite substrate for use in a true bipolar lead acid battery. Efforts were refocused on metallic substrate technology in Month 33, and concluded with the delivery of battery systems to Wright Laboratory.

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## 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 $A/cm^2$ 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+ $A/cm^2$) capability from a 400+ $cm^2$ 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) |

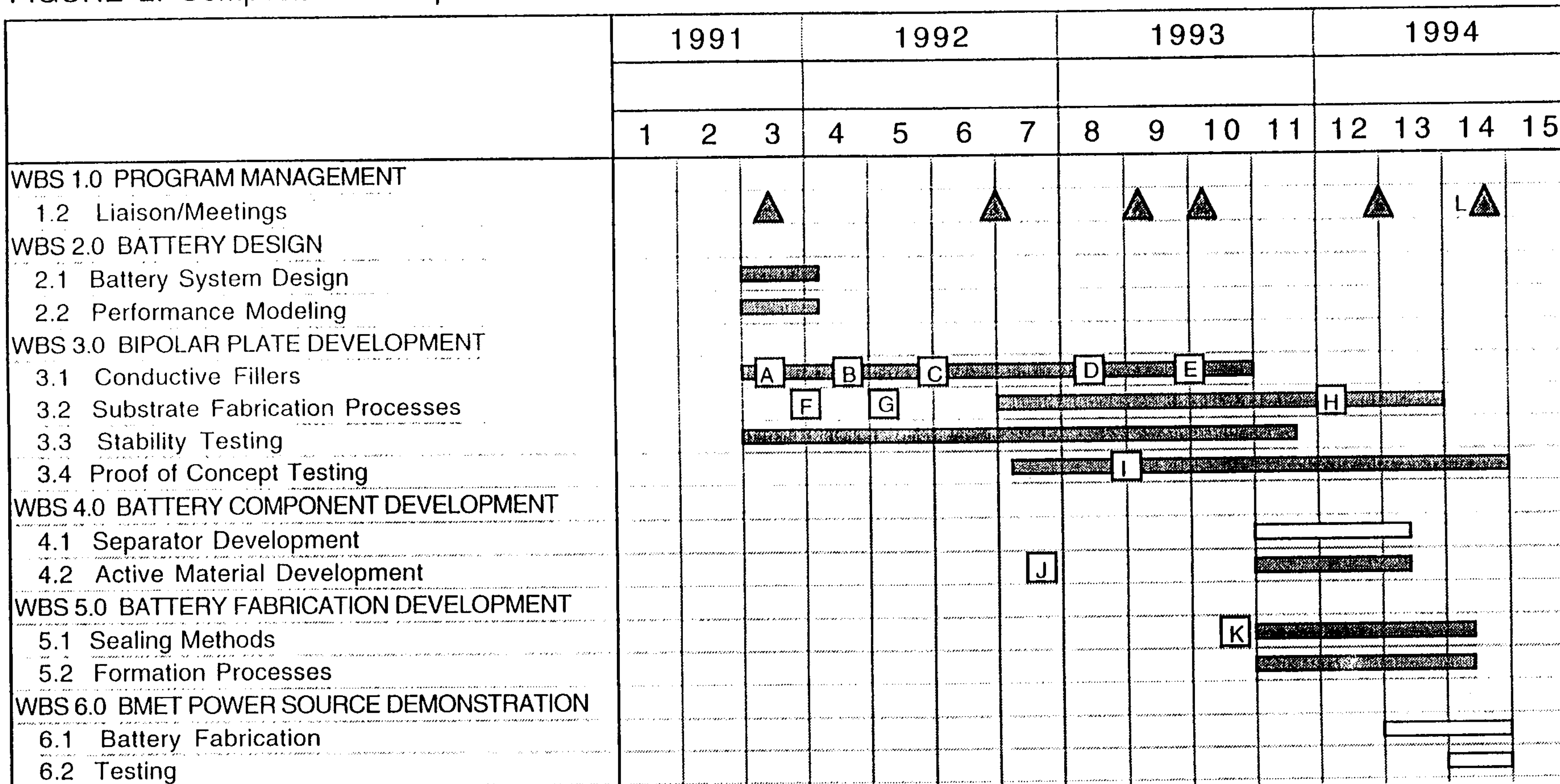
Given this, JCBGI proceeded to use its proprietary lead/acid battery mathematical model to design near- and far-term bipolar systems having 5- and 10- year development time frames. Near-term modeling assumed that substrate program goals were reached and conventional active materials were used. The 10-year 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 $ft^3$ with a system mass of 33 pounds to as much as 8.13 $ft^3$ 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 hydgrogen overpotentials in $H_2SO_4$, and to be readily manufactured.

FIGURE 2: Composite Development Gantt Chart with Milestones




[A] Qualified doped oxide supplier
[B] Stability of doped oxide proven. Single filler to be pursued.
[C] Cooperative development and supply agreement with oxide vendor discussed.
[D] Consistently stable 0.025-0.030" thick parts produced.
[E] Conductive filler work completed.
[F] Begin LDPE substrate fabrication development.
[G] Consistently stable 0.080" thick parts produced.
[H] Extrusion trial.
[I] Composite bipolar batteries achieve 2 A/in2 for 30 sec and 32 cycles.
[J] Begin substrate to paste interface adhesion studies.
[K] Injection molded container trial proven feasible with composite substrate.
[L] Technical direction refocussed on metallic substrate development.

FIGURE 3

# NEAR AND FAR TERM BMET BIPOLAR BATTERY SPECIFICATIONS

| BATTERY TYPE | NEAR TERM | FAR TERM |
|---|---|---|
| **Main Engine Starting** | | |
| Mass | 450 lbs. | 389 lbs. |
| Volume | 2.45 $ft^3$ | 2.00 $ft^3$ |
| **Ground Power** | | |
| Lower Capacity Unit | | |
| Mass | 1000 lbs. | 865 lbs. |
| Volume | 6.15 $ft^3$ | 4.85 $ft^3$ |
| Higher Capacity Unit | | |
| Mass | 1349 lbs. | 1235 lbs |
| Volume | 8.13 $ft^3$ | 6.72 $ft^3$ |
| **APU Starting** | | |
| Mass Volume | 33.4 lbs. | 30.6 lbs |
| Volume | 0.18 $ft^3$ | 0.16 $ft^3$ |
| **Assumptions:** | | |
| Substrate Thickness | 0.025" | 0.010" |
| Substrate Weight | 150 $mg/cm^2$ | 80 $mg/cm^2$ |
| Substrate Resistivity | 2.0 Ω-cm | ~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<br>APV Starting<br>Hybrid Emergency | 17.6"x15.5"x15.5" | 2.45 ft3 | 450 lbs | 747.9 | 2.2 | 12.25 | 0.036 |
| Main Engine Starting<br>Ground Power<br>Emergency Power<br>APU Starting<br>Hybrid Emergency | | | | | | | |
| Scenario 1<br>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<br>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<br>APV Starting<br>Hybrid Emergency | 14.4"x15.5"x15.5" | 2.00 ft3 | 389 lbs | 895.3 | 2.8 | 14.17 | 0.044 |
| Main Engine Starting<br>Ground Power<br>Emergency Power<br>APU Starting<br>Hybrid Emergency | | | | | | | |
| Scenario 1<br>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<br>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**

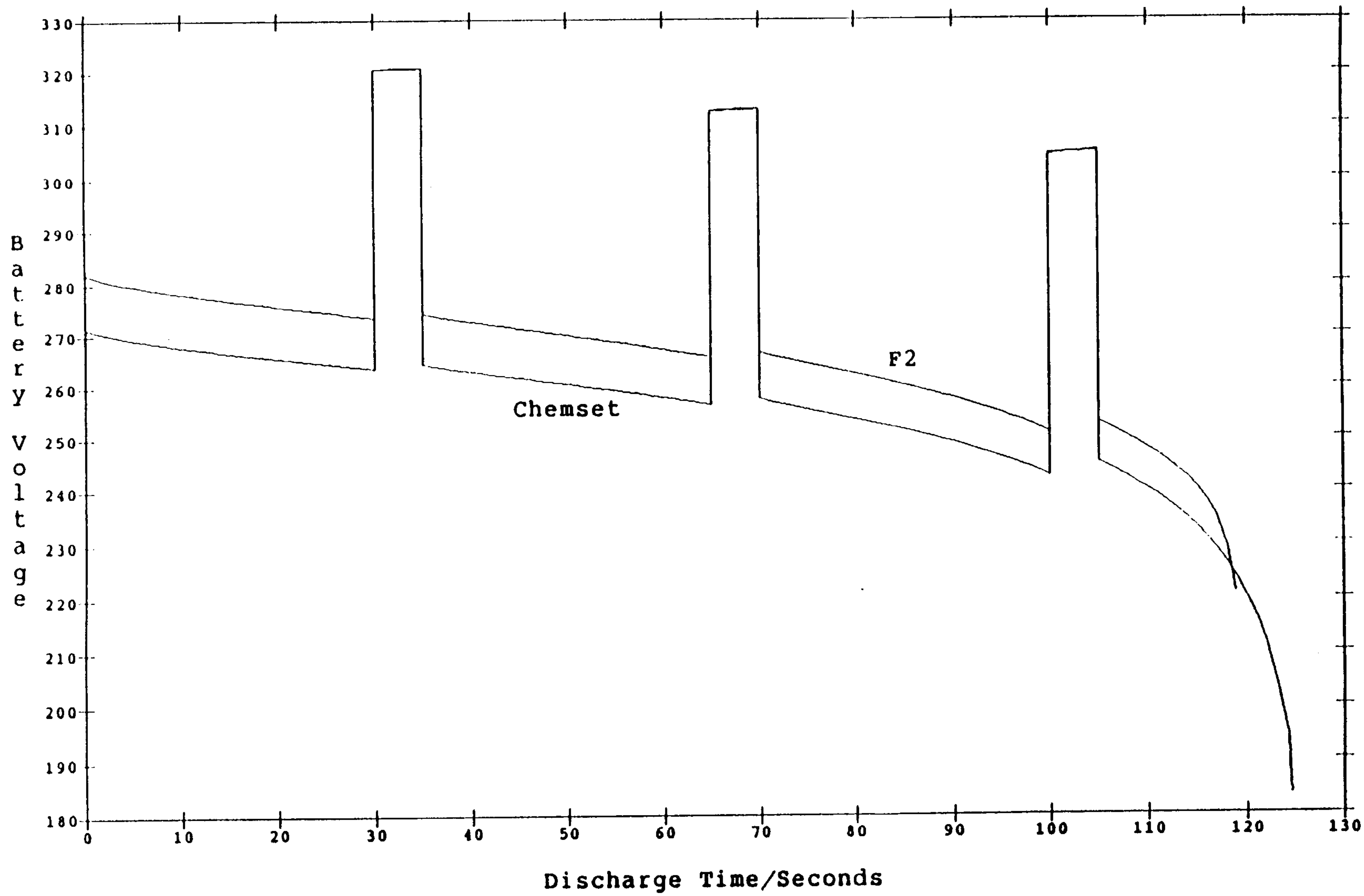


FIGURE 7

Effect of Temperature on Performance of Main Engine Starting Battery

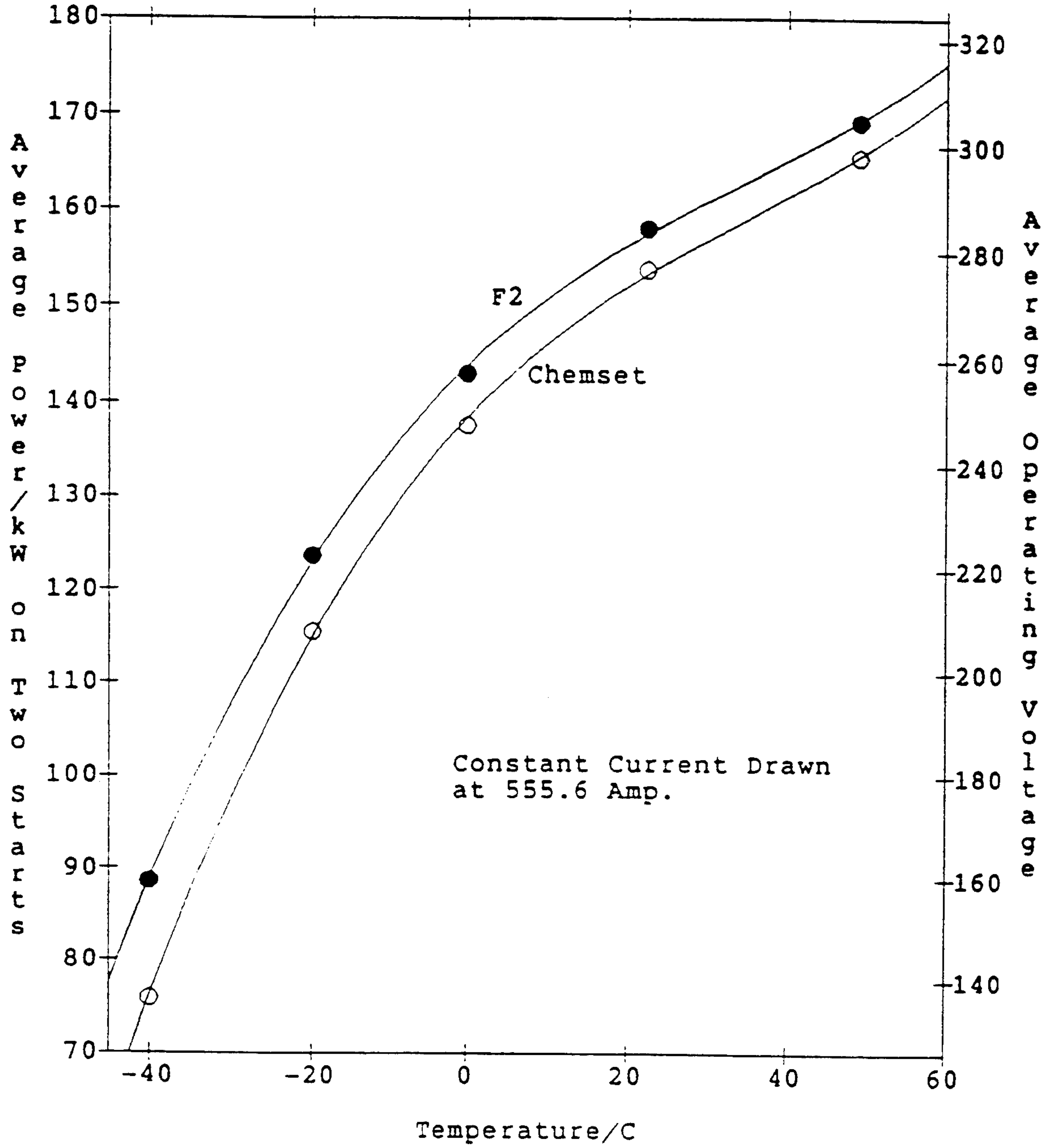


FIGURE 8

**Comparison of Chemset and F2 Plates for Ground Power Units**

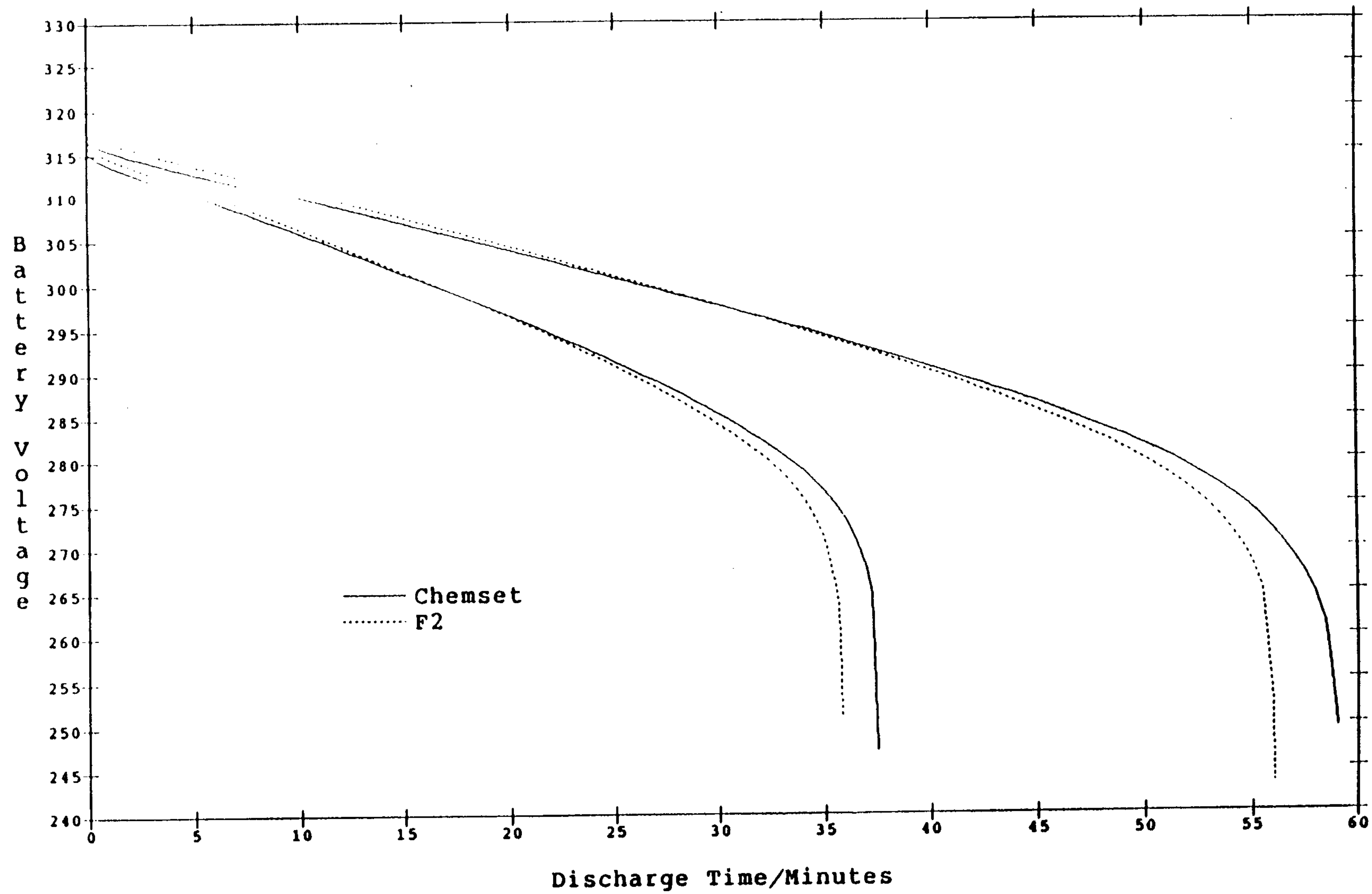


FIGURE 9

**Effect of Temperature on Power Output of the Ground Units**

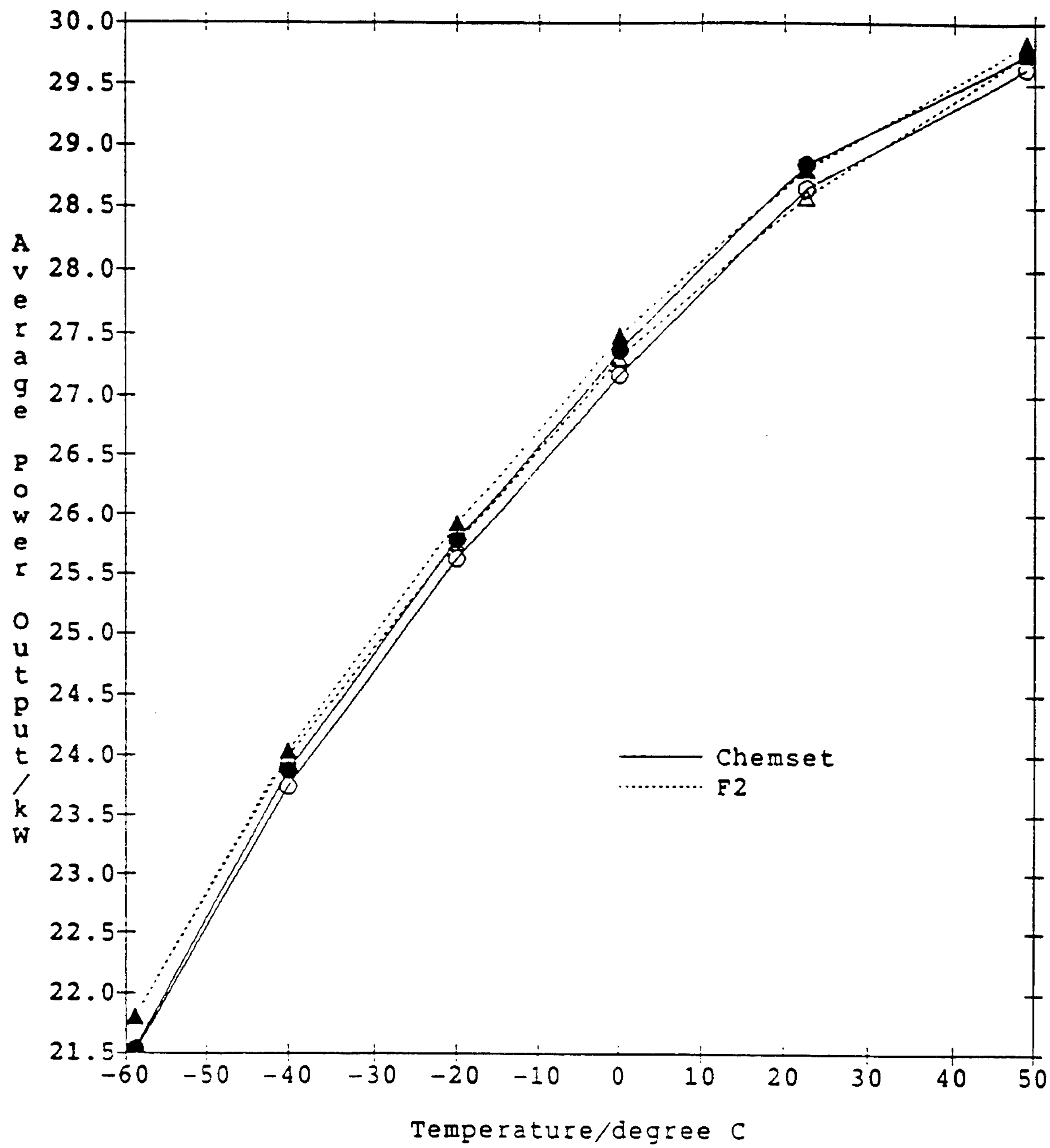


FIGURE 10

**Effect of Temperature on Capacity of the Ground Units**

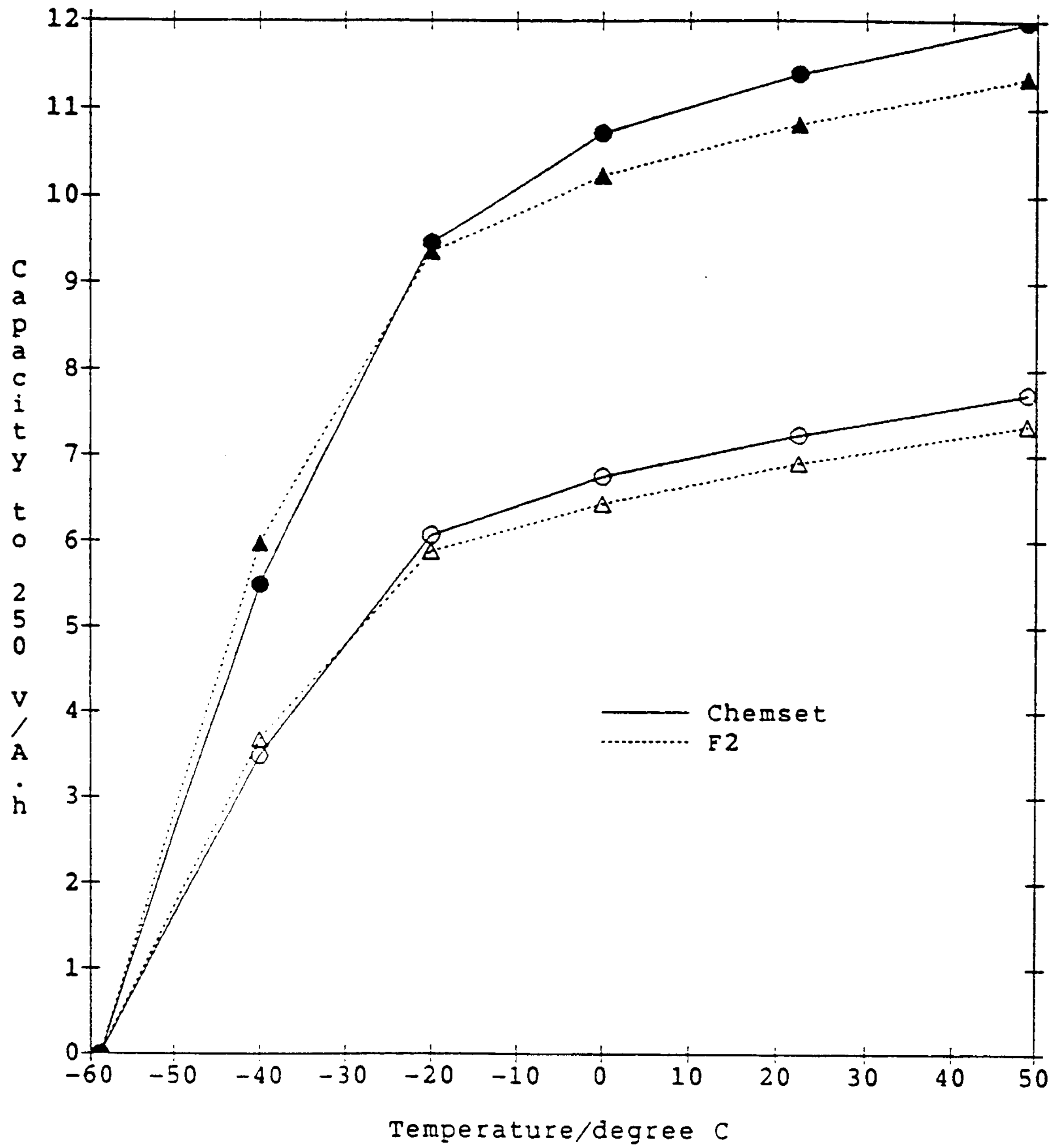


FIGURE 11
Comparison of Chemset and F2 Plates for APU Starting Battery

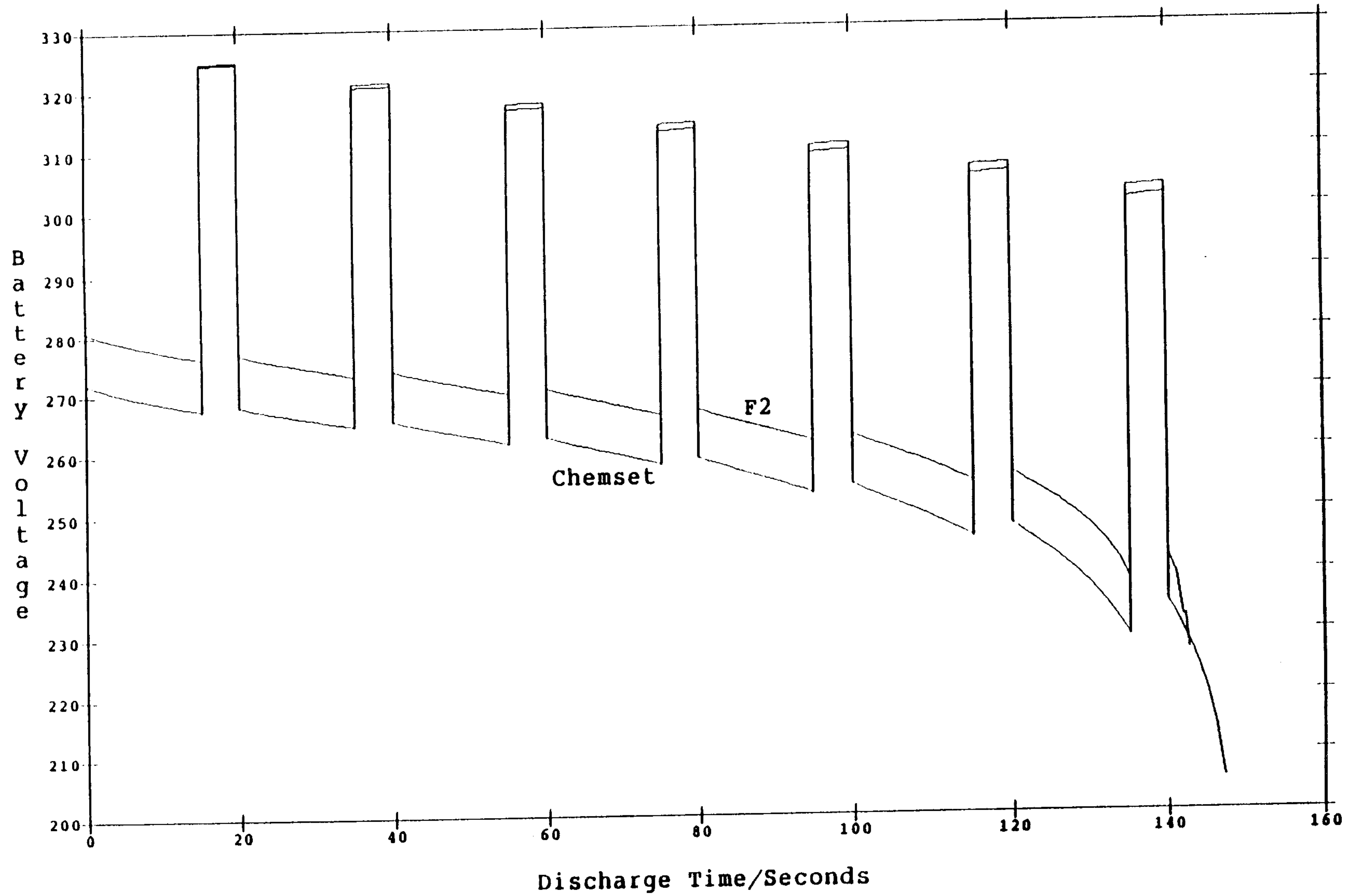


FIGURE 12

**Effect of Temperature on Performance of APU Starting Battery**

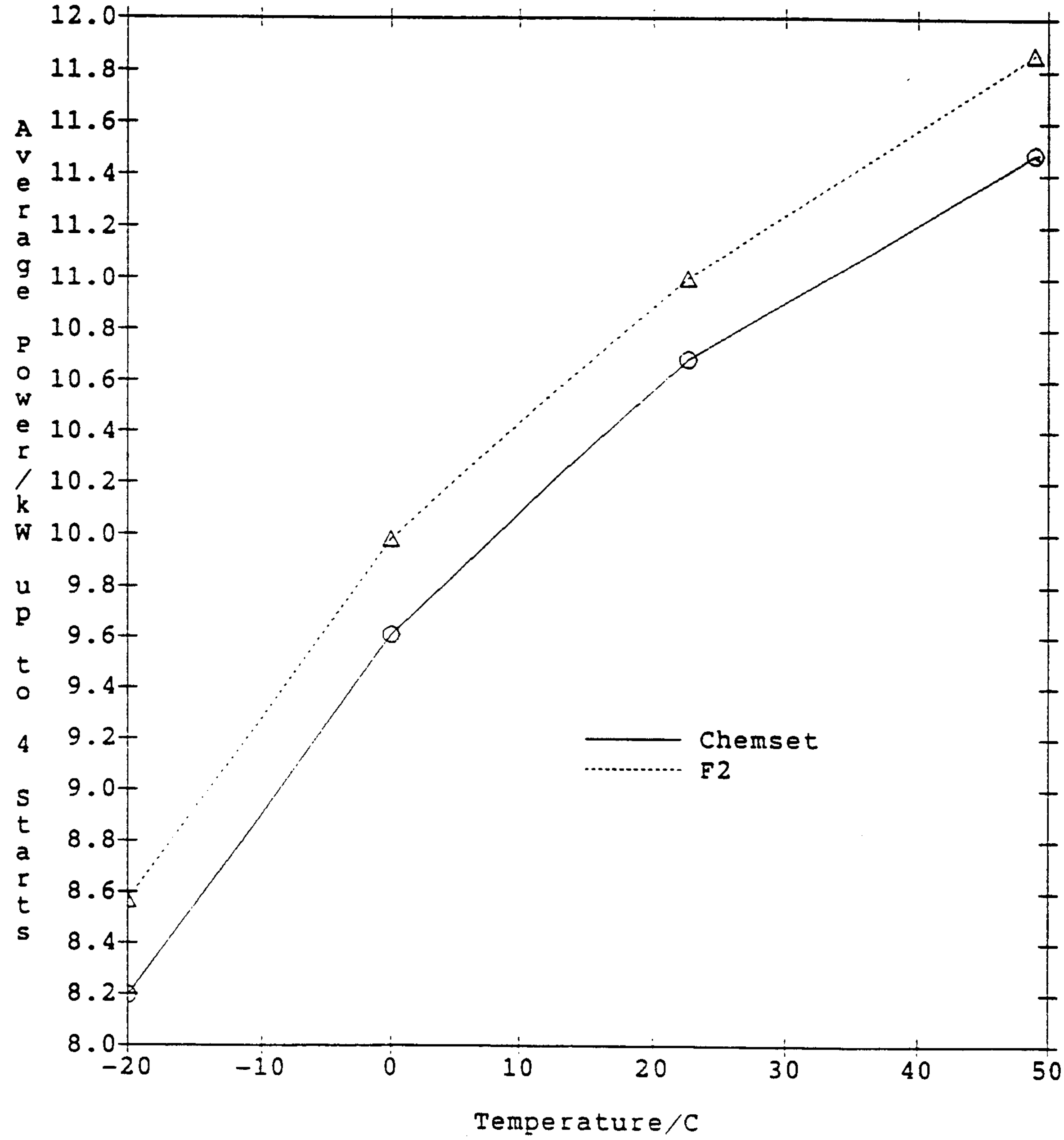


FIGURE 13

**Comparison of Chemset and F2 Plates for Emergency Power Unit**

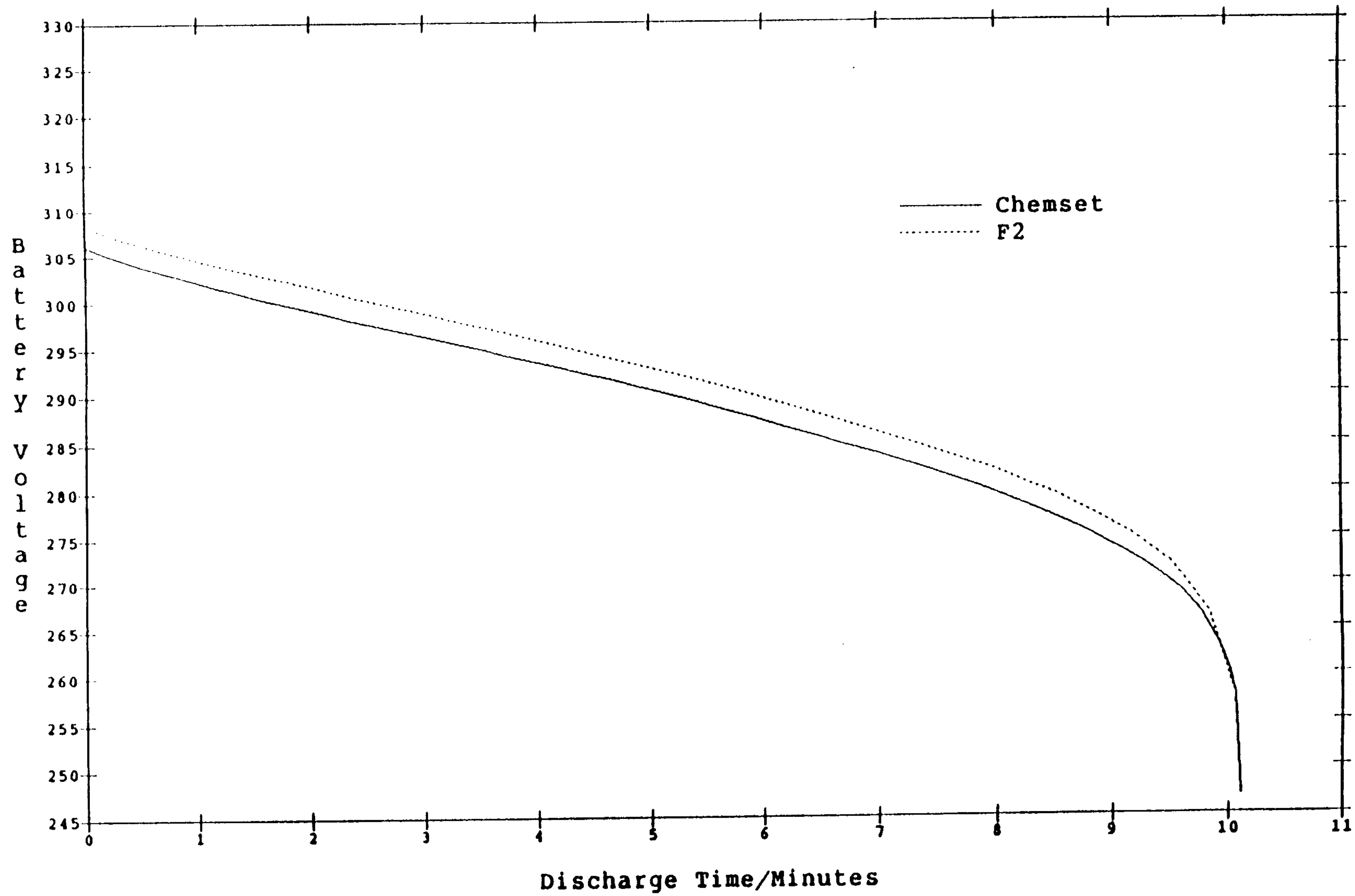
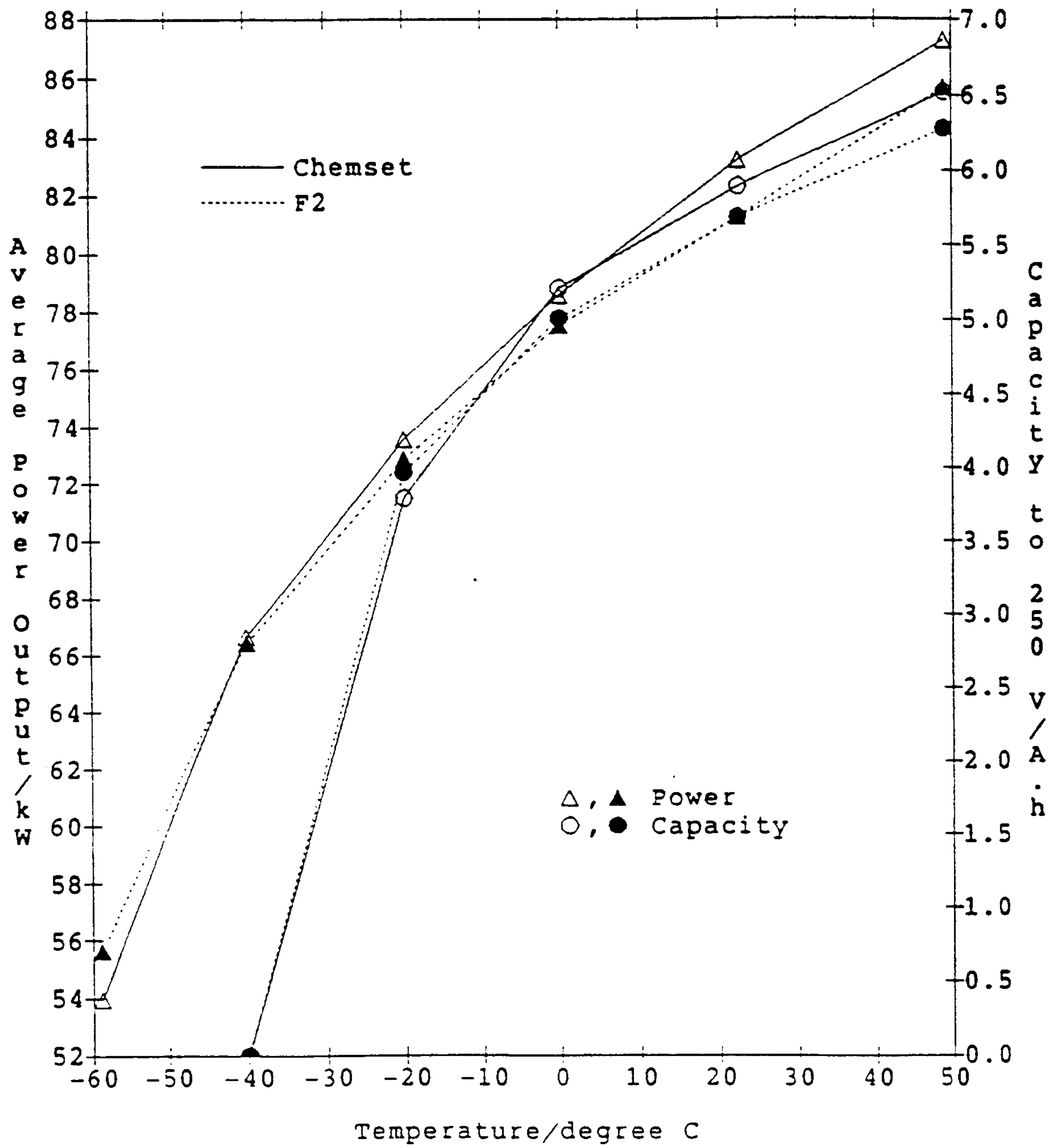


FIGURE 14

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.

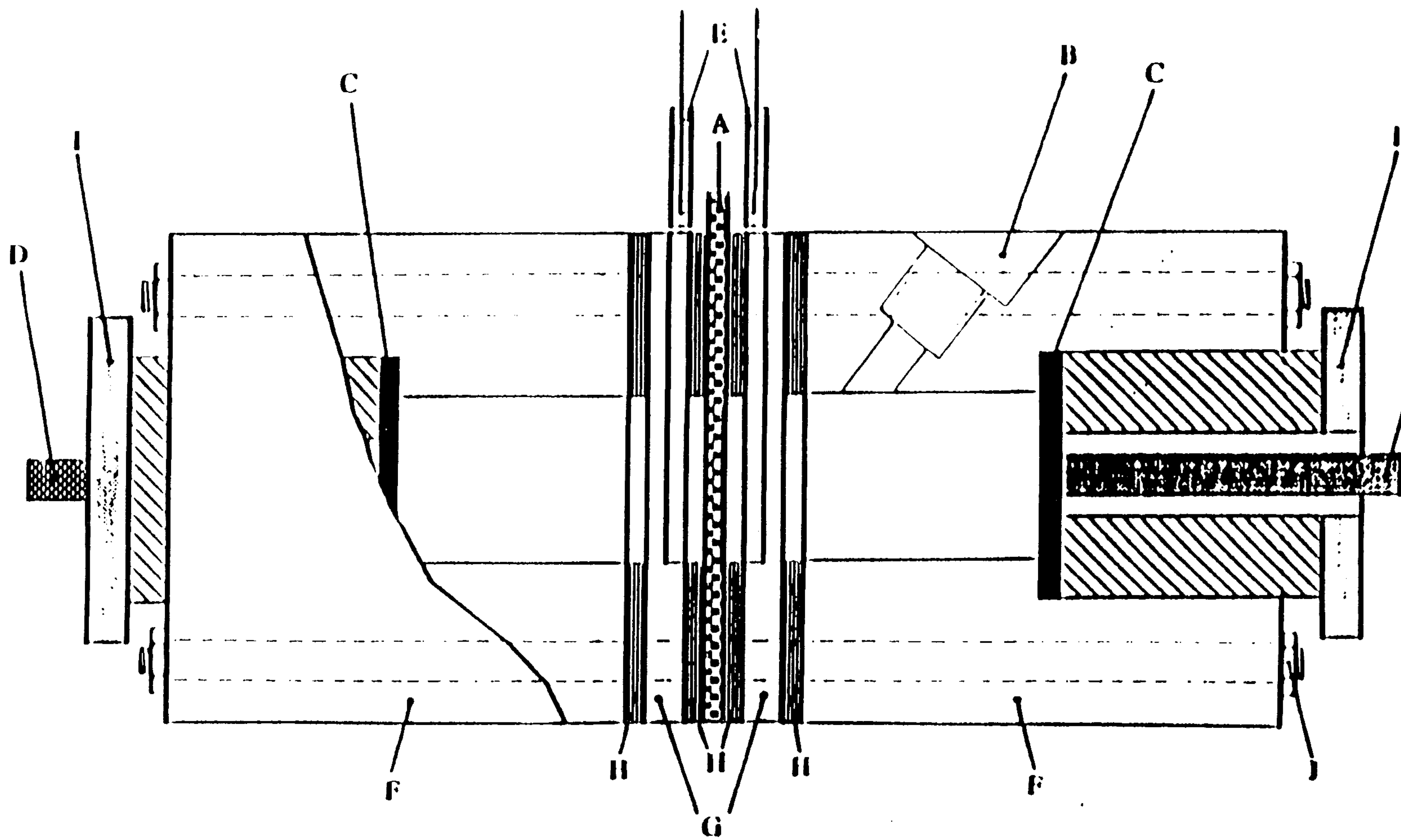
### 3.3.4 Subtask 3.4 Proof of Concept Testing

Over 60 batteries of various voltages were assembled and tested. Dry, unformed electrodes with 10 $in^2$ 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
B. Reference Electrode Socket
C. Counter Electrode
D. Current Collector
E. Resistance Sensor
F. Lexan Block
G. Spacer with Sensor Socket
H. Gasket
I. Counter Electrode Bushing
J. Clamping Hardware



gasket. Discharge performance routinely surpassed 5 minutes at 1 A/in$^2$, 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 | | 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 | | 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

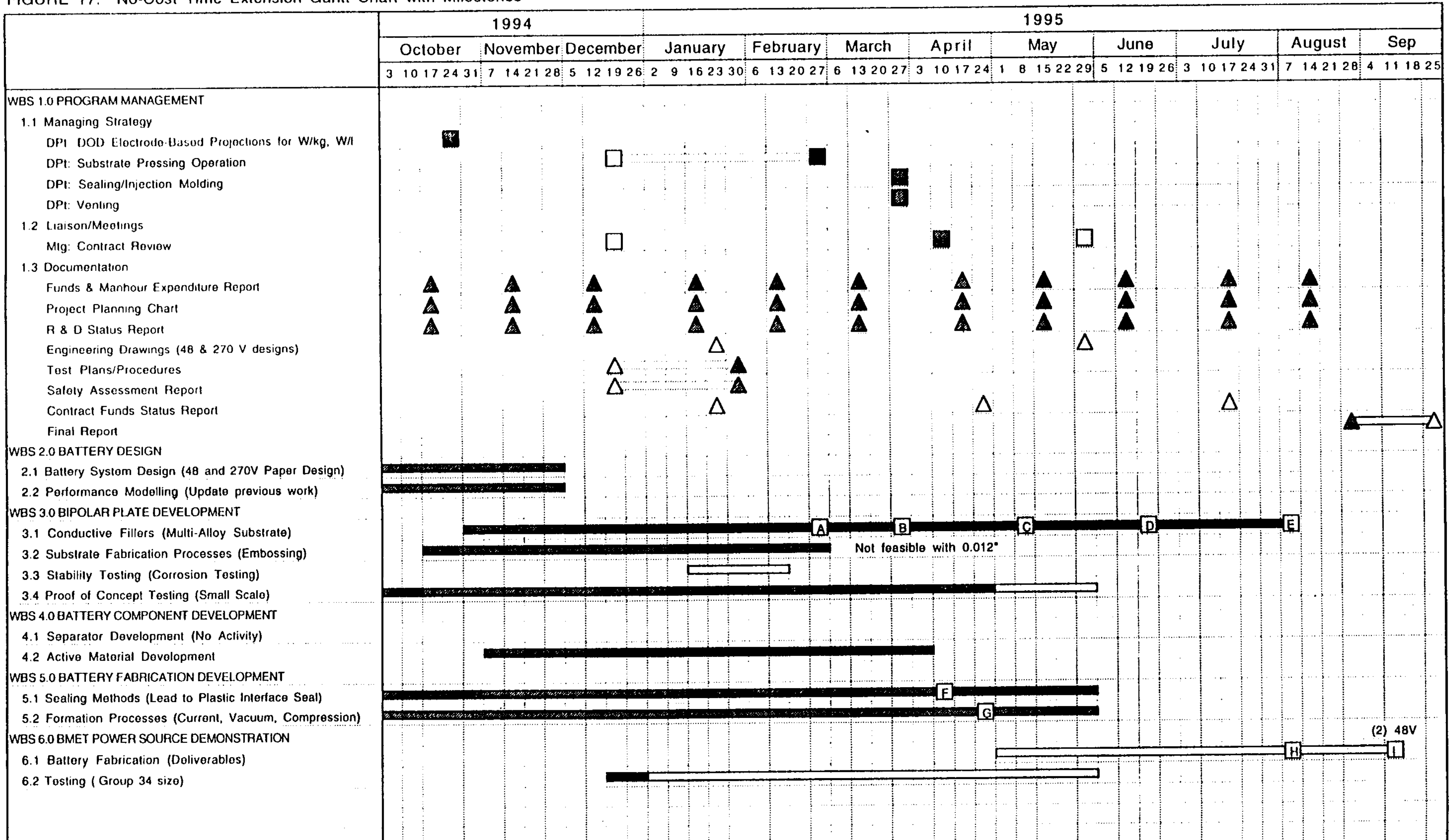
The existing small metallic bipolar battery design was scaled up and modeled to investigate high power performance. Results suggested the use of a thinner cell design to be critical to achieving rates of 500 W/kg and higher. Per these findings, work was redirected to designing a 24-volt module within 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

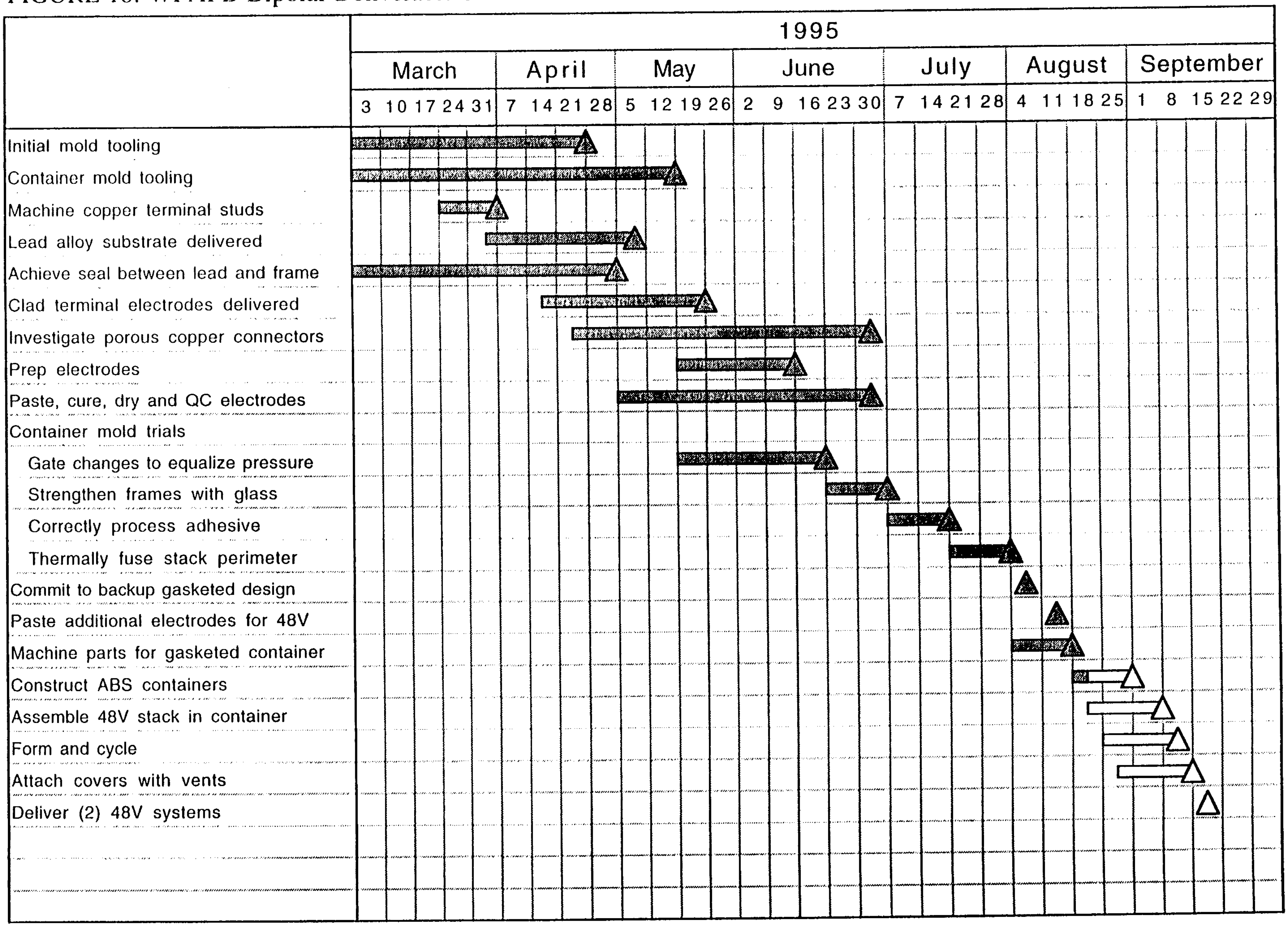
Under separate contract, JCBGI began investigations into laminated metal substrates in November 1993. Corrosion testing of three, four and five layer samples and constituent alloys was performed in a bipolar configuration to assess time to breakthrough. Unpasted samples were mounted in the previously 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

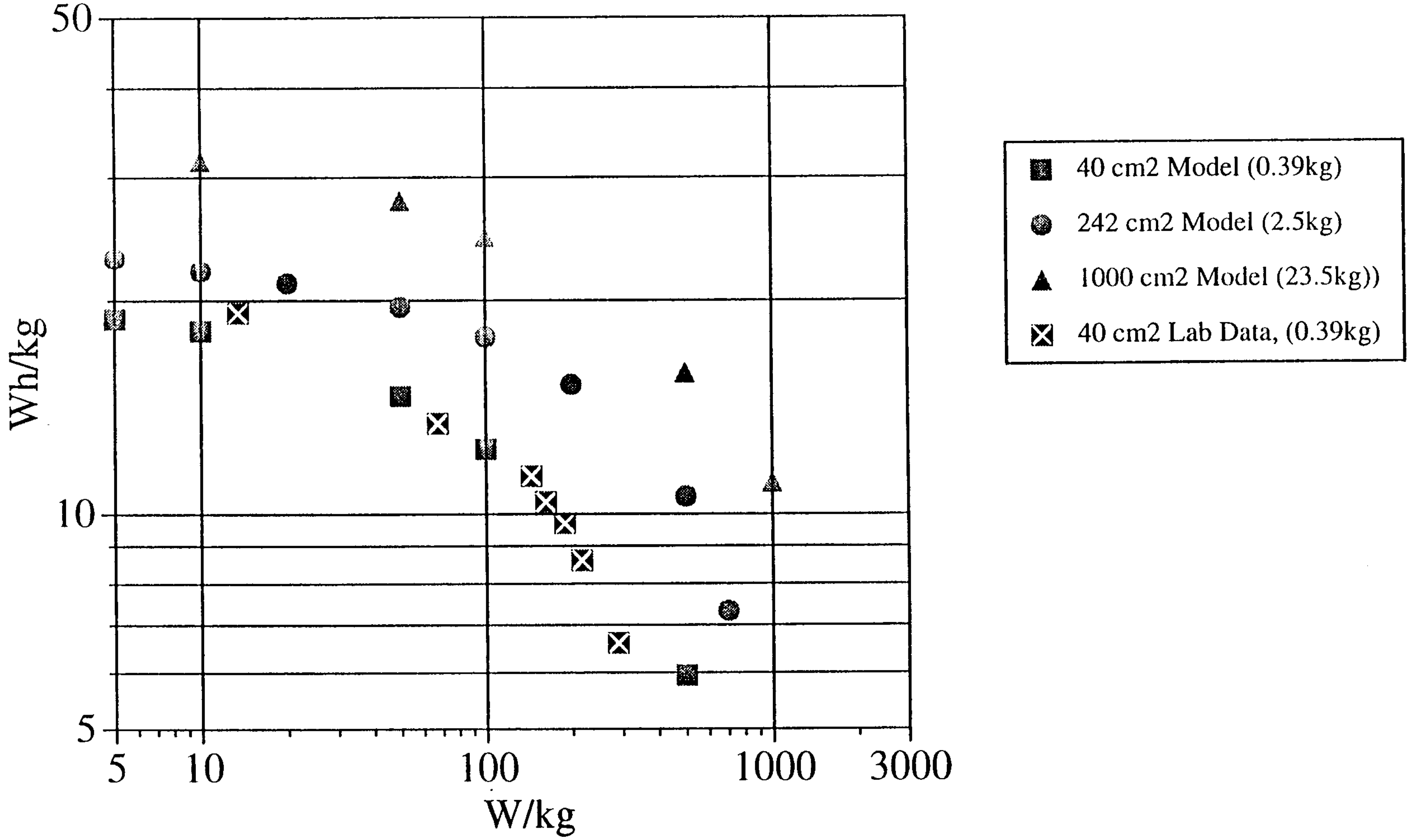



[A] Rolling work discontinued due to inconsistent rib height. Texas Instruments and Vacco Industries brought on board.
[B] Chatter encountered during TI rolling trial. Starting materials too thick. Lead on copper terminals ordered from another vendor.
[C] Terminal laminate received on time. Stud solder joint strength exceeds SLI specification.
[D] 0.032" thick, 4-layer laminate produced by TI. Too thick. Vacco examining electrowinning to reduce $58/pc etching cost.
[E] Chatter eliminated, but necking now a problem.
[F] Pressure sensitive adhesive reprocessed and applied to surface treated frames. Stacks successfully pressurized.
[G] 24-volt stacks of frames and electrodes short in formation.
[H] Work to deliver 24-volt injection molded batteries discontinued in favor of backup gasketed container design.
[I] Two 48-volt batteries delivered to WPAFB.

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.

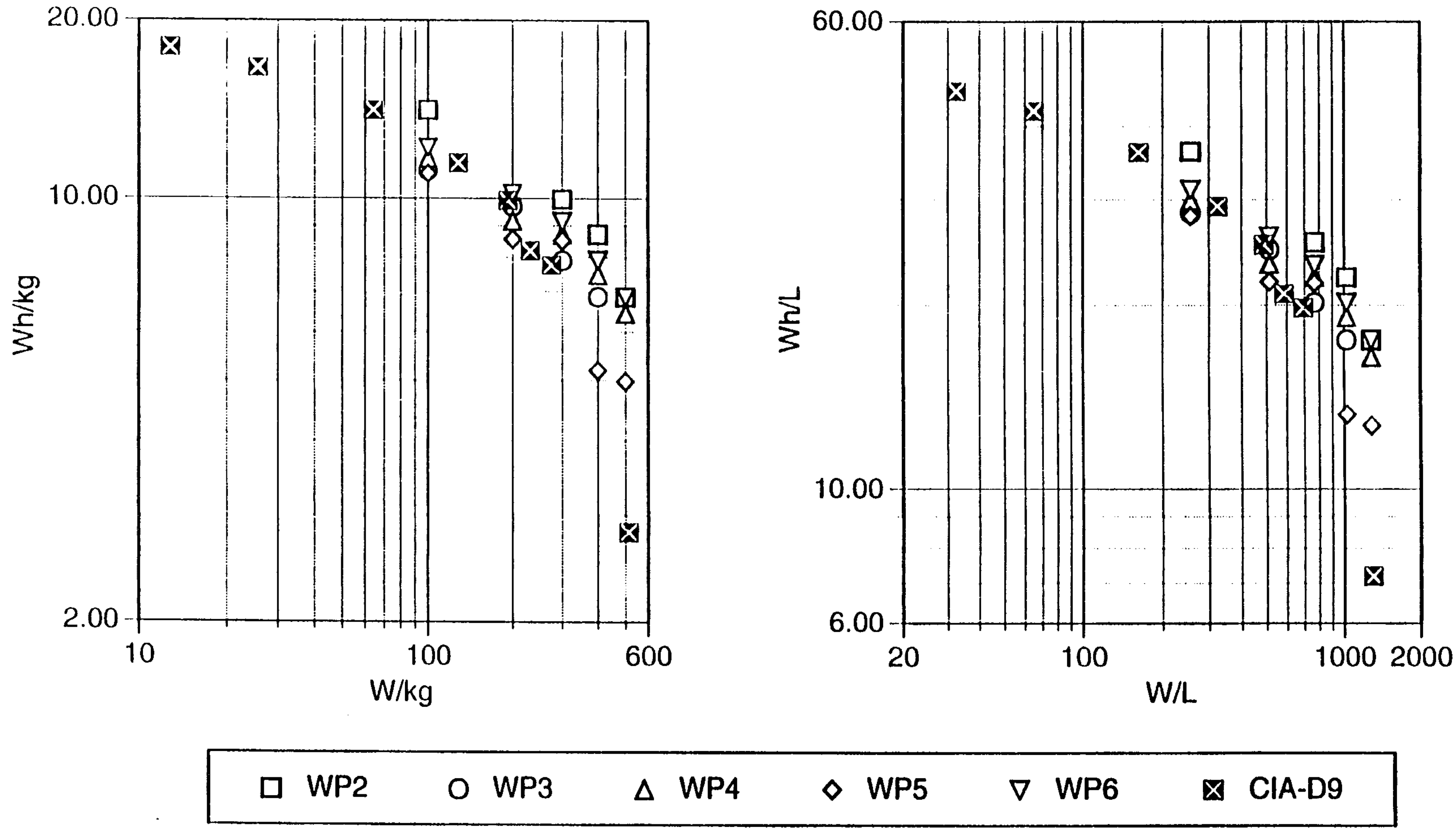
### 4.3.3 Subtask 3.3 Substrate Corrosion Testing

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

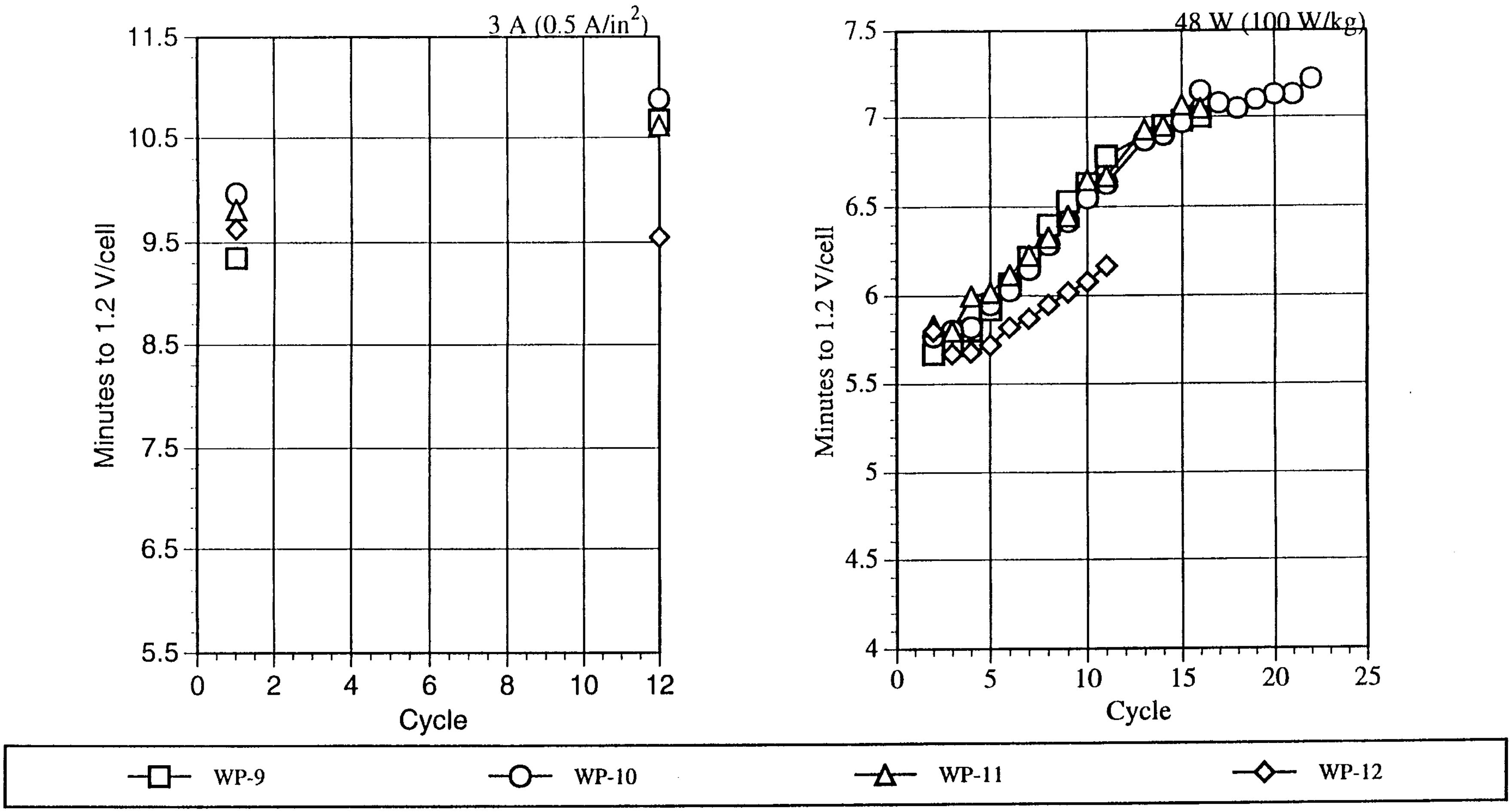


FIGURE 22
Small Scale Characterization
Peukert Relationship, 24 deg C

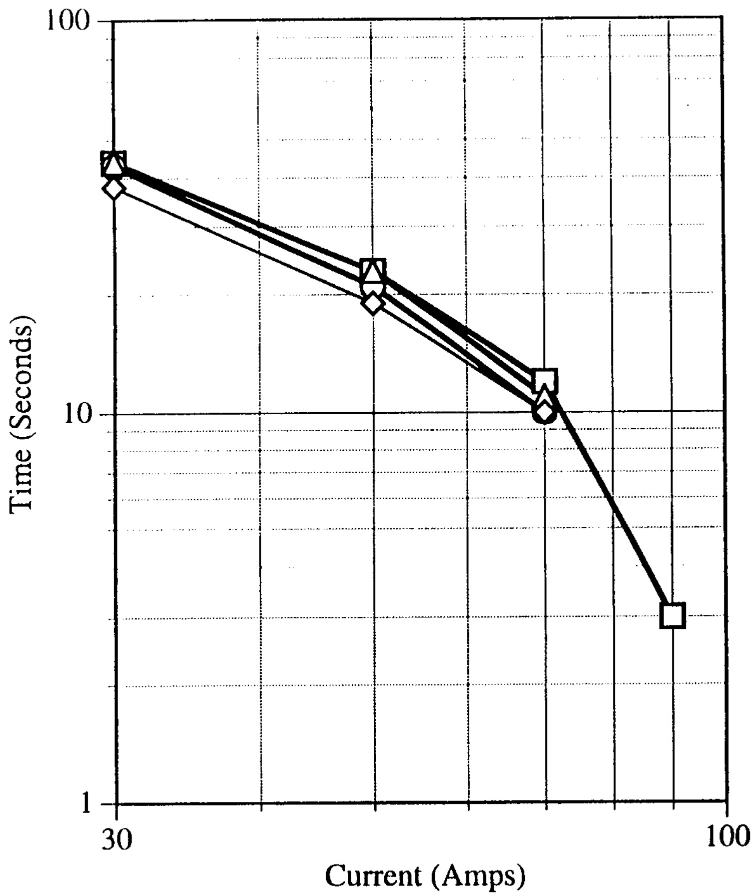



FIGURE 23
Small Scale Characterization
Ragone Relationship, 24 deg C

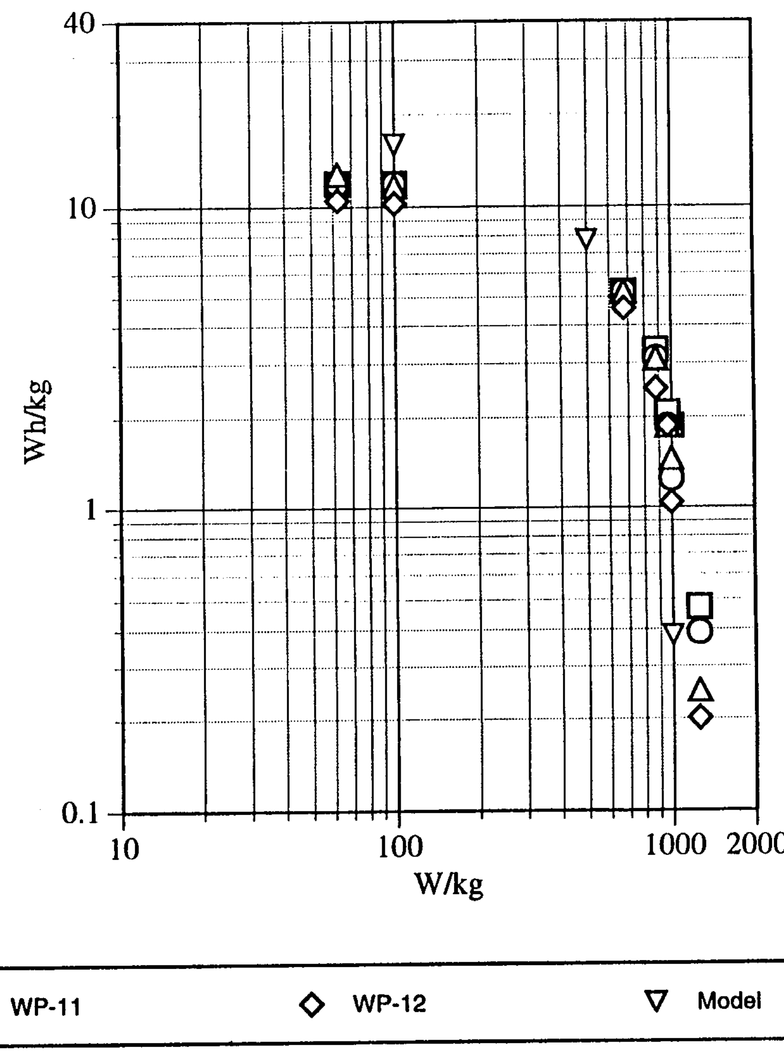
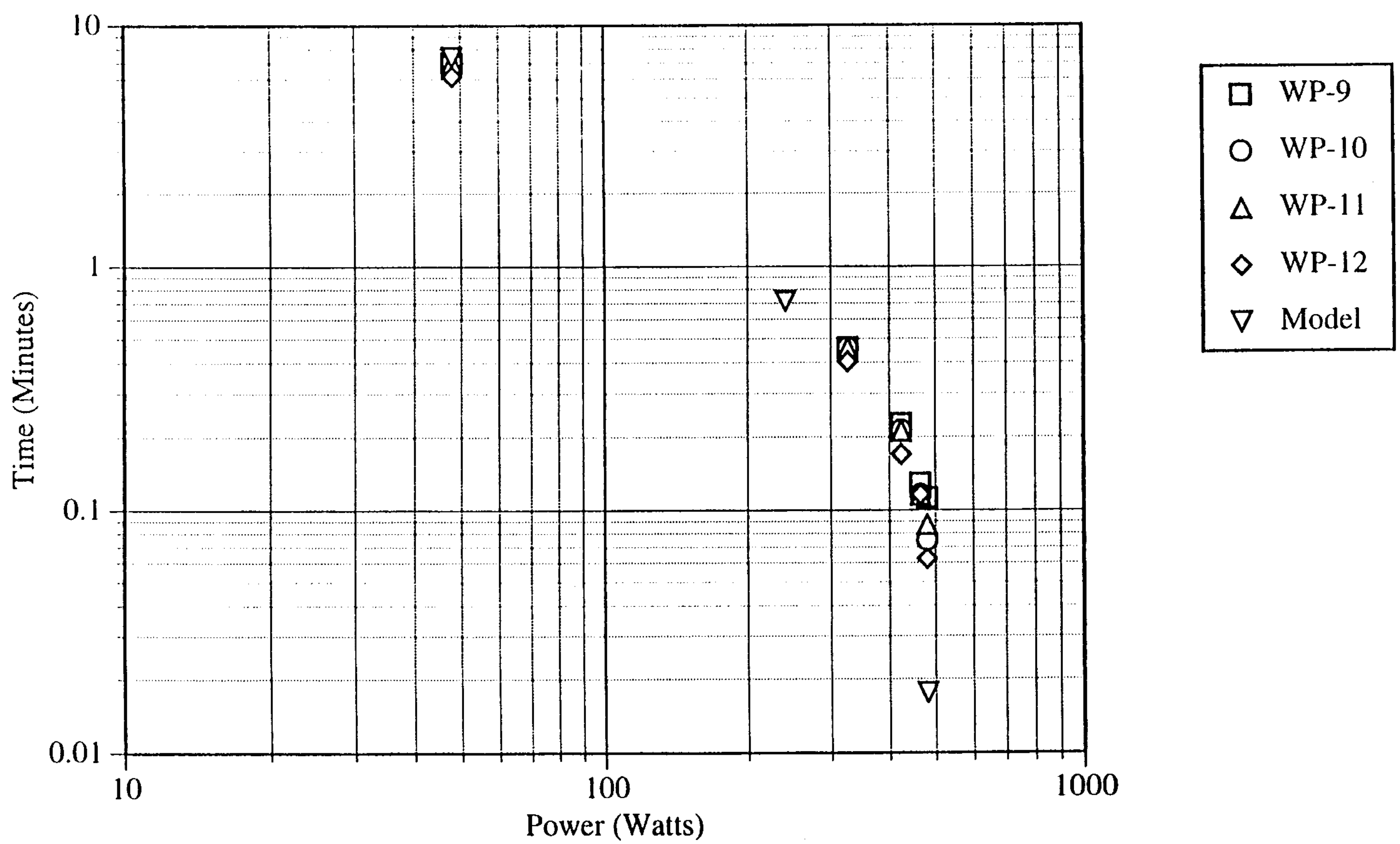


FIGURE 24
Small Scale Characterization
Discharge Time vs Power, 24 deg C



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

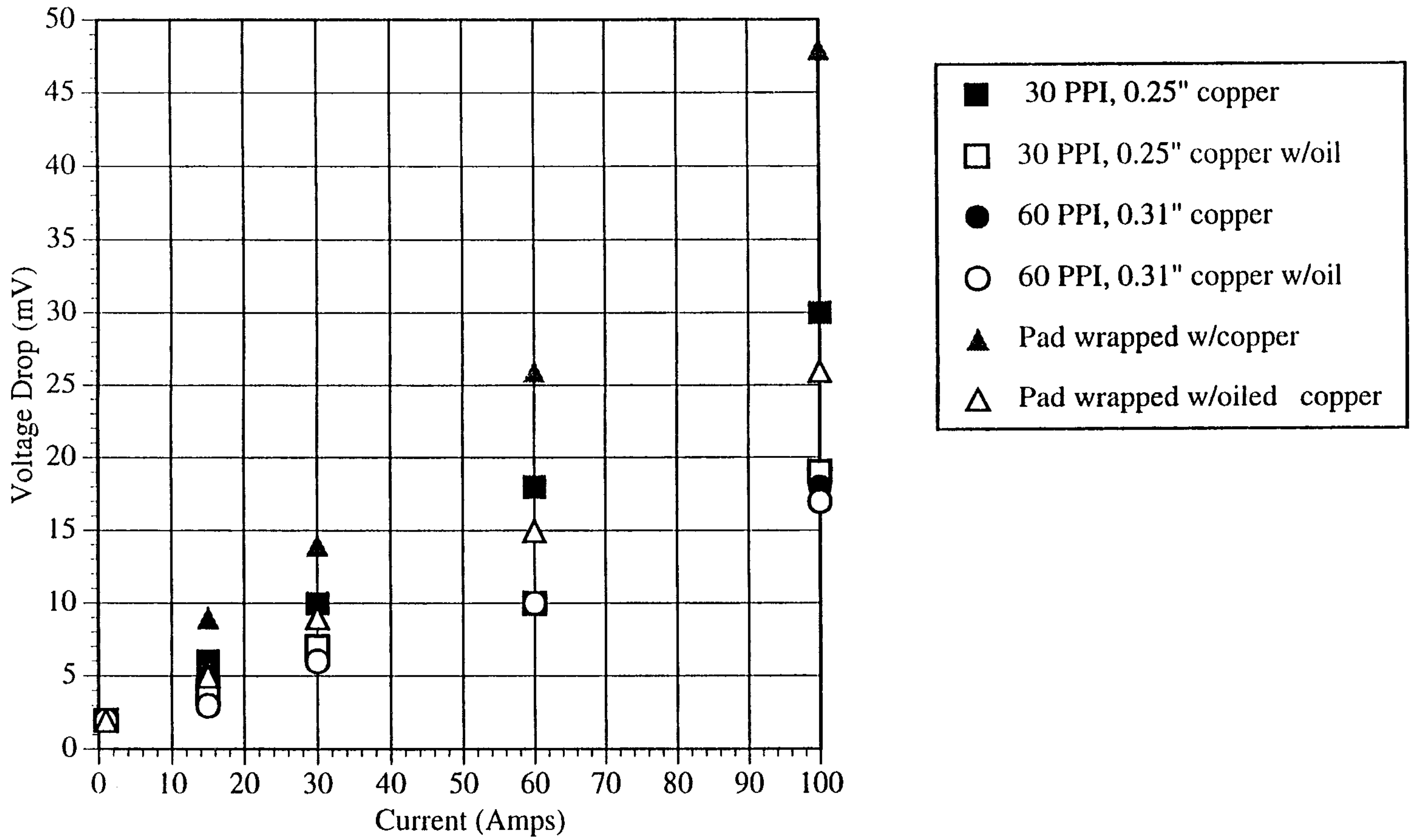
Given the difficulties encountered in achieving hermetic cell-to-cell seals with the injection molded containment concept, WPAFB accepted deliverable batteries assembled using neoprene spacers and machined ABS container components (Appendix B).

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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| 47A | 4/2/92 | LAMINATED 85% GC23N | 0.365 | 0.023 | 6.248 | 0.960 | 0.042 | 8.999 | |
| | | W/O CA | 0.450 | 0.024 | 7.382 | 0.640 | 0.042 | 5.999 | |
| | | 15% MICROTHENE | 0.270 | 0.023 | 4.622 | 1.060 | 0.042 | 9.936 | |
| | | 4.5 M.I. | | | 6.084 | | | 8.311 | 36.6158656 |
| | | C-PLASTIC | | | | | | | |
| 48A | 4/2/92 | LAMINATED 85% GC23N | 0.630 | 0.025 | 9.921 | 1.000 | 0.040 | 9.843 | |
| | | WITH CA | 0.570 | 0.024 | 9.350 | 1.500 | 0.040 | 14.764 | |
| | | 15% MICROTHENE | 0.635 | 0.024 | 10.417 | 0.740 | 0.040 | 7.283 | |
| | | 4.5 M.I. | | | 9.896 | | | 10.630 | 7.415184 |
| | | C-PLASTIC | | | | | | | |
| 52 | 4/9/92 | LAMINATED 84% GC23N | 1.180 | 0.053 | 8.765 | 19.500 | 0.062 | 123.825 | |
| | | & 16%PTFE TO | | | | 17.500 | 0.062 | 111.125 | |
| | | C-PLASTIC & Pb FOIL | | | | 38.000 | 0.063 | 237.470 | |
| | | SINGLE APPLICATION | | | | | | 157.474 | 1696.53351 |
| | | OF RESIN | | | | | | | |
| 53 | 4/9/92 | LAMINATED 84% GC23N | 3.630 | 0.061 | 23.428 | 169.000 | 0.054 | 1232.138 | |
| | | & 16%PTFE TO | | | | 161.000 | 0.054 | 1173.812 | |
| | | C-PLASTIC & Pb FOIL | | | | 188.000 | 0.054 | 1370.662 | |
| | | DOUBLE APPLICATION | | | | | | 1258.870 | 5273.26123 |
| | | OF RESIN | | | | | | | |
| 54B | 4/14/92 | LAMINBATED 85% GC23N-1 | 0.195 | 0.040 | 1.919 | 0.440 | 0.040 | 4.331 | |
| | | 15% MICROTHENE | | | | 0.483 | 0.040 | 4.754 | |
| | | 4.5 M.I. | | | | 0.470 | 0.040 | 4.626 | |
| | | WITH Pb FOIL | | | | | | 4.570 | 138.119658 |
| 55B | 4/14/92 | LAMINATED 85% GC23N-2 | 0.250 | 0.030 | 3.281 | 1.730 | 0.030 | 22.703 | |
| | | 15% MICROTHENE | | | | 2.350 | 0.030 | 30.840 | |
| | | 4.5 M.I. | | | | 3.600 | 0.030 | 47.244 | |
| | | W/O pb FOIL | | | | | | 33.596 | 924 |
| 71A | 4/24/92 | LAMINATED | 0.295 | 0.206 | 0.564 | 0.390 | 0.209 | 0.735 | |
| | | THICK/THICK | 0.300 | 0.208 | 0.568 | 0.430 | 0.211 | 0.802 | |
| | | GC23N-1 /C-PLASTIC | 0.280 | 0.208 | 0.530 | 0.400 | 0.208 | 0.757 | |
| | | | | | 0.554 | | | 0.765 | 38.0646797 |
| 72A | 4/24/92 | LAMINATED | 0.275 | 0.208 | 0.521 | 0.495 | 0.210 | 0.928 | |
| | | THIN/THIN | 0.265 | 0.208 | 0.502 | 0.410 | 0.210 | 0.769 | |
| | | GC23N-2 /C-PLASTIC | 0.275 | 0.207 | 0.523 | 0.500 | 0.209 | 0.942 | |
| | | | | | 0.515 | | | 0.880 | 70.763192 |
| 73A | 4/24/92 | LAMINATED | 0.420 | 0.031 | 5.334 | 3.800 | 0.031 | 48.260 | |
| | | THICK/THIN | 0.250 | 0.032 | 3.076 | 8.800 | 0.031 | 111.760 | |
| | | GC23N-3 /C-PLASTIC | 0.220 | 0.033 | 2.625 | 6.400 | 0.032 | 78.740 | |
| | | | | | 3.678 | | | 79.587 | 2063.76933 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| 74A | 4/24/92 | LAMINATED | 0.380 | 0.032 | 4.675 | 4.300 | 0.032 | 52.904 | |
| | | THIN/THIN | 0.440 | 0.033 | 5.249 | 5.100 | 0.033 | 60.845 | |
| | | GC23N-4 /C-PLASTIC | 0.430 | 0.031 | 5.461 | 5.500 | 0.032 | 67.667 | |
| | | | | | 5.129 | | | 60.472 | 1079.12921 |
| 75A | 4/24/92 | LAMINATED | 0.350 | 0.121 | 1.139 | 0.570 | 0.122 | 1.839 | |
| | | THICK/THIN | 0.580 | 0.122 | 1.872 | 0.520 | 0.123 | 1.664 | |
| | | GC23N-5 /C-PLASTIC | 0.280 | 0.123 | 0.896 | 0.320 | 0.123 | 1.024 | |
| | | | | | 1.302 | | | 1.509 | 15.9055035 |
| 76A | 4/24/92 | LAMINATED | 0.285 | 0.124 | 0.905 | 2.350 | 0.125 | 7.402 | |
| | | THIN/THICK | 0.275 | 0.126 | 0.859 | 2.580 | 0.124 | 8.192 | |
| | | GC23N-6 /C-PLASTIC | 0.270 | 0.126 | 0.844 | 2.300 | 0.123 | 7.362 | |
| | | | | | 0.869 | | | 7.652 | 780.246688 |
| 77A | 5/12/92 | LAMINATED | | | | | | | |
| | | GC23N-A-3/92 | | | | | | | |
| | | Pb-FOIL | | | | | | | |
| | | C-PLASTIC | 0.36 | 0.026 | 5.451 | | | | |
| | | LAMINATED | | | | | | | |
| | | GC23N-B-3/92 | | | | | | | |
| | | Pb-FOIL | | | | | | | |
| | | C-PLASTIC | 0.22 | 0.026 | 3.331 | | | | |
| | | LAMINATED | | | | | | | |
| | | GC23N-B-3/92 | | | | | | | |
| | | Pb-FOIL | | | | | | | |
| | | C-PLASTIC | 0.66 | 0.027 | 9.624 | | | | |
| 78A | 6/5/92 | LAMINATED | | | | | | | |
| | | GC23N,MICROTHENE & | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | | 1R | 0.228 | 0.03 | 2.992 | 0.38 | 0.03 | 4.987 | 66.6666667 |
| | | 2R | 0.185 | 0.03 | 2.428 | 5.8 | 0.03 | 76.115 | 3035.13514 |
| | | 3R | 0.21 | 0.027 | 3.062 | 0.66 | 0.028 | 9.280 | 203.061224 |
| 79A | 5/20/92 | LAMINATE | | | | | | | |
| | | GC23N-1-85% | 0.52 | 0.046 | 4.451 | 3.7 | 0.046 | 31.667 | 611.538462 |
| | | MICROTHENE/CA | | | | | | | |
| | | GC23N-2-85% | 0.335 | 0.044 | 2.997 | 2.2 | 0.044 | 19.685 | 556.716418 |
| | | MICROTHENE | | | | | | | |
| | | GC23N-3-80.3% | 0.49 | 0.039 | 4.946 | 21 | 0.041 | 201.652 | 3976.65505 |
| | | KY | | | | | | | |
| | | GC23N-4-80.3% | 0.435 | 0.037 | 4.629 | 13.5 | 0.038 | 139.867 | 2921.77858 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | KY/CA | | | | | | | |
| 80A | 5/27/92 | LAMINATE | | | | | | | |
| | | GC23N-1-85% | 0.36 | 0.04 | 3.543 | 0.445 | 0.04 | 4.380 | 23.6111111 |
| | PG.139/141 | MICROTHENE/CA | | | | | | | |
| | | GC23N-2-85% | 0.495 | 0.039 | 4.997 | 0.525 | 0.038 | 5.439 | 8.85167464 |
| | | MICROTHENE | | | | | | | |
| | | GC23N-3-80.3% | 0.223 | 0.044 | 1.995 | 0.253 | 0.044 | 2.264 | 13.4529148 |
| | | KY | | | | | | | |
| | | GC23N-4-80.3% | 0.305 | 0.042 | 2.859 | 0.35 | 0.041 | 3.361 | 17.5529788 |
| | | KY/CA | | | | | | | |
| 81A | 6/9/92 | LAMINATED | | | | | | | |
| | | GC23N,MICROTHENE & | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | | 5/92-1R | | | | | | | |
| | | 5/92-2R | | | | | | | |
| | | 5/92-3R | | | | | | | |
| | | 5/92-4R | | | | | | | |
| 82A | 6/10/92 | LAMINATED | | | | | | | |
| | | DOPED OXIDE/SCW | | | | | | | |
| | | AND C-PLASTIC | 0.38 | 0.098 | 1.527 | 23.3 | 0.098 | 93.604 | 6031.57895 |
| 84A | 6/26/92 | LAMINATED | | | | | | | |
| | | DOPED OXIDE-5/92 | | | | | | | |
| | | KY 7201 & 711 | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | | CA | | | | | | | |
| | | 70%-7201 | 1.7 | 0.031 | 21.590 | 26.3 | 0.031 | 334.011 | 1447.05882 |
| | | 75%-7201 | 0.54 | 0.031 | 6.858 | 220 | 0.033 | 2624.672 | 38171.6049 |
| | | 85%-711 | 0.45 | 0.059 | 3.003 | | | | |
| | | 70%-7201 & CA | 0.785 | 0.032 | 9.658 | 1.75 | 0.031 | 22.225 | 130.121225 |
| | | 75%-7201 & CA | 0.68 | 0.033 | 8.113 | 6.4 | 0.032 | 78.740 | 870.588235 |
| | | 85%-711 & CA | 0.32 | 0.062 | 2.032 | | | | |
| 85A | 6/30/92 | LAMINATES | | | | | | | |
| | | DOPED OXIDE, CA | | | | | | | |
| | | C-PLASTIC , Pb FOIL | | | | | | | |
| | | 711 KYANR & Pb DUST | | | | | | | |
| | | 70%-W/CA-FOIL | 3.7 | 0.022 | 66.213 | | | | |
| | | 70%-W/CA-DUST | 0.6 | 0.022 | 10.737 | | | | |
| | | 70%-W/O CA-FOIL | 2.15 | 0.022 | 38.475 | | | | |
| | | 70%-W/O CA-DUST | 0.32 | 0.025 | 5.039 | 71.5 | 0.025 | 1125.984 | 22243.75 |
| | | 75%-W/CA-FOIL | 0.097 | 0.024 | 1.591 | 12 | 0.025 | 188.976 | 11776.2887 |
| | | 75%-W/CA-DUST | 0.43 | 0.024 | 7.054 | 73 | 0.026 | 1105.391 | 15570.8408 |
| | | 75%-W/O CA-FOIL | 1.25 | 0.025 | 19.685 | | | | |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 75%-W/O CA-DUST | 0.3 | 0.026 | 4.543 | 70 | 0.028 | 984.252 | 21566.6667 |
| 88A | 7/13/92 | 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 | | | | |
| | | .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 |
| 92A | 7/22/92 | LEAD DUST & | 0.043 | 0.028 | 0.605 | | | | |
| | | POLYSULFONE | | | | | | | |
| | PG.167 | PREMIXED W/1.1.1 | | | | | | | |
| | | DRIED PRESSED AT | | | | | | | |
| | | 599F 30 TONS | | | | | | | |
| | | 55% BY WT. | | | | | | | |
| 94A | 7/28/92 | LAMINATE | | | | | | | |
| | | DOPED OXIDE(5/92) | | | | | | | |
| | | KY-711 | | | | | | | |
| | | & | | | | | | | |
| | | KET WITH | | | | | | | |
| | | KY-711 | | | | | | | |
| | | 14%-KET/KYN-.050 | 0.305 | 0.068 | 1.766 | 0.48 | 0.068 | 2.779 | 57.3770492 |
| | | 14%-KET/KYN-.040 | 0.38 | 0.061 | 2.453 | 0.4 | 0.061 | 2.582 | 5.26315789 |
| | | 14%-KET/KYN-.030 | 0.5 | 0.051 | 3.860 | 0.74 | 0.051 | 5.713 | 48 |
| | | Pb/POLYSULFONE | 0.066 | 0.025 | 1.039 | 0.57 | 0.025 | 8.976 | 763.636364 |
| 95A | 7/30/92 | LAMINATE | | | | | | | |
| | | DOPED OXIDE(5/92) | | | | | | | |
| | | KY-7201 | | | | | | | |
| | | & | | | | | | | |
| | | KET WITH | | | | | | | |
| | | KY-7201 | | | | | | | |
| | | 14%-KET/KYN-.050 | 0.305 | 0.066 | 1.819 | 0.345 | 0.066 | 2.058 | 13.1147541 |
| | | 14%-KET/KYN-.040 | 0.295 | 0.061 | 1.904 | 0.4 | 0.061 | 2.582 | 35.5932203 |
| | | 14%-KET/KYN-.030 | 0.27 | 0.052 | 2.044 | 1.15 | 0.052 | 8.707 | 325.925926 |
| | | 14%-KET/KYN-.020 | 0.255 | 0.043 | 2.335 | 4.2 | 0.043 | 38.454 | 1547.05882 |
| | | 14%-KET/KYN-.026 | 0.243 | 0.047 | 2.036 | SAMPLE | FOR | SHOW | |
| 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 |

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|---|---|---|---|---|---|---|---|---|---|
| 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 |
| | | 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 |
| 99A | 8/21/92 | LAMINATES | | | | | | | |
| | | DOPED OXIDE/KY | | | | | | | |
| | | KET/KY | | | | | | | |
| | | 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 |
| 102A | 9/16/92 | 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 |
| | | 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 |
| 103A | 9/23/92 | LAMINATES | | | | | | | |
| | | WASHED DOPED OXIDE | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | | 103A-1 | 0.58 | 0.08 | 2.854 | 1.5 | 0.08 | 7.382 | 158.62069 |
| | | 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 |
| 104A | 9/29/92 | LAMINATES | | | | | | | |
| | | WASHED DOPED OXIDE | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | | 104A-1 | 0.33 | 0.047 | 2.764 | 8.5 | 0.047 | 71.201 | 2475.75758 |
| | | 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 |
| | | 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 |
| 105A | 10/9/92 | KY (7/92) & | | | | | | | |
| | | MICROTHENE (5/92) | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|
| | | 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 |
| | | 40%KY/60%MIC.-105A-4 | 0.165 | 0.05 | 1.299 | 2.8 | 0.05 | 22.047 | 1596.9697 |
| 109A | | KY (7/92) & | | | | | | | |
| | | MICROTHENE (5/92) | | | | | | | |
| | | 80%-LOADING | | | | | | | |
| | | DOPED OXIDE (5/92) | | | | | | | |
| | | 109A-1 | 0.29 | 0.041 | 2.785 | | | | |
| | | 109A-2 | 0.36 | 0.04 | 3.543 | 0.87 | 0.04 | 8.563 | 141.666667 |
| | | 109A-3 | 0.33 | 0.041 | 3.169 | 44 | 0.042 | 412.448 | 12915.873 |
| | | 109A-4 | 0.44 | 0.039 | 4.442 | 0.85 | 0.041 | 8.162 | 83.7583149 |
| 110A | 10-26-92 | LAMINATES | | | | | | | |
| | | 80% DOPED OXIDE(5/92) | | | | | | | |
| | | MICRO.(5/92) & | | | | | | | |
| | | KY(7/92) | | | | | | | |
| | 400F/3 TONS | 110A-1 | 0.225 | 0.038 | 2.331 | 4.9 | 0.038 | 50.767 | 2077.77778 |
| | 400F/3 TONS | 110A-2 | 0.35 | 0.039 | 3.533 | 4.8 | 0.039 | 48.455 | 1271.42857 |
| | 400F/3 TONS | 110A-3 | 0.22 | 0.042 | 2.062 | 1.75 | 0.042 | 16.404 | 695.454545 |
| | 400F/3 TONS | 110A-4 | 0.33 | 0.041 | 3.169 | 0.57 | 0.041 | 5.473 | 72.7272727 |
| 111A | 10/29/92 | LAMINATES | | | | | | | |
| | 5MIN.SOAK/3MIN.CYC. | PRECOMPOUNDED | | | | | | | |
| | | MICRO./DOPED OXIDE | | | | | | | |
| | 350F/3 TONS | 85%-LOADING | | | | | | | |
| | | 111A-1 | 1 | 0.042 | 9.374 | 1.95 | 0.042 | 18.279 | 95 |
| | 350F/3 TONS | 80%-LOADING | | | | | | | |
| | | 111A-2 | 2.1 | 0.043 | 19.227 | 3 | 0.043 | 27.467 | 42.8571429 |
| | | KY/DOPED OXIDE | | | | | | | |
| | 400F/3 TONS | 75%-LOADING | | | | | | | |
| | | 111A-3 | 0.8 | 0.053 | 5.943 | 1.2 | 0.053 | 8.914 | 50 |
| | | MICRO./DOPED OXIDE | | | | | | | |
| | 350F/3 TONS | 80%-LOADING | | | | | | | |
| | | 111A-4 | 1.8 | 0.036 | 19.685 | 2 | 0.036 | 21.872 | 11.1111111 |
| 112A | 11/5/92 | LAMINATES | | | | | | | |
| | | 75% LOADING | | | | | | | |
| | | DOPED OXIDE(7/92) | | | | | | | |
| | | KY(7/92) | | | | | | | |
| | | 14%KET(9/92) | | | | | | | |
| | | KY(7/92) | | | | | | | |
| | 400F/3 TONS | 112A-1 | 0.15 | 0.089 | 0.664 | | 0.089 | 0.000 | -100 |
| | 400F/3 TONS | 112A-2 | 0.165 | 0.088 | 0.738 | | 0.088 | 0.000 | -100 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | LAMINATES | | | | | | | |
| | | 80% LOADING | | | | | | | |
| | | DOPED OXIDE(7/92) | | | | | | | |
| | | MICROTHENE(5/92) | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | 325F/3 TONS | 112A-3 | 0.46 | 0.069 | 2.625 | | 0.069 | 0.000 | -100 |
| | 325F/3 TONS | 112A-4 | 0.58 | 0.075 | 3.045 | | 0.075 | 0.000 | -100 |
| 113A | 11/10/92 | LAMINATES | | | | | | | |
| | | 80% DOPED OXIDE(7/92) | | | | | | | |
| | | MICROTHENE(5/92) | | | | | | | |
| | | CA | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | 325F/3 TONS | 113A-1 | 0.49 | 0.064 | 3.014 | 4.7 | 0.064 | 28.912 | 859.183673 |
| | 325F/3 TONS | 113A-2 | 0.37 | 0.066 | 2.207 | 4.6 | 0.066 | 27.440 | 1143.24324 |
| | 325F/3 TONS | 113A-3 | 0.36 | 0.074 | 1.915 | 0.85 | 0.074 | 4.522 | 136.111111 |
| | 325F/3 TONS | 113A-4 | 0.41 | 0.068 | 2.374 | 0.71 | 0.068 | 4.111 | 73.1707317 |
| 114A | 11/10/92 | LAMINATES | | | | | | | |
| | | 80% DOPED OXIDE(7/92) | | | | | | | |
| | | MICROTHENE(5/92) | | | | | | | |
| | | CA | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | 325F/3 TONS | 114A-1 | 0.43 | 0.062 | 2.731 | 1.75 | 0.062 | 11.113 | 306.976744 |
| | 325F/3 TONS | 114A-2 | 0.42 | 0.069 | 2.396 | 1.36 | 0.069 | 7.760 | 223.809524 |
| | 325F/3 TONS | 114A-3 | 0.46 | 0.068 | 2.663 | 0.97 | 0.068 | 5.616 | 110.869565 |
| | 325F/3 TONS | 114A-4 | 0.64 | 0.076 | 3.315 | 1.05 | 0.076 | 5.439 | 64.0625 |
| 115A | 11/24/92 | LAMINATES | | | | | | | |
| | | 80% LOADING DOPED OXIDE | | | | | | | |
| | | 20% MICROTHENE | | | | | | | |
| | | WASHING TECH. | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | | .2%/.07GMS CA | | | | | | | |
| | | 325F/3 TONS | | | | | | | |
| | 325F/3 TONS | 115A-1 COARSE-X | 0.38 | 0.073 | 2.049 | 0.52 | 0.072 | 2.843 | 38.7426901 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| 116A | 11/25/92 | LAMINATES | | | | | | | |
| | | 80% LOADING DOPED OXIDE | | | | | | | |
| | | 20% MICROTHENE | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | | C-PLASTIC | | | | | | | |
| | | .2%/.07GMS CA | | | | | | | |
| | | 325F/3 TONS | | | | | | | |
| | 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 | | | | | | | |
| | | 325F/3 TONS | | | | | | | |
| | | 117-1A (.15%) | 0.38 | 0.071 | 2.107 | 0.98 | 0.071 | 5.434 | 157.894737 |
| | | 117-2A (.20%) | 0.51 | 0.071 | 2.828 | 1.15 | 0.071 | 6.377 | 125.490196 |
| | | 117-3A (.25%) | 0.42 | 0.068 | 2.432 | 0.7 | 0.066 | 4.176 | 71.7171717 |
| | | 117-4A (.30%) | 0.56 | 0.068 | 3.242 | 0.98 | 0.068 | 5.674 | 75 |
| | | 117-5A (.35%) | 0.42 | 0.071 | 2.329 | | | | |
| | | 117-6A (.40%) | 0.46 | 0.065 | 2.786 | | | | |
| | | 117-7A (.45%) | 0.64 | 0.064 | 3.937 | | | | |
| 118A | 12/07/92 | LAMINATES | | | | | | | |
| | | 80% LOADING DOPED OXIDE | | | | | | | |
| | | 20% MICROTHENE | | | | | | | |
| | | PRECOMPOUNDED | | | | | | | |
| | 118 | C-PLASTIC | | | | | | | |
| | | .15% TO .45% CA | | | | | | | |
| | | 325F/3 TONS | | | | | | | |
| | | 118-1A (.15%) | 0.4 | 0.068 | 2.316 | | | | |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 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 | 35.3233831 |
| | | 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 |
| 119A | 12/04/92 | THIN LAMINATES | | | | | | | |
| | 119A | 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 | | | | |
| 120A | 12/16/92 | 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 |
| | | 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 |
| | 121A | | | | | | | | |
| 121 | 12/17/92 | LAMINATES | | | | | | | |
| | | 80% LOADING DOPED OXIDE | | | | | | | |
| | | 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 | | | | | | | | |
| 122A | 12/17/92 | LAMINATES | | | | | | | |
| | | 2.60G KETBLACK | | | | | | | |
| | | 10.37G MICRO (5/92) | | | | | | | |
| | | 325F/15 TONS | | | | | | | |
| | | 0.060" SHIM | | | | | | | |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 122-1A | 0.46 | 0.051 | 3.551 | 1.4 | 0.051 | 10.807 | 204.347826 |
| | | 122-2A | 0.43 | 0.05 | 3.386 | 5.4 | 0.051 | 41.686 | 1131.19015 |
| | | 122-3A | 0.41 | 0.05 | 3.228 | 1.45 | 0.051 | 11.193 | 246.724055 |
| | | 122-4A | 0.43 | 0.052 | 3.256 | 0.82 | 0.052 | 6.208 | 90.6976744 |
| 123A | 123A 01/04/93 | LAMINATES 80% LOADING DOPED OXIDE | | | | | | | |
| | | 20% MICROTHENE HANDCOMPOUNDED C-PLASTIC .30% TO 1.00% CA | | | | | | | |
| | | 325F/3 TONS | | | | | | | |
| | | 123-1A (.30%) | 0.49 | 0.08 | 2.411 | 0.58 | 0.08 | 2.854 | 18.3673469 |
| | | 123-2A (.35%) | 0.36 | 0.081 | 1.750 | 0.37 | 0.081 | 1.798 | 2.77777778 |
| | | 123-3A (.40%) | 0.58 | 0.08 | 2.854 | 0.74 | 0.081 | 3.597 | 26.0110685 |
| | | 123-4A (.45%) | 0.43 | 0.081 | 2.090 | 0.51 | 0.08 | 2.510 | 20.0872093 |
| | | 123-5A (.50%) | 0.44 | 0.078 | 2.221 | | | | |
| | | 123-6A (.55%) | 0.65 | 0.078 | 3.281 | | | | |
| | | 123-7A (.60%) | 0.62 | 0.076 | 3.212 | | | | |
| | | 123-8A (.65%) | 0.6 | 0.076 | 3.108 | | | | |
| | | 123-9A (.70%) | 0.66 | 0.078 | 3.331 | | | | |
| | | 123-10A (.75%) | 0.6 | 0.076 | 3.108 | | | | |
| | | 123-11A (.80%) | 0.9 | 0.08 | 4.429 | | | | |
| | | 123-12A (.85%) | 0.68 | 0.08 | 3.346 | | | | |
| | | 123-13A (.90%) | 0.6 | 0.072 | 3.281 | | | | |
| | | 123-14A (.95%) | 0.52 | 0.075 | 2.730 | | | | |
| | | 123-15A (1.00%) | 0.54 | 0.075 | 2.835 | | | | |
| 124 | 124A 07-JAN-93 | LAMINATES 80% LOADING DOPED OXIDE | | | | | | | |
| | | 20% MICROTHENE HANDCOMPOUNDED C-PLASTIC 1.5% TO 3.0% CA | | | | | | | |
| | | 325F/3 TONS | | | | | | | |
| | | 124-1A (1.5%) | 0.62 | 0.075 | 3.255 | | | | |
| | | 124-2A (2.0%) | 0.98 | 0.077 | 5.011 | | | | |
| | | 124-3A (2.5%) | 0.83 | 0.076 | 4.300 | | | | |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 124-4A (3.0%) | 0.66 | 0.077 | 3.375 | | | | |
| 125A | 125A | LAMINATES | | | | | | | |
| | 01/12/93 | 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 | | | | |
| | | 125-11A (275F) | 0.58 | 0.057 | 4.006 | | | | |
| | | 125-12A (275F) | 0.38 | 0.057 | 2.625 | | | | |
| 126 | 126A | LAMINATES | | | | | | | |
| | 01/14/93 | 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 | | | | |
| | | 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 |
| 129A | 01/15/93 | 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 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 | | | | |
| 130A | 130A | LAMINATE 325F/3 TONS | | | | | | | |
| | 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 | LAMINATE 325F/3 TONS | | | | | | | |
| | 01/27/93 | 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 | LAMINATE 325F/3 TONS | | | | | | | |
| | 01/28/93 | 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 | LAMINATE 325F/3 TONS | | | | | | | |
| | 01/28/93 | 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 | LAMINATE 325F/3 TONS | | | | | | | |
| | 01/28/93 | 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 136-2A(22%) | 0.57 | 0.033 | 6.800 | | | | |
| | | 136-3A(24%) | 0.34 | 0.035 | 3.825 | | | | |
| | | 136-4A(24%) | 0.39 | 0.034 | 4.516 | | | | |
| 137A | 02/03/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 137-1A | 0.24 | 0.041 | 2.305 | | | | |
| | | 137-2A | 0.235 | 0.043 | 2.152 | | | | |
| | | 137-3A | 0.305 | 0.042 | 2.859 | | | | |
| | | 137-4A | 0.215 | 0.043 | 1.969 | | | | |
| MRP | 02/03/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | MRP-1 | 0.48 | 0.056 | 3.375 | 0.59 | 0.056 | 4.148 | 22.9166667 |
| | | MRP-2 | 0.41 | 0.061 | 2.646 | 0.48 | 0.06 | 3.150 | 19.0243902 |
| | | MRP-3 | 0.49 | 0.054 | 3.572 | 0.89 | 0.054 | 6.489 | 81.6326531 |
| | | MRP-4 | 0.43 | 0.058 | 2.919 | 0.47 | 0.058 | 3.190 | 9.30232558 |
| 138A | 02/04/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 138-1A | 0.34 | 0.03 | 4.462 | | | | |
| | | 138-2A | 0.6 | 0.032 | 7.382 | | | | |
| | | 138-3A | 0.43 | 0.036 | 4.703 | | | | |
| | | 138-4A | 0.35 | 0.035 | 3.937 | | | | |
| 139A | 02/05/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 139-1A(18%) | 0.39 | 0.022 | 6.979 | | | | |
| | | 139-2A(18%) | 0.36 | 0.025 | 5.669 | | | | |
| | | 139-3A(22%) | 0.33 | 0.026 | 4.997 | | | | |
| | | 139-4A(22%) | 0.4 | 0.027 | 4.997 | | | | |
| BR AND R3 | 02/05/93 | LAMINATE 325/3 TONS | | | | | | | |
| | | BR-1 | 0.76 | 0.039 | 7.672 | | | | |
| | | BR-2 | 0.85 | 0.039 | 8.581 | | | | |
| | | R3-1 | 0.47 | 0.042 | 4.406 | | | | |
| | | R3-2 | 0.51 | 0.049 | 4.098 | | | | |
| EXTRUDED 3/24/93 | | 168-1A 100/115/120/125 | 1.2 | | | | | | |
| | | 168-2A 100/110/120/125 168-3A | IR TOO HIGH. LAMINATION STOPPED. | | | | | | |
| 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | *176-3A | 0.38 | 0.039 | 4.134 | 0.9 | 0.04 | 8.858267717 | 114.278368 |
| | | *SAMPLE TESTED FOR 30 DAYS | | | | | | | |
| | | 176-3A | 0.38 | 0.039 | 4.134 | 0.64 | 0.039 | 6.46073087 | 56.282798 |
| | | READING TAKEN AFTER 1 DAY | | | | | | | |
| | | 176-3A | 0.38 | 0.039 | 4.134 | 0.833 | 0.04 | 8.198818898 | 98.3265336 |
| | | READING TAKEN AFTER 2 DAYS | | | | | | | |
| 177A | 04/12/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 177-1A(160) | 0.61 | 0.041 | 5.8574995 | 0.53 | 0.041 | 5.089302862 | -13.1147541 |
| | | 177-2A(160) | 0.81 | 0.044 | 7.2476736 | 0.74 | 0.042 | 6.936632921 | -4.29159318 |
| | | 177-3A(180) | 1.05 | 0.043 | 9.6136239 | 0.77 | 0.042 | 7.217847769 | -24.9206349 |
| | | 177-4A(180) | 0.84 | 0.044 | 7.5161059 | 0.65 | 0.043 | 5.951290972 | -20.8194906 |
| 178A | 04/14/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 178-1A(160) | 0.54 | 0.046 | 4.6217049 | 0.58 | 0.046 | 4.964053406 | 7.40740741 |
| | | 178-2A(160) | 0.64 | 0.047 | 5.361032 | 0.68 | 0.045 | 5.949256343 | 10.9722222 |
| | | 178-3A(180) | 0.53 | 0.045 | 4.6369204 | 0.48 | 0.045 | 4.199475066 | -9.43396226 |
| | | 178-4A(180) | 0.45 | 0.041 | 4.3211062 | 0.48 | 0.041 | 4.60917995 | 6.66666667 |
| 179A | 04/15/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 179-1A(160) | 0.39 | 0.045 | 3.4120735 | 0.46 | 0.045 | 4.024496938 | 17.9487179 |
| | | 179-2A(160) | 0.31 | 0.043 | 2.838308 | 0.39 | 0.043 | 3.570774583 | 25.8064516 |
| | | 179-3A(180) | 0.28 | 0.043 | 2.563633 | 0.34 | 0.043 | 3.11298297 | 21.4285714 |
| | | 179-4A(180) | 0.31 | 0.043 | 2.838308 | 0.38 | 0.043 | 3.479216261 | 22.5806452 |
| 181A | 04/28/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 181-1A(200) | 0.47 | 0.063 | 2.9371329 | 0.58 | 0.062 | 3.683007366 | 25.3946465 |
| | | 181-2A(200) | 0.4 | 0.059 | 2.6691579 | 0.56 | 0.057 | 3.86793756 | 44.9122807 |
| | | 181-3A(180) | 0.54 | 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 181-4A(180) | 0.55 | 0.064 | 3.3833661 | 0.58 | 0.064 | 3.567913386 | 5.45454545 |
| 182A | 04/28/93 | LAMINATE 325F/3 TONS | | | | | | | |
| 4V BATTERIES | | | | | | | | | |
| FOR PASTE | | 182-1A(200) | 0.68 | 0.073 | 3.6673498 | | | | |
| ADHESION | | SANDED | | | | | | | |
| | | 182-2A(200) | 0.7 | 0.06 | 4.5931759 | | | | |
| | | Pb THEN SANDED | | | | | | | |
| | | 182-3A(180) | 0.68 | 0.071 | 3.7706554 | | | | |
| | | SANDED | | | | | | | |
| | | 182-4A(180) | 0.6 | 0.058 | 4.0727668 | | | | |
| | | Pb THEN SANDED | | | | | | | |
| | | | IR at corner. | | | | | | |
| 183A | 04/29/93 | LAMINATE 325F/3 TONS | | | | | | | |
| | | 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 187-2A | 0.135 | 0.029 | 1.832745 | 20 | 0.029 | 271.5177844 | 14714.8148 |
| | | 187-3A | 0.135 | 0.029 | 1.832745 | 6.2 | 0.029 | 84.17051317 | 4492.59259 |
| | | 187-4A | 0.155 | 0.03 | 2.0341207 | 8.1 | 0.03 | 106.2992126 | 5125.80645 |
| 188A | | LAMINATE 330F/2 TONS | | | | | | | |
| | | 188-1A | 0.14 | 0.028 | 1.9685039 | 6 | 0.03 | 78.74015748 | 3900 |
| | | 188-2A | 0.14 | 0.031 | 1.7780036 | 9 | 0.03 | 118.1102362 | 6542.85714 |
| | | 188-3A | 0.135 | 0.031 | 1.7145034 | 8.1 | 0.031 | 102.8702057 | 5900 |
| | | 188-4A | 0.155 | 0.031 | 1.9685039 | 9.6 | 0.031 | 121.9202438 | 6093.54839 |
| 189A | 06/14/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 189-1A | 0.97 | 0.045 | 8.486 | | | | |
| 06/14/93 | IR OF SAMPLE WAS TOO HIGH. NEW SAMPLES WILL BE MADE AND TESTED | | | | | | | | |
| | | 189-3A(SANDED) | 0.47 | 0.051 | 3.6282229 | 0.7 | 0.051 | 5.403736298 | 48.9361702 |
| | | 189-4A(SANDED) | 0.54 | 0.045 | 4.7244094 | 0.83 | 0.045 | 7.261592301 | 53.7037037 |
| 190A | 06/16/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 190-1A | 0.74 | 0.086 | 3.3876579 | | | | |
| | | 190-2A | 0.78 | 0.092 | 3.337898 | | | | |
| | | 190-3A | 0.73 | 0.086 | 3.3418788 | | | | |
| | | 190-4A | 0.66 | 0.086 | 3.0214246 | | | | |
| 191A | 06/18/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 191-1A(006)SANDED | 0.25 | 0.044 | 2.2369363 | 1.6 | 0.044 | 14.31639227 | 540 |
| | | 191-2A(006) | 0.255 | 0.045 | 2.2309711 | 0.97 | 0.044 | 8.679312813 | 289.037433 |
| | | 191-2A | 0.255 | 0.045 | 2.2309711 | 0.38 | 0.044 | 3.400143164 | 52.4064171 |
| | READING TAKEN AFTER BEING STORED FOR 2.5 MONTHS | | | | | | | | |
| | | 191-3A(007)SANDED | 0.23 | 0.043 | 2.1058414 | 0.48 | 0.044 | 4.294917681 | 103.952569 |
| | | 191-4A(007) | 0.29 | 0.044 | 2.5948461 | 0.58 | 0.044 | 5.189692198 | 100 |
| 192A | 06/18/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 192-1A | 1.3 | 0.051 | 10.03551 | 3.5 | 0.049 | 28.12148481 | 180.21978 |
| | | 192-2A | 1.9 | 0.049 | 15.265949 | 4.4 | 0.05 | 34.64566929 | 126.947368 |
| 193A | 06/18/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 193-1A(SANDED) | 0.19 | 0.062 | 1.2065024 | 0.82 | 0.062 | 5.207010414 | 331.578947 |
| | | 193-2A | 0.26 | 0.058 | 1.7648656 | 2.2 | 0.059 | 14.68036834 | 731.812256 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| 194A | 06/24/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 194-1A(.008") | 0.265 | 0.031 | 3.3655067 | 8.5 | 0.032 | 104.5767717 | 3007.31132 |
| | | 194-2A(.008") | 0.32 | 0.042 | 2.999625 | >100 | 0.043 | | |
| | | 194-3A(.010") | 0.29 | 0.04 | 2.8543307 | >100 | 0.04 | | |
| | | 194-4A(.010") | 0.31 | 0.034 | 3.5896248 | 44 | 0.034 | 509.4951366 | 14093.5484 |
| 195A | 06/28/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 195-1A | 0.46 | 0.046 | 3.9370079 | 0.65 | 0.046 | 5.5631633 | 41.3043478 |
| | | 195-2A | 0.58 | 0.046 | 4.9640534 | 0.72 | 0.046 | 6.162273194 | 24.137931 |
| 196A | 06/28/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 196-1A | 1.15 | 0.044 | 10.289907 | 1.15 | 0.045 | 10.06124234 | -2.22222222 |
| | | 196-2A | 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) | 0.24 | 0.044 | 2.1474588 | 0.7 | 0.045 | 6.124234471 | 185.185185 |
| | | 197-2A(315F) | 0.275 | 0.045 | 2.4059493 | 0.65 | 0.045 | 5.686789151 | 136.363636 |
| | | 197-3A(335F) | 0.225 | 0.045 | 1.9685039 | 0.73 | 0.045 | 6.386701662 | 224.444444 |
| | | 197-4A(335F) | 0.36 | 0.051 | 2.7790644 | 0.81 | 0.051 | 6.252894859 | 125 |
| | | 197-5A(355F) | 0.24 | 0.044 | 2.1474588 | 0.37 | 0.045 | 3.237095363 | 50.7407407 |
| | | 197-6A(355F) | 0.22 | 0.045 | 1.9247594 | 0.275 | 0.045 | 2.405949256 | 25 |
| | | 197-7A(375F) | 0.235 | 0.045 | 2.055993 | 0.29 | 0.045 | 2.537182852 | 23.4042553 |
| | | 197-8A(375F) | 0.215 | 0.045 | 1.8810149 | 0.3 | 0.045 | 2.624671916 | 39.5348837 |
| | | 197-9A(400F) | 0.205 | 0.045 | 1.7935258 | 0.275 | 0.045 | 2.405949256 | 34.1463415 |
| | | 197-10A(400F) | 0.2 | 0.046 | 1.7117426 | 0.275 | 0.045 | 2.405949256 | 40.5555556 |
| 198A | 06/29/93 | LAMINATE 295F/3TONS | | | | | | | |
| | | 198-1A(315F) | 0.43 | 0.049 | 3.4549253 | 0.86 | 0.049 | 6.909850554 | 100 |
| | | 198-2A(315F) | 0.41 | 0.05 | 3.2283465 | 1.25 | 0.05 | 9.842519685 | 204.878049 |
| | | 198-3A(335F) | 0.295 | 0.047 | 2.4711007 | 0.82 | 0.047 | 6.868822248 | 177.966102 |
| | | 198-4A(335F) | 0.32 | 0.052 | 2.4227741 | 0.54 | 0.052 | 4.088431254 | 68.75 |
| | | 198-5A(355F) | 0.28 | 0.046 | 2.3964396 | 1.75 | 0.044 | 15.65855404 | 553.409091 |
| | | 198-6A(355F) | 0.23 | 0.046 | 1.9685039 | 4 | 0.044 | 35.79098067 | 1718.18182 |
| | | 198-7A(375F) | 0.21 | 0.047 | 1.7590886 | 1.95 | 0.046 | 16.6894899 | 848.757764 |
| | | 198-8A(375F) | 0.36 | 0.049 | 2.8924956 | 0.65 | 0.048 | 5.331364829 | 84.3171296 |
| | | 198-9A(400F) | 0.245 | 0.048 | 2.0095144 | 1.2 | 0.046 | 10.27045532 | 411.091393 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 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 | | | | | | | |
| 199A | 07/21/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 199-1A(NOT SANDED) | 0.66 | 0.044 | 5.9055118 | | | | |
| | | 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 |
| 200A | 07/23/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 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 |
| 201A | 07/23/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 201-1(325) | 0.32 | 0.046 | 2.7387881 | 0.4 | 0.043 | 3.662332906 | 33.7209302 |
| | | 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 |
| 202A | 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 |
| | | 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 |
| 203A | 07/23/93 | LAMINATE 295F/3 TONS | | | | | | | |
| | | 203-1(325) | 0.34 | 0.044 | 3.0422334 | 3.1 | 0.042 | 29.05886764 | 855.182073 |
| | | 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 |
| 204A | 07/27/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 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 | 84.4444444 |
| | | 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 | 92.1568627 |
| | | 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| 205A SEE BATTERY BUIL D | | | | | | | | | |
| 206A | 8/10/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 206-1A(SP006) | 0.275 | 0.053 | 2.0427871 | 0.34 | 0.053 | 2.525627693 | 23.6363636 |
| | | 206-2A(SP006) | 0.25 | 0 052 | 1.8927922 | 0.31 | 0.053 | 2.30277819 | 21.6603774 |
| | | 206-3A(SP007) | 0.36 | 0.052 | 2.7256208 | 0.48 | 0 052 | 3.634161114 | 33 3333333 |
| | | 206-4A(SP007) | 0.23 | 0.053 | 1.7085129 | 0.34 | 0.052 | 2.574197456 | 50.6688963 |
| 207A | 8/10/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 207-1A(SP006) | 0.83 | 0.043 | 7.5993408 | 1.65 | 0.042 | 15.46681665 | 103.528399 |
| | | 207-2A(SP006) | 0.48 | 0.041 | 4.60918 | 0.64 | 0.042 | 5.999250094 | 30.1587302 |
| | | 207-3A(SP007) | 0.96 | 0.043 | 8.789599 | 1 | 0.044 | 8.947745168 | 1.79924242 |
| | | 207-4A(SP007) | 0.89 | 0.042 | 8.3427072 | 0.86 | 0.041 | 8.258114077 | -1.01397643 |
| 208A | 8/11/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 208-1A | 0.4 | 0.037 | 4.2562247 | 0.6 | 0.039 | 6.056935191 | 42.3076923 |
| | | 208-2A | 0.5 | 0.038 | 5.1802735 | 0.7 | 0.038 | 7.252382926 | 40 |
| | | 208-3A | 0.3 | 0.036 | 3.2808399 | 0.54 | 0.037 | 5.745903384 | 75.1351351 |
| | | 208-4A | 0.32 | 0.038 | 3.3153751 | 0.73 | 0.039 | 7.369271149 | 122.275641 |
| 209A | 8/16/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 209-1A(SANDED) | 0.96 | 0.051 | 7.4108384 | 3.4 | 0.051 | 26.24671916 | 254.166667 |
| | | 209-2A | 1.35 | 0.053 | 10.028228 | 4.3 | 0.053 | 31.941762 | 218.518519 |
| 210A | 8/24/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 210-1A | 0.28 | 0.033 | 3.3404915 | 13.75 | 0.033 | 164.0419948 | 4810.71429 |
| RIBBON | | 210-2A | 0.23 | 0.033 | 2.7439752 | 11 | 0.034 | 127.3737842 | 4541.94373 |
| FROM | | 210-3A | 0.41 | 0.041 | 3.9370079 | 2.4 | 0.043 | 21.97399744 | 458.139535 |
| DE WAL | | 210-4A | 0.56 | 0.042 | 5.2493438 | 24 | 0.043 | 219.7399744 | 4086.04651 |
| 211A | 9/2/93 | LAMINATE 300F/3 TONS | | | | | | | |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 211-1A | 0.56 | 0.032 | 6.8897638 | 0.69 | 0.03 | 9.05511811 | 31.4285714 |
| | | 211-2A | 0.41 | 0.031 | 5.2070104 | 0.62 | 0.031 | 7.874015748 | 51.2195122 |
| | | 211-3A | 0.32 | 0.024 | 5.2493438 | 0.56 | 0.024 | 9.186351706 | 75 |
| | | 211-4A | 0.33 | 0.023 | 5.6487504 | 0.8 | 0.024 | 13.12335958 | 132.323232 |
| 212A | 9/8/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 212-1A | 0.86 | 0.044 | 7.6950608 | 1.25 | 0.044 | 11.18468146 | 45.3488372 |
| | | 212-2A | 0.99 | 0.044 | 8.8582677 | 4.4 | 0.044 | 39.37007874 | 344.444444 |
| | | 212-3A | 0.64 | 0.043 | 5.8597326 | 2.3 | 0.043 | 21.05841421 | 259.375 |
| | | 212-4A | 0.72 | 0.043 | 6.5921992 | 1.9 | 0.043 | 17.3960813 | 163.888889 |
| 213A | 9/16/93 | LAMINATE 350F/3 TONS | | | | | | | |
| | | 213-1A | 2.6 | 0.035 | 29.246344 | | | | |
| | | 213-2A | 3.4 | 0.036 | 37.182852 | | | | |
| | | 213-3A | 3.8 | 0.035 | 42.744657 | | | | |
| | | 213-4A | 2.8 | 0.036 | 30.621172 | | | | |
| | | 213-5A | 2.5 | 0.04 | 24.606299 | | | | |
| | | 213-6A | 3 | 0.036 | 32.808399 | | | | |
| 214A | 9/20/93 | LAMINATE 350F/3 TONS | | | | | | | |
| | | 214-1A | 0.5 | 0.067 | 2.9380656 | | | | |
| | | 214-2A | 0.6 | 0.082 | 2.8807375 | | | | |
| | | 214-3A | 0.84 | 0.081 | 4.082823 | | | | |
| | | *214-4A | 0.82 | 0.081 | 3.9856129 | | | | |
| | | *214-5A | 0.86 | 0.081 | 4.1800331 | | | | |
| | | *SAMPLES NOT SURFACE TREATED | | | | | | | |
| 215A | 9/22/93 | LAMINATE 350F/3 TONS | | | | | | | |
| | | 215-1A | 0.45 | 0.022 | 8.0529707 | 8.3 | 0.022 | 148.5325698 | 1744.44444 |
| | | 215-2A | 0.3 | 0.021 | 5.624297 | 6.9 | 0.022 | 123.4788833 | 2095.45455 |
| | | 215-3A | 0.34 | 0.022 | 6.0844667 | 9.5 | 0.022 | 170.0071582 | 2694.11765 |
| | | 215-4A | 0.36 | 0.022 | 6.4423765 | 16 | 0.022 | 286.3278454 | 4344.44444 |
| 216A | 9/27/93 | LAMINATE 350F/3 TONS | | | | | | | |
| | | LAMINATE 350F/30 TONS | | | | | | | |
| | | 216-1A | 0.37 | 0.024 | 6.0695538 | 3.7 | 0.024 | 60.69553806 | 900 |
| | | 216-2A | 0.285 | 0.022 | 5.1002147 | 1.7 | 0.021 | 31.87101612 | 524.895572 |
| | | 216-3A | 0.34 | 0.021 | 6.3742032 | 0.92 | 0.021 | 17.24784402 | 170.588235 |
| | | 216-4A | 0.37 | 0.02 | 7.2834646 | 1.9 | 0.02 | 37.4015748 | 413.513514 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| 217A | 9/29/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 217-1A | 0.48 | 0.052 | 3.6341611 | 0.66 | 0.052 | 4.996971532 | 37.5 |
| | | 217-2A | 0.43 | 0.05 | 3.3858268 | 0.5 | 0.05 | 3.937007874 | 16.2790698 |
| | | 217-3A | 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 | | | | | | | |
| | | 218-1A | 0.9 | 0.051 | 6.947661 | | | | |
| | | 218-2A | 1 | 0.051 | 7.7196233 | | | | |
| | | 218-3A | 0.7 | 0.051 | 5.4037363 | | | | |
| | | 218-4A | 0.73 | 0.051 | 5.635325 | | | | |
| 219A | 10/4/93 | LAMINATE 350F/3 TONS | | | | | | | |
| | | LAMINATE 350F/30 TONS | | | | | | | |
| | | 219-1A(30 TONS) | 0.46 | 0.038 | 4.7658516 | 0.73 | 0.038 | 7.563199337 | 58.6956522 |
| | | 219-2A(30 TONS) | 0.4 | 0.038 | 4.1442188 | 0.74 | 0.038 | 7.666804807 | 85 |
| | | 219-3A(3 TONS) | 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 | | | | | | | |
| | | 220-1A | 0.34 | 0.021 | 6.3742032 | 0.88 | 0.022 | 15.7480315 | 147.058824 |
| | | 220-2A | 0.3 | 0.019 | 6.2163282 | 0.69 | 0.019 | 14.29755491 | 130 |
| | | 220-3A | 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 | | | | | | | |
| | | 221-1A | 0.83 | 0.045 | 7.2615923 | 1.15 | 0.045 | 10.06124234 | 38.5542169 |
| | | 221-2A | 0.81 | 0.044 | 7.2476736 | 1.1 | 0.044 | 9.842519685 | 35.8024691 |
| | | 221-3A | 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 | | | | | | | |
| | | 222-1A | 0.8 | 0.026 | 12.11387 | 1.15 | 0.026 | 17.41368867 | 43.75 |
| | | 222-2A | 1.2 | 0.025 | 18.897638 | 1.1 | 0.025 | 17.32283465 | -8.33333333 |
| | | 222-3A | 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 30OF/3 TONS | | | | | | | |
| | | 223-1A | 0.54 | 0.044 | 4.8317824 | 0.55 | 0.045 | 4.811898513 | -0.41152263 |
| | | 223-2A | 0.49 | 0.044 | 4.3843951 | 0.7 | 0.044 | 6.263421618 | 42.8571429 |
| | | 223-3A(WI) | .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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 224-2A | 1.65 | 0.08 | 8.1200787 | | | | |
| | | 224-3A | 1.7 | 0.08 | 8.3661417 | | | | |
| | | *224-4A | 1.65 | 0.08 | 8.1200787 | | | | |
| | | *224-5A | 1.6 | 0.081 | 7.7768057 | | | | |
| | | 224-6A | 1.75 | 0.08 | 8.6122047 | | | | |
| | | 224-7A | 1.85 | 0.08 | 9.1043307 | | | | |
| | | 224-8A | 1.8 | 0.08 | 8.8582677 | | | | |
| | | 224-9A | 2 | 0.081 | 9.7210071 | | | | |
| | | 224-10A | 1 8 | 0 081 | 8.7489064 | | | | |
| | | *SAMPLES SURFACE TREATED | | | | | | | |
| 225A | 10/20/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | (TTS)225-1A | 0.175 | 0.046 | 1.4977747 | 0.36 | 0.045 | 3.149606299 | 110.285714 |
| | | (TTS)225-2A | 0.195 | 0.045 | 1.7060367 | 0.46 | 0.044 | 4.115962777 | 141.258741 |
| | | (138S)225-3A | 0.235 | 0.046 | 2.0112975 | 0.285 | 0.045 | 2.49343832 | 23.9716312 |
| | | (138S)225-4A | 0.21 | 0.045 | 1.8372703 | 0.245 | 0.046 | 2.096884629 | 14.1304348 |
| 226A | 10/21/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | (TTS)226-1A | 0.14 | 0.028 | 1.9685039 | 100 | 0.028 | 1406.074241 | 71328.5714 |
| | | (TTS)226-2A | 0.16 | 0.028 | 2.2497188 | 100 | 0.028 | 1406.074241 | 62400 |
| | | (138S)226-3A | 0.23 | 0.028 | 3.2339708 | 0.23 | 0.028 | 3.233970754 | 0 |
| | | (138S)226-4A | 0.28 | 0.027 | 4.082823 | 0.34 | 0.029 | 4.615802335 | 13.0541872 |
| | | (30 DAYS)226-3A | 0.23 | 0.028 | 3.2339708 | 0.28 | 0.028 | 3.937007874 | 21.7391304 |
| 227A | 10/22/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 227-1A | 0.84 | 0.044 | 7.5161059 | 0.9 | 0.044 | 8.052970651 | 7.14285714 |
| | | 227-2A | 0.96 | 0.043 | 8.789599 | 1.15 | 0.043 | 10.5292071 | 19.7916667 |
| | | 227-3A | 0.94 | 0.044 | 8.4108805 | 1.1 | 0.044 | 9.842519685 | 17.0212766 |
| | | 227-4A | 0.94 | 0.043 | 8.6064823 | 1 | 0.045 | 8.748906387 | 1.65484634 |
| 228A | 10/25/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 228-1A(TTS) | 0.35 | 0.046 | 2.9955495 | 0.73 | 0.046 | 6.247860322 | 108.571429 |
| | | 228-1A(TTS) | 0.3 | 0.045 | 2.6246719 | 0.67 | 0.045 | 5.861767279 | 123.333333 |
| | | 228-3A(138S) | 0.47 | 0.045 | 4.111986 | 0.62 | 0.045 | 5.42432196 | 31.9148936 |
| | | 228-4A(138S) | 0.44 | 0.045 | 3.8495188 | 0.54 | 0.045 | 4.724409449 | 22.7272727 |
| 229A | 10/26/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 229-1A(TTS) | 0.47 | 0.045 | 4.111986 | 0.68 | 0.044 | 6.084466714 | 47.9690522 |
| | | 229-1A(TTS) | 0.57 | 0.045 | 4.9868766 | 0.74 | 0.045 | 6.474190726 | 29.8245614 |
| | | 229-3A(138S) | 0.74 | 0.044 | 6.6213314 | 0.92 | 0.044 | 8.231925555 | 24.3243243 |
| | | 229-4A(138S) | 0.6 | 0.044 | 5.3686471 | 0.75 | 0.044 | 6.710808876 | 25 |

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

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 236-1A(TTS) | 0.8 | 0.031 | 10.16002 | | | | |
| | | 236-3A(138S) | 1.05 | 0.043 | 9.6136239 | 1.3 | 0.043 | 11.90258194 | 23.8095238 |
| | | 236-4A(138S) | 0.95 | 0.042 | 8.9051369 | 1.2 | 0.044 | 10.7372942 | 20.5741627 |
| 237A | 11/7/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 237-1A(TTS) | 0.67 | 0.043 | 6.1344076 | | | | |
| | | 237-1A(TTS) | 0.8 | 0.044 | 7.1581961 | | | | |
| | | 237-3A(138S) | 0.67 | 0.043 | 6.1344076 | 0.96 | 0.044 | 8.589835361 | 40.027137 |
| | | 237-4A(138S) | 0.49 | 0.044 | 4.3843951 | 1.2 | 0.044 | 10.7372942 | 144.897959 |
| 238A | 11/7/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 238-1A | 0.42 | 0.044 | 3.758053 | 0.55 | 0.044 | 4.921259843 | 30.952381 |
| | | 238-2A | 0.38 | 0.045 | 3.3245844 | 0.4 | 0.045 | 3.499562555 | 5.26315789 |
| | | 238-3A | 0.36 | 0.044 | 3.2211883 | 0.48 | 0.044 | 4.294917681 | 33.3333333 |
| | | 238-4A | 0.34 | 0.045 | 2.9746282 | 0.5 | 0.045 | 4.374453193 | 47.0588235 |
| 239A | 11/10/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 239-1A | 0.459 | 0.045 | 4.015748 | 0.64 | 0.045 | 5.599300087 | 39.4335512 |
| | | 239-2A | 0.39 | 0.045 | 3.4120735 | 0.45 | 0.045 | 3.937007874 | 15.3846154 |
| | | 239-3A | 0.45 | 0.045 | 3.9370079 | 0.79 | 0.045 | 6.911636045 | 75.5555556 |
| | | 239-4A | 0.44 | 0.044 | 3.9370079 | 0.58 | 0.044 | 5.189692198 | 31.8181818 |
| 240A | 11/16/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 240-1A | 0.54 | 0.045 | 4.7244094 | 0.64 | 0.045 | 5.599300087 | 18.5185185 |
| | | 240-2A | 0.66 | 0.044 | 5.9055118 | | | | |
| | | 240-3A | 0.6 | 0.045 | 5.2493438 | 0.84 | 0.044 | 7.516105941 | 43.1818182 |
| | | 240-4A | 0.77 | 0.044 | 6.8897638 | | | | |
| 241A | 11/15/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 241-1A | 0.72 | 0.077 | 3.681358 | | | | |
| | | 241-2A | 0.78 | 0.077 | 3.9881378 | FOR BATTERY BUILD | | | |
| | | 241-3A | 0.79 | 0.076 | 4.0924161 | | | | |
| 242A | 11/18/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 242-1A | 0.59 | 0.066 | 3.5194464 | | | | |
| | | 242-2A | 0.64 | 0.066 | 3.8177046 | FOR BATTERY BUILD | | | |
| | | 242-3A | 0.67 | 0.067 | 3.9370079 | | | | |
| | | 242-4A(NO PB) | 0.72 | 0.066 | 4.2949177 | | | | |
| 243A | 11/18/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 243-1A | 0.38 | 0.066 | 2.2667621 | | | | |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 243-2A | 0.42 | 0.067 | 2.4679751 | ı FOR BATTERY BUILD | | | |
| | | 243-3A | 0.41 | 0.066 | 2.445717 | | | | |
| | | 242-4A(NO PB) | 0.41 | 0.067 | 2.4092138 | | | | |
| 244A | 11/18/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 244-1A | 0.56 | 0.066 | 3.3404915 | ı FOR BATTERY BUILD | | | |
| | | 244-2A | 0.49 | 0.066 | 2.9229301 | ;ITIVE SIDE WITH NEG PASTE | | | |
| | | 244-3A | 0.5 | 0.066 | 2.9825817 | | | | |
| | | 244-4A(NO PB) | 0.49 | 0.066 | 2.9229301 | | | | |
| 245A | 12/1/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 245-1A | 0.59 | 0.041 | 5.6654504 | 0.62 | 0.041 | 5.953524102 | 5.08474576 |
| | | 245-2A | 0.55 | 0.042 | 5.1556055 | 0.71 | 0.041 | 6.817745343 | 32.2394678 |
| | | 245-3A | 0.66 | 0.041 | 6.3376224 | 0.77 | 0.041 | 7.393892837 | 16.6666667 |
| | | 245-4A | 0.7 | 0.041 | 6.7217208 | 1 | 0.04 | 9.842519685 | 46.4285714 |
| 246A | 12/13/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 246-1A | 0.6 | 0.019 | 12.432656 | SAMPLE BROKE | | | |
| | | 246-2A | 0.42 | 0.018 | 9.1863517 | 0.5 | 0.018 | 10.93613298 | 19.047619 |
| | | 246-3A | 0.54 | 0.019 | 11.189391 | 0.52 | 0.019 | 10.77496892 | -3.7037037 |
| | | 246-4A | 0.42 | 0.019 | 8.7028595 | 0.52 | 0.019 | 10.77496892 | 23.8095238 |
| 247A | 12/13/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 247-1A | 0.285 | 0.02 | 5.6102362 | 0.39 | 0.02 | 7.677165354 | 36.8421053 |
| | | 247-2A | 0.34 | 0.02 | 6.6929134 | 0.38 | 0.021 | 7.124109486 | 6.44257703 |
| | | 247-3A | 0.36 | 0.02 | 7.0866142 | 0.52 | 0.02 | 10.23622047 | 44.4444444 |
| | | 247-4A | 0.31 | 0.02 | 6.1023622 | 0.45 | 0.02 | 8.858267717 | 45.1612903 |
| 248A | 12/27/93 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 248-1A | 0.52 | 0.019 | 10.774969 | 1 | 0.019 | 20.72109407 | 92.3076923 |
| | | 248-2A | 0.4 | 0.018 | 8.7489064 | 0.66 | 0.018 | 14.43569554 | 65 |
| | | 248-3A | 0.48 | 0.02 | 9.4488189 | 1 | 0.02 | 19.68503937 | 108.333333 |
| | | 248-4A | 0.46 | 0.018 | 10.061242 | 0.66 | 0.019 | 13.67592209 | 35.9267735 |
| 249A | 1/5/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | *249-1A | 0.88 | 0.02 | 17.322835 | 0.8 | 0.02 | 15.7480315 | -9.09090909 |
| | | 249-2A | 0.38 | 0.019 | 7.8740157 | 0.34 | 0.019 | 7.045171985 | -10.5263158 |
| | | 249-3A | 0.38 | 0.019 | 7.8740157 | 0.42 | 0.019 | 8.702859511 | 10.5263158 |
| | | 249-4A | 0.4 | 0.02 | 7.8740157 | 0.44 | 0.02 | 8.661417323 | 10 |
| | | *SAMPLE NOT SANDED PRIOR TO LAMINATION | | | | | | | |
| 250A | 1/5/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 250-1A | 0.88 | 0.041 | 8.4501632 | 0.84 | 0.041 | 8.066064913 | -4.54545455 |
| | | 250-2A | 0.5 | 0.041 | 4.8012291 | 0.46 | 0.041 | 4.417130785 | -8 |

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

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 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 |
| 258A | 1/25/94 | 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 | :RACKED DURI) 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 |
| | | 258-5A | 0.33 | 0.029 | 4.4800434 | 0.4 | 0.029 | 5.430355688 | 21.2121212 |
| 259A | 1/26/94 | 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 | | | | | | | |
| | | 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 |
| 260A | 2/4/94 | 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 | | -FULL PB SHEET | |
| | | 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 |
| 262A | 2/4/94 | LAMINATE 375F/3 TONS | | | | | | | |
| | | NO SHIM | | | | | | | |
| | | 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| 263A | 2/1/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 0.045" SHIM | | | | | | | |
| | | 263-1A | 0.5 | 0.043 | 4.5779161 | ATTERY #263 6V-FULL PB SHEET | | | |
| | | 263-2A | 0.49 | 0.043 | 4.4863578 | " " " | | | |
| 264A | 2/4/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 0.031" SHIM | | | | | | | |
| | | 264-1A | 0.46 | 0.034 | 5.3265401 | MAKE BATTERY #264 4V | | | |
| | | 264-2A | 0.41 | 0.034 | 4.7475683 | 3STRATE CRACKED | | | |
| 265A | 2/4/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 0.031" SHIM | | | | | | | |
| | | 265-1A | 0.3 | 0.033 | 3.5790981 | MAKE BATTERY #265-6V | | | |
| | | 265-2A | 0.28 | 0.033 | 3.3404915 | " " " | | | |
| | | 265-3A | 0.33 | 0.032 | 4.0600394 | DELAMINATED AT CORNER | | | |
| | | 265-4A | 0.33 | 0.032 | 4.0600394 | MAKE BATTERY #265-4V | | | |
| | | 265-5A | 0.33 | 0.032 | 4.0600394 | MINATE CRACKED | | | |
| 266A | 2/18/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 0.051" SHIM | | | | | | | |
| | | 266-1A | 0.36 | 0.046 | 3.0811366 | 0.37 | 0.045 | 3.237095363 | 5.0617284 |
| | | 266-2A | 0.38 | 0.045 | 3.3245844 | 0.48 | 0.044 | 4.294917681 | 29.1866029 |
| | | 266-3A | 0.41 | 0.046 | 3.5090722 | 0.84 | 0.045 | 7.349081365 | 109.430894 |
| | | 266-4A | 0.4 | 0.045 | 3.4995626 | 0.46 | 0.045 | 4.024496938 | 15 |
| 267A | 3-3-94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 267-1A(C) | 0.52 | 0.039 | 5.2493438 | 0.73 | 0.044 | 6.531853973 | W/ PB SHEET |
| | | 267-2A(P) | 0.61 | 0.037 | 6.4907427 | 0.6 | 0.041 | 5.761474938 | " |
| | | 267-3A(P) | 0.63 | 0.038 | 6.5271446 | 0.55 | 0.041 | 5.281352026 | " |
| | | 267-4A(P) | 0.45 | 0.036 | 4.9212598 | 0.56 | 0.041 | 5.377376608 | " |
| | | 267-5A(P) | 0.43 | 0.036 | 4.7025372 | 0.56 | 0.039 | 5.653139511 | " |
| | | 267-6A(P) | | | | 0.54 | 0.04 | 5.31496063 | IINATED, PB SHI |
| | | 267-7A(P) | | | | 0.5 | 0.04 | 4.921259843 | " " |
| | | 267-8A(C) | | | | 0.4 | 0.04 | 3.937007874 | " " |
| | | 267-9A(C) | | | | 0.37 | 0.04 | 3.641732283 | " " |
| | | 267-10A(C) | | | | 0.53 | 0.041 | 5.089302862 | " " |
| | | 267-11A(C) | | | | 0.56 | 0.041 | 5.377376608 | " " |
| | | 267-12A | 0.45 | 0.036 | 4.9212598 | 0.44 | 0.037 | 4.681847202 | -4.86486486 |
| | | 267-13A | 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) BEFORE | THICKNESS (INCH) BEFORE | RESISTIVITY (OHM-CM) BEFORE | RESISTANCE (OHM) AFTER | THICKNESS (INCH) AFTER | RESISTIVITY (OHM-CM) AFTER | PERCENT CHANGE (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 268-2A | 0.6 | 0.045 | 5.2493438 | 0.65 | 0.046 | 5.5631633 | " |
| | | 268-3A | 0.53 | 0.044 | 4.7423049 | 0.58 | 0.046 | 4.964053406 | " |
| | | 268-4A | 0.49 | 0.044 | 4.3843951 | 0.57 | 0.046 | 4.878466279 | " |
| | | 268-5A | 0.54 | 0.04 | 5.3149606 | 0.62 | 0.047 | 5.193499749 | " |
| | | 268-6A | | | | 0.49 | 0.048 | 4.019028871 | INATED, PB SH |
| | | 268-7A | | | | 0.46 | 0.048 | 3.772965879 | " " |
| | | 268-8A | | | | 0.5 | 0.049 | 4.017354973 | " " |
| | | 268-9A | MOVED FOR Q.C. DUE TO BLISTERING | | | | | | |
| | | 268-10A | | | | 0.46 | 0.048 | 3.772965879 | " " |
| | | 268-11A | | | | 0.94 | 0.045 | 8.223972003 | " " |
| | | 268-12A | 0.52 | 0.043 | 4.7610328 | 0.54 | 0.044 | 4.831782391 | 1.48601399 |
| | | 268-13A | 0.48 | 0.043 | 4.3947995 | 0.56 | 0.044 | 5.010737294 | 14.0151515 |
| 269A | 3/3/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 269-1A | 0.6 | 0.025 | 9.4488189 | 0.81 | 0.027 | 11.81102362 | 25 |
| | | 269-2A | 0.44 | 0.028 | 6.1867267 | 0.6 | 0.028 | 8.436445444 | 36.3636364 |
| | | 269-3A | 0.55 | 0.028 | 7.7334083 | 0.68 | 0.028 | 9.561304837 | 23.6363636 |
| | | 269-4A | 0.36 | 0.021 | 6.7491564 | 0.6 | 0.021 | 11.24859393 | 66.6666667 |
| 270A | 3/4/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 270-1A | 0.94 | 0.018 | 20.55993 | 0.35 | 0.018 | 7.655293088 | -62.7659574 |
| | | 270-2A | 0.824 | 0.022 | 14.745884 | 0.98 | 0.022 | 17.53758053 | 18.9320388 |
| | | 270-3A | 0.745 | 0.02 | 14.665354 | PLASTIC CRACKED | | | |
| | | 270-4A | 0.4 | 0.018 | 8.7489064 | 0.44 | 0.018 | 9.623797025 | 10 |
| | | 270-5A | 0.59 | 0.022 | 10.558339 | 0.74 | 0.021 | 13.87326584 | 31.3962873 |
| 271A | 3/10/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 271-1A | 0.37 | 0.02 | 7.2834646 | 0.39 | 0.02 | 7.677165354 | 5.40540541 |
| | | 271-2A | 0.34 | 0.02 | 6.6929134 | 0.31 | 0.02 | 6.102362205 | -8.82352941 |
| | | 271-3A | 0.245 | 0.019 | 5.076668 | 0.43 | 0.02 | 8.464566929 | 66.7346939 |
| | | 271-4A | 0.345 | 0.02 | 6.7913386 | 0.35 | 0.022 | 6.263421618 | -7.77338603 |
| 272A | 3/17/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 272-1A | 0.3 | 0.028 | 4.2182227 | 0.58 | 0.027 | 8.457276174 | 100.493827 |
| | | 272-2A | 0.33 | 0.028 | 4.640045 | 0.65 | 0.028 | 9.139482565 | 96.969697 |
| | | 272-3A | 0.36 | 0.028 | 5.0618673 | 0.43 | 0.028 | 6.046119235 | 19.4444444 |
| | | 272-4A | 0.36 | 0.028 | 5.0618673 | 0.41 | 0.028 | 5.764904387 | 13.8888889 |
| 273A | 3/17/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 273-1A | 0.38 | 0.04 | 3.7401575 | 0.94 | 0.041 | 9.026310736 | 141.335045 |
| | | 273-2A | 0.34 | 0.04 | 3.3464567 | 0.72 | 0.04 | 7.086614173 | 111.764706 |
| | | 273-3A | 0.39 | 0.041 | 3.7449587 | 0.65 | 0.041 | 6.241597849 | 66.6666667 |
| | | 273-4A | 0.37 | 0.042 | 3.4683165 | 0.52 | 0.041 | 4.993278279 | 43.9683586 |
| 274A | 4/28/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 274-1A | 2.8 | 0.052 | 21.199273 | 9 | 0.054 | 65.6167979 | 209.52381 |
| | | 274-2A | 3 | 0.058 | 20.363834 | 10 | 0.059 | 66.72894702 | 227.683616 |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| 275A | 4/28/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 275-1A | 2.65 | 0.044 | 23.711525 | 24.5 | 0.044 | 219.2197566 | 824.528302 |
| | | 275-2A | 1.95 | 0.042 | 18.278965 | 50 | 0.044 | 447.3872584 | 2347.55245 |
| 276A | 4/28/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 276-1A | 3.2 | 0.06 | 20.997375 | 6.8 | 0.064 | 41.83070866 | 99.21875 |
| | | 276-2A | 3.8 | 0.06 | 24.934383 | 5 | 0.062 | 31.7500635 | 27.3344652 |
| 277A | 5/2/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 277-1A | 0.58 | 0.047 | 4.8584352 | )R 4V BATTERY 277-1 C | | | |
| | | 277-2A | NA | 0.041 | NA | )R 4V BATTERY 277-2 C | | | |
| | | 277-3A | NA | 0.042 | NA | 'R 6V BATTERY 277-6V C | | | |
| | | 277-4A | NA | 0.042 | NA | " " " | | | |
| 278A | 5/2/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 278-1A | NA | 0.04 | NA | )R 4V BATTERY 278-1 C | | | |
| | | 278-2A | NA | 0.039 | NA | 'R 6V BATTERY 278-6V C | | | |
| | | 278-3A | NA | 0.04 | NA | " " " | | | |
| 279A | 5/2/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 279-1A | NA | 0.042 | NA | )R 4V BATTERY 279-1 C | | | |
| | | 279-2A | NA | 0.039 | NA | )R 4V BATTERY 279-2 C | | | |
| | | 279-3A | NA | 0.04 | NA | 'R 6V BATTERY 279-6V C | | | |
| | | 279-4A | NA | 0.039 | NA | " " " | | | |
| 280A | 5/9/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 280-1A | 0.38 | 0.035 | 4.2744657 | 2.75 | 0.037 | 29.26154501 | 584.566145 |
| | | 280-2A | 0.31 | 0.039 | 3.1294165 | 8.1 | 0.04 | 79.72440945 | 2447.58065 |
| | | 280-3A | 0.28 | 0.035 | 3.1496063 | 3 | 0.037 | 31.92168546 | 913.513514 |
| | | 280-4A | 0.3 | 0.035 | 3.3745782 | 2.3 | 0.037 | 24.47329219 | 625.225225 |
| 281A | 5/12/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 281-1A | 0.43 | 0.033 | 5.1300406 | )R 4V BATTERY 281-1 C | | | |
| | | 281-2A | 0.41 | 0.035 | 4.6119235 | )R 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 281-3A | 0.3 | 0.034 | 3.4738305 | 'R 6V BATTERY 281-6V C | | | |
| | | 281-4A | 0.36 | 0.034 | 4.1685966 | " " " | | | |
| 282A | 5/13/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 282-1A | 0.4 | 0.035 | 4.4994376 | )R 4V BATTERY 282-1 C | | | |
| | | 282-2A | 0.42 | 0.037 | 4.469036 | )R 4V BATTERY 282-2 C | | | |
| | | 282-3A | 0.38 | 0.036 | 4.1557305 | 'R 6V BATTERY 282-6V C | | | |
| | | 282-4A | 0.4 | 0.036 | 4.3744532 | " " " | | | |
| 283A | 5/13/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 283-1A | 0.52 | 0.025 | 8.1889764 | 2.85 | 0.025 | 44.88188976 | 448.076923 |
| | | 283-2A | 0.5 | 0.025 | 7.8740157 | 2.35 | 0.025 | 37.00787402 | 370 |
| | | 283-3A | 0.45 | 0.025 | 7.0866142 | 3.3 | 0.025 | 51.96850394 | 633.333333 |
| | | 283-4A | 0.36 | 0.024 | 5.9055118 | 2.5 | 0.024 | 41.01049869 | 594.444444 |
| 284A | 5/25/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 284-1A | 0.5 | 0.041 | 4.8012291 | 1.1 | 0.041 | 10.56270405 | 120 |
| | | 284-2A | 0.54 | 0.041 | 5.1853274 | 1.4 | 0.041 | 13.44344152 | 159.259259 |
| | | 284-3A | 0.55 | 0.041 | 5.281352 | 1.6 | 0.041 | 15.36393317 | 190.909091 |
| | | 284-4A | 0.7 | 0.04 | 6.8897638 | 1.6 | 0.041 | 15.36393317 | 122.996516 |
| 285A | 6/2/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 285-1A | 0.89 | 0.045 | 7.7865267 | 'OR 4V BATTERY 285-1 | | | |
| | | 285-2A | 1.15 | 0.046 | 9.8425197 | | | | |
| | | 285-3A | 1.25 | 0.048 | 10.252625 | | | | |
| | | 285-4A | 1.35 | 0.047 | 11.308427 | | | | |
| 286A | 6/2/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 286-1A | 1.1 | 0.047 | 9.2142737 | DON'T USE | | | |
| | | 286-2A | 1.25 | 0.049 | 10.043387 | 'OR 4V BATTERY 286-2 | | | |
| | | 286-3A | 1.05 | 0.05 | 8.2677165 | | | | |
| | | 286-4A | 1.25 | 0.051 | 9.6495291 | DON'T USE | | | |
| 287A | 6/3/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 287-1A | 0.9 | 0.047 | 7.5389512 | DON'T USE | | | |
| | | 287-2A | 0.6 | 0.043 | 5.4934994 | 'OR 4V BATTERY 287-2 | | | |
| | | 287-3A | 0.595 | 0.044 | 5.3239084 | 'OR 4V BATTERY 287-3 | | | |
| | | 287-4A | 0.53 | 0.043 | 4.8525911 | | | | |
| 288A | 6/15/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 288-1A | 0.66 | 0.041 | 6.3376224 | E, SUBSTRATE CRACKED | | | |

| 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 (%) |
|---|---|---|---|---|---|---|---|---|---|
| | | 288-2A | 0.8 | 0.042 | 7.4990626 | 'OR 4V BATTERY 288-2 | | | |
| | | 288-3A | 0.54 | 0.041 | 5.1853274 | | | | |
| | | 288-4A | 0.92 | 0.042 | 8.623922 | | | | |
| 289A | 6/16/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 289-1A | 0.56 | 0.04 | 5.511811 | 'OR 4V BATTERY 289-1 | | | |
| | | 289-2A | 0.52 | 0.04 | 5.1181102 | | | | |
| | | 289-3A | 0.53 | 0.041 | 5.0893029 | | | | |
| | | 289-4A | 0.55 | 0.04 | 5.4133858 | | | | |
| 290A | 6/23/94 | LAMINATE 300F/3 TONS | | | | | | | |
| | | 290-1A | 0.68 | 0.018 | 14.873141 | 'OR 4V BATTERY 290-1 | | | |
| | | 290-2A | 0.7 | 0.019 | 14.504766 | OR 4V BATTERY 290-6V | | | |
| | | 290-3A | 0.62 | 0.019 | 12.847078 | " " " | | | |
| | | 290-4A | 0.66 | 0.02 | 12.992126 | | | | |
| | | 290-5A | 0.52 | 0.02 | 10.23622 | | | | |
| | | 290-6A | 0.49 | 0.02 | 9.6456693 | | | | |
| | | 290-7A | 0.44 | 0.019 | 9.1172814 | | | | |
| | | 290-8A | 0.5 | 0.019 | 10.360547 | | | | |
| | | 290-9A | 0.5 | 0.021 | 9.3738283 | | | | |
| | | 290-10A | 0.5 | 0.021 | 9.3738283 | | | | |
| | | 290-11A | 0.52 | 0.021 | 9.7487814 | | | | |
| | | 290-12A | 0.54 | 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

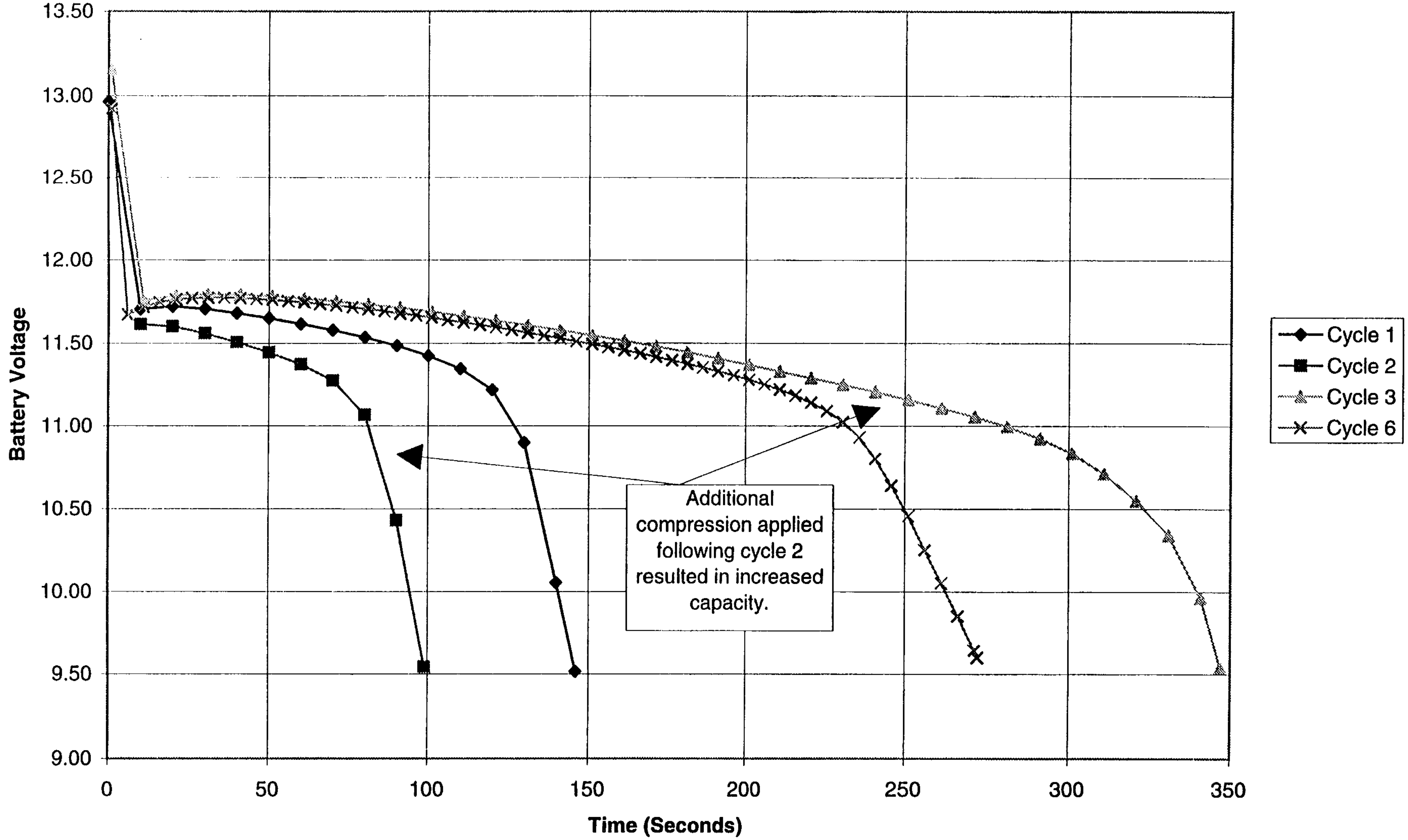
| | |
|---|---|
| Acid Gravity | Chilled 1.265 |
| % Sodium Sulfate | 1.5 |
| Method of Fill | Vacuum |

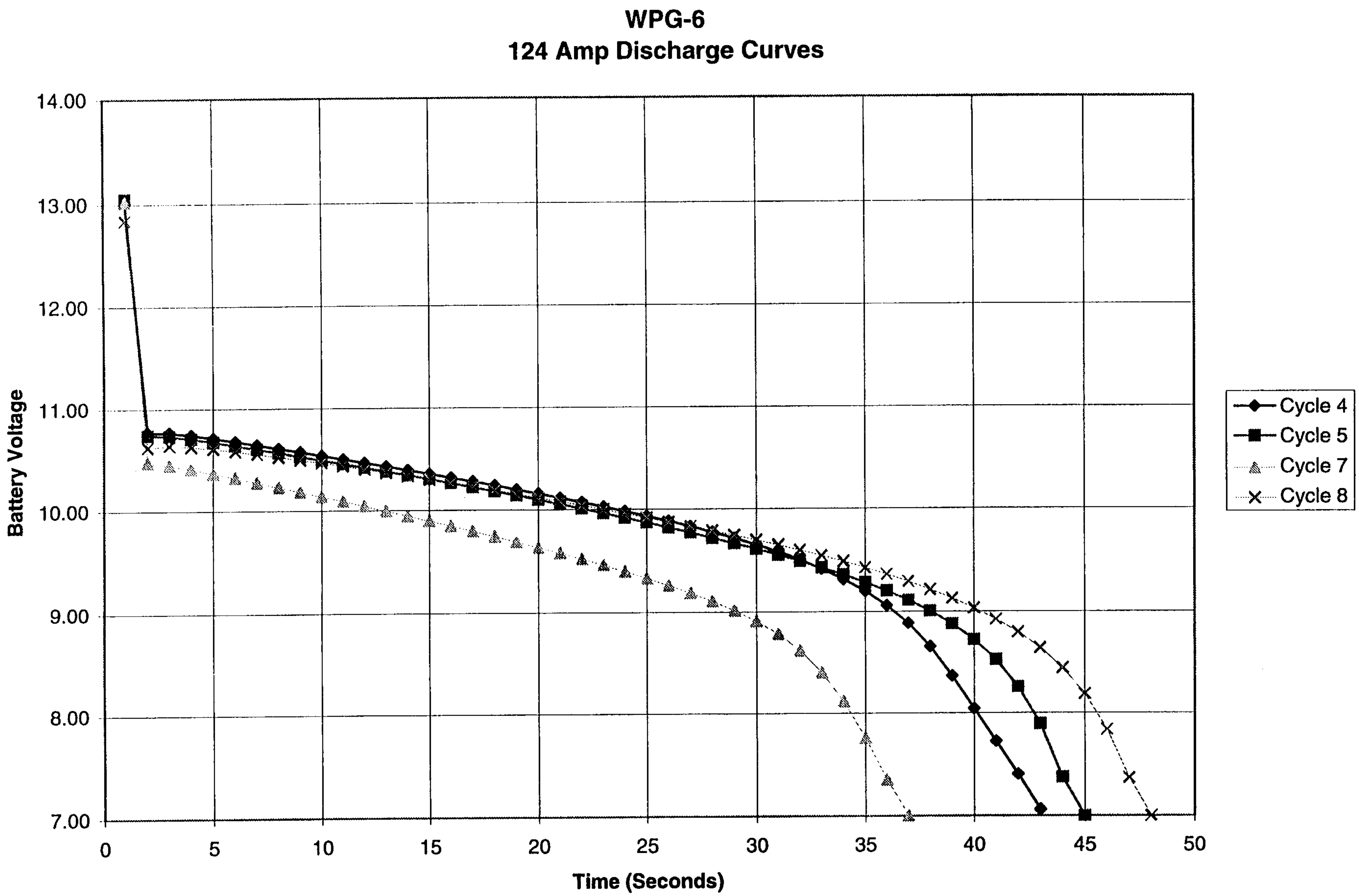
| | |
|---|---|
| Time | 27H:55M:04S |
| Amps | 1.0 |
| Voltage Limit | 16.32 |
| Amp Hours | 20.62 |
| Watt Hours | 311.8 |
| Internal Resistance | 13.5 mΩ |

## CYCLING HISTORY

| | | | | Discharge | | | | Recharge | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycle | Date | IR (mW) | OCV | 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
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
Battery Voltage
0
5
10
15
20
25
30
35
40
45
50
Time (Seconds)
Cycle 4
Cycle 5
Cycle 7
Cycle 8

**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 |

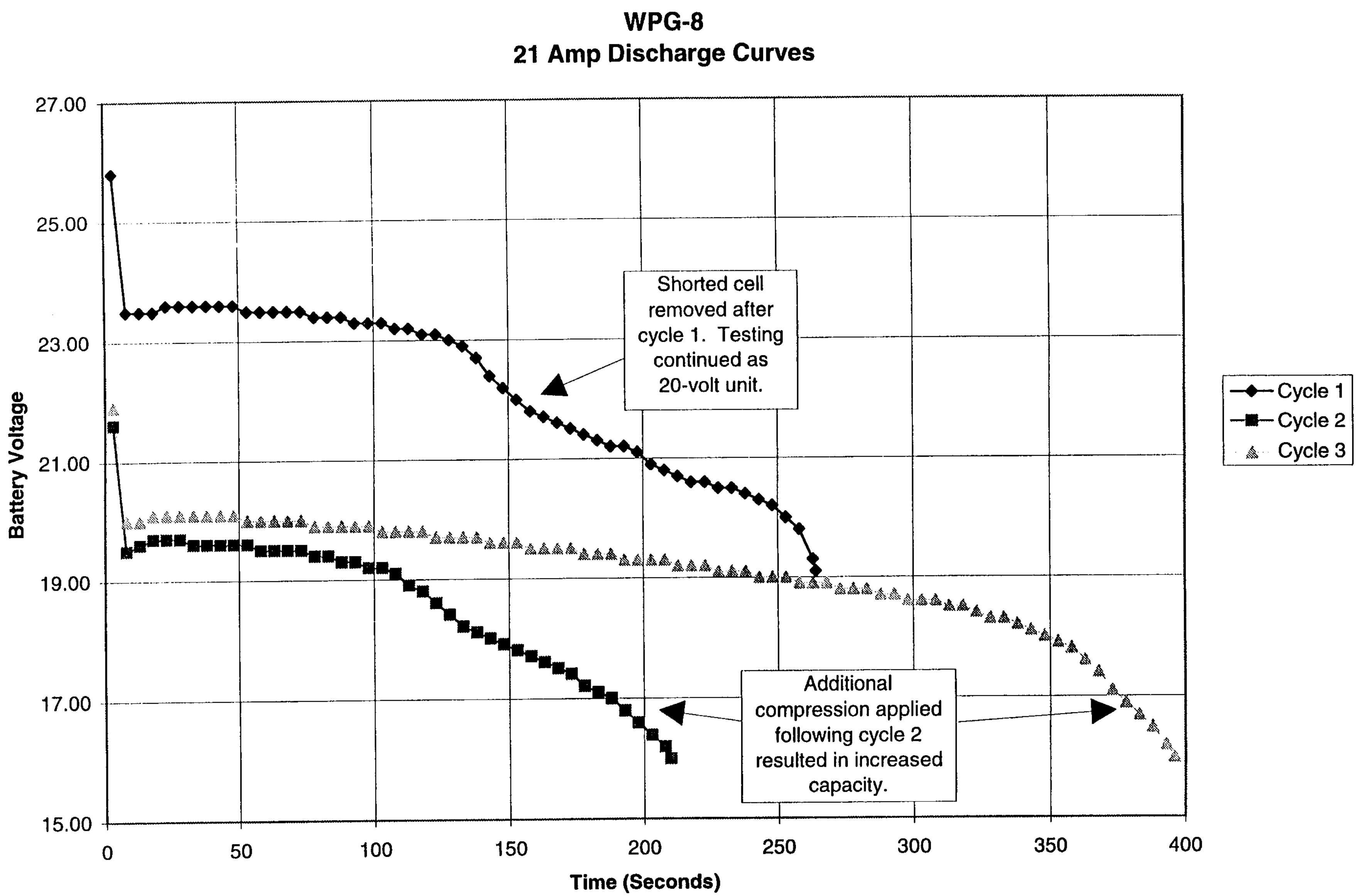
## FORMATION

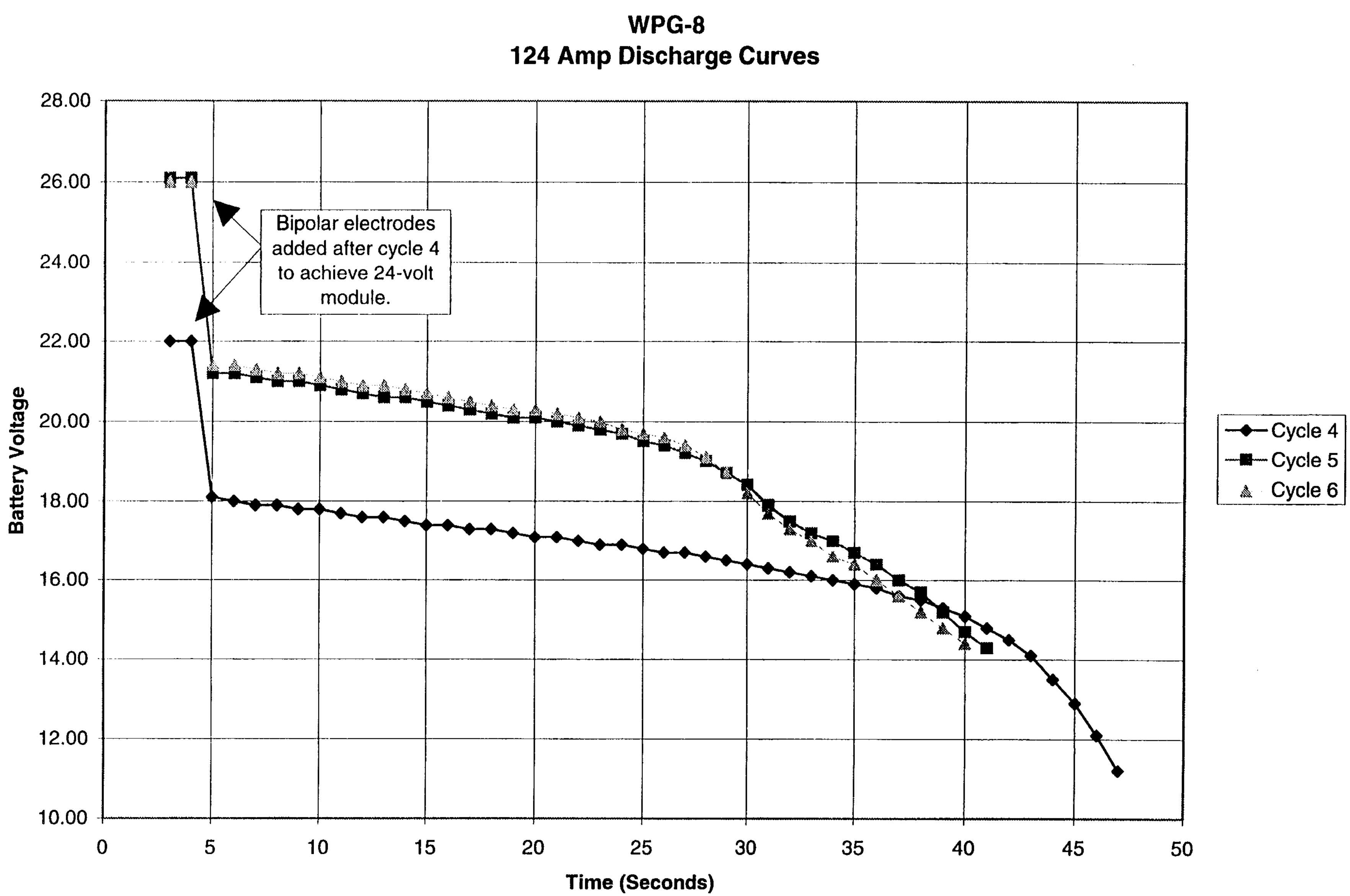
| | |
|---|---|
| Acid Gravity | Chilled 1.265 |
| % Sodium Sulfate | 1.5 |
| Method of Fill | Vacuum |

| | |
|---|---|
| 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

| | | | | Discharge | | | | Recharge | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycle | Date | IR (mW) | OCV | 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
Battery Voltage
27.00
25.00
23.00
21.00
19.00
17.00
15.00
0
50
100
150
200
250
300
350
400
Time (Seconds)
Shorted cell removed after cycle 1. Testing continued as 20-volt unit.
Additional compression applied following cycle 2 resulted in increased capacity.
Cycle 1
Cycle 2
Cycle 3


WPG-8
124 Amp Discharge Curves
Bipolar electrodes added after cycle 4 to achieve 24-volt module.
Battery Voltage
28.00
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
0
5
10
15
20
25
30
35
40
45
50
Time (Seconds)
Cycle 4
Cycle 5
Cycle 6

**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

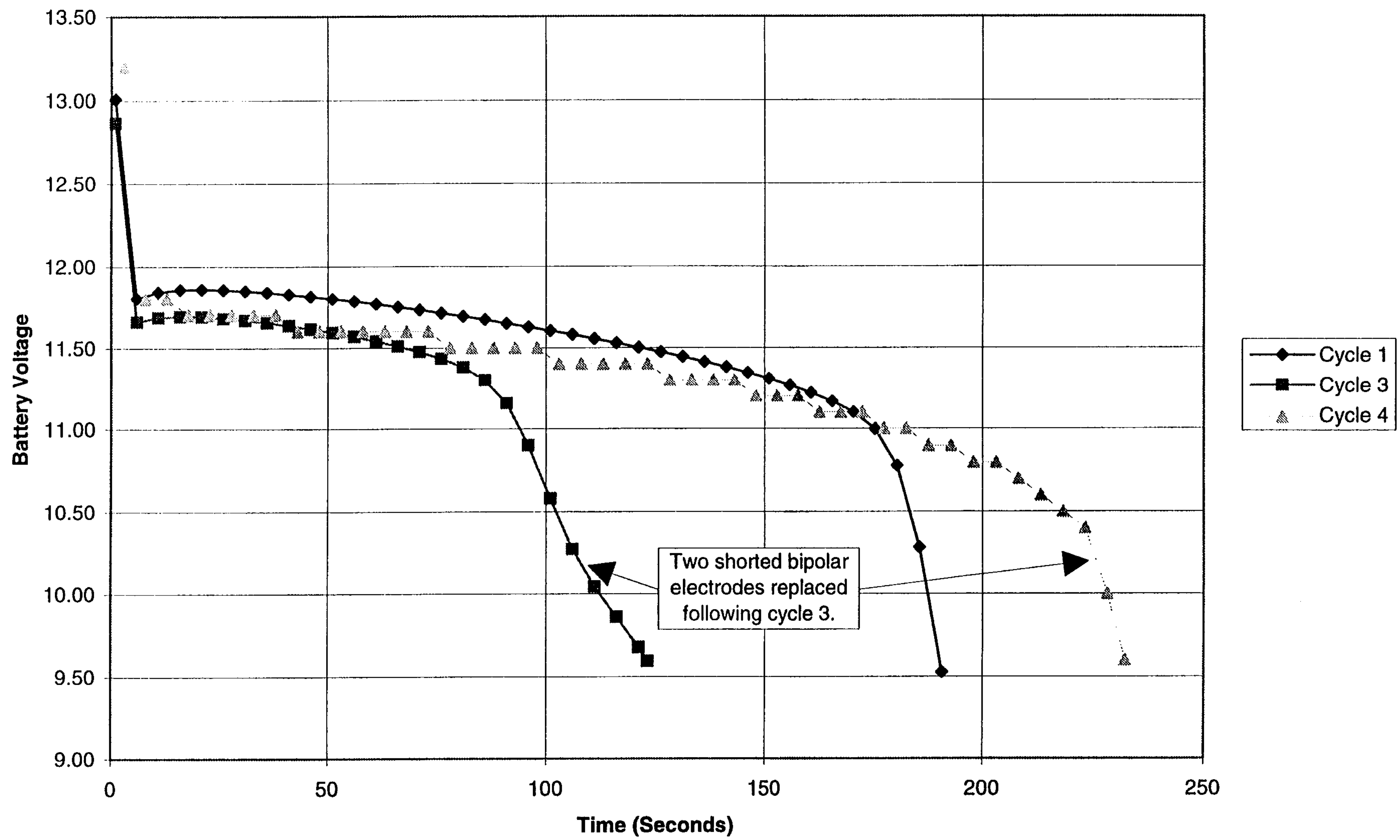
| | |
|---|---|
| Acid Gravity | Chilled 1.265 |
| % Sodium Sulfate | 1.5 |
| Method of Fill | Vacuum |

| | |
|---|---|
| Time | |
| Amps | 1 |
| Voltage Limit | 16.32 |
| Amp Hours | 20.62 |
| Watt Hours | NA |
| Internal Resistance | 12 mΩ |

## CYCLING HISTORY

| | | | | Discharge | | | | Recharge | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycle | Date | IR (mW) | OCV | 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**