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RECHARGEABLE ALKALINE ZINC/FERRICYANIDE BATTERY

Final Report, September 29, 1978--September 28, 1979

By
George B. Adams
Roger P. Hollandsworth
Bruce D. Webber

Work Performed Under Contract No. EM-78-C-01-5163

Lockheed Missiles & Space Company, Inc.
Lockheed Palo Alto Research Laboratory
Palo Alto, California

U. S. DEPARTMENT OF ENERGY

Division of Energy Storage Systems

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ABSTRACT

First-year contract effort was directed primarily to assessing technical and economic feasibility of the alkaline zinc/ferricyanide rechargeable battery for utility load-leveling applications.

This battery meets the requirements for this application with cell voltages of 1.94 V on charge and 1.78 V on discharge. (35 mA/cm^2) at 40°C, with peak power density of 4.5 kW/m^2. Mean energy efficiency is 84% at 760 and 86% at 1110 4-hour cycles in full-cell, and redox half-cell cycling, respectively.

An updated, upgraded economic analysis suggests a battery selling price of $32/kWh, installed price of $230/kW and footprint of 8.7 kWh/ft^2 as realistic goals for a 20 MW 100-MWh system.

A major effort was successfully completed on design, construction, programming, and debugging of a microprocessor-controlled battery cycling system, which is the heart of the cell cycling test facility developed on this project.

Other technical areas addressed include: electrode substrate evaluation, solubilities and conductivities of zinc oxide and sodium ferro- and ferricyanide in sodium hydroxide electrolytes, mechanism of the slow chemical deligation of alkaline ferricyanide and its reversal, optimal compositions of zincate and iron redox electrolytes, effect of electrolyte flow rate and additions on quality of zinc electrodeposits, cell and electrode design and fabrication, and full and half-cell cyclic testing.

In overview, significant technical progress was made in concept configuration and improving performance of the alkaline zinc/ferricyanide battery.

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SUMMARY

This project was directed primarily to assessing the technical and economic feasibility of the alkaline zinc/ferricyanide rechargeable battery for utility load leveling application. During this first year contract (Phase I), many of the most critical issues have been probed on a laboratory scale. Also, our previous preliminary economic analysis has been updated and upgraded. Cyclic cell test results over many hundreds of four-hour charge-discharge cycles indicate that the performance of the alkaline zinc/ferricyanide system exceeds the original proposed goal of 70% for turnaround energy efficiency by over 10%; the economic analysis suggests that a battery selling price of ca $32/kWh and an installed price of $230/kW are realistic goals for a 20 MW, 100 MWh system.

Specifically, the following accomplishments are highlighted:

- In full-cell cyclic testing, after 760 four-hour cycles, overall energy efficiency is 84%, with cycling continuing (sec. 4.6.5).

- A ferro-ferricyanide-redox half-cell currently stands at 1110 four-hour cycles (4440 hours), with a mean energy efficiency of 86%, with cycling continuing (sec. 4.5.2.4). With this redox couple, mean coulombic and voltaic efficiencies were determined as functions of electrolyte flow rate and current density. Optimal efficiency values are 98.5% coulombic and 96% voltaic at 35 mA/cm^2 (sec. 4.5.2).

- Mean coulombic and voltaic efficiencies as functions of current density and electrolyte concentration were determined for the zinc electrode in half-cell testing. Optimal values are 97% coulombic and 92% voltaic at 35 mA/cm^2 (sec. 4.5.1).

- An updated and upgraded cost analysis, based on a production rate of twenty-five, 20 MW, 100-MWh batteries per year, indicates a battery selling price of $31.50/kWh. Battery footprint is 8.7 kWh/ft^2 (sec. 4.7).

- A major effort was completed on design, construction, programming, and debugging of a microprocessor-controlled battery cycling system. This system is the heart of the cell cycling test facility. It controls the charge and discharge cycles of six or more test cells, based upon five different operator-selected cell parameters. It computes, at the end of each cycle, the voltaic, coulombic, and energy efficiencies for each cell (sec. 3.3).

- An instrumented test stand was built to independently service six full or half cells for long-term cyclic testing. Six 60-cm^2 test cells were designed, fabricated, and checked for hydrodynamic flow characteristics. Operational characteristics were found to be excellent (sec. 3.2).

- The first step in the long-term very slow chemical degradation of the alkaline iron redox couple has been tentatively identified as the abstraction of a cyanide ion from the ferricyanide ion to form a pentacyanoaqua iron(III) specie. The metals, Cu, Ag, and Hg have been found to accelerate this process, while Zn, Cd, and Ni, which are used in cell components, are inert (sec. 4.2.2) The religation of ferricyanide in cyclically aged redox electrolyte has been demonstrated, with subsequent recovery of redox electrode capacity (Sec. 4.2.3).

- Ten materials have been evaluated by cyclic voltammetry for use as substrates for the zinc electrode. Three of these were run in half-cell tests. A cadmium-plated iron substrate was found to be optimal (secs. 4.1, 4.5.1). Eight ferro-ferricyanide redox electrode substrate materials have been evaluated by cyclic voltammetry. Porous nickel has been selected as optimal but other less expensive candidates have been identified (Sec. 4.2.1, 4.5.2.1).

- Solubilities of sodium ferro- and ferricyanides in sodium hydroxide electrolytes and of potassium ferro- and ferricyanides in both sodium and potassium hydroxide electrolytes, and conductivities of these saturated solutions were

measured over the temperature range 22^{o} - 50^{o}C (sec 4.3.2). Solubilities of ZnO in ZnO-saturated sodium hydroxide electrolytes and conductivities of the electrolytes were determined, over the temperature range 28^{o} - 50^{o}C (sec. 4.3.1).

- A limiting factor affecting the redox electrode coulombic efficiency at high charge capacity was identified as concentration polarization in 5N NaOH occurring in the last 15% of the charge cycle. The redox electrolyte concentration was found to be optimal at 2.2 N NaOH. With this electrolyte at 40^{o}C, coulombic efficiency is 99% (sec. 4.5.2.3).

- The optimal zincate electrolyte is saturated in zinc oxide. Coulombic efficiency is temperature independent from 25^{o} to 50^{o}C (secs. 4.5.1.2, 4.5.1.5). Physical characteristics of zinc electrodeposits were found to relate to electrolyte face velocity (sec. 4.5.1.3). Four zincate electrolyte additives have been evaluated. Of these, sodium silicate appears the most promising (sec. 4.5.1.7). The presence of ferrocyanide ion does not seriously affect the energy efficiency of the zinc electrode on long-term cycling (sec. 4.5.1.4). Passivation of the zinc electrode by formation of an insoluble film of zinc ferrocyanide due to cross-diffusion of ferro- or ferricyanide into the anolyte is precluded since zinc ferrocyanide is soluble in 2 - 5N NaOH electrolyte (sec. 4.3.1).

- Five teflon-based battery separator materials have been evaluated (sec. 4.4).

Those technical areas requiring additional effort have been identified, and are the subject of a proposed Phase II follow-on program (sec. 5).

In overview, it is felt that significant technical progress has been made in confirming and improving the performance of the alkaline zinc/ferricyanide battery. None of the results from Phase I experimental work to date would point to a change in the original concept, in which system size is minimized by using saturated solutions of reactants and products and storing them in solid form. In fact, the overall system concept and electrochemical performance have exceeded expectations.

Section 1
INTRODUCTION

This report details technical results achieved on the first 12-month phase of a research and development effort conducted at Lockheed Missiles & Space Co., Inc. Palo Alto Research Laboratory for the Division of Energy Storage Systems of the Department of Energy under Contract EM-78-C-01-5163, on a "Rechargeable Alkaline Zinc/Ferricyanide Hybrid Redox Battery," This battery is a low-cost electrical energy storage system which is adaptable to either solar photovoltaic/ wind or distributed energy storage for electric utility load-leveling applications.

Increasing demands for electric power in the face of rising energy costs have created an acute problem for the electric utility industry in meeting the intensive peak power demands of industry. Leveling or peak-shaving these loads and using off-peak stored energy allow more efficient utilization of base-load energy, with consequent significant savings in hydrocarbon fuels as required for base-load power generation. An alternative or supplemental* method to a pumped hydroelectric system for large-scale energy storage is urgently required to meet the pressure of these rapidly growing electric power demands, since placement of pumped hydroelectric systems is severely limited by environmental restrictions. An electrochemical system for bulk electrical energy storage has a number of advantages over pumped hydroelectric storage. These advantages include minimal environmental and siting problems, short construction lead times, instant start-up capability, potentially high operational efficiency, and in common with other energy storage options, batteries confer substantial spinning-reserve and system regulation benefits because of their operating characteristics. The modular construction of battery systems would allow location at utility substations in order to meet the specific needs of a local industrial, commercial, or resi-

*A 1977 Electric Power Research Institute (EPRI) assessment indicates that oil consumption in the United States would be reduced, in the year 2000, by some ten to one-hundred million barrels annually for total installed electrical storage capacities of 18-50 GW.

dential market. Battery cost and performance goals established by EPRI for utility load-leveling application include:

- Installed cost: $25/kWh + $75/kW or $40/kWh overall (1977$)
- Overall energy efficiency: 70%
- Footprint: 8kWh/ft^2
- Useful life: 2500 charge/discharge cycles over a 10-year system service life
- Height: 20 feet, maximum
- Minimum siting restrictions

In addition, EPRI standardized cost estimating guidelines for computing battery installed capital cost, specify an annual production rate of 25 100-MWh batteries per year and the definition of a standard manufacturing facility for battery production.

The objective of Phase I of the present program was to determine, within the constraints of allocated funding, the technical feasibility of the alkaline zinc/ferricyanide rechargeable battery for ultimate application in utility load leveling. Results to date are most promising based on the electrochemical operating characteristics of the system and an upgraded cost estimate for a 100 MWh storage facility using this battery.

This battery has a number of advantages that should be stressed. It is an alkaline aqueous electrolyte battery which operates best at a temperature slightly above ambient. The advantages of an alkaline over a strongly acidic electrolyte become apparent when one considers the number of successful alkaline electrolyte batteries that have been developed compared to successful acid electrolyte batteries (primary and secondary nonreserve type). Thus, on the alkaline side we have zinc/copper oxide; zinc/oxygen; zinc/mercuric oxide; zinc/silver oxide; cadmium/nickel oxide; iron/nickel oxide; cadmium/silver oxide and, of more recent vintage, zinc/nickel oxide and hydrogen/nickel oxide. Commercially only the lead/lead dioxide battery, which is a unique system, stands out as the sole acid electrolyte contender.

When cost is a prime consideration, an alkaline electrolyte battery has decided advantages, which are mainly due to the much less corrosive electrolyte which allows the use of lower cost electrode substrate materials and system auxiliaries.

The alkaline zinc/ferricyanide battery is an ambient temperature, flowing electrolyte system using zinc/zincate and ferro/ferricyanide electrode couples.

A major advantage of this system is the high cell voltage (1.86 V OCV) and electrode reversibility (1.78 V at 35 mA/cm^2 or 60 mW/cm^2). Peak power density is over 4.5 kW/m^2 with present cell design; mean energy efficiency is 84% over 698 4-hour cycles to date, with cyclic testing continuing. At 690 cycles, energy efficiency has increased to 87%.

The basic chemical components of this battery are zinc, iron, carbon, nitrogen, and sodium, all of which are abundant and low in cost. The alkaline electrolyte allows the use of relatively inexpensive electrode substrate materials and systems auxiliaries, which contribute to a lower capital cost per kilowatt-hour of energy stored. A preliminary analysis of capital costs for this system, based on a projected design for a utility load-leveling battery sized at 20 MW, 100 MWh, and a production rate of 25 batteries per year, suggests a battery selling price of $32/kWh.

Other advantages of this battery include the use of relatively low cost separator materials; flat charge-discharge curves due to circulation of saturated solutions of reactants; minimal storage volume required for reactants because of external storage as solids; deep depth of discharge; low toxicity components, and long cycle life inherent to redox-type electrodes.

Technical achievements to date under the current contract (Phase I) have confirmed concept viability. In fact, the predicted performance has exceeded the original proposed goals of 70% for energy efficiency by some 10% in long-term cell cycling studies.

Section 2
TECHNICAL BACKGROUND

2.1 INTRODUCTION

The principal criteria to be met in the selection of a new secondary battery for utility load-leveling applications are those of maximum allowed cost per unit of electrical energy output and the ability to provide this energy efficiently over thousands of deep charge-discharge cycles. Battery cost and performance goals for electric utility load leveling application include round-trip energy efficiency of 70 percent, initial battery cost of $30/kWh, and cycle life of 2500 cycles (Ref. 1).

A redox battery system has the intrinsic advantages of extensive deep-cycling life potential due to charge transfer from an inert conducting substrate to dissolved reactant/products, low-temperature operation, and low-cost storage of reactants/products externally to the battery itself. Disadvantages of those redox systems having sufficient electrode reversibility to be practical usually involve low-cell voltages and corrosive electrolytes. The low-cell voltage problem is eliminated in metal-halogen systems, such as zinc-chlorine or zinc-bromine, but serious corrosion and halogen storage problems remain that require costly solutions in terms of higher cost materials of construction.

The hybrid redox zinc/ferricyanide battery is an alkaline electrolyte system that is subject to only minimal corrosion problems and has a high reversible cell voltage. The two electrochemical couples involved are thermodynamically reversible and operate under mass transfer control.

Single-cell tests with this system have demonstrated high coulombic and turn-around energy efficiencies over hundreds of charge/deep discharge cycles. The system has been analyzed on a preliminary basis for cost, and has been found to meet those capital cost requirements generally accepted for commercial applicability of utility load-leveling.

The following paragraphs provide a description of the overall system concept, as applied to utility load-leveling, a description of a novel approach for storing cell reactants externally as solids, and technical background information on the zinc and ferro-ferricyanide redox electrodes.

2.2 ZINC/FERRICYANIDE BULK ELECTRICAL ENERGY STORAGE SYSTEM

The complete bulk electrical energy storage system based on the alkaline zinc/ferro-ferricyanide battery is depicted in Fig. 2.2.1.

In the charged state, metallic zinc is stored in the redox converter, and sodium ferricyanide monohydrate is stored externally as a solid in a storage tank C. On discharge, zinc dissolves as the zincate ion and is stored in an external Tank B, as solid zinc oxide. Solid sodium ferricyanide monohydrate in Tank C is converted to solid sodium ferrocyanide decahydrate. The cell is operated at some temperature above ambient so that the reactant solids will crystallize out of the supersaturated solutions in the storage tanks, at ambient temperature.

This approach has two important advantages: It minimizes storage tank volume requirements and also maintains discharge voltage more nearly constant over the complete charge and discharge cycles, since the ferrocyanide and ferricyanide ion concentrations are automatically maintained constant at the ambient temperature saturation values. Minimal amounts of electrolyte are circulated through the system.

After a prolonged period of operation (perhaps every 1000 cycles), sufficient sodium ferrocyanide decahydrate solid will accumulate in Tank B necessitating recovery. This recovery is accomplished as follows. The cells would be charged fully to dissolve all zinc oxide solid in the anolyte. Tank B would then be drained of free electrolyte by pumping into Tank A. The crystalline sodium ferrocyanide slurry would then be pumped back into Tank C. Tank B would be refilled with anolyte from Tank A, and the system would be ready for

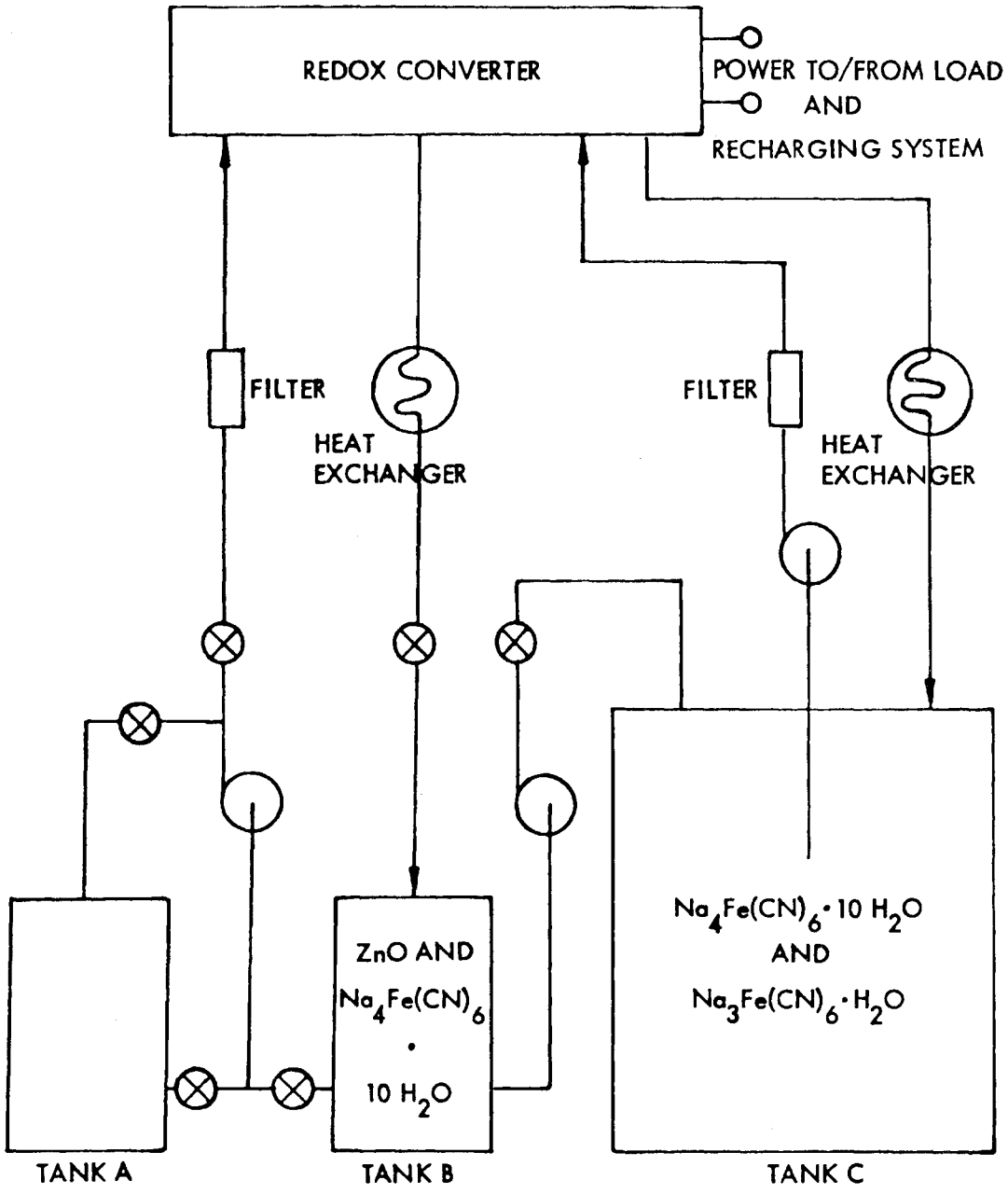

Fig. 2.2.1 Electrically Rechargeable Hybrid Redox Bulk Energy Storage System

discharge. It should be noted that Tank C capacity is about 40 times that of A or B. A mechanical stirrer could be incorporated in Tank B to facilitate removal of the crystalline slurry. If necessary, liquor from Tank C would be used to facilitate the transfer.

The zinc/ferricyanide storage system has the following features:

- This recycling concept should permit the use of relatively low-cost membrane separator material with significant reduction in overall capital cost.
- The intermixing of reactants does not cause irreversible voltage degradation, as discussed in Section 4.5.1.
- Any zinc lost from the electrode by mechanical dislodgement will be slowly redissolved by reaction with ferricyanide ion diffusing in from the catholyte compartment, and reenter the system as zincate ion.

2.3 ZINC ELECTRODE

2.3.1 Electrode Substrate

In the operation of the battery, zinc is electrodeposited at the negative electrode on charge and anodically stripped from this current-conducting substrate upon discharge. The nature of the substrate used for the electrode affects the adhesion characteristics of the deposit (Ref. 2).

Certain criteria can be used in selecting substrate materials for the zinc electrode. These criteria relate to hydrogen overvoltage, adherency of the metal deposit, and corrosion inhibition and can be listed as follows:

- The substrate should have a high hydrogen overvoltage (Ref. 3)
  (Pb > Hg > Cd > Ag > Cu > Fe > Ni > Pt)
- The substrate should exhibit properties of good zinc adherency (Ref. 4 , 5)
  (Zn(Hg) > Zn > Cd > Ag > Cu > Pb > Sn)
- Zinc corrosion inhibitors are beneficial (Cd^{++},Al^{+++},Pb^{++}) (Ref. 6)
- Zinc corrosion accelerators are to be avoided (Refs. 6 , 7, 8)
  (Cu^{++}, Fe^{++}, Sb^{+++}, As^{+++}, Ag^{+})

2.3.2 Zinc Electrodeposition

The electrochemistry of zinc in static secondary alkaline batteries has been studied for many years. The formation of voluminous, porous and/or dendritic growths rather than compact, low porosity crystalline deposits in zinc electrodeposition is a problem that has been investigated, mainly in quiescent solutions. Studies in vigorously stirred electrolytes are not as well documented. It has been reported that smooth deposits are formed at low overpotentials in stirred electrolytes, whereas in quiescent solutions mossy deposits are formed at low overpotentials (<75 mV) and dendritic deposits occur at overpotentials above 75 mV (Refs. 2, 9). Dendritic deposits are formed when the rate of the electrode reaction is controlled by mass transport of the zincate species to the electrode surface, i.e., when the surface

concentration of the electroactive species is less than the bulk concentration (Ref. 9). Studies of morphology of alkaline deposited zinc as a function of current density and face velocity under both turbulent and laminar flow show that flow conditions greatly modify the deposit morphologies. Flat crystalline deposits are obtained at 50 mA/cm^2 for a Reynold's number of 1500 and at 300 mA/cm^2 for a Reynold's number of 14,000 (Ref. 10).

Rotating disc investigations have shown that there is a very narrow current density range where smooth zinc electrodeposits are obtained, which is intermediate to those for moss and dendrite formation (Refs. 11, 12). It is well known that small amounts of Pb^{++} inhibit mossy zinc formation (Ref. 13, 14); lead additions in the range of 5×10^{-5} to 3×10^{-4} M drastically alter the electrode double-layer capacity and the impedance diagram (Ref. 15). Additions of other metal ions such as Sn^{++}, Hg^{++}, and Cd^{++} and various organics such as ethylene glycol polymers and derivatives have all been reported to induce crystalline deposits in static zinc batteries (Refs.11, 12, 16-23).

A current German patent (Ref. 24) specifies the use of sodium silicate as an additive to zincate baths for improving the quality and grain structure of the electroplate over a broad range of current densities.

It would appear that most of the cycle-life problems reported with alkaline zinc batteries are related to concentration gradients of zincate ion building up in the static electrolyte, and to sizable changes of zincate ion concentration occurring in the boundary layer during charge and discharge. When a circulating electrolyte is used, these problems largely disappear due to thinning of the boundary layer and elimination of concentration gradients in the cell. This has been observed in practice with a fluidized bed zinc electrode which performs well at charge-discharge rates of 1 A/cm^2 (Ref. 25). Continuous electrolyte circulation has also proven out in the zinc-air system (Ref. 26). Circulation produces adherent zinc deposits because of the reduced thickness of the diffusion layer. Zinc oxide settles out in the storage tank from the supersaturated zincate solution produced in the battery.

The cycle-life problem with zinc should be diminished greatly by completely stripping the zinc from the electrode surface on each discharge. It is believed that the use of a zinc electrolyte composition optimized for zinc adherence, combined with the strip-discharging of zinc on each cycle, will provide the most successful approach to achieving extended cycle life on the zinc electrode.

2.4 FERRO- FERRICYANIDE ELECTRODE

2.4.1 Reversible Potential

The ferro-ferricyanide ion couple reaches a rapid,reversible equilibrium, and many concordant values have been obtained for cells employing this couple in the form of the potassium salts. The potential, however, is a function of the potassium ion concentration, and the correction to an accurate standard EMF value becomes very large. With equal concentrations of the two anions, the observed potential is 0.48 V, whereas the standard potential is 0.36 V (Ref. 27). In a recent study (Ref. 28) of this cation effect on the equilibrium potential of the couple (using a supporting electrolyte of $LiNO_3$, over a concentration range of 0.2 to 10 M), the equilibrium potential ranged from 0.43 to 0.57 V. The explanation for this surprisingly large effect is that the $Fe(CN)_6^{-4}$ ion with a higher negative charge forms ion pairs with the cations of the supporting electrolyte more strongly than the $Fe(CN)_6^{-3}$ ion. As a result, the activity of the reduced species is lowered to a greater extent than that of the oxidized species, with increasing supporting electrolyte concentration and with the resultant rise in EMF.

In our cell tests, open circuit potentials of 1.8 to 1.9 V have been observed in the charged state. The standard reversible potential is only 1.58 V. The difference of 0.27 V is quite large and of course beneficial. It can be approximately accounted for by taking 0.48 V as the equilibrium potential of the ferro-ferricyanide couple, uncorrected for cationic effects, to compute the EMF of the zinc/ferricyanide cell, charged to a ferricyanide-ferrocyanide ion ratio of 1.0 in an electrolyte of 5 M NaOH. This estimated EMF is 1.79 V; the 70-mV

difference is no doubt largely due to the additional cationic coupling effect of 5M Na^+ compared to about 1M K^+. This work suggests that it may actually be possible to further increase the reversible potential of the ferro-ferricyanide couple by addition of inert salts to the alkaline electrolyte.

2.4.2 Reversibility of the Couple

A recent kinetic study on the ferro-ferricyanide ion couple in acidic,neutral, and alkaline solutions (Ref. 29), using a lithiated nickel-oxide electrode, shows that,in alkaline solution, the electrode reaction is sufficiently fast that both oxidation and reduction are under almost pure diffusion control.

In another study (Ref. 30), the effect of flow velocity in the range 1 to 10 m/s on the electrochemical reduction of potassium ferricyanide to ferrocyanide was measured. No activation polarization was found; only concentration polarization is observed. Linear increases in current densities with increasing velocities were obtained at all polarization potentials.

In other work (Ref. 31), the redox reaction was done on a graphite rotating disk electrode in 0.5 M KCl over the concentration range 10^{-2} to 10^{-4} M. The presence of a dimer is postulated in the absorption layer from which transfer occurs, which consists of one molecule of oxidized to one of reduced form. The dimer is more rapidly converted electrochemically than the monomer. The system was found to be reversible, although somewhat more complex than previous work had indicated.

Current-voltage curves were obtained for electrolytes 10^{-4} M in potassium ferrocyanide, potassium ferricyanide, and also for mixed ferro- ferricyanide ions, all in 1 M KCl at 21°C, using a tubular graphite electrode at flow rates of 6 to 14 mℓ/min (Ref. 32). It was found that the oxidation-reduction of ferro-ferricyanide ion is reversible under either quiescent or dynamic conditions.

In recent research (Ref. 28), the influence of alkali metal cations on the rate of the ferro-ferricyanide redox reaction was determined, using a current impulse

technique on a spherical gold microelectrode. In concentrated electrolytes, the reaction rate shows a first-order dependence on the electrolyte cation concentration due to an activated species which contains one or more cations. The catalytic influence of alkali metal cations on rate increases in the order $Li^+ < Na^+ < K^+ < Cs^+$.

From these studies, it is evident that the ferro- ferricyanide couple is thermodynamically reversible, with no activation polarization involved in the electrode reaction. This electrode operates solely under mass transfer control.

2.5.3 Chemical Stability

The chemistry of saturated ferro- and ferricyanide in highly alkaline solutions has not been thoroughly studied; however, between pH 3 and 10, ferro- and ferricyanide are both inert with respect to exchange of bound cyanides for free radiolabeled cyanide (Ref. 33). Loss of cyanide from these complexes is, therefore, not spontaneous but must be promoted for decomposition to occur. Past work on the decomposition of hexacyano iron species has been conducted principally in acid solutions, where decomposition occurs by successive protonation of cyanide and loss of HCN, followed by aquation (Ref. 34). Loss of cyanide with formation of the aquopentacyano iron specie can occur in the presence of acid (Ref. 8, 33, 34), UV light, (Ref. 36), and certain metal ions such as Hg^{2+} and Ag^+ (Ref. 37). The first intermediate in these decompositions, $Fe(CN)_5OH_2^{2,3-}$, is isolatable, and many pentacyano iron(III)complexes have been characterized (Ref. 38). Aquopentacyano iron (II) may also be prepared by reduction of nitroprusside (Ref. 35) and by solvolysis of aminopentacyano iron (II) (Ref. 54). In alkaline solution, aquopentacyano iron(II)and(III)behave as monoprotic acids (Ref. 39) and show appreciable stability. More highly aquated iron cyanides have been prepared (Ref. 40), but they are much less stable toward basic decomposition (Ref. 41).

Electrochemical (Ref. 42), substitution kinetic (Ref. 43), and electronic spectral (Ref. 44, 45) evidence has been presented in support of an equilibrium between monomeric and dimeric forms of aquopentacyano iron(II)and(III)in solution. Formation of dimers is favored by high ionic strength, low temperature, and high

$Fe(CN)_5OH_2^{2,3-}$ concentration; addition of lithium salts, urea, and high pH favor the monomer (Ref. 46, 47). Equilibrium between monomer and dimer is established slowly enough that they may be separated chromatographically (Ref. 47, 48).

Other binuclear species formed by the association of penta- and hexacyano iron complexes have been prepared and characterized (Ref. 49, 50). Bridging Fe-C≡N-Fe units are proposed for these complexes. In such a complex, the bridging CN would be expected to display an infrared stretching absorption shifted to higher frequency, in line with similar complexes of Co and Ni (Ref. 51, 52).

The photochemical decomposition of $Fe(CN)_6^{4-}$ has also been studied. Excitation with light of 360 nm or less causes the loss of CN^- producing $Fe(CN)_5^{3-}$, which aquates to $Fe(CN)_5OH_2^{3-}$. If irradiation is stopped after a short time, $Fe(CN)_5OH_2^{3-}$ and CN^- recombine to give ferrocyanide. Prolonged irradiation gives $Fe^{2+}(aq)$ and HCN or, if oxygen is present, prussian blue (Ref. 53).

The involvement of pentacyano iron species in the decomposition of alkaline ferro- ferricyanide electrolyte has been verified experimentally by the development of a distinctive violet color (λ_{max} = 430 nm) when reduced samples of old electrolyte are treated with nitrosobenzene in buffered solution. A spectrophotometric method based upon this color reaction (Ref. 8) allows the decomposition of the electrolyte to be followed during long-term cycling of operating cells.

Section 3
TECHNICAL APPROACH

3.1 CYCLIC VOLTAMMETRY

Initial substrate evaluations were conducted, using cyclic voltammetry, in the test setup shown in figure 3.1.1. The 5N NaOH electrolyte, saturated in ZnO or an electrochemically formed mixture of $Na_4Fe(CN)_6$ and $Na_3Fe(CN)_6$ was circulated at a nominal flow of 2.3 ℓpm and maintained at a temperature of 50^oC. A platinum screen having a surface area of 100 cm^2 was used as the counterelectrode, while the working electrode, the candidate substrate as typically shown in Figure 3.1.2, was installed perpendicular to the electrolyte flow path. The substrate, having a surface area reduced to approximately 0.5 cm^2 by Miccroflex stop-off lacquer was electrically monitored using a Hg/HgO reference electrode (0.098 V vs SHE) via a Luggin capillary placed 1-2 mm from its surface.

Cyclic voltammetric studies were carried out using the instrumentation shown in figure 3.1.3 which consists of a Princeton Applied Research (PAR) model 173 Potentiostat/Galvanostat equipped with a PAR model 176 Current Follower and controlled by a PAR model 175 Universal Programmer operating at 10 mV/sec scan speed. The current and voltage were monitored using a Houston Instruments model 2000 Omnigraphic X-Y recorder.

Typical methodology for the Zinc investigation consisted of starting the scan at OCV for the substrate, scanning negative to -1.30 V vs SHE, reversal of the scan direction, followed by positive scanning to -1.00 V vs SHE. Multiple scans were performed in order to determine any surface effects caused by the substrate.

Similarly, the methodology for the Redox electrode involved multiple cyclic scanning from OCV in a positive direction to 0.8 V vs SHE, reversal of the scan direction, followed by negative scanning to -0.4 V vs SHE.

3.2 TEST STAND AND CELL CONFIGURATION

The test stand, shown in figure 3.2.1, consists of six cell test setups with a common thermostated sandbox for electrolyte thermoconditioning and a water bath for general thermal control via a YSI model 74 Temperature Controller using

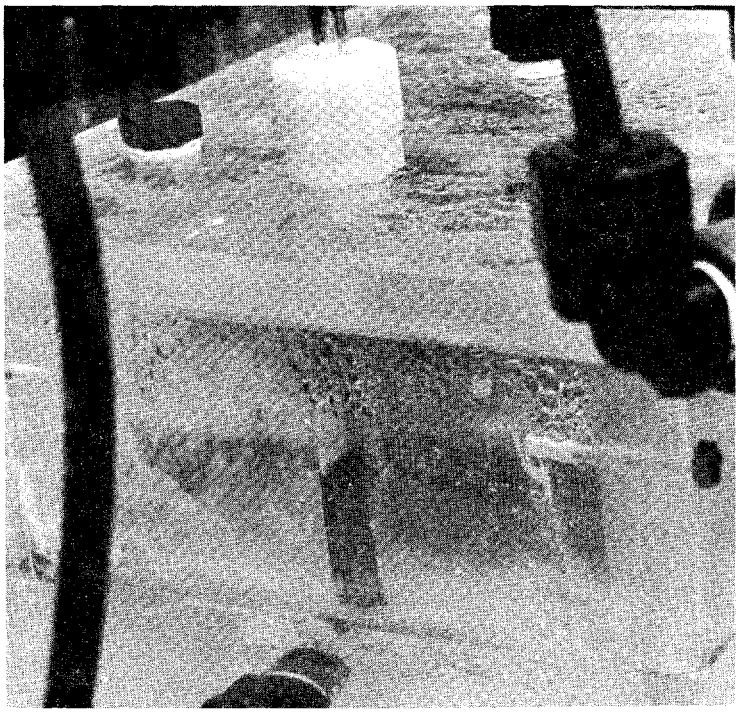

Figure 3.1.1 Cyclic Voltammetry Test Cell

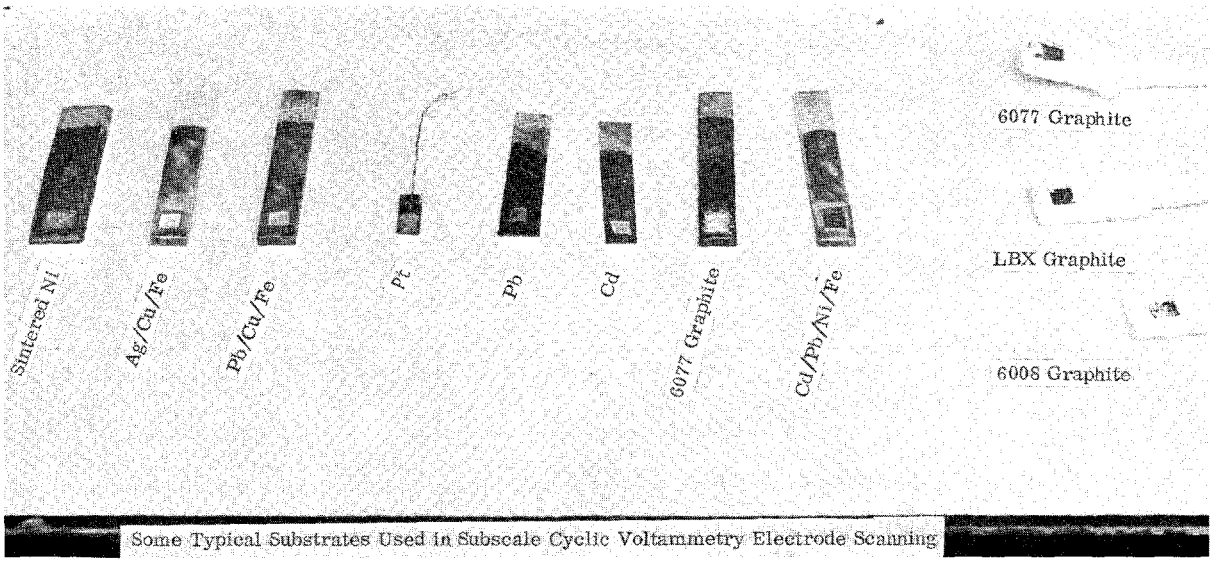

Figure 3.1.2 Typical Cyclic Voltammetry Substrates

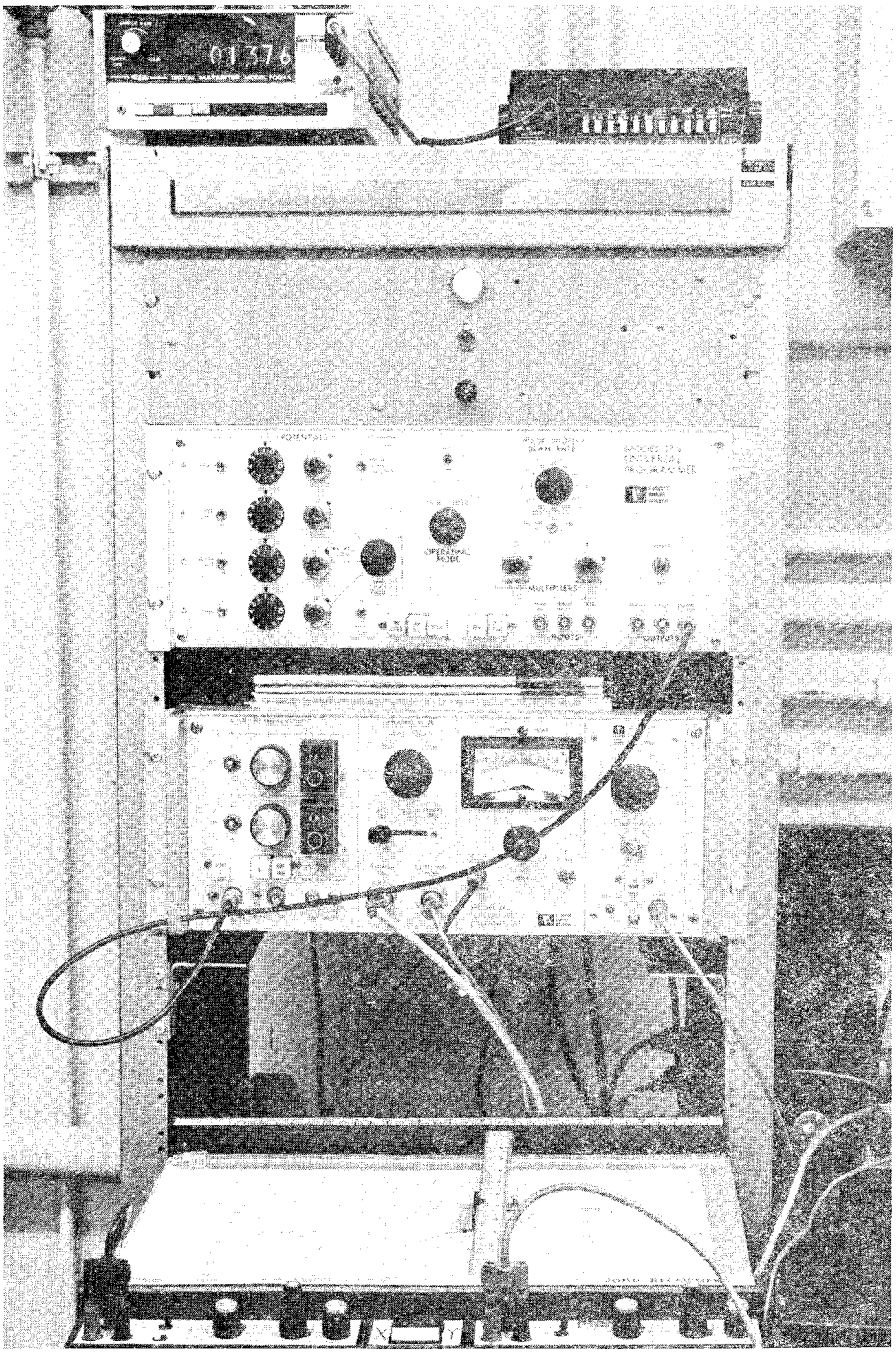

Figure 3.1.3 Cyclic Voltammetry Instrumentation

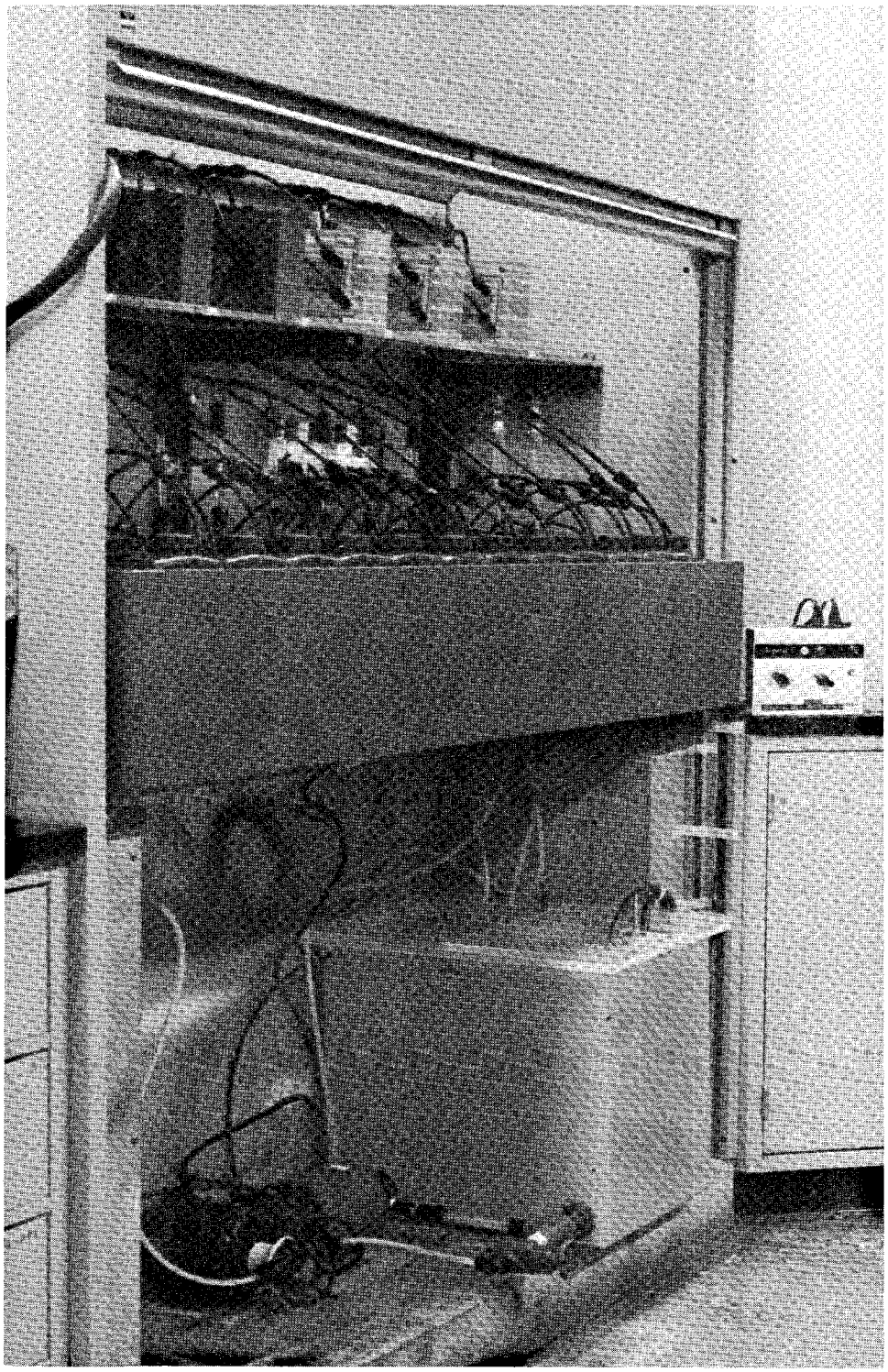

Figure 3.2.1 Test Stand

a YSI model 416 thermister probe embedded centrally in the sandbox. The five-gallon water bath is equipped with constant level control, a 1000-watt Glo-Quartz Type L1000 quartz heater on 100% duty cycle, a second 1000 watt quartz heater whose duty cycle is controlled by the temperature controller which also controls cooling via a Skinner model V52DA2100 solenoid valve actuating cold water flow through a stainless steel cooling coil, and an Eastern model D-6 pump to circulate the water through 3/8" copper tubing within the sandbox and then returning through the cell's acrylic thermojacketing.

Each electrolyte loop consists of an electrolyte reservoir and filter housing (Figure 3.2.2) embedded in sand, a pump, a valve to control flow rate and a flowmeter. The one-liter opaque polyethylene bottle reservoir, plastic filter housing containing a five-inch-long medium-density (25-50 micron) polypropylene web cartridge, March model MDX-MT3 Ryton pump, 1/2" PVC globe valve, and Gilmont size 5 flowmeter are all connected within the electrolyte loop with 3/8" O.D. opaque polyethylene tubing using opaque polypropylene Parker fittings.

Figure 3.2.3 shows a close-up of a 60 cm^2 disassembled cell detailing the sintered nickel electrode on the left, the Hg/HgO reference electrode and Luggin capillary, the cadmium-plated iron substrate on the right, and two of the separators used in this study on top of the cell. The cells are configured with internal thermojacketed acrylic endplates for maintaining the cells at desired set operating temperatures and are coated with opaque lacquer to eliminate photochemical decomposition of the redox electrolyte.

The sintered nickel electrodes for the flowing electrolyte ferro-ferricyanide redox couple, obtained from the Clevite Corp., are 3.175-mm thick sheets formed by pressing nickel carbonyl powder onto a nickel screen and sintering in a hydrogen atmosphere. The sheets are cut to 6.35 x 10.15 cm and an electrode stud strip spot-welded to it for electrical contact. The electrode stud strip is comprised of a 10 x 1 x 0.0635 cm nickel sheet to which two 4.76 mm diameter steel studs, 5.33 cm long, are silver-soldered 7.36 cm apart and are threaded to receive #10-32 nuts for the last 1.27 cm. The area around the silver-solder joint is coated with Trucor chemical milling mask to prevent contact with the electrolyte.

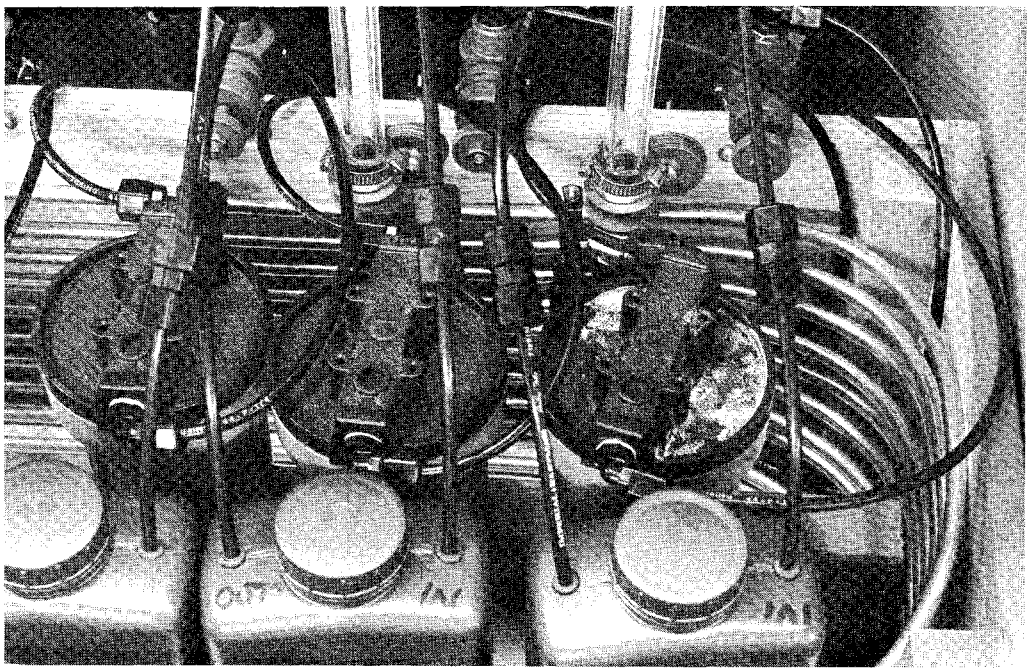

Figure 3.2.2 Section of Sandbox showing electrolyte reservoir, filter housing and copper cooling coils

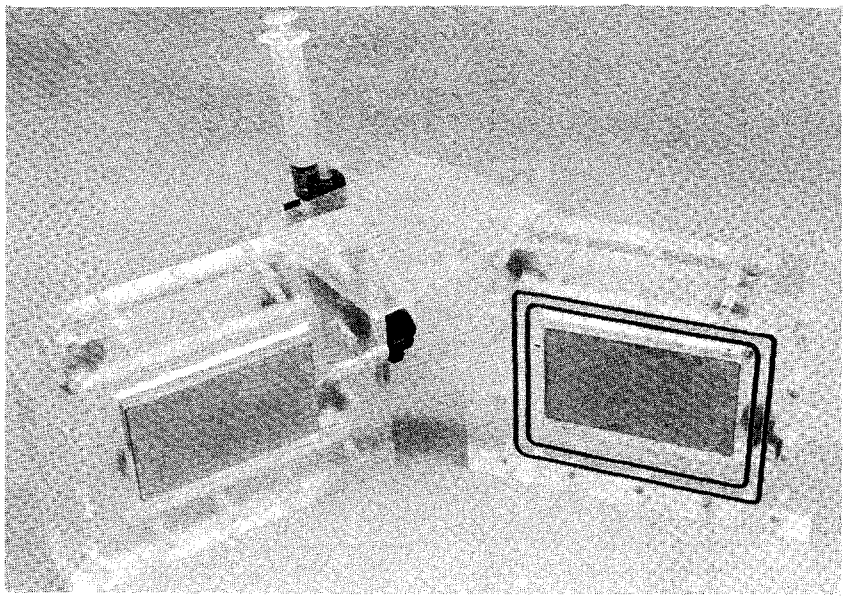

Figure 3.2.3 Disassembled Test Cell (60 cm^2)

The zinc electrode is constructed from 2.54-mm thick iron which is cut to 5.97 x 9.98 cm. A 6.35-mm hole is drilled at the geometric center and a 6.35-mm diameter stud, 5.33-cm long, is silver-soldered in place while the outer 1.27 cm of the stud is threaded for a #1/4-28 nut. The entire backside, the stud side, is coated with Trucor chemical milling mask for electrical insulation. The front is sandblasted and 25 microns of cadmium is electrodeposited from a cyanide plating solution.

The reference electrode, a standard Hg/HgO (0.098 vs SHE), is encased in a separate acrylic holder, shown in figure 3.2.4, and is comprised of a platinum wire contacting a pool of mercury which is in contact with a paste formed by mixing mercury and mercuric oxide with 5N NaOH. The sodium hydroxide acts as the supporting electrolyte in contact with the redox electrolyte via the Luggin capillary. The syringe, on top of the reference electrode compartment, is for clearing air blockages from the capillary.

3.3 MICROCOMPUTER SYSTEM AND INSTRUMENTATION

A major effort of this project was the design, construction, and implementation of a microcomputer system for complete control of half- and full-cell long-term cyclic testing including preliminary data reduction. The system is composed of two consoles having six basic modules. These are the microcomputer; the keypad and display panel; the data output and storage devices; the current sources panel; the current source power supplies; and the cell parameter selector panel for analog recorder output. Figure 3.3.1 shows the microcomputer console with microcomputer, keypad/display panel, teletype, and digital tape cassette recorder. Figure 3.3.2 shows the power source console with the cell parameter panel, the current source panel, and power supplies for the constant current sources.

The National Semiconductor Model RMC 80/11 microcomputer chassis contains the single board microcomputer (μC) board, a Burr-Brown model MP8632 8-bit, 32 differential channel analog to digital (A/D) converter board, and two Electronic Solutions, Inc. model RAM-8 8K-byte Random Access Memory (RAM) boards. The

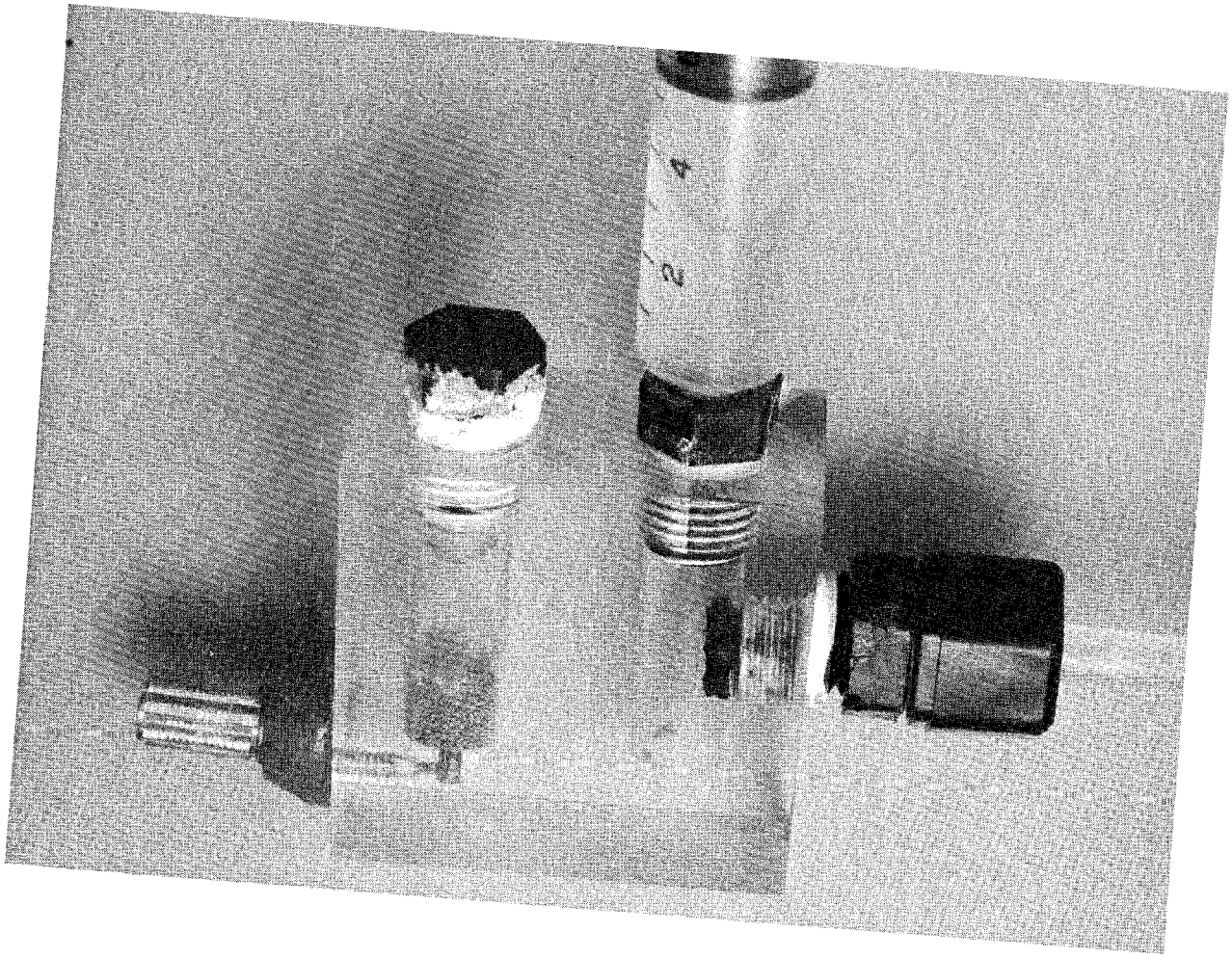

Figure 3.2.4 Acrylic Hg/HgO reference electrode holder

Figure 3.3.1 Microcomputer Console

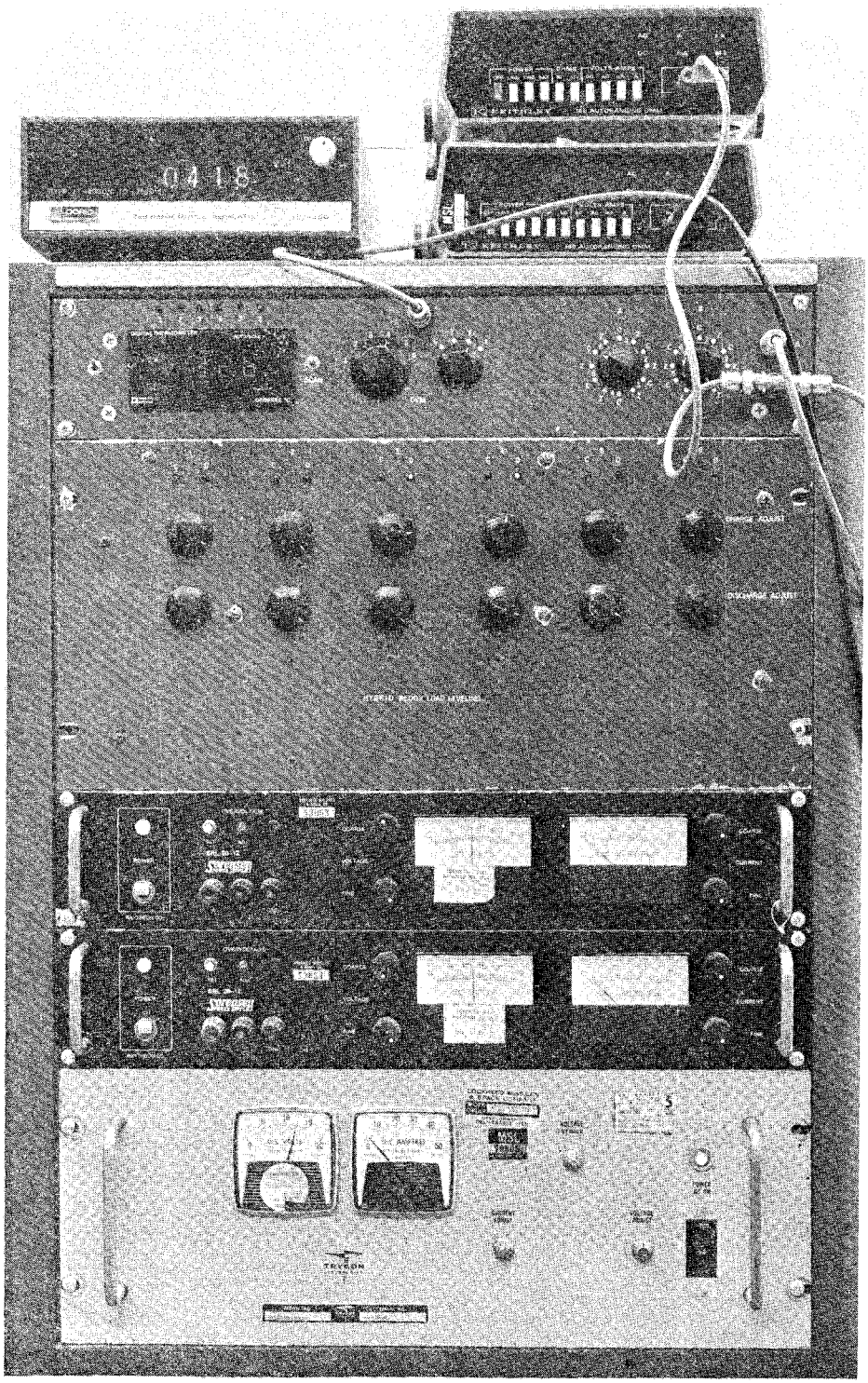

Figure 3.3.2 Power Source Console

present total memory is 8 Kbyte of UV-Erasable Programmable Read Only Memory (E-PROM) located on the μC board and 17 Kbyte of RAM with 1K located on the μC board.

The Keypad/display panel contains the keypad (circuitry shown in Appendix A) for operator control of the cells and for setting operational parameters; a 12-digit alphanumeric display (circuitry detailed in Appendix A) enabling the operator to monitor cell operation, setpoints, and cell parameters; and a real-time clock (circuit shown in Appendix A) for continuous update of time while the microcomputer makes various time-consuming excursions for data input and output. The microcomputer controls the cell operation via optically isolated relays which turn on constant current sources to charge or discharge the cells. The current source (circuitry shown in Appendix A) is a 3-amp adjustable voltage regulator used in the constant current mode with current adjusted by a variable potentiometer on the current source panel. Feedback to the microcomputer is provided by input into the A/D converter, of cell potential, zinc-reference potential, iron-reference potential, and current, as potentials developed across a precision current shunts and amplified by an instrumentation amplifier as the circuitry in Appendix A details.

The control program, written in "Tiny Basic" with slower portions written in assembly language consists of over 424 lines of Tiny Basic code (Appendix B) and 484 lines of assembly code (Appendix C) and utilizes virtually all of the available 17 Kbytes of RAM while the Tiny Basic interpreter resides in 3 Kbytes of E-PROM. The program is capable of controlling any number of batteries simultaneously but is limited to six with the present input/output devices and RAM size. The microcomputer controls the charge/discharge cycles of the rechargeable cells based upon the operator-determined cell parameters of charge time, overcharge potential, usable energy potential, zinc depletion potential versus a reference electrode. The current is integrated in each computer cycle and the amp-hours are continually updated so that at the end of the charge/discharge cycle the voltaic, coulombic, and energy efficiency is computed. These efficiencies and the cell parameters, voltage and current, at several points in the cycle are then data logged to a teletype and onto a digital tape

cassette recorder for later data manipulation and graphic representation using an IBM 360 Tymshare computer. The logic flow diagram for the control program is detailed in Figure 3.3.3. A more concise description of the microcomputer and its operations is given in Reference 56.

3.4 ELECTROLYTE PREPARATION

The redox electrolyte was prepared using reagent grade sodium hydroxide obtained from J. T. Baker, sodium ferrocyanide decahydrate (99%) from Research Inorganic Chemical Co., and deionized water.

The zincate electrolyte was prepared using reagent grade sodium hydroxide and zinc oxide obtained from J. T. Baker, and deionized water.

Reagents were introduced into the electrolyte reservoir and thoroughly mixed by pumping through the electrolyte loop to obtain saturation and thermal equilibrium.

3.5 EXPERIMENTAL METHODOLOGY

The electrolytes are circulated for 24 hours to achieve equilibrium prior to cell assembly. The cell is assembled in the following steps:

1. Install o-ring on electrical stud of zinc substrate.

2. Insert zinc substrate into position in acrylic half-cell.

3. Install o-ring, acrylic seal, and nut on electric stud then seal tight.

4. Repeat above procedures with the sintered nickel electrode modified by using several coats of Trucor chemical milling mask to seal the edges to prevent liquid leakage.

5. Cut and install a wet separator of proper dimensions onto o-ring of zinc half-cell.

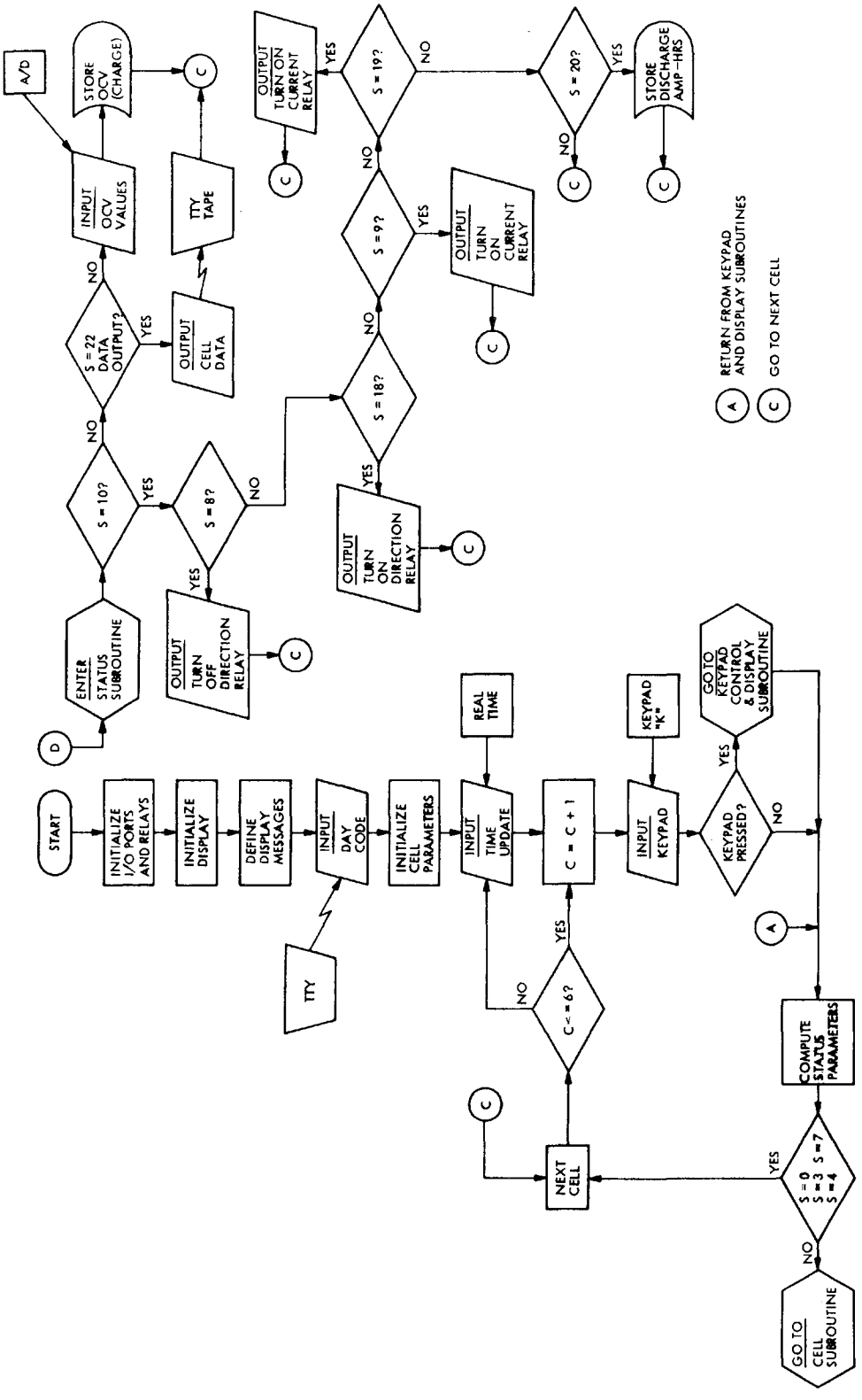

Figure 3.3.3 Microcomputer control program
Logic flow diagram (Start and Status Subroutine)

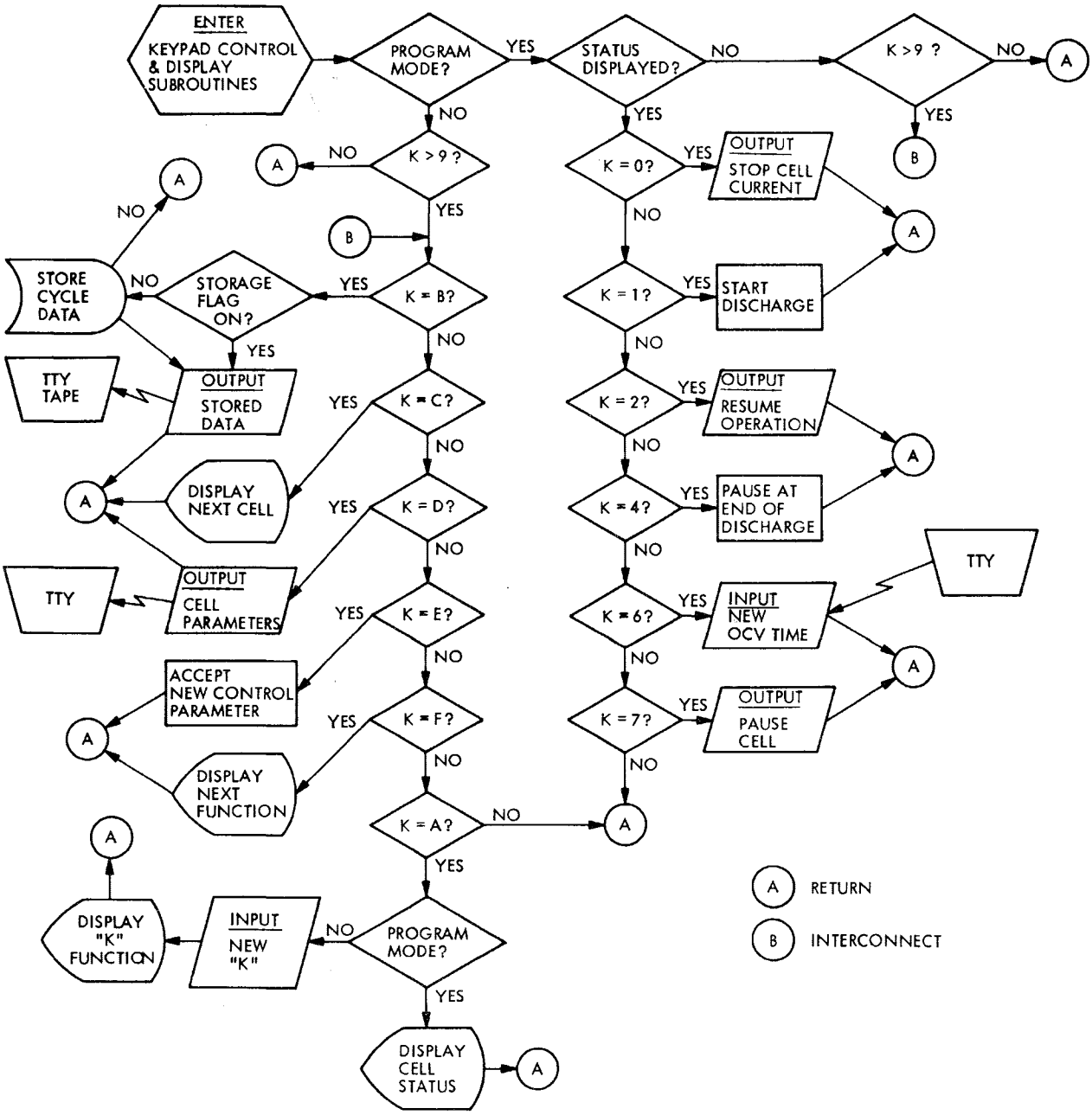

Figure 3.3.3 (continued) (Key Pad Control & Display Subroutines)

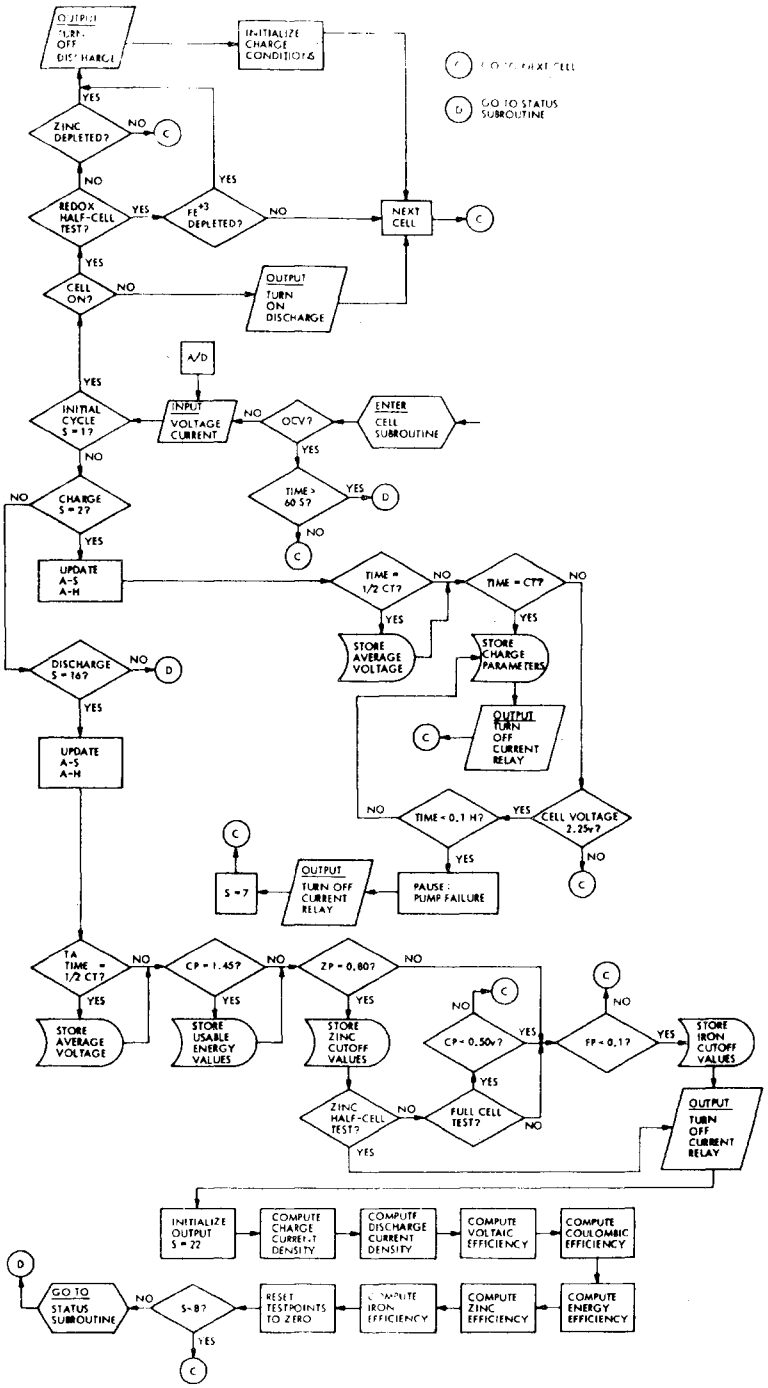

Figure 3.3.3 (continued) (Cell Control Subroutine)

6. Complete assembly with 14 bolts and nuts for total closure.

7. Install thermojacket water tube between two halves.

8. Install Hg/HgO reference electrode.

9. Place on test stand and complete electrolyte linkages and electrical hook-ups, and thermojacketing linkages.

A close-up of a cell assembled and in position for testing is shown in Figure 3.5.1. Separate wires are connected to each electrode to carry the current and to monitor voltage.

Unless otherwise noted, all testing was done at 40°C with equal charge/discharge periods of 2.0 hours; an overcharge potential of 2.25 volts for full cell tests and 2.50 volts for half-cell tests; an arbitrary usable energy potential of 1.45 V; a zinc depletion cutoff potential vs Hg/HgO of 0.80 V; and an iron depletion cut-off potential vs Hg/HgO of 0.10 V. Redox electrolyte flow rate was nominally 8 cm/sec while the zincate electrolyte was nominally 10 cm/sec, decreasing during charge due to decreased cell volume.

3.6 ANALYTICAL PROCEDURES

Chemical analyses of electrolytes were made using the following procedures:

Hydroxide - A standard acid-base titration with 1 N HCl, obtained from Ricca Chemical Co. and having NBS traceable standardization, to a phenolphthalein endpoint

Ferrocyanide - A standard ceric sulfate titraion of an acidified (4M H_2SO_4) aliquot with 0.1 N ceric sulfate, obtained from Fischer Scientific and having NBS traceable standardization, to a ferroin endpoint

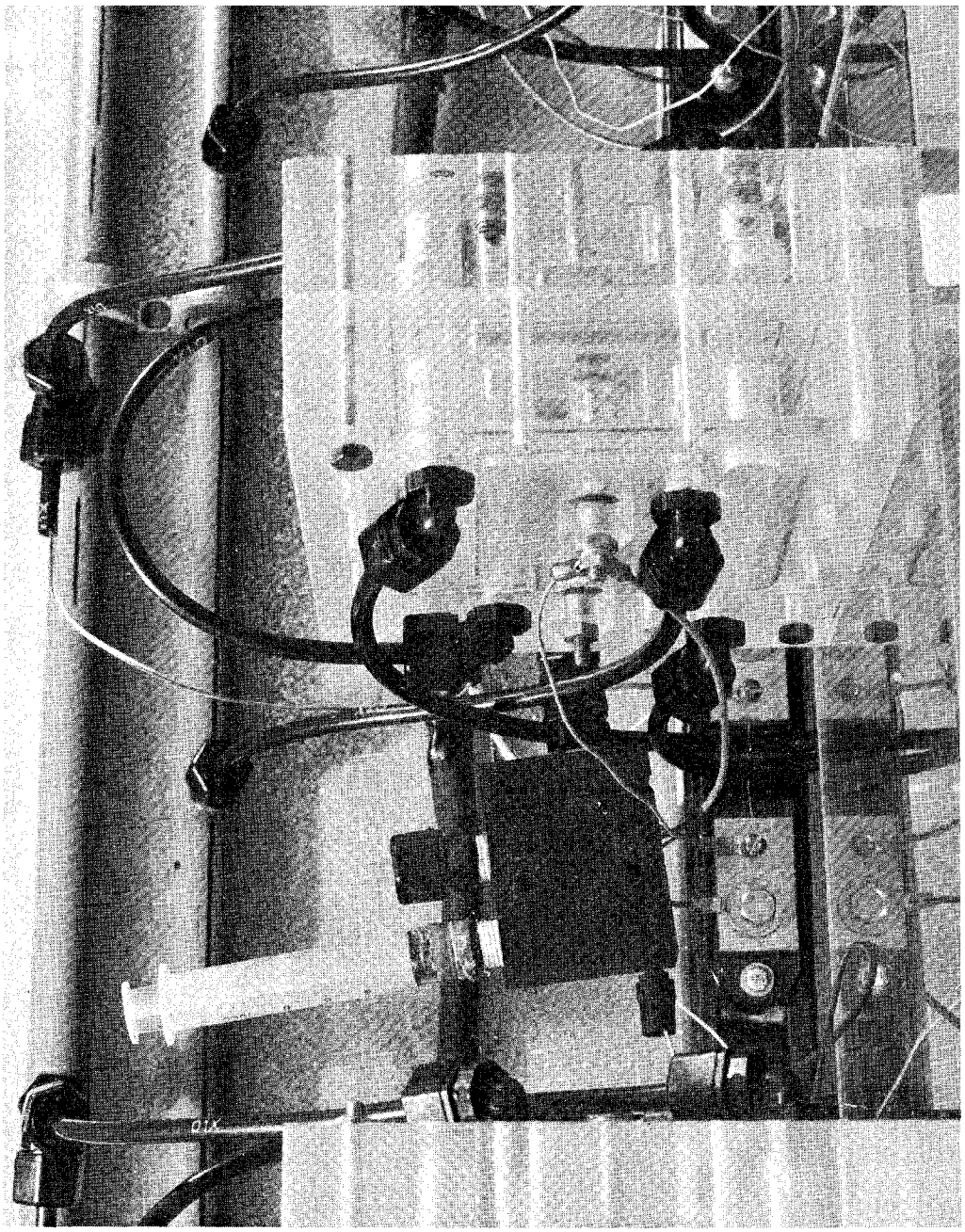

Figure 3.5.1 Close-up of 60 cm^2 cell undergoing cyclic testing

Ferricyanide - A standard indirect iodine-starch titration of the acidified (4M H_2SO_4) aliquot with 0.1 N sodium thiosulfate, obtained from Ricca Chemical Co. and having NBS traceable standardization, to a starch endpoint.

Zincate - Atomic absorption analysis of the acidified supernatant at 3075.9 Å using the method of standard additions on a Varian model 1200 Atomic Absorption Spectrophotometer.

Aquopentacyano iron (II or III)

Concentrations of aquopentacyano iron(II) and(III) were determined by an adaptation of a published method involving spectrophotometric determination of the violet complex with nitrosobenzene $[Fe(CN)_5C_6H_5NO]^{3-}$(ref 35). Because Fe (III) oxidizes nitrosobenzene, and prevents the violet complex from forming, samples must be treated with a noncoordinating reducing agent before adding the nitrosobenzene reagent. For the alkaline samples usually studied, 37% formalin solution was a convenient and effective reducing agent which did not interfere with the color reaction. After reduction of a sample was judged complete by the disappearance of any yellow color, the pH of the solution was adjusted to 9.9 in a carbonate buffer, and treated with at least a two-fold excess of nitrosobenzene as a 0.4% ethanol solution. After at least one hour, the sample was diluted and its absorbance at 5300 Å was measured on a Cary model 14 UV-visible spectrophotometer. Absorbance was related to $[Fe(CN)_5C_6H_5NO]^{3-}$ concentration through a standard curve. Standards were prepared from $Na_2NH_4Fe(CN)_5NH_3$ followed by confirmation of Fe concentration by atomic absorption analysis.

Infrared solution spectra were recorded in a CaF_2 cell using a Nicolet 7000 FTIR system. The spectrum of a NaOH blank was subtracted from that of the samples dissolved in NaOH solution before the spectrum was plotted.

3.7 BASELINE CALCULATIONS AND DATA PROCESSING

The calculations performed by the microcomputer are the voltaic, coulombic, and energy efficiencies of the full cell, and coulombic efficiency of each half-cell. The voltaic efficiency is calculated by dividing the cell potential at half discharge by the cell potential at half charge. The coulombic efficiencies are computed by dividing the amp-hours discharge by the amp-hours charge. The amp-hours discharge is picked up at three points during the discharge cycle; the usable energy potential of 1.45 volts; the zinc depletion potential of 0.80 volts vs Hg/HgO; and the iron depletion potential of 0.10 volts vs Hg/HgO. The usable energy efficiency for the cell is calculated by multiplying the voltaic efficiency by the usable energy coulombic efficiency. Another calculation done by the microcomputer is the average current density on charge and discharge, which is computed by dividing the accumulated amp-hours by the total hours and 60 cm^2 to report a current density in units of mA/cm^2. It should be noted that the voltaic and energy efficiencies obtained from half-cells are not meaningful in an absolute sense, since the voltage difference measured is from the electrode to a reference electrode. In a relative sense, they are valuable for following single-electrode performance with cycle life. The product of the two half-cell voltaic, coulombic, or energy efficiencies, will, of course, give the true corresponding single cell efficiency. At the end of each discharge cycle, cell data is outputted to a Texas Instruments model 735 silent terminal and a Tymshare model 600 digital data cassette recorder. Typical cell data output by the microcomputer is shown in figure 3.7.1 with the following identification.

a	b	c	d	e	f	g	h	i	j	k	l
79/253	12:41:55	6	606	2.0	37.0	36.7	91.5	96.8	88.3	97.7	97.7

m	n	o	p	q	r	s	t	u	v	w	x	y
1.43	0.47	1.89	1.82	1.31	0.43	1.13	0.33	0.78	0.23	0.78	0.23	1.70

Figure 3.7.1 Typical Cell Data Output by Microcomputer

First line

a. Year/Day
b. Time
c. Cell number
d. Number of cycles
e. Charge time (hours)
f. Current density charge
g. Current density discharge
h. Voltaic efficiency
i. Coulombic efficiency
j. Usable energy efficiency
k. Zinc coulombic efficiency
l. Iron coulombic efficiency

Second Line

m. Zinc potential vs Hg/HgO at 1/2 charged
n. Iron potential vs Hg/HgO at 1/2 charged
o. Cell potential at end of charge
p. Open circuit potential charged
q. Zinc potential vs Hg/HgO at 1/2 discharged
r. Iron " at 1/2 discharged
s. Zinc " at usable energy point of discharge
t. Iron " at usable energy point of discharge
u. Zinc " at Zinc depletion point of discharge
v. Iron " at Zinc depletion point of discharge
w. Zinc " at Iron depletion point of discharge
x. Iron " at Iron depletion point of discharge
y. Open circuit potential discharged

Due to the 8-bit resolution of the A/D comverter the accuracy of all potentials is ± 20 mV while the accuracy of the efficiency calculations is ± 10%.

Every four days, or when necessary, the data stored on the digital cassette is transferred to a Tymshare IBM 360 computer. At the end of each month the data is sorted into individual cell data using the program detailed in Appendix D. After merging the month's data for a particular cell with data from previous months of testing,the cell data report program, detailed in Appendix E, is used to itemize and average the accumulated cell data and then generate a report form as shown in Appendix F for the cycle life test in progress. The program also calculates statistical averages and denotes when a particular cycle energy efficiency exceeds 1σ, 2σ, or 3σ's. Cycles exceeding 3σ are not included in the calculations and are indicative of thermal control, micro computer control, reference electrode plugging, or pump malfunction problems.

The report program creates a reduced data file which a plotting program, Appendix G, uses to compute a 5, 7, or 11-point smoothing of the data and creates a

plot data file. The plot data file consists of x and y values for cycle number and efficiency, respectively, which are then used to create a final graph on a Zeta model 500 digital plotter using the plotting routines shown in Appendix H. The program prints a point for each individual cycle and then draws a line which represents 5- or 7-point smoothing, less than 100 cyles, or 11-point smoothing, for more than 100 cycles of data.

Section 4
RESULTS AND DISCUSSION

4.1 ZINC SUBSTRATE EVALUATION

Using those factors affecting zinc-zincate electrode substrate selection discussed in Section 2.3.1 as guidelines, the following substrates were evaluated for polarization characteristics by cyclic voltammetry, with platinum included as a control: Pt, Cu, Ag, Pb, Sn, Cd, and four types of anode-grade graphite. Typical cyclic voltammograms at 10 mV/s are shown in figures 4.1.1 - 4.1.7 and are indicative of the reaction:

$$Zn(OH)_2 + 2e^- \rightleftarrows Zn + 2OH^- \qquad E^0 = -1.245$$

Other effects are indicated by several of the voltammograms such as the formation of a copper-zinc alloy on the copper substrate, Figure 4.1.1, and a porous silver coating on the silver substrate prepared by electrodeposition of silver onto iron with an intermediate copper strike. Evidence for copper-zinc alloy appears as a shoulder at -1.2V in figure 4.1.2. Platinum, figure 4.1.3, is known to exhibit a low hydrogen overvoltage which the cyclic voltammogram confirms. Onset of hydrogen evolution occurs at -.95 V vs SHE in alkaline zincate electrolyte which compares with the standard potential of -0.828 V in alkaline electrolyte. The graphites all present very poor performances except for the Stackpole 6077 graphite, figure 4.1.7, commonly used in the chlor-alkali industry. The other graphites evaluated were all from Stackpole Carbon Co. and consisted of 6015 and 6008 graphites and baked LXB carbon. The remaining cyclic voltammograms were similar and indicative of good zinc cyclic conditions. Figure 4.1.8 details the polarization characteristics of the candidate substrates which shows decreasing overvoltage on charge for the sequence lead, tin, cadmium, and 6077 graphite, while on discharge the order is slightly different; namely, lead, cadmium, tin, and then 6077 graphite.

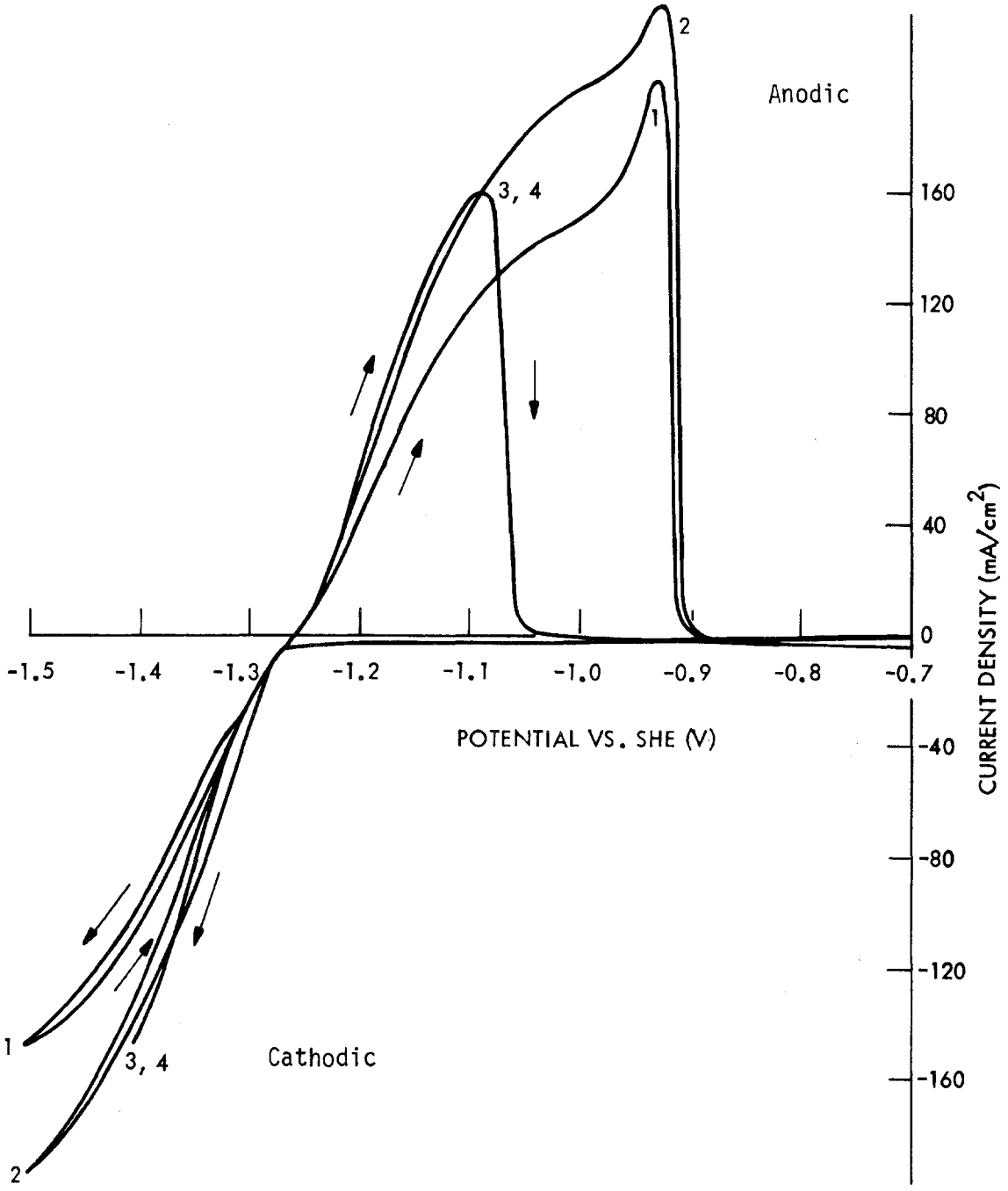

Figure 4.1.1 Zinc Cyclic Voltammetry on Copper

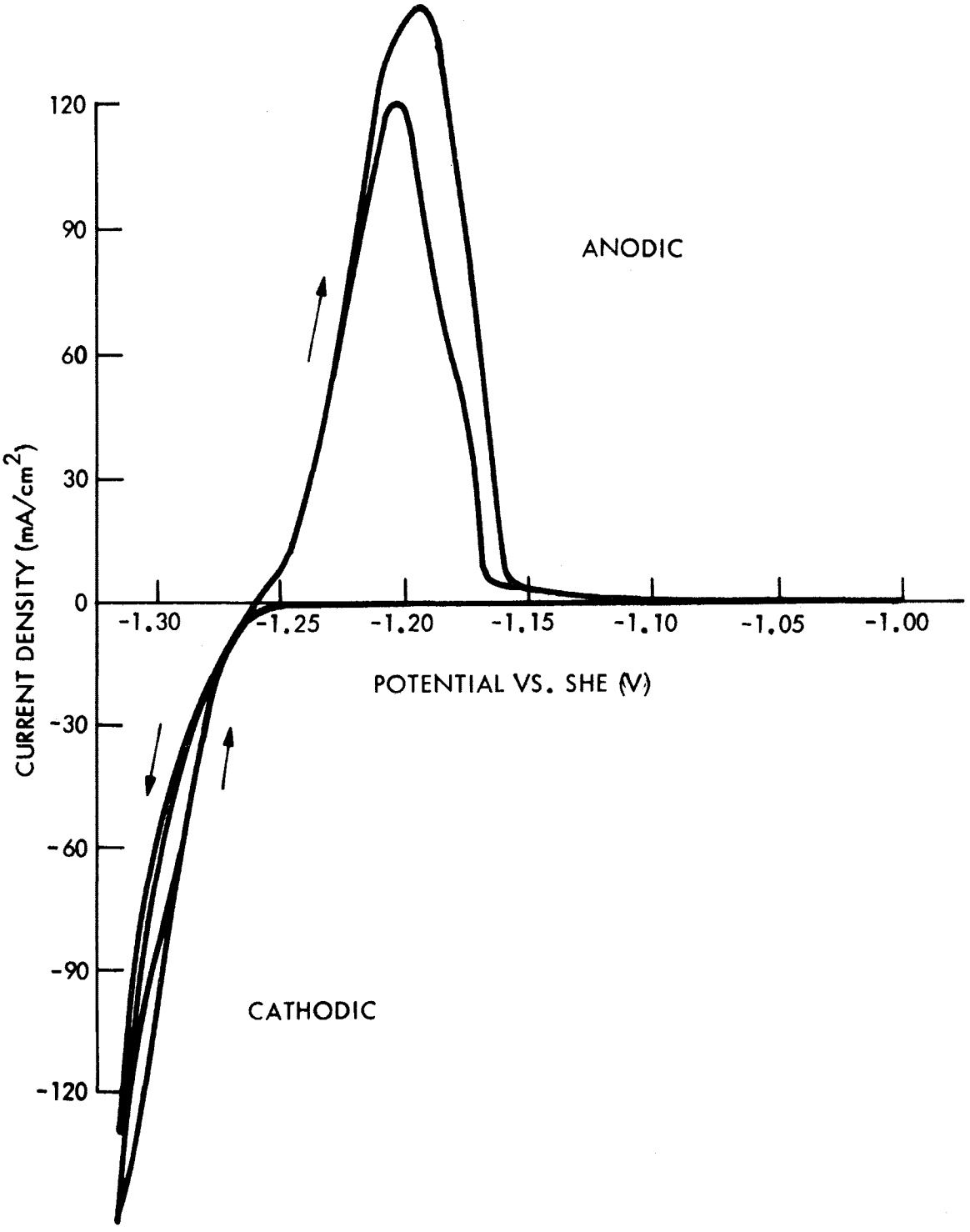

Figure 4.1.2 Zinc Cyclic Voltammetry on Electrodeposited Silver (Ag/Cu/Fe)

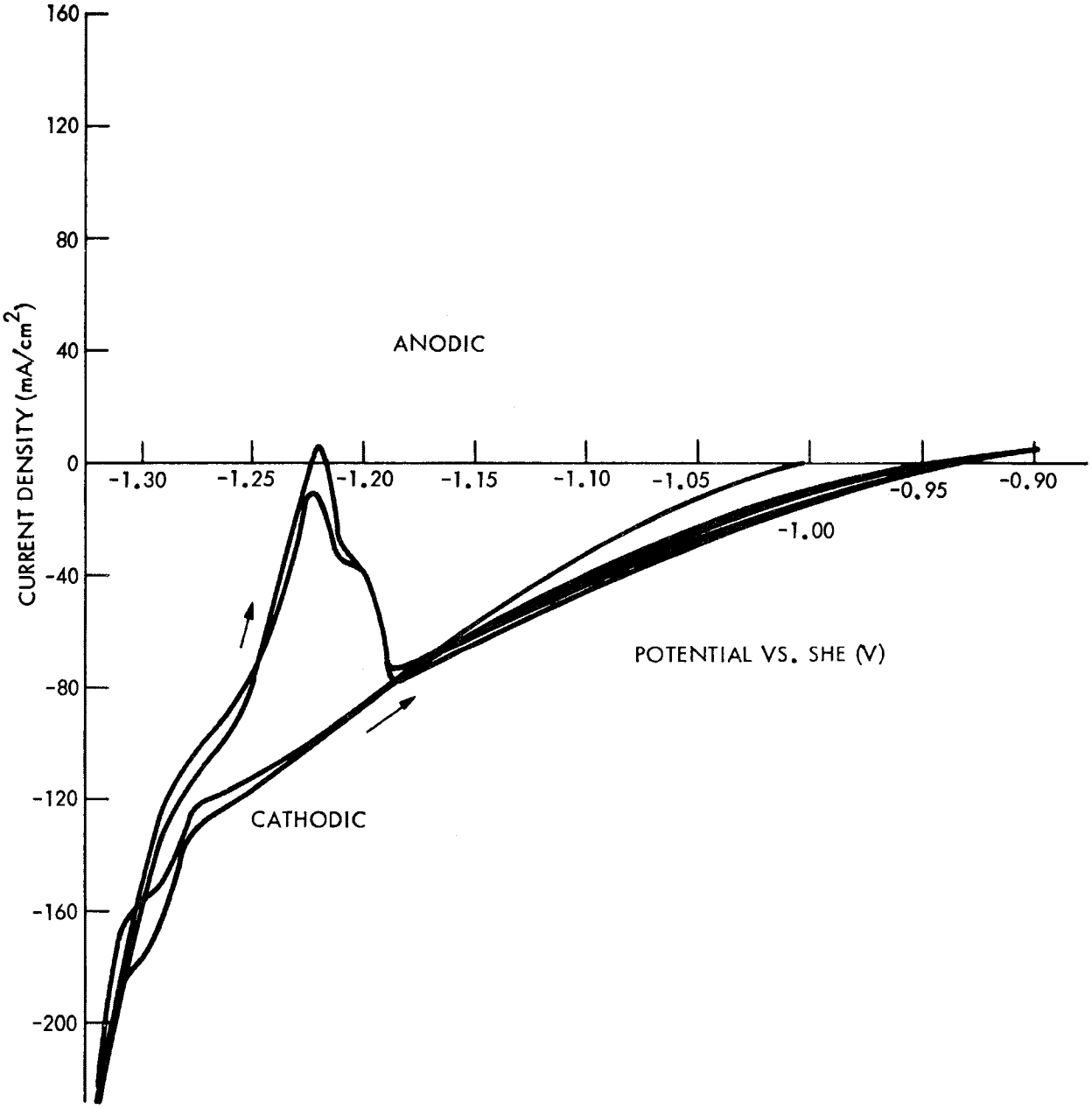

Figure 4.1.3 Zinc Cyclic Voltammetry on Platinum

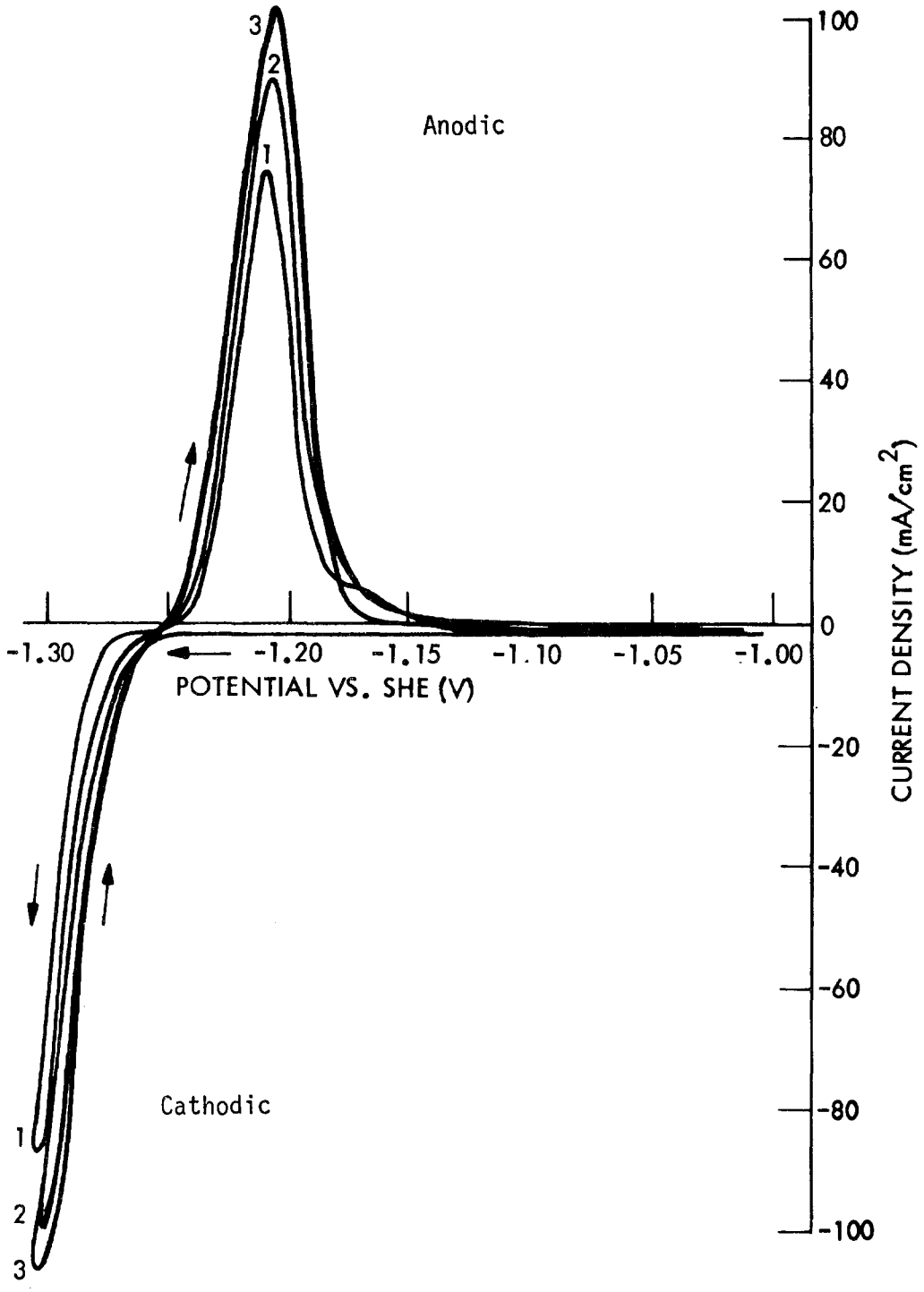

Figure 4.1.4 Zinc Cyclic Voltammetry on Lead

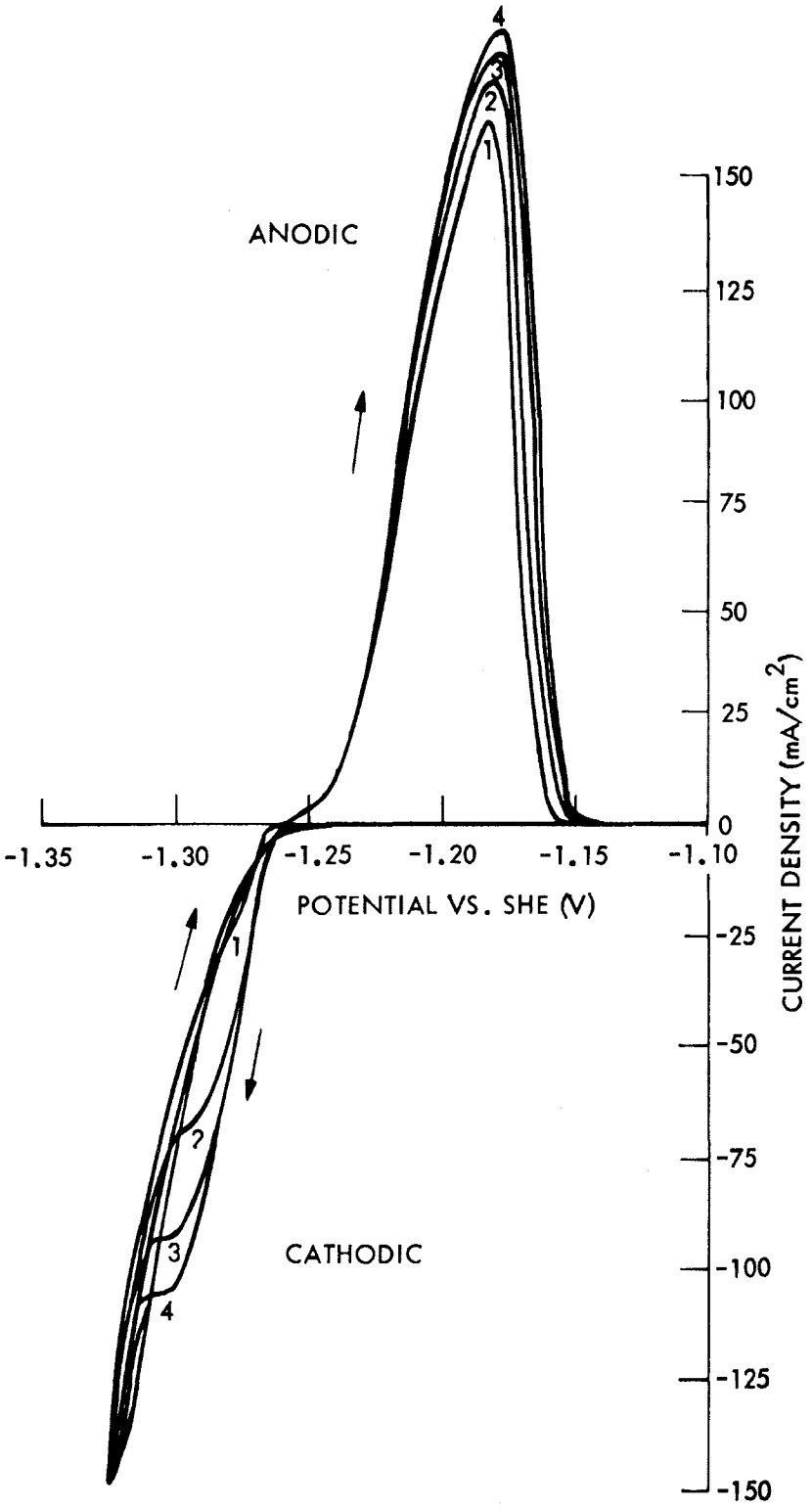

Figure 4.1.5 Zinc Cyclic Voltammetry on Tin

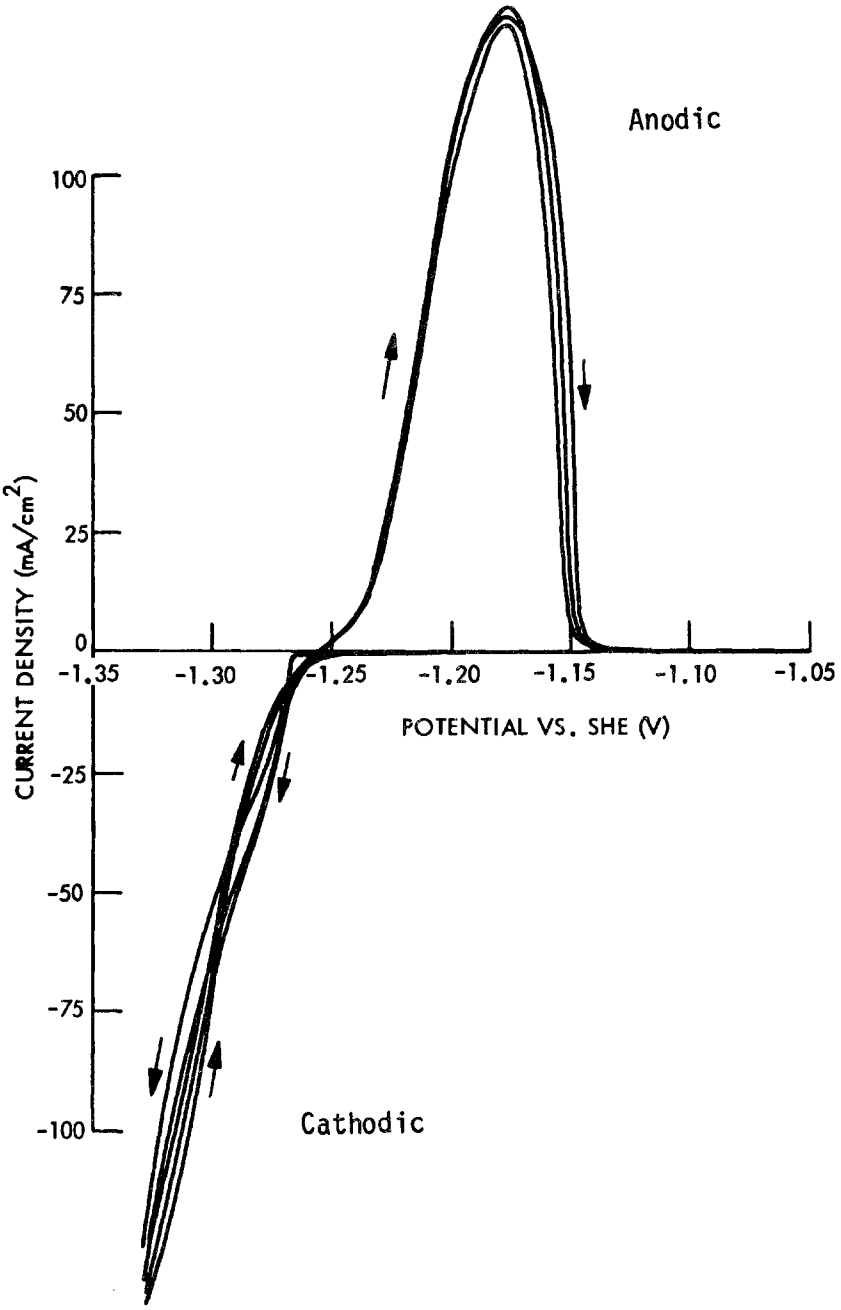

Figure 4.1.6 Zinc Cyclic Voltammetry on Cadmium

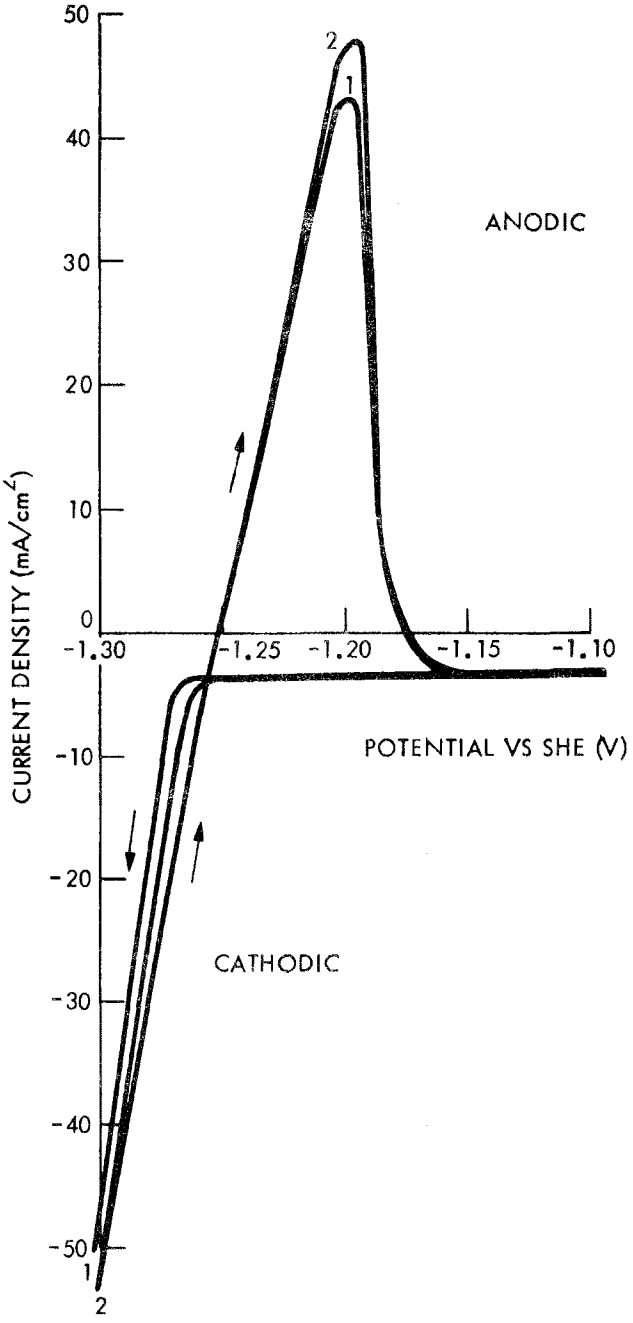

Figure 4.1.7 Zinc Cyclic Voltammetry on Stackpole 6077 Graphite

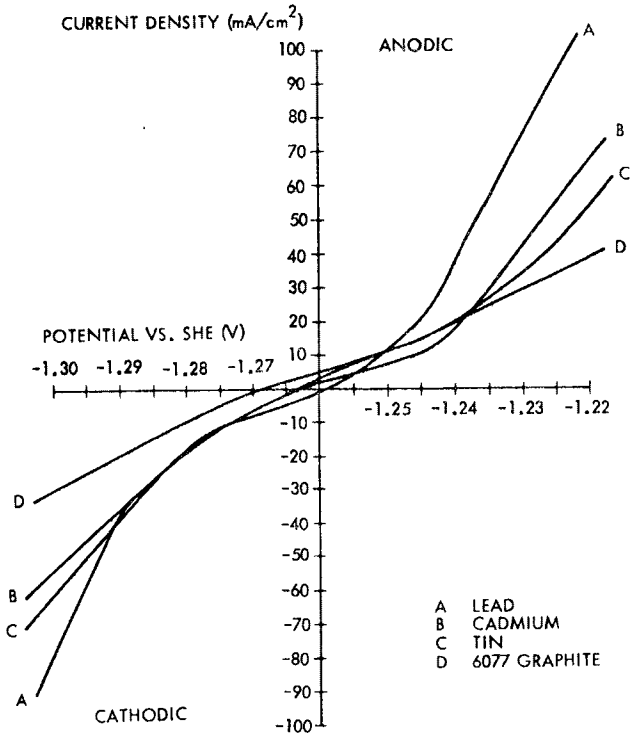

Figure 4.1.8 Zinc Polarization on Selected Substrates

In an actual battery, the selected substrate material would be electrodeposited upon an inexpensive backing material such as iron. Candidate substrates prepared by electrodeposition via various intermediate strikes were evaluated by cyclic voltammetry and the results are shown in figures 4.1.9 - 4.1.13. Except for tin electrodeposited over copper and nickel strikes, which displays a porous deposit as evidenced by the appearance of a copper-zinc alloy peak at -1.17 V vs SHE, all candidate substrates display encouraging polarization characteristics as shown in figure 4.1.14.

Comparing the current densities with those obtained for the pure metal evaluation, the roughness factor for the electrodeposited substrates is ca. 3. Cadmium plated via two different procedures displays similar overpotentials, whereas lead electrodeposited with a copper strike exhibits a slightly higher overvoltage on charge.

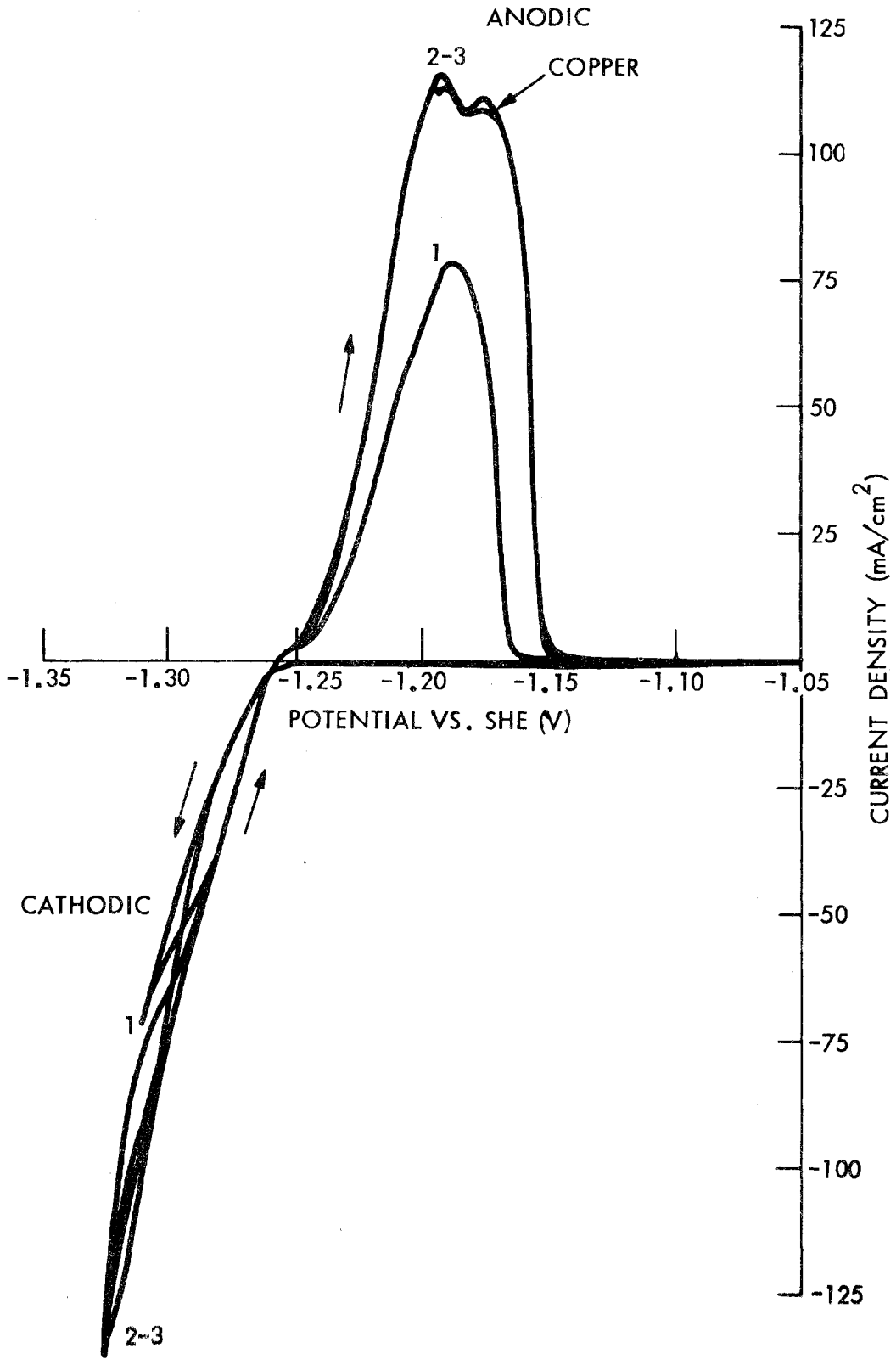

Figure 4.1.9 Zinc Cyclic Voltammogram on Electrodeposited Tin Sn/Cu/Fe

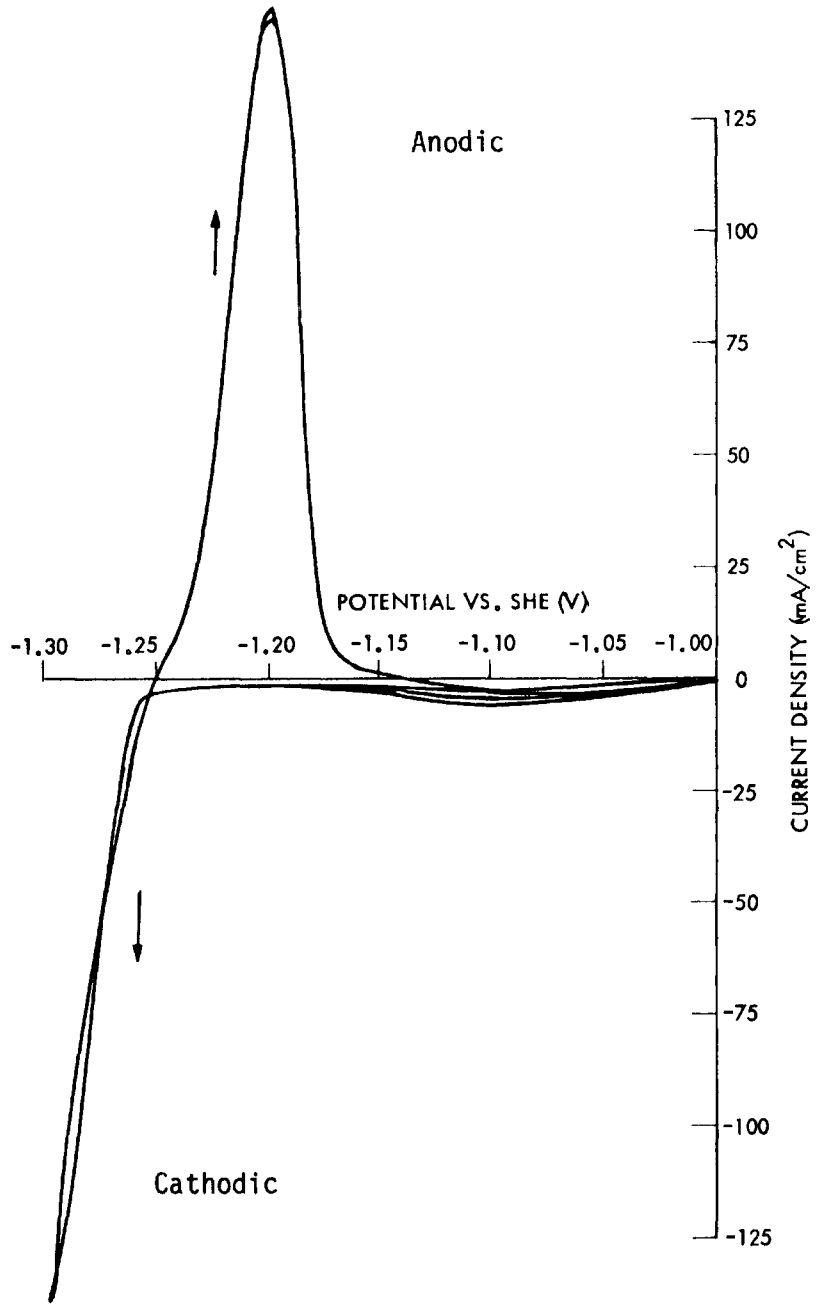

Figure 4.1.10 Zinc Cyclic Voltammogram on Electrodeposited Cadmium (Cd/Cu/Fe)

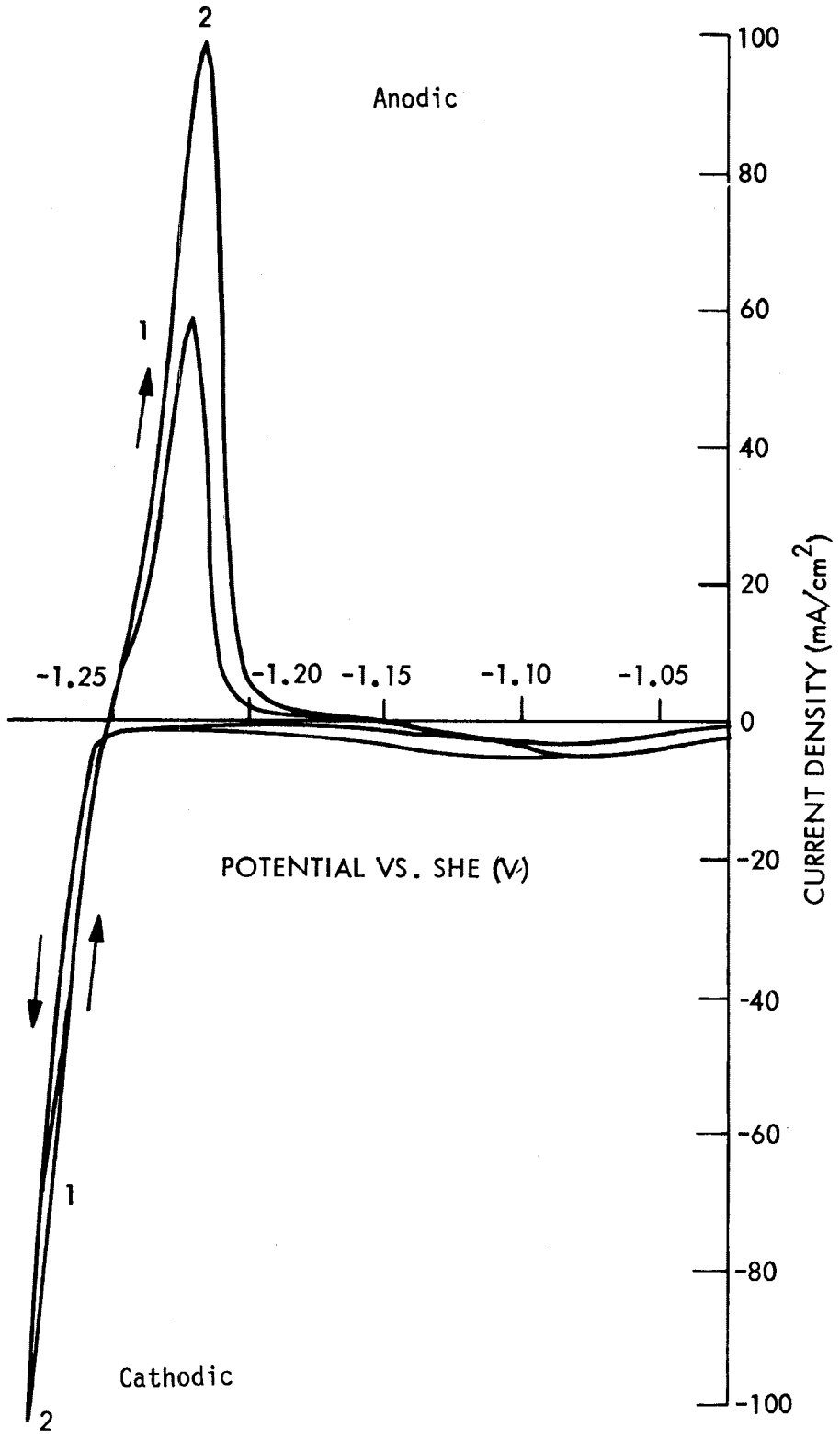

Figure 4.1.11 Zinc Cyclic Voltammogram on Electrodeposited Cadmium (Cd/Pb/Ni/Fe)

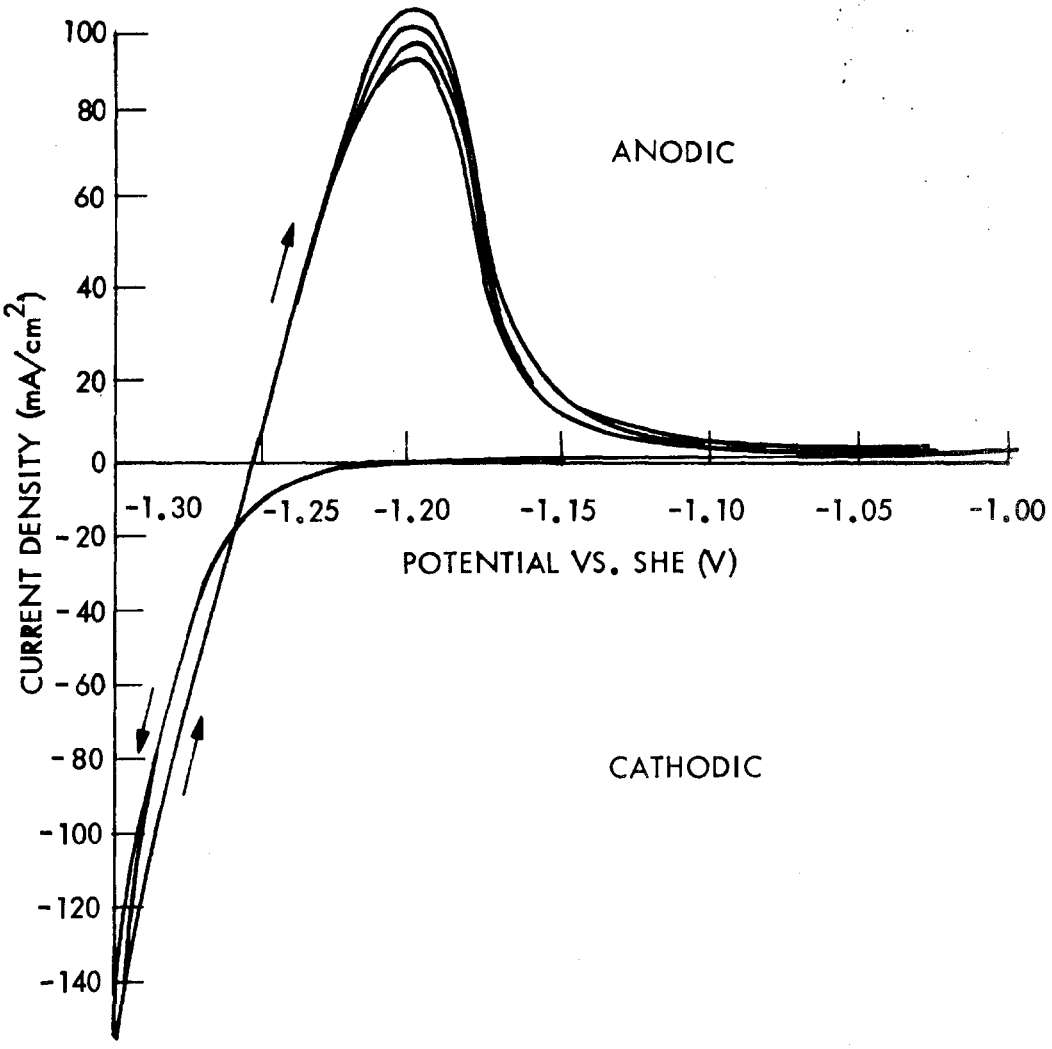

Figure 4.1.12 Zinc Cyclic Voltammogram on Electrodeposited Lead (Pb/Cu/Fe)

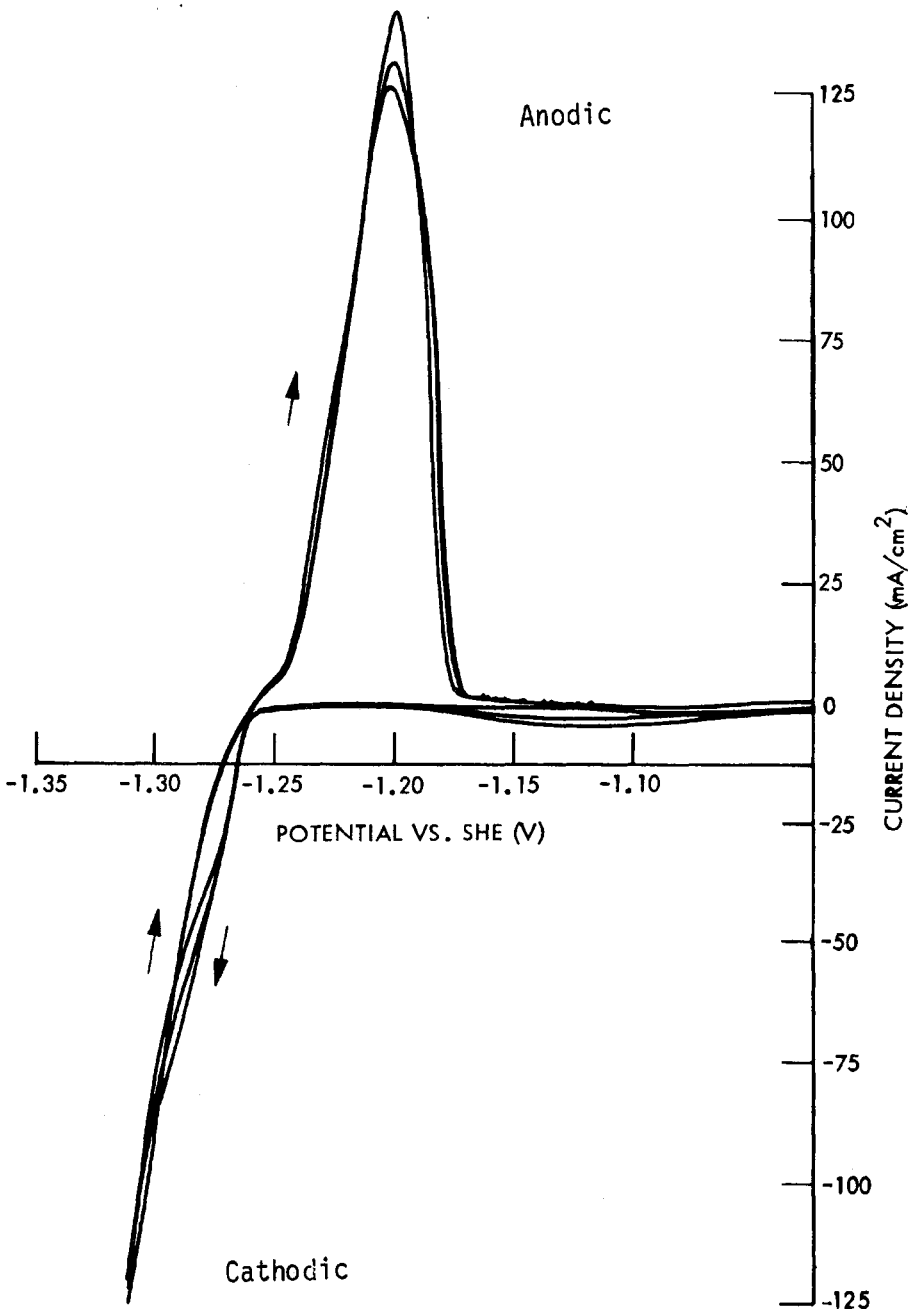

Figure 4.1.13 Zinc Cyclic Voltammogram on Electrodeposited Tin (Sn/Ni/Fe)

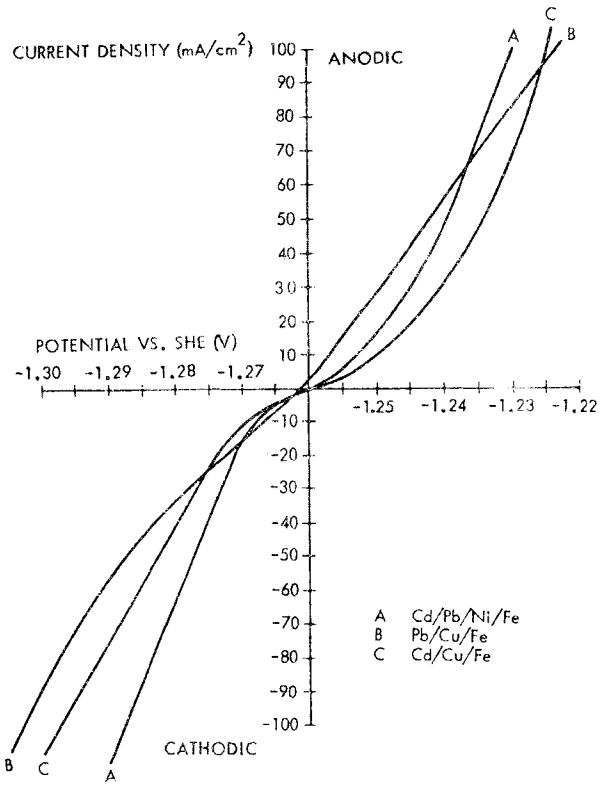

Figure 4.1.14 Zinc Electrode Polarization on Electrodeposited Metallic Substrates

Substrates prepared with cadmium plated iron (Cd/Cu/Fe), lead plated iron (Pb/Cu/Fe), and 6077 graphite were evaluated for adherency of zinc deposit using cyclic efficiency measurements which are discussed in section 4.5.1.

4.2 FERRO-FERRICYANIDE REDOX ELECTRODE INVESTIGATION

4.2.1 Substrate Evaluation

The prime requirements for this redox substrate are: inertness to anodic oxidation in sodium hydroxide electrolyte; a high oxygen overvoltage; reversibility with the ferro-ferricyanide redox couple; and chemical inertness to ferricyanide. Nine candidate substrates were evaluated by cyclic voltammetry using the procedure described in section 3.1. Substrates examined were nickel sheet, sintered nickel, copper, lead dioxide, Stackpole 6077, 6015, and 6008 graphites, Stackpole baked LXB carbon, and platinum as a control. In each case the sub-

strate exhibited low limiting current densities and low oxygen overvoltages as shown representatively in figures 4.2.1 and 4.2.2. Notice that for sintered nickel oxygen evolution occurs at potentials very close to ferrocyanide oxidation while the 6077 graphite displays a well defined oxidation plateau but the hysteresis indicates an oxygen reduction taking place on the surface of the graphite which would be counterproductive. The results of the subscale cyclic voltammetry studies were contrary to results from precontractual investigations in which a porous nickel flow-through electrode was used with good redox performance.

Transferring the redox substrate evaluations to the 60 cm^2 half-cell configuration described in section 3.2, and using laminar flow parallel to the substrate, similar results to those with sheet nickel were obtained using a sintered nickel substrate, as shown in figure 4.2.3. However, when the flow was directed through the porous nickel much better results were obtained, as shown in figure 4.2.4.

The redox substrate investigation is summarized in figure 4.2.5. It is evident that by operating the porous electrode in the flow-through mode, concentration polarization is reduced dramatically. Nickel is the only porous substrate evaluated to date. Tests with a 100 pore per inch Reticulated Vitreous Carbon obtained from FluoroCarbon Corp. were unsuccessful because of the inability to obtain a low resistance bond for attachment of conductive tabs with this fragile material, either with epoxy or contact bonding. Porous carbon or graphite is preferred to nickel on a cost basis.

4.2.2 Chemical Stability

During the precontractual work on the hybrid redox battery, slow decomposition of the alkaline ferricyanide electrolyte was observed. This was characterized by a gradual darkening of the solution, accumulation of ferric species which were not electrochemically reducible, eventual precipitation of ferric hydroxide, and loss of cell capacity. While slow, such decomposition could be significant

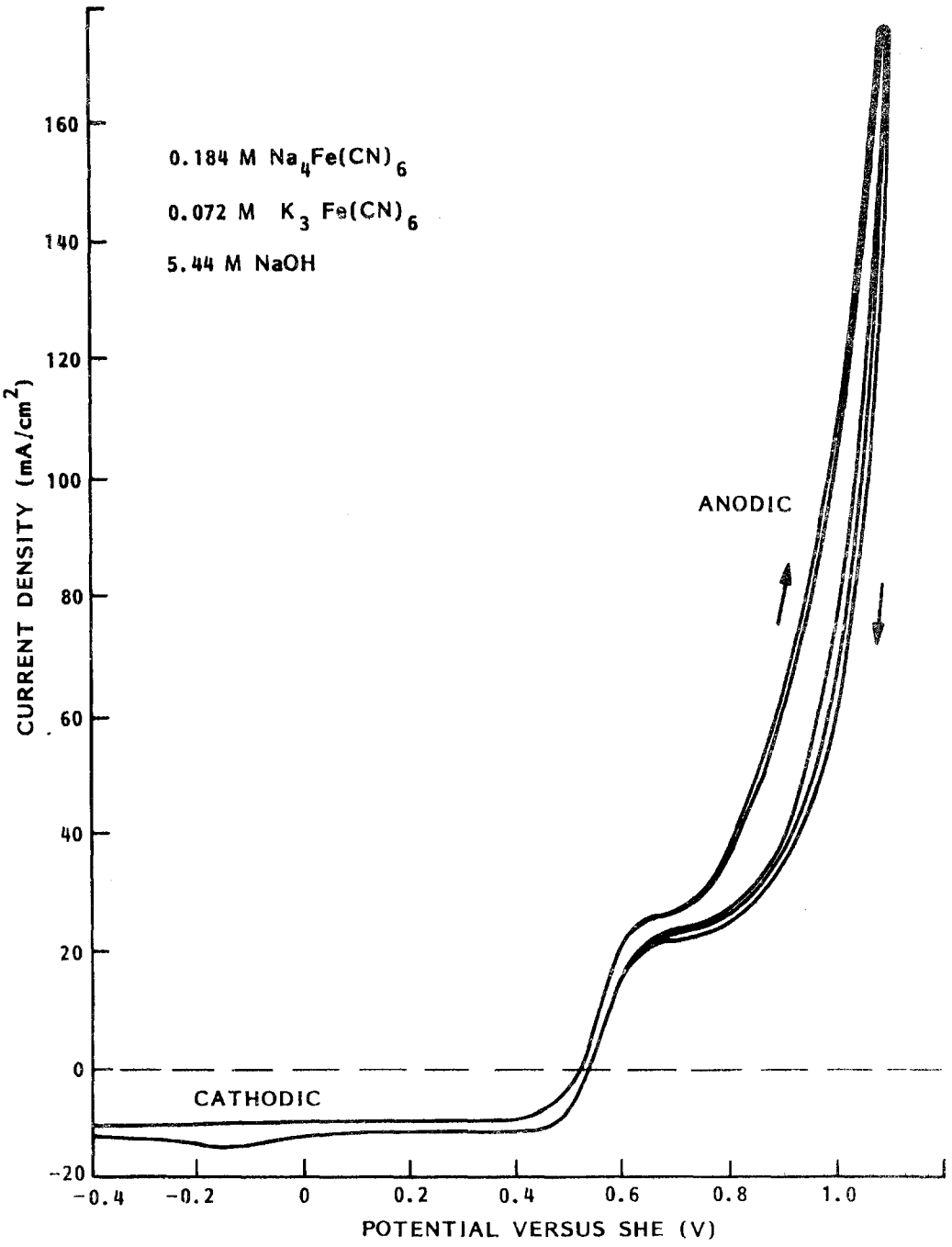

Figure 4.2.1 Ferro- Ferricyanide Cyclic Voltammetry on Sintered Nickel (1.0 cm^2)

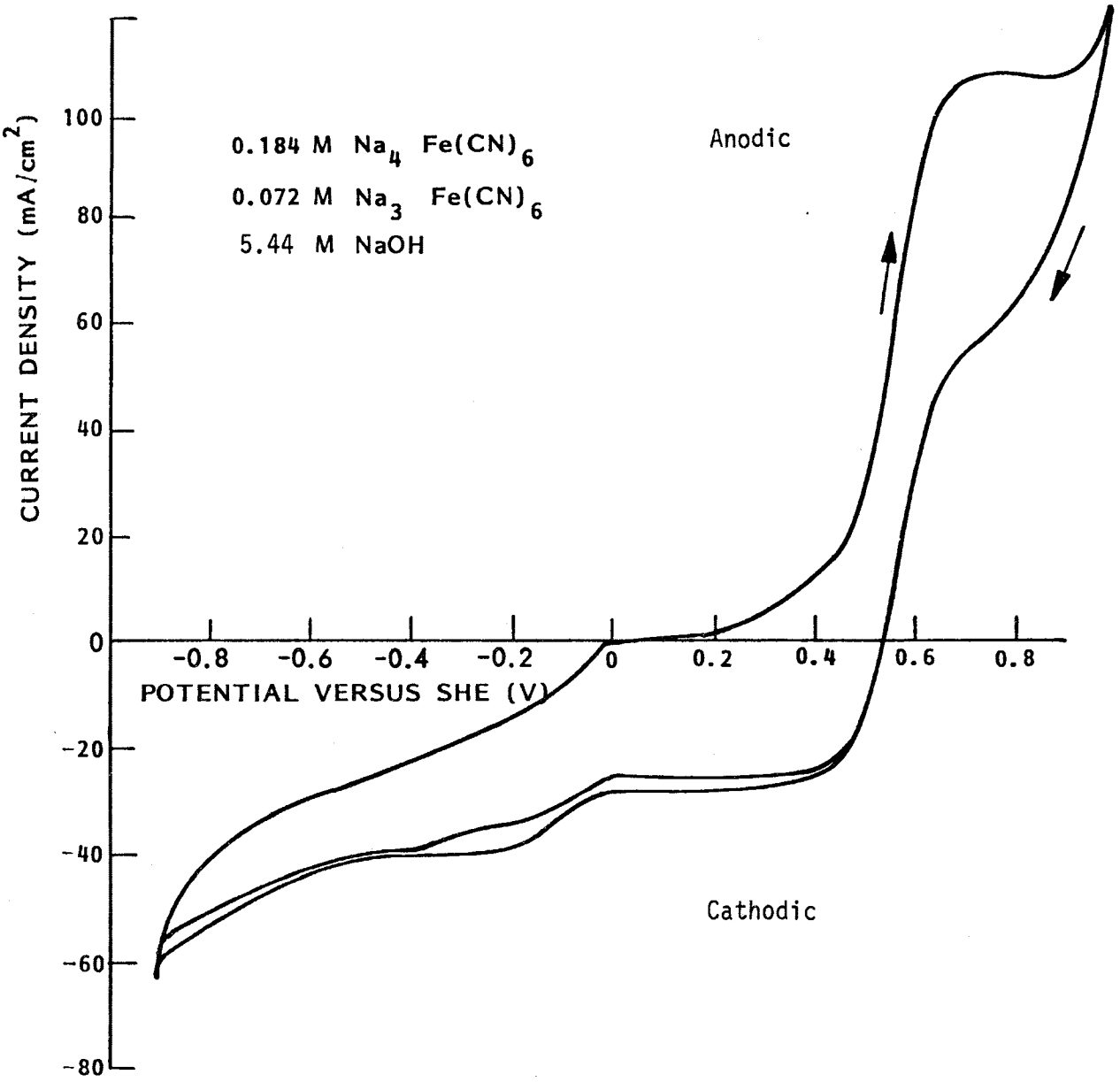

Figure 4.2.2 Ferro-Ferricyanide Cyclic Voltammetry on Stackpole 6077 Graphite (1.0 cm^2)

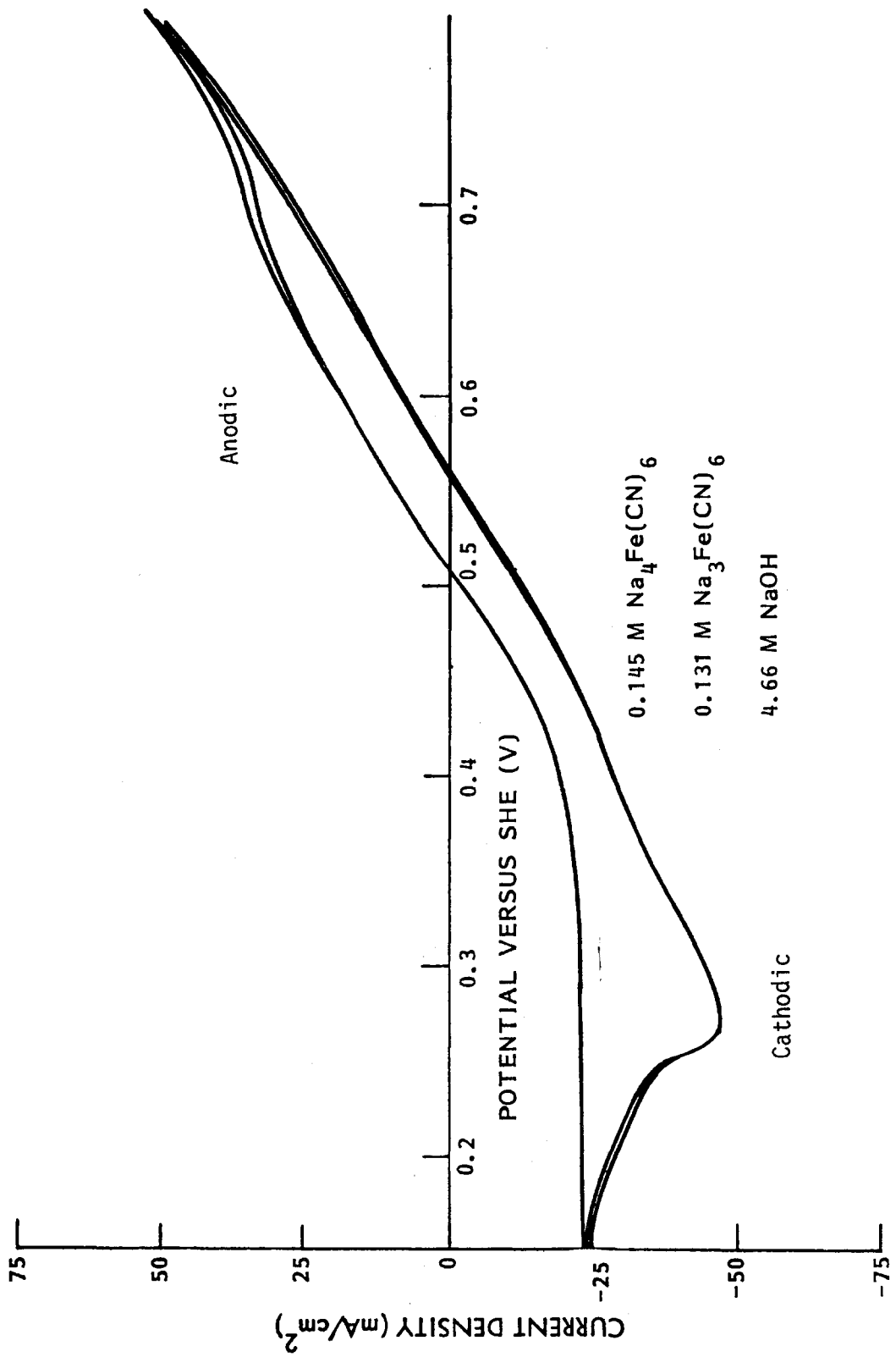

Figure 4.2.3 Ferro- Ferricyanide Cyclic Voltammetry on Sintered Nickel ($60\ cm^2$ Flow-by configuration)

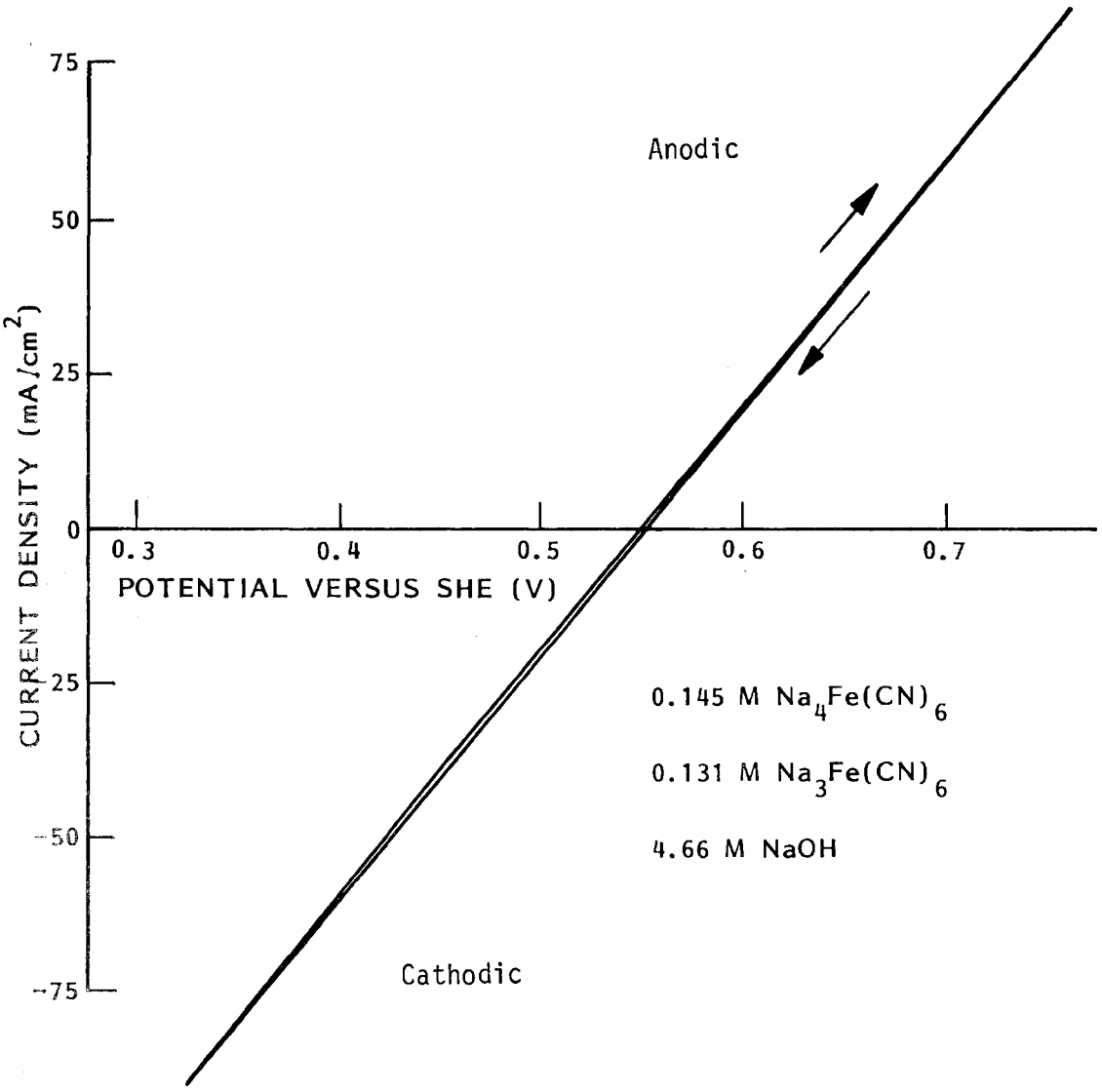

Figure 4.2.4 Ferro-Ferricyanide Cyclic Voltammetry on Sintered Nickel (60 cm^2 Flow-through Configuration)

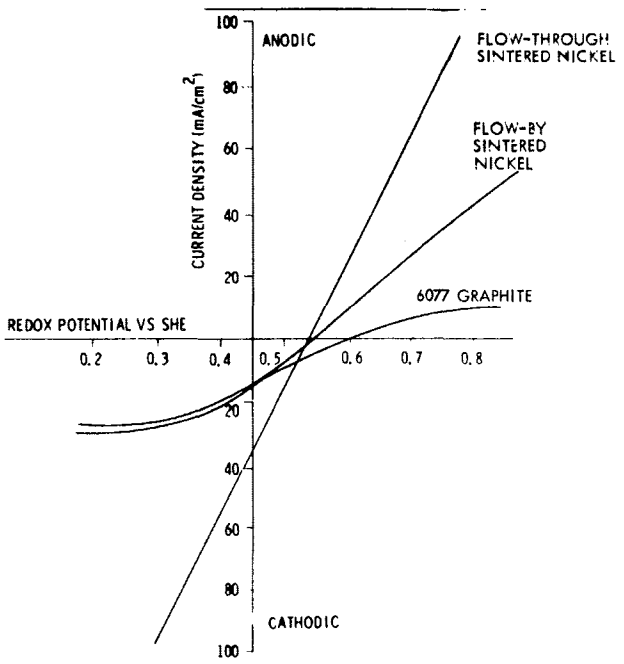

Figure 4.2.5 Ferro-Ferricyanide Electrode Polarization on Nickel and Graphite Substrates

over the lifetime projected for the hybrid redox battery, and so an investigation of the stability of alkaline ferro-ferricyanide solutions was conducted.

Since aquopentacyano iron(II)and(III)have been identified as the most stable intermediates in the decomposition of ferro- and ferricyanide by light[36], acids [8, 33, 34], and metal ions[37], it was reasonable to propose their involvement in the decomposition of the alkaline electrolyte. Using the nitrosobenzene colorimetric method of pentacyano iron determination[8], studies of the unpromoted decomposition of ferrocyanide and of ferricyanide in various concentrations of NaOH at 20^{o} and $50^{o}C$ were made. These results are presented in figures 4.2.6 and 4.2.7.

The commercial $Na_4Fe(CN)_6 \cdot 10\ H_2O$ and $Na_3Fe(CN)_6 \cdot H_2O$ used in these experiments contain pentacyano iron as an impurity, so that some aquopentacyano iron is present in solution at the start of the experiments.

In static tests using polyethylene containers, the level of pentacyano iron in saturated solutions of ferrocyanide remained nearly constant under all conditions examined, indicating that ferrocyanide is stable up to 7N NaOH at temperatures as high as 50°C. Solutions saturated with $Na_3Fe(CN)_6 \cdot H_2O$ at 20°C displayed a gradual decrease in the amount of pentacyano iron III initially present, indicating that at this temperature, its decomposition is more rapid than its formation. However, at 50°C, aquopentacyano iron production outpaces its decomposition and there is a gradual increase in its concentration. Ferricyanide is, therefore, the species through which the electrolyte decomposes, initially producing $Fe(CN)_5OH^{3-}$ and, eventually, Fe(O)OH, which may be recovered from the filter of an operating cell after several hundred cycles.

The change in $Fe(CN)_5OH^{3,4-}$ concentration in an operating cell was also studied over the course of a 4-hour charge/discharge cycle of an iron redox half-cell containing a sintered nickel electrode. The data, detailed in figure 4.2.8, shows a rise in pentacyano iron concentration during charge, and a decrease during discharge. Subsequent static experiments showed that the nickel electrode material did not in itself cause loss of cyanide ion from electrolyte but did appear to promote the decomposition of aquopentacyano iron. It seems likely that the rise in pentacyano iron during charge is due mostly to an increased concentration of ferricyanide in solution and that the decrease during discharge is due at least in part to nickel-promoted decomposition, although other processes, such as electrode-assisted cyanide ion loss cannot be ruled out at this time.

Figures 4.2.9 and 4.2.10 show the appearance of a new peak in the infrared spectrum of the electrolyte after many cycles. Combined with other studies, this provides evidence for the formation of an electrochemically inactive Fe(III)binuclear complex from aquopentacyano iron(III) in NaOH solution which contains a bridging cyanide group. Further experimentation is planned to elucidate the relationship between this complex and the electrochemically nonreducible Fe(III)observed in old electrolyte.

In our system, the major pathway for electrolyte decomposition seems to be slow deligation of cyanide from ferricyanide by hydroxide. Photochemical reactions

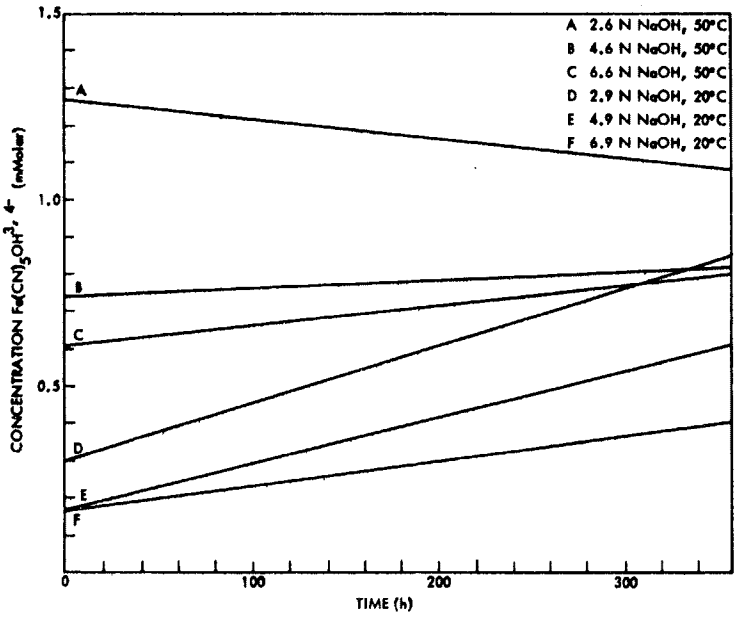

Figure 4.2.6 Variation of $Fe(CN)_5OH^{4-}$ Concentration with Time in $Na_4Fe(CN)_6$-saturated NaOH solutions at 20° and 50°C

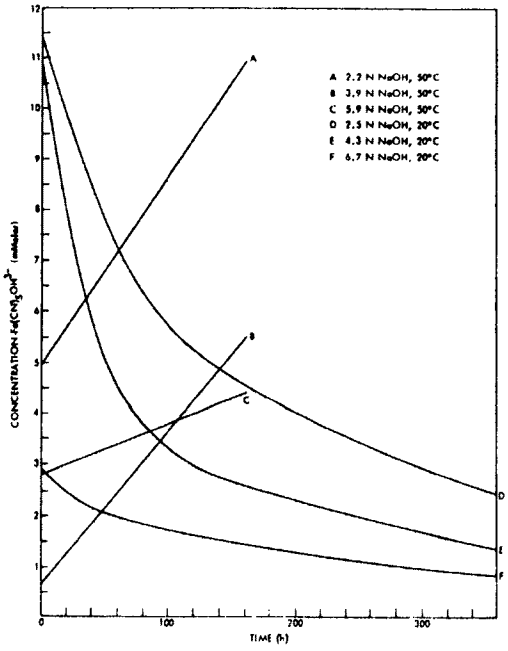

Figure 4.2.7 Variation of $Fe(CN)_5OH^{3-}$ Concentration with Time in $Na_3Fe(CN)_6$ -Saturated NaOH Solutions at 20° and 50°C

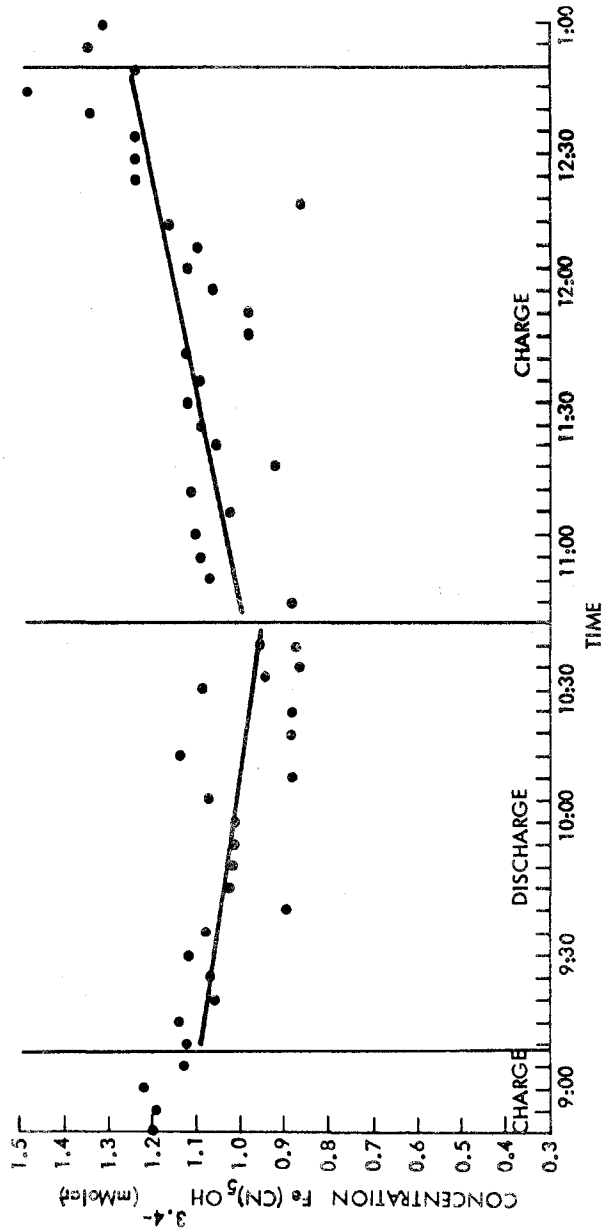

Figure 4.2.8 Variation of $Fe(CN)_5OH^{3,4-}$ Concentration with Time During Cell Cycling

Figures 4.2.9 and 4.2.10:

Infrared spectra in CN stretching region of ferro-ferricyanide electrolyte taken from operating cells after 5 and 852 4-hour charge/discharge cycles

2039.9 cm^{-1} $Fe(CN)_6^{4-}$ terminal CN stretch

2117.5 cm^{-1} $Fe(CN)_6^{3-}$ terminal CN stretch

2173.9 cm^{-1} possible stretch of CN bridging two Fe(III) centers.

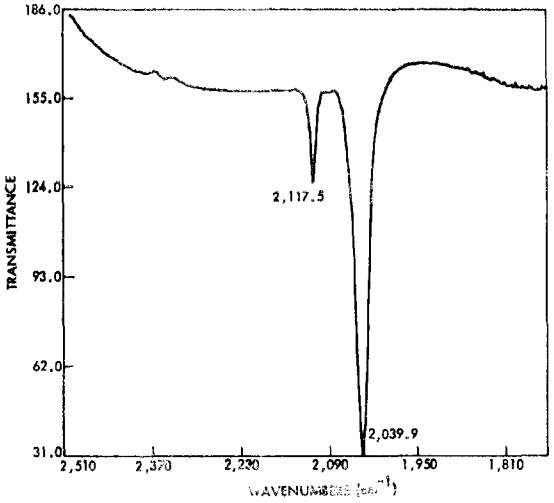

Figure 4.2.9 Electrolyte after 5 Cycles

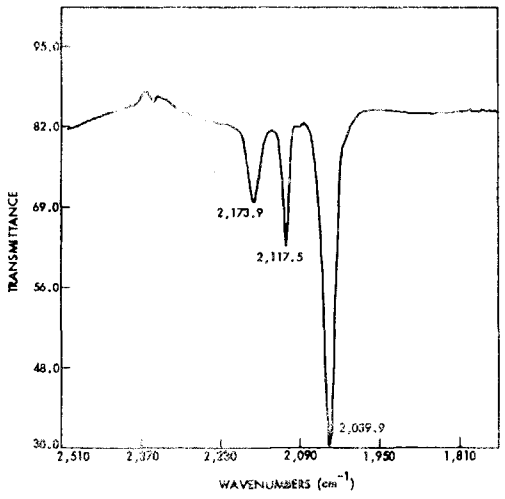

Figure 4.2.10 Electrolyte after 852 Cycles

are prevented by the use of opaque materials of construction. Acid and metal ion-catalyzed decompositions, which proceed through tight ion pairs with a cyanide ligand promoting its loss from iron as HCN or MCN^{37} are precluded by the high hydroxide concentration. A possible source of contamination, $HHgO_2^-$ estimated to be $6x10^{-5}$M in the Hg/HgO reference electrode compartment, is minimized by the capillary connection between the reference electrode and the cell compartment.

4.2.3 Religation of Pentacyano Iron

If hydroxide can displace cyanide from an iron complex, then microscopic reversibility requires that a pathway exists for cyanide replacement under similar conditions. Benchtop experiments showed that 7 - 10 equivalents of NaCN would rapidly convert $Fe(CN)_5OH^{4-}$ to ferrocyanide in NaOH solution at 50°C. Encouraged by this result, a procedure was developed for fully reducing the electrochemically inert Fe(III)to Fe(II)and then religating the pentacyano iron species, using NaCN.

In an early trial, arbitrarily conducted on a cell electrolyte after 74 cycles for concept evaluation, NaCN was added in small portions over 2 days until free cyanide ion persisted in solution; in this experiment, cyanide served as both reducing agent and religating agent. After oxidizing excess cyanide with $K_3Fe(CN)_6$ additions, the cell was placed back in operation. This procedure decreased the $Fe(CN)_5OH^{3,4-}$ level from 3×10^{-3} to 8×10^{-4} M; coulombic efficiency of the cell increased from 85% to 95%. In a more recent trial, cell electrolyte which had operated for 460 cycles, was treated with formalin to reduce all Fe(III),and then only one equivalent of NaCN, calculated from the measured concentration of $Fe(CN)_5OH^{4-}$, was added. After waiting two hours for completion, ferricyanide was added to destroy any unreacted free cyanide, and cell cycling was reinitiated. This method, which requires considerably less NaCN than the first approach, reduced the $Fe(CN)_5OH^{4-}$ concentration from 1×10^{-3} M to less than 2×10^{-6} M, and immediately increased the redox half-cell coulombic efficiency from 71% to 88%.

This approach to electrolyte rejuvenation appears promising, both technically and economically. Further work is planned to define optimal religation conditions.

4.3 ELECTROLYTE INVESTIGATION

4.3.1 Zincate Electrolyte

The solubilities of zincate in sodium hydroxide are shown in figure 4.3.1 and were determined by two solubilization procedures: (1) chemical dissolution of ZnO powder introduced into the electrolyte; (2) anodic dissolution of 99.99% pure zinc plate. In each case the particulates were allowed to settle for two weeks at a given temperature (28, 35, and 50°C) at which time a 5 ml aliquot of the clear supernatant was removed, acidified, and the zinc content determined by atomic absorption analysis.

Resistances of the above zincate saturated solutions (figures 4.3.2) were measured using an Industrial Instruments conductivity dip cell model CEL-BB1, having a cell constant of 1.07, in conjunction with a General Radio Co. type 1650-A Impedance Bridge.

From this study the optimal NaOH electrolyte concentration was taken as 5 N.

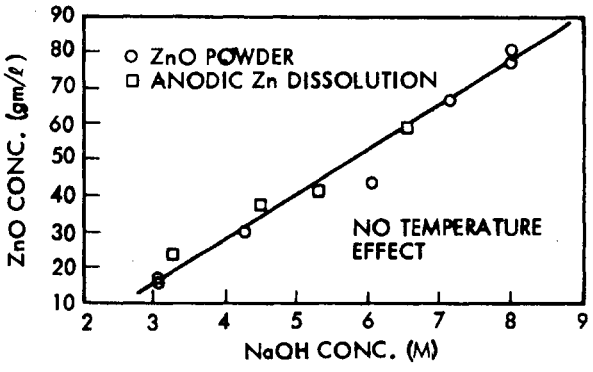

Fig. 4.3.1 Solubilities of ZnO in Sodium Hydroxide Electrolytes

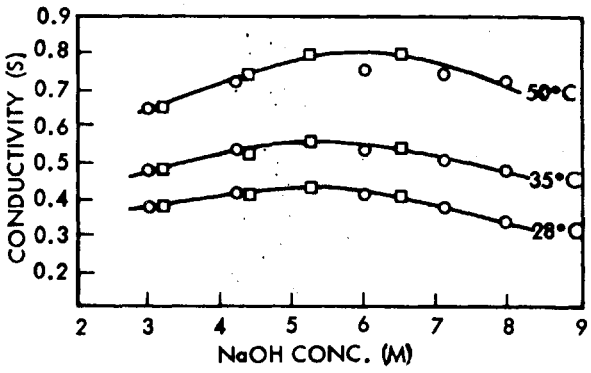

Fig. 4.3.2 Conductivities of ZnO-saturated Sodium Hydroxide Electrolytes

Since zinc ferrocyanide is insoluble in neutral solutions and could therefore be a potential passivator for a zinc anode, its solubility in sodium hydroxide electrolyte was estimated from available equilibria data. It was found that at pH 10.8 or greater, all zinc is present as the zincate ion and zinc ferrocyanide is completely soluble under these conditions. Passivation of zinc would not therefore be expected under the moderate current densities used in this cell.

4.3.2 Ferro-Ferricyanide Redox Electrolyte

Using the techniques described above, the solubilities of sodium ferrocyanide decahydrate and sodium ferricyanide monohydrate in NaOH and conductivities of these saturated solutions were determined; they are shown in figures 4.3.3 through 4.3.6.

Solubility of the ferrocyanide salt is relatively insensitive to sodium hydroxide concentration at 22°C, but at 50°C solubility increases rapidly with decreasing sodium hydroxide concentration. With sodium ferricyanide solubility rises very rapidly with decreasing sodium hydroxide concentration at both 20° and 50°C. Interestingly, the conductivity of a sodium ferrocyanide-saturated sodium hydroxide is higher than that of the equivalent ferricyanide-saturated electrolyte, even though the solubility of the ferricyanide salt is much higher. This is no doubt due to the overriding conductivity of the 5N NaOH. The above data for 5N NaOH reduced to a 22°C temperature basis are as follows:

Table 4.3.1

Conductivities of 5N Sodium Hydroxide/Reactant Salt Saturated Electrolytes at 22°C

Reactant Salt	Concentration (M)	Conductivity $(\Omega^{-1}cm)^{-1}(S)$
ZnO	0.48	0.31
$Na_4Fe(CN)_6 \cdot 10H_2O$	0.05	0.35
$Na_3Fe(CN)_6 . H_3O$	0.40	0.27
None	n.a	0.38[54]

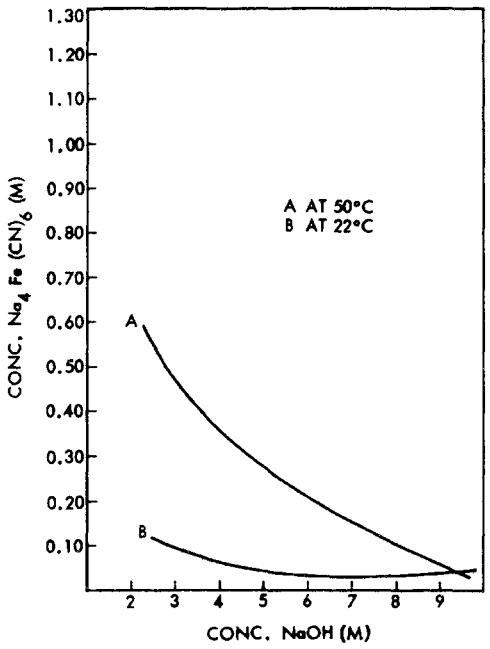

Fig. 4.3.3 Solubilities of Sodium Ferrocyanide in Sodium Hydroxide Electrolytes

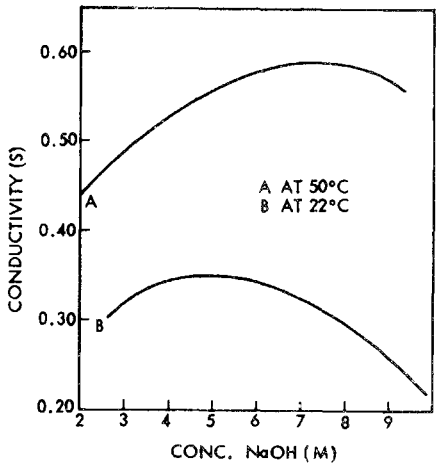

Fig. 4.3.4 Conductivities of Sodium Ferrocyanide-Saturated Sodium Hydroxide Electrolytes

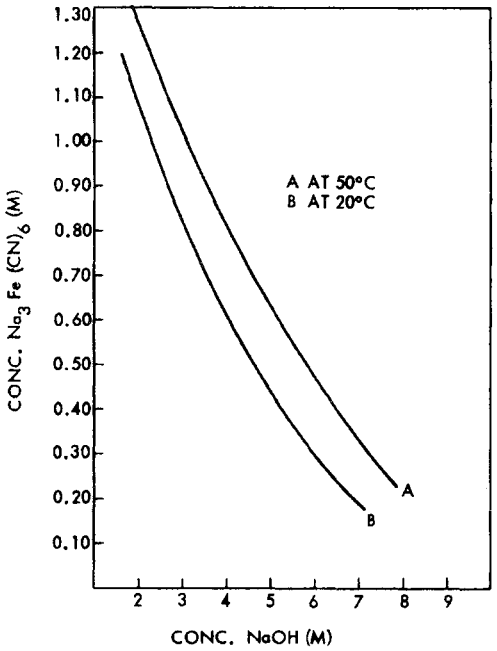

Fig. 4.3.5 Solubilities of Sodium Ferricyanide in Sodium Hydroxide Electrolytes

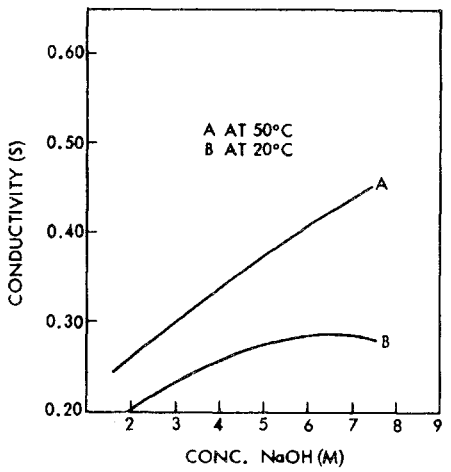

Fig. 4.3.6 Conductivities of Sodium Ferricyanide-Saturated Sodium Hydroxide Electrolytes

The conductivities of the reactant-saturated 5N NaOH electrolytes are all lower than that for 5 N NaOH. Sodium ferricyanide lowers the conductivity considerably more than zincate for equivalent concentrations. This is probably due to cationic pairing with the ferricyanide ion. A 5N NaOH electrolyte concentration has been tentatively selected as optimal, taking into consideration conductivity, electrode concentration polarization, electrolyte stability, and solubility of the ferrocyanide salt.

The results of an examination of the mixed solubilities at 40°C, of ferro- and ferricyanide as the sodium or potassium salt in sodium hydroxide or potassium hydroxide are shown in Table 4.3.2.

Table 4.3.2
Solubilities of Sodium and Potassium Ferro- and Ferricyanide in Sodium and Potassium Hydroxide Electrolytes at 40°C

Hydroxide conc.	salt	Ferrocyanide conc.	salt	Ferricyanide conc.	salt
4.38 M	NaOH	0.106 M	Na	0.358 M	Na
4.40	NaOH	0.341	K	0.299	K
4.70	KOH	0.045	Na	0.36	Na
4.95	KOH	0.029	K	0.13	K

Note that the potassium salts are more soluble in NaOH electrolyte than in a KOH electrolyte. The sodium salt solubilities appear to be largely unaffected by the supporting electrolyte. Hence sodium hydroxide is preferred over potassium hydroxide on a solubility basis and the sodium ferrocyanide salt is preferred to the potassium salt because of lower unit cost.

4.4 SEPARATOR SELECTION

The criteria for a suitable separator are low resistivity, high chemical stability, mechanical strength, and moderate cost. To date, six separators have been

evaluated for resistivity in 5N NaOH at 25°and 50°C. The five low resistivity separators were used in the half-cell cyclic testing phase to determine mechanical integrity and chemical stability. Table 4.4.1 lists the separators evaluated, their specific resistances, costs in small quantities, and observations regarding performance.

Table 4.4.1

EVALUATION OF SEPARATOR MATERIALS

Manufacturer	Material	Area Resistivity ($m\Omega/cm^2$)	Cost ($/$m^2$)	Comments
RAI Industries	P-1010	10	113	Low tear strength
RAI Industries	P-1040	2	57	Low tear strength
RAI Industries	X1125-34-4	4		Experimental separator. High electrolyte intermixing rate.
DuPont	Nafion - 002	108	323	High resistance
DuPont	Nafion - 115	18	323	Effective
DuPont	Nafion - 114	14	323	In use

One of the problems not addressed as yet is the tearing of the RAI membranes caused by separator flutter in the flowing electrolyte streams. It is believed that lower cost, thinner materials will be viable if support techniques are employed to eliminate flutter. These techniques will be investigated in a Phase II Study.

4.5 HALF-CELL TESTING

The purpose of the half-cell testing was to gain insight into the performance of individual half-cells with regard to substrates, electrolyte flow rate and concentration, current density, and charge capacity. Optimum configurations were then used in full-cell cyclic testing. A nickel counterelectrode in 5N NaOH electrolyte is used in the opposing half-cell.

4.5.1 Zinc Electrode Half-Cell Testing

4.5.1.1 Substrate Evaluation. Three substrates, selected from preliminary cyclic voltammetric scanning were installed in the 60 cm^2 half-cell configuration with nickel-plated counterelectrodes and a separator in place. These were tested for cyclic energy efficiency at similar flow rates and current density (35 mA/cm^2) conditions. The results are shown in Table 4.5.1. The lead substrate test was terminated after 14 cycles due to extreme variations in coulombic efficiency.

4.5.1.2 Effects of Current Density and Sodium Hydroxide Concentration. Using a cadmium substrate, the cyclic energy efficiency was then determined as a function of current density (Figure 4.5.1) and NaOH concentration (Figure 4.5.2). At the lower NaOH concentrations, the cell performance becomes very erratic and large quantities of gas are observed to evolve during charge periods. An electrolyte concentration 5N in NaOH appears optimal for the concentration range investigated.

4.5.1.3 Adherency. Adherency and the nature of the zinc electrodeposit were found qualitatively to be functions of face velocity in that at a face velocity of ca. 5 cm/sec the deposit was nodular (figure 4.5.3); whereas above 12 cm/sec it was primarily crystalline in appearance (figure 4.5.4) for similar charge capacities of 4.4 A-Hr. In these photographs, direction of electrolyte flow is upward. Quantitative data was not obtained due to the face velocity decrease and increase as the zinc was charged and discharged.

4.5.1.4 Ferrocyanide Effect. Ferrocyanide ion concentration may build up gradually in the zinc electrolyte by diffusion through microporous membranes used as separators. The ferrocyanide ion was found to cause initial erratic fluctuations in the coulombic efficiency of the zinc electrode (Figure 4.5.5) but these anomalies gradually disappeared with time on cycling. The mean coulombic efficiency remained constant at a high value.

Table 4.5.1

CYCLIC ZINC SUBSTRATE HALF-CELL RESULTS
(35 mA/cm^2)

Substrate	Cycles (4 Hr)	Voltaic Efficiency (%)	Coulombic Efficiency (%)	Energy Efficiency (%)
Cadmium	85	94.3	94.9	89.4
Graphite (6077)	84	93.6	85.8	80.4
Lead	14	89.3	88.0	79.0

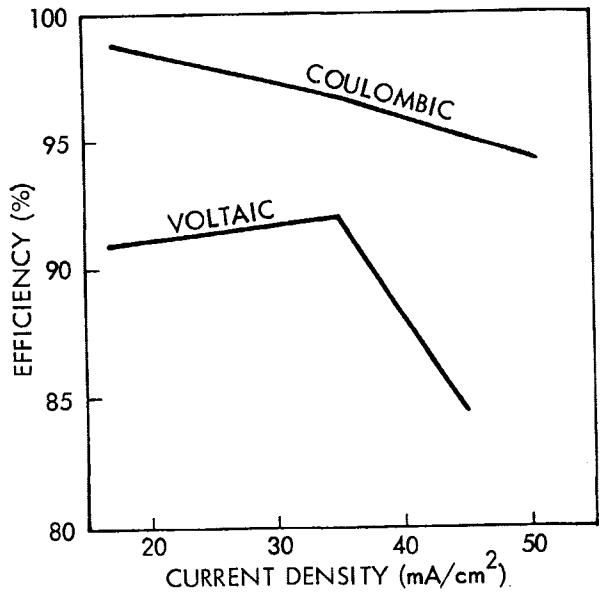

Fig. 4.5.1 Effect of Current Density on Zinc Half-cell Cyclic Efficiency

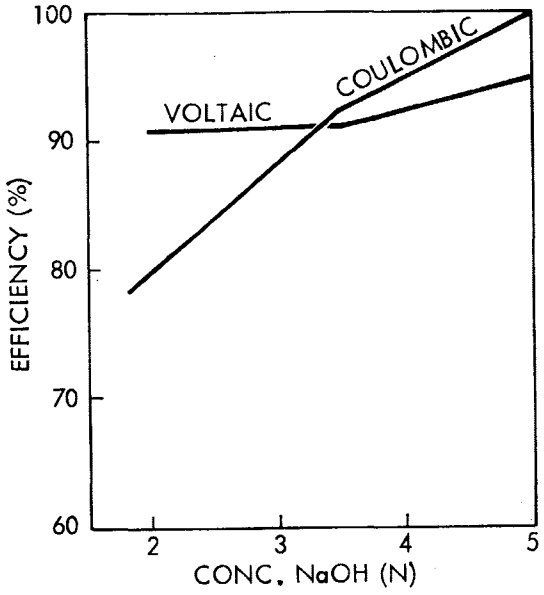

Fig. 4.5.2 Effect of NaOH Concentration on Zinc Half-cell Cyclic Efficiency

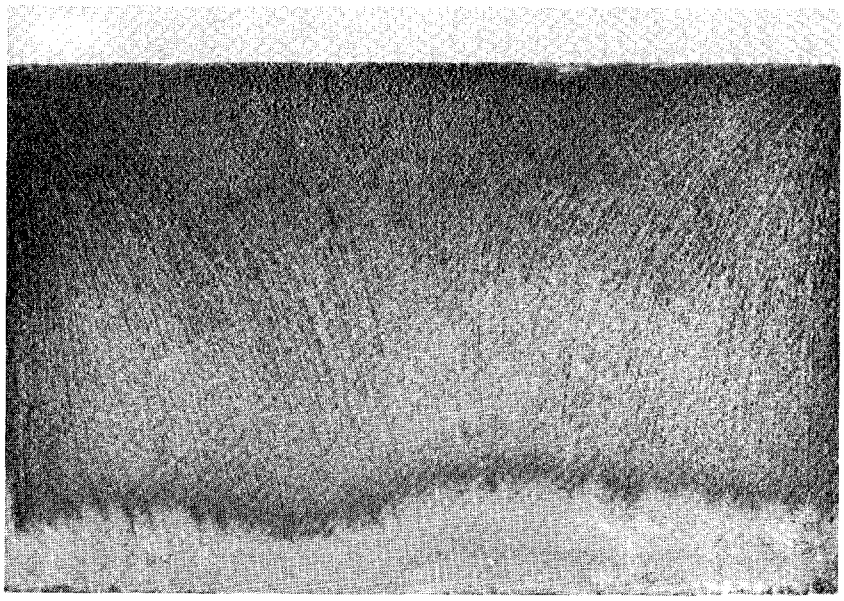

Figure 4.5.3 Electrodeposited Zinc Morphology at Low Face Velocity (5 cm/sec)

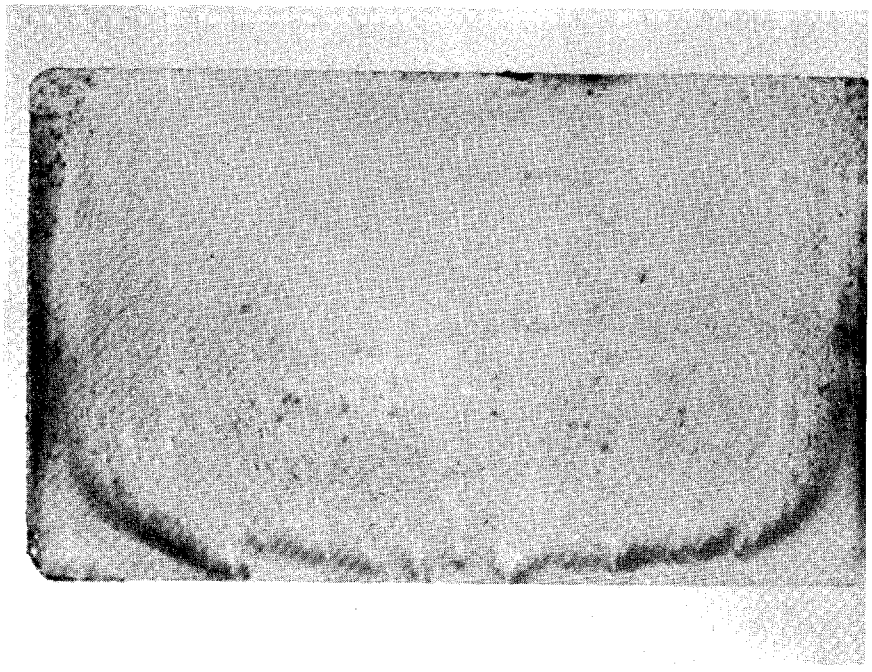

Figure 4.5.4 Electrodeposited Zinc Morphology at High Face Velocity (12.5 cm/sec)

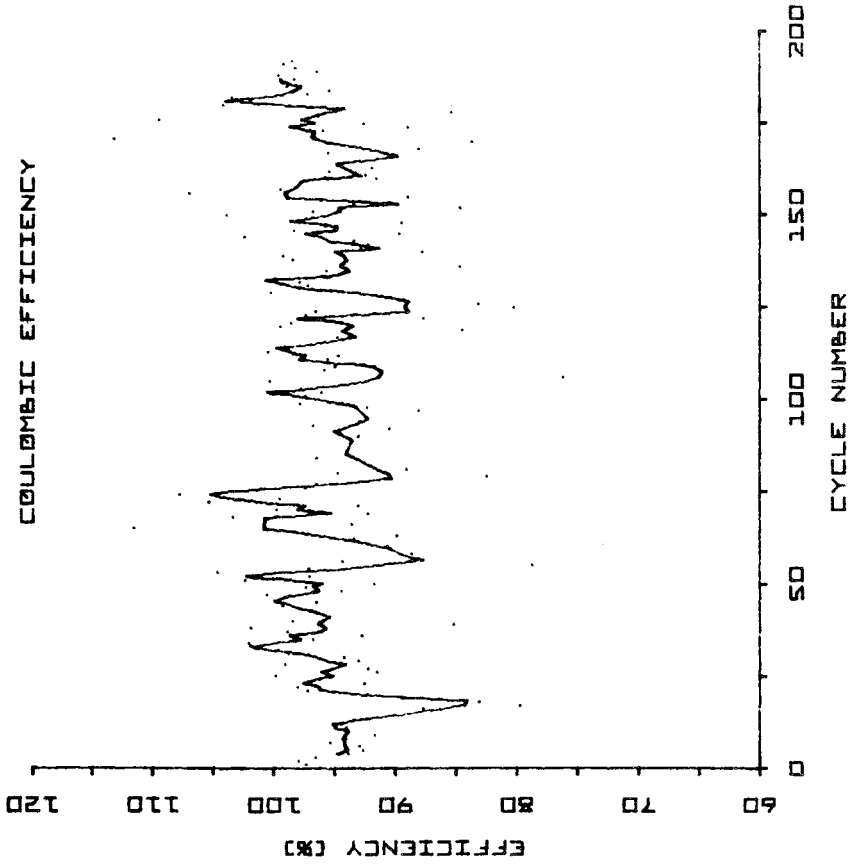

Figure 4.5.5 Cyclic Coulombic Efficiency of Zinc Half-cell with Addition of $Na_4Fe(CN)_6$

4.5.1.5 Temperature Study. Evaluation of a zinc-zincate half-cell at 30^{o}, 40^{o}, and $50^{o}C$ showed that cyclic coulombic efficiencies were identical at each temperature

4.5.1.6 Charge Capacity. The present battery design uses a zinc substrate-to-separator distance of 1.9 mm, for a fully discharged substrate. Assuming a crystalline deposit having a porosity as great as that typical of statically electrodeposited alkaline zinc, and occupying 50% of the internal half-cell volume, this design should have a minimum zinc capacity of 167 mA-hr/cm^2. Experimentally the time of charge was slowly increased until blockage of the electrolyte flow channels occurred, as shown in figure 4.5.6. This resulted in a charge capacity for the present design of 92 mA-hr/cm^2. As the figure shows, the electrode area of this fully discharged substrate is encouragingly clear of zinc deposit; however, both inlet and outlet flow channels are encrusted with zinc with the heaviest concentration at the top exit channel. It is felt that the low capacity limit is due to a combination of poor cell geometry, which induces the deposition of dendritic and/or mossy zinc instead of dense crystalline deposits, the adhesion of particulates (zinc and zinc oxide) to the walls of the acrylic flow channels leading to low flow rates, and flow blockage due to mossy zinc deposition. A microscopic study of this phenomenon is proposed in the Phase II investigations to elucidate the flow and geometry factors contributing to flow blockage. It is believed that once blockage is eliminated capacities of 160 to 300 mA-hr/cm^2 can be obtained with the present electrode clearances.

4.5.1.7 Electrolyte Additives Study. Studies to evaluate the effects of various electrolyte additives upon zinc half-cell cyclic efficiency have been completed using sodium stannate, lead acetate, sodium silicate, and polyethylene glycol of mean molecular weight 600.

Sodium stannate was added to the zincate electrolyte at a concentration of 10^{-4}, 10^{-3}, and 10^{-2} $Sn^{+4}M$. Cyclic coulombic efficiency increased from 86% to 99%, as the tin concentration was increased. However, the zinc half-cell charge potential increased from a normal 1.25 V vs SHE to 1.9 V vs SHE during the initial

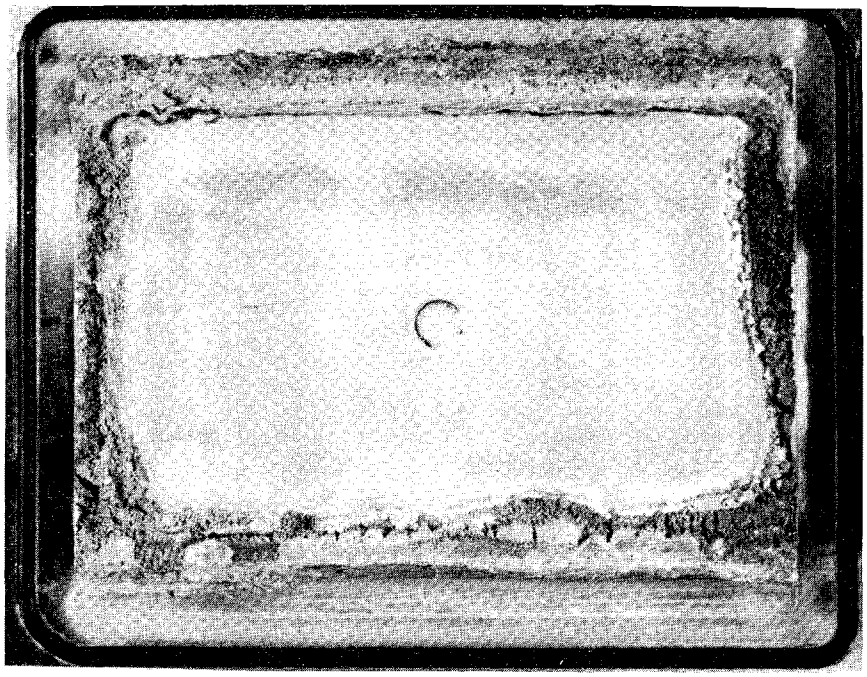

Figure 4.5.6 Cell Channel Blockage Leading to Reduced Charge Capacity.

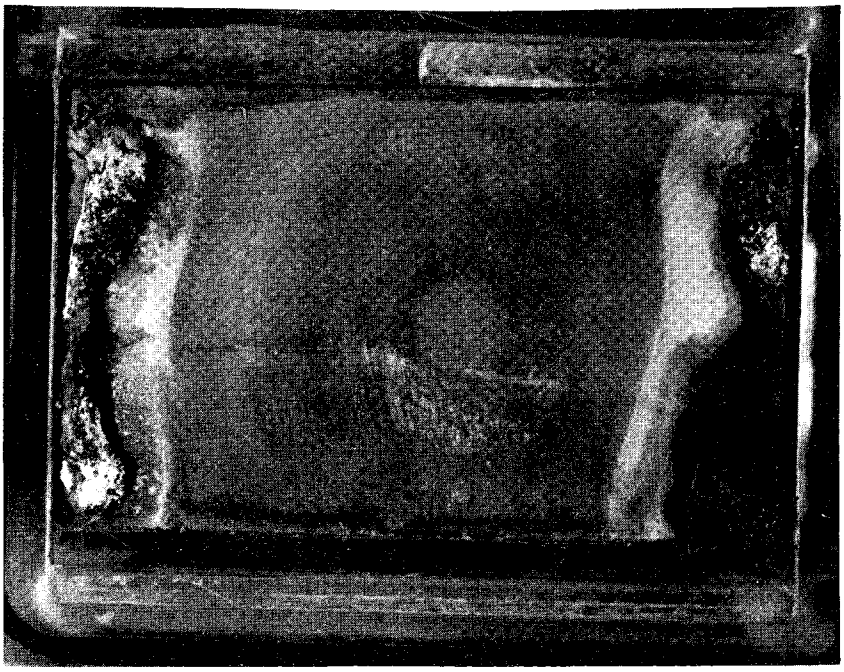

Figure 4.5.7 Zinc Ridges Caused by Lead Additives

thirty minutes of charge and then decreased to the normal level. High resistance film formation during discharge might be implied; however, cyclic voltammetry of the tin substrates,Section 4.1, indicates the absence of such a film. Another possible explanation is that a power source anomaly occurred. This particular test was ultimately terminated due to a microcomputer malfunction.

Lead acetate was studied at the 10^{-4} M Pb level. Prior to introduction, the half-cell coulombic efficiency was constant at 90±5% over 50 cycles; however, for the first cycle after Pb addition, the efficiency was 137%, followed by 319% and 336% for the second and third cycles. Post mortem examination revealed two ridges of zinc, figure 4.5.7, which accounted for the abnormally high coulombic efficiency, because the reference electrode continued to sense the presence of zinc and maintained a constant current discharge.

Sodium silicate was added to a zincate solution at the 10^{-2} M level with a resultant increase in cyclic coulombic efficiency to 99.9%. After 50 cycles, however, the flow channels became increasingly encrusted with zinc, and flow blockage resulted. Post mortem examination revealed zinc deposited in the nonsubstrate flow area blocking the flow, with greatest blockage at the upper electrolyte exit channel. A second test of silicate in zincate solution gave similar results.

Polyethylene glycol of mean molecular weight 600 was tested at the 0.05wt% level in zincate solution. Immediately after addition the coulombic efficiency decreased to 75%, the half-cell potential increased, and the power supply was unable to maintain a constant 35 mA/cm^2. This would indicate a greatly increased cell resistance, either at the separator due to pore blockage or at the substrate surface, due to deposition of a poorly conducting organic film. Post mortem examination revealed a very dense, crystalline zinc deposit, but the separator showed signs (discoloration, abnormal wrinkling) of attack by the polyethylene glycol additive.

Of the additives tested, only sodium silicate gave results worthy of further investigation. More work with this additive is planned in a Phase II study.

4.5.2 Ferro- Ferricyanide Redox Half-Cell Testing

4.5.2.1 Substrate Study. Data comparison of cyclic efficiencies of a sintered porous nickel substrate in the flow-by configuration and the flow-through configuration are given in Table 4.5.2 and illustrate concentration polarization effects which necessitate the use of porous electrodes for dilute redox electrolytes.

4.5.2.2 Flow Rate and Current Density Studies. Using the flow-through configuration in half-cell tests, the effects of flow rate and current density upon the cyclic efficiencies have been determined and are shown in Figures 4.5.8 and 4.5.9 respectively. Energy efficiency is not seriously affected by flow rate or current density at face velocities above 1.5 cm/sec and usable current densities up to 50 mA/cm^2.

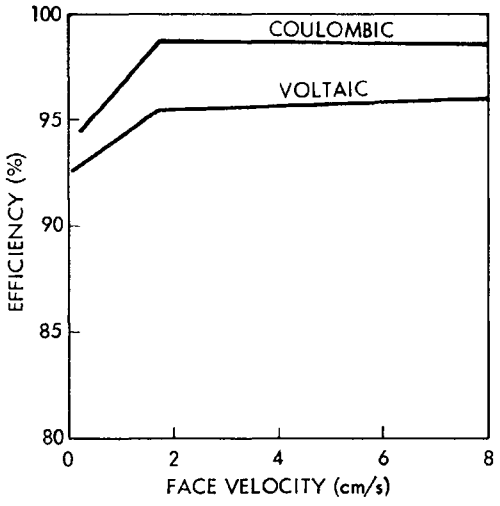

Fig. 4.5.8 Effect of Face Velocity on Redox Half-cell Cyclic Efficiency

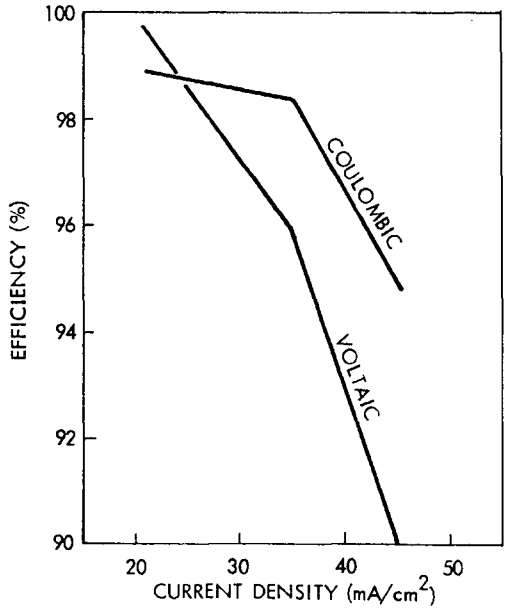

Fig. 4.5.9 Effect of Current Density on Redox Half-cell Cyclic Efficiency

Table 4.5.2

EFFECT OF FLOW GEOMETRY ON REDOX ELECTRODE EFFICIENCIES
(35 mA/cm^2)

Geometry	Limiting Current Density, (mA/cm^2)	Voltage Efficiency (%)	Coulombic Efficiency (%)	Energy Efficiency (%)
Flow-By	20	91.5	78.8	72.1
Flow-Through	100	95.9	98.9	94.8

4.5.2.3 Charge Capacity Variation with Temperature and NaOH Concentration. The variables of temperature and NaOH concentration are important to the overall capacity of the redox half-cell, since both control reactant concentration which, in turn, affects the half-cell potential, moving it either toward or away from the oxygen evolution potential. Figure 4.5.10 details the effect of NaOH concentration and temperature upon the redox half-cell potential as a function of state of charge. As noted in figures 4.3.3 and 4.3.4 the solubilities of sodium ferro- and ferricyanide are directly related to temperature and inversely related to NaOH concentration, so that at low temperatures and high NaOH concentrations the evolution of oxygen becomes a serious competing reaction, degrading the coulombic efficiency. Thus the cyclic coulombic efficiency is only 85% for a 5N NaOH electrolyte over a 12-hour cycle at 12.1 A-hr and 73% state of charge, whereas, with 2.2 N NaOH, the coulombic efficiency is 99% during a 16-hour cycle at 15.6 A-hr and 70.3% state of charge.

Testing at 30^{o}C resulted in 65% cyclic coulombic efficiencies due to low solubility of sodium ferrocyanide whereas,at 40 and 50^{o}C, there was sufficient redox reactant concentration due to increased solubilities to prevent concentration polarization-induced oxygen evolution, and good cyclic efficiencies (90-99%) were realized.

4.5.2.4 Redox Half-cell Cyclic Life Study. At the present time, cyclic life testing of a ferro- ferricyanide redox half-cell, operating at a charge/discharge current density of 35 mA/cm^2, stands at 1040 4-hour cycles (4160 hours) with a statistical mean energy efficiency of 86$\pm$13%. Figure 4.5.11 shows the cycle-by-cycle energy efficiency with 11-point data smoothing applied. The data scatter is due to several contributors listed in order of importance: (1) Gassing or crystallization of ferrocyanide leading to blockage of the reference electrode causing erroneous discharge cutoffs; (2) occasional thermo-control malfunctions with resultant flow blockage due to crystallization of ferrocyanide at lower ambient temperatures; (3) variations in electrolyte flow rate in the counterelectrode resulting in erroneous half-cell potentials due to gas blockage of current paths; and (4) poor resolution of the 8-bit A/D converter which can only resolve the 400 mV controlling redox half-cell potential to $\pm$ 20 mV. The downward trend in energy efficiency occurring after 600 4-hour cycles is tentatively attributed to a decreased volumetric flow rate caused by partial plugging of the sintered nickel electrode with consequent increased concentration polarization and decreased voltaic efficiency (figure 4.5.12). Coulombic efficiency remains unaffected (figure 4.5.13).

4.6 SINGLE CELL CYCLIC TESTING

4.6.1 Current Density

Full cell cyclic testing to evaluate the influence of current density reveals an optimum energy efficiency of 88% at a current density of 25 mA/cm^2 as shown in figure 4.6.1. Extrapolation of the energy efficiency curve down to 70% implies a maximum current density of 55 mA/cm^2 for both the charge and discharge cycles. However, higher discharge rates are obtainable if an unbalanced charge/discharge power profile is used; i.e., 35 mA/cm^2 charge and 100 mA/cm^2 discharge. Thus, from Figures 4.6.3 and 4.6.2 the voltaic efficiency for this charge/discharge profile is 83%. Figure 4.6.2 shows the variation of cell polarization with current density for charge and discharge modes.

The difference in the open circuit potential (OCV) of a charged and a discharged cell is due to the redox electrode. This half-cell OCV is a function of the state of charge.

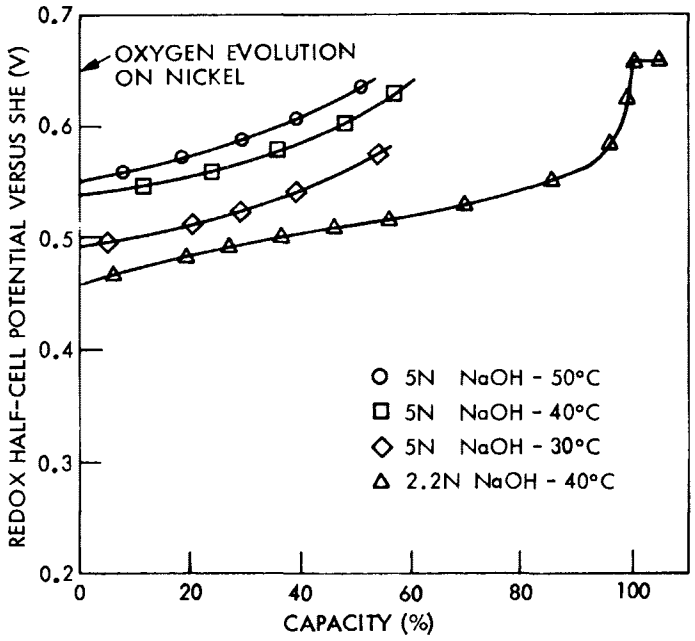

Figure 4.5.10 Effect of NaOH Concentration and Temperature upon Redox Half-cell Potential as a Function of State of Charge

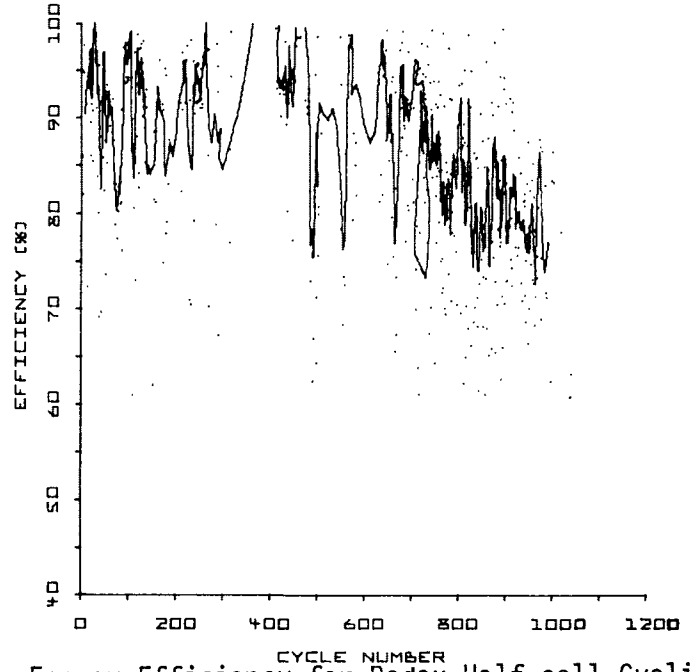

Figure 4.5.11 Energy Efficiency for Redox Half-cell Cyclic Life Test (continuing)

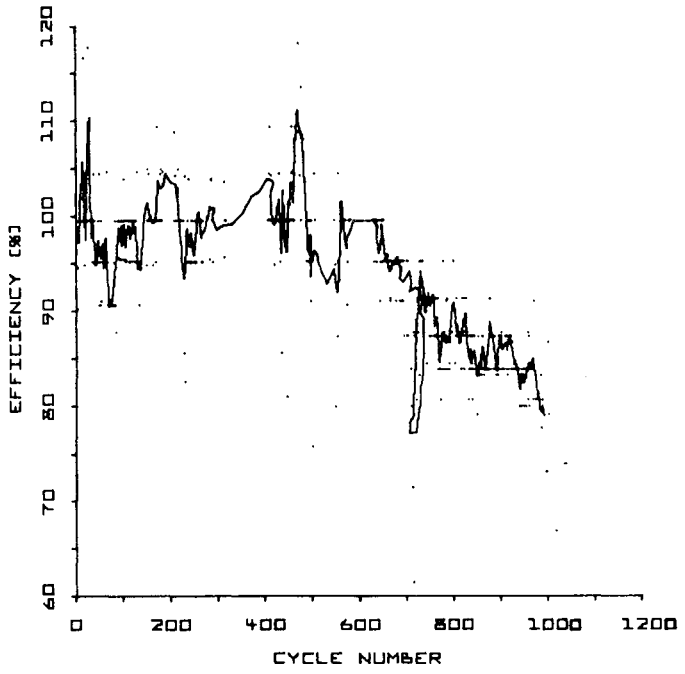

Figure 4.5.12 Voltaic Efficiency for Redox Half-cell Cyclic Life Test (continuing)

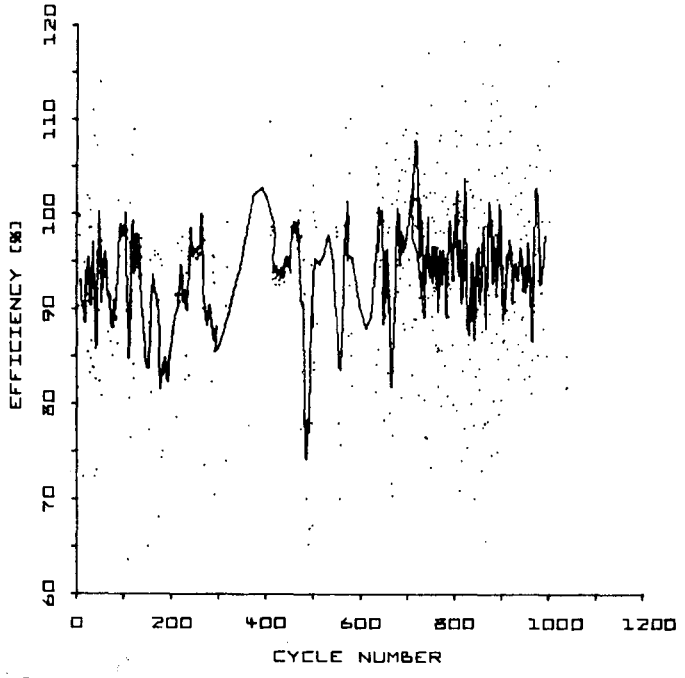

Figure 4.5.13 Coulombic Efficiency for Redox Half-cell Cyclic Life Test (continuing)

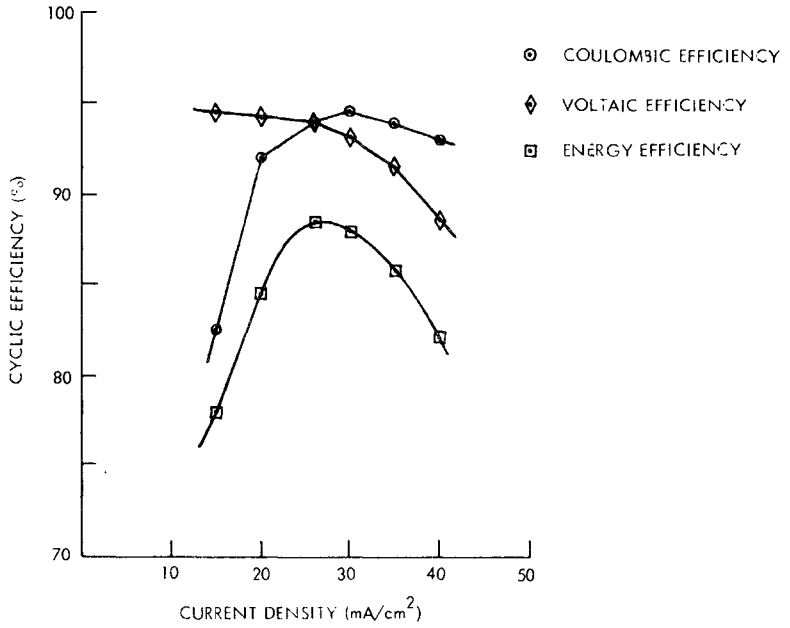

Fig. 4.6.1 Variation of Voltaic and Coulombic Efficiencies with Current Density for a Zinc-ferricyanide Hybrid Redox Battery

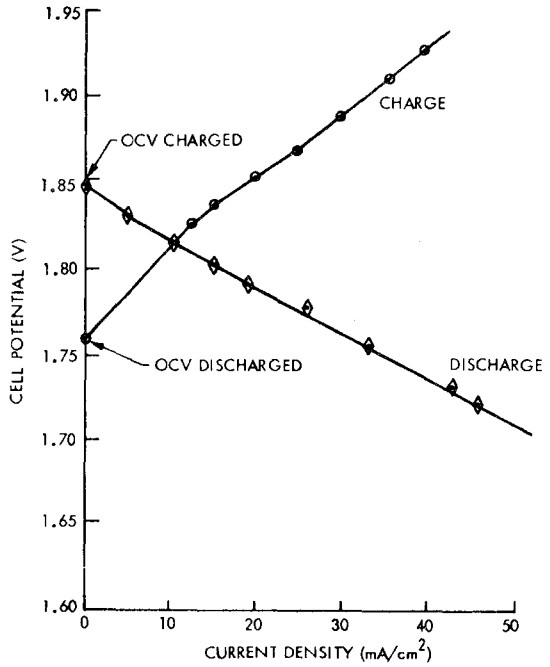

Fig. 4.6.2 Variation of Cell Polarization with Current Density

Figure 4.6.3 shows the power output curve for the zinc-ferricyanide hybrid redox battery. As can be seen, this battery system is capable of high energy discharge rates. From this curve, assuming an energy efficiency cut-off at 70% and a coulombic efficiency of 85%, approximately 217 watts/ft^2 is obtainable. The present design of the electronic control hardware limits the discharge rates to 56 watts/ft^2; thus, battery performance should be investigated at high discharge rates and, since zinc passivation may occur at high current densities, it will be necessary to determine the effect of electrolyte flow rate upon the efficiency of discharge.

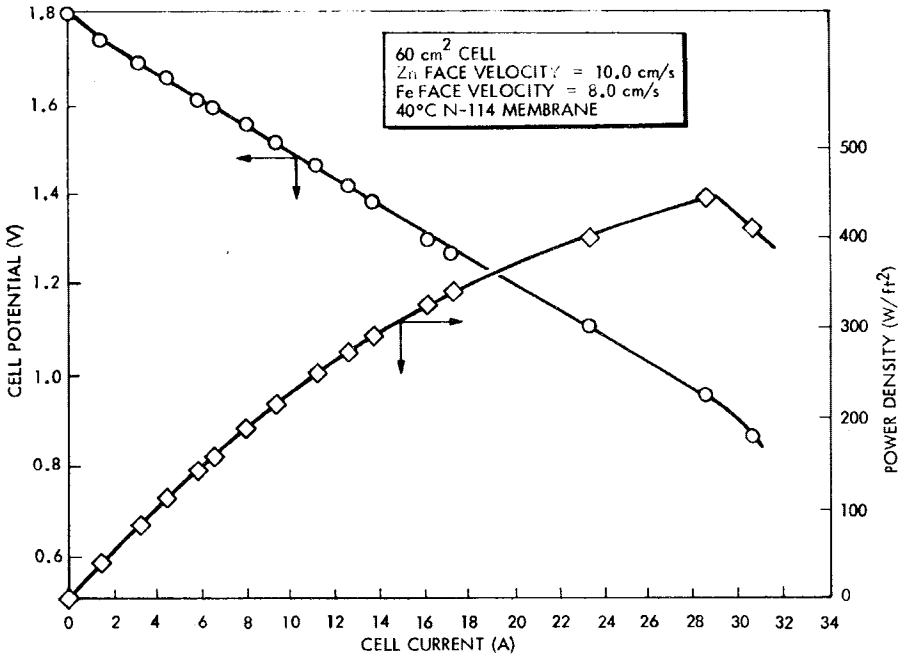

Fig. 4.6.3 Power Output of Zinc-Ferricyanide Hybrid Redox Battery

4.6.2 Charge Capacity

Due to a zinc capacity limit of 92 mA-hr/cm^2 for the present cell design, section 4.5.1.6, tests were not conducted upon the full cell configuration beyond this capacity limit; however, up to this limit, the cell operates with uniform cyclic efficiency.

4.6.3 Sodium Hydroxide Concentration

Similarly, due to low zinc half-cell coulombic efficiency at lower sodium hydroxide concentrations, full cell tests were not conducted at NaOH electrolyte concentrations below 5N.

4.6.4 Temperature

Half-cell cyclic efficiency evaluations as a function of temperature showed that zinc is not affected by temperature whereas the redox electrolyte solubility varies with temperature and hence the cyclic efficiency is affected. Full cell cyclic testing to study the influence of temperature upon cyclic efficiencies again supports these observations as shown in figure 4.6.4 where good performance is obtained at or above $40^{o}C$. Redox half-cell potentials indicate low solubility of sodium ferrocyanide is the prime cause for low efficiency at $30^{o}C$.

4.6.5 Full Cell Cyclic Life Testing

Cyclic life testing of two full cells has been conducted. The first test ran for 267 cycles at 4.2 - 4.6 A-Hr capacity, an average current density of 35 mA/cm^2 and had the following full-cell efficiencies.

Voltaic	87±6%
Coulombic	90±8%
Energy	79±7%

The test was terminated due to an electrolyte leakage problem. Upon disassembly, the electrode surfaces were seen to be in very good condition with no signs of corrosion or nonuniform zinc deposition.

Figure 4.6.5 displays the cycle-by-cycle energy efficiencies with 11-point data smoothing applied. Data scatter has been discussed in section 4.5.2. Figures 4.6.6 and 4.6.7 display the voltaic and coulombic efficiencies respectively.

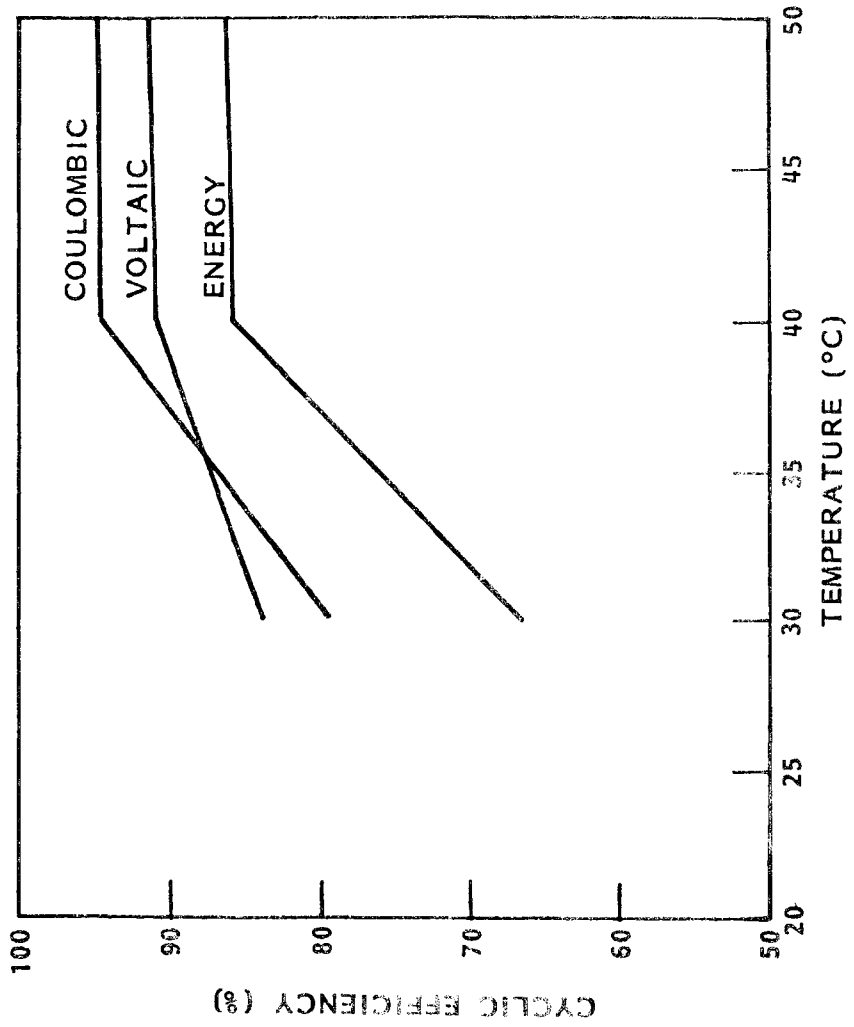

Figure 4.6.4 Variation of Full-Cell Cyclic Efficiency with Temperature

A second full cell test currently has accumulated 698 cycles with an appreciable upward trend in coulombic efficiency as shown in Figure 4.5.8. Figures 4.5.9 and 4.5.10 depict the voltaic and energy efficiencies for this battery. Test cycling is continuing with the current statistical mean efficiencies of

Voltaic 91±2 %
Coulombic 92±9 %
Energy 84±9 %

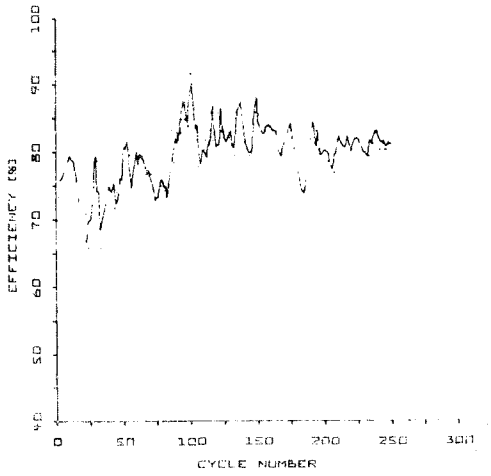

Figure 4.6.5 Energy Efficiency for Full Cell Cyclic Life Test (terminated)

4.6.6 Cell Operation Without Separator

A test was conducted to evaluate cell performance without a separator and having a common electrolyte reservoir. The cell was constructed having the highly permeable RAI experimental X1125-34-4 separator to maintain flow patterns, but to allow easy intermixing of electrolyte. The cell performed normally during a 2-hour charge having a cell potential of 1.9 volts; however, upon discharge the cell went into voltage reversal after one minute with the half-cell potentials indicating normal zinc operation but no ferricyanide reduction occurring. Apparently, ferricyanide is reduced about as rapidly as it is produced; hence it appears that a separator will be required for the battery.

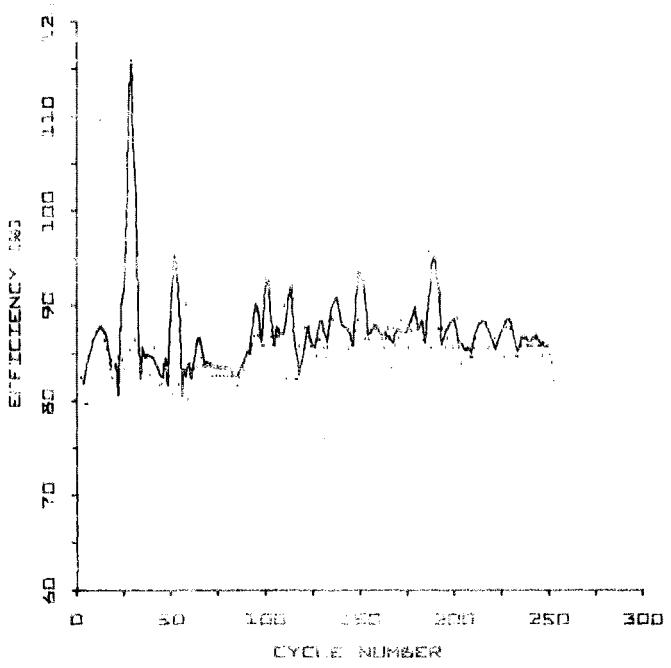

Figure 4.6.6 Voltaic Efficiency for Full Cell Cyclic Life Test (terminated)

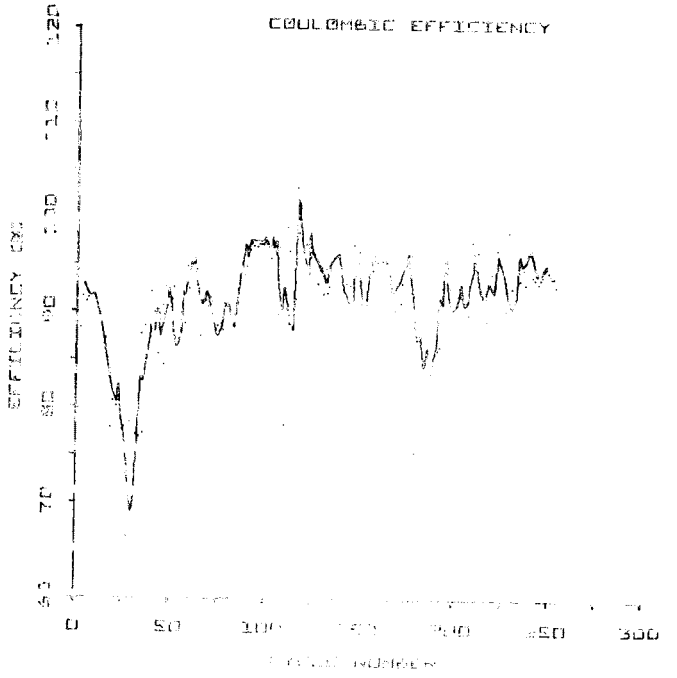

Figure 4.6.7 Coulombic Efficiency for Full Cell Cyclic Life Test (terminated)

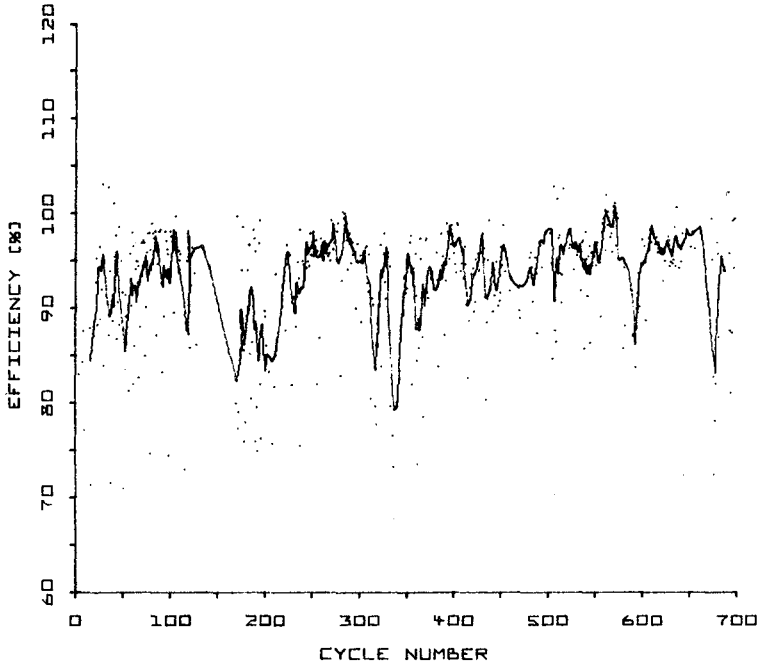

Figure 4.6.8 Coulombic Efficiency for Full Cell Cyclic Life Test (continuing)

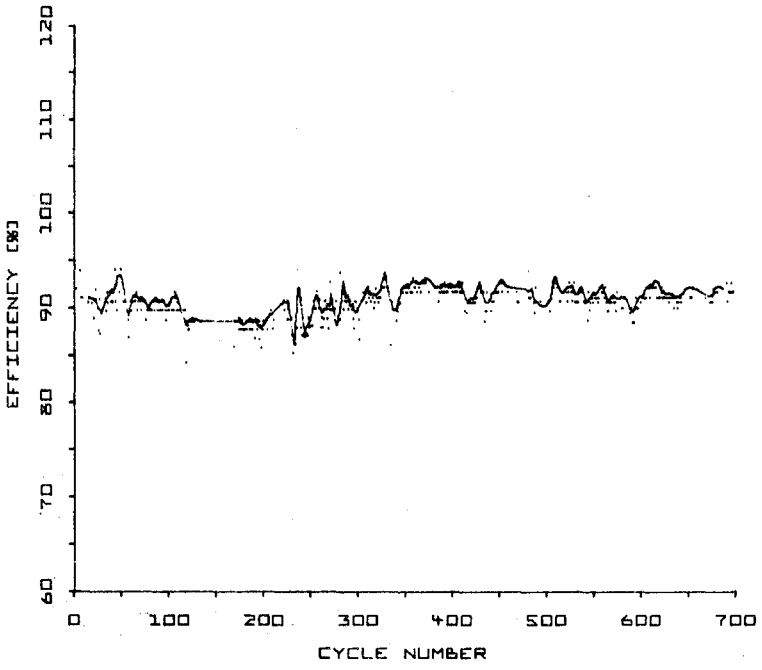

Figure 4.6.9 Voltaic Efficiency for Full Cell Cyclic Life Test (continuing)

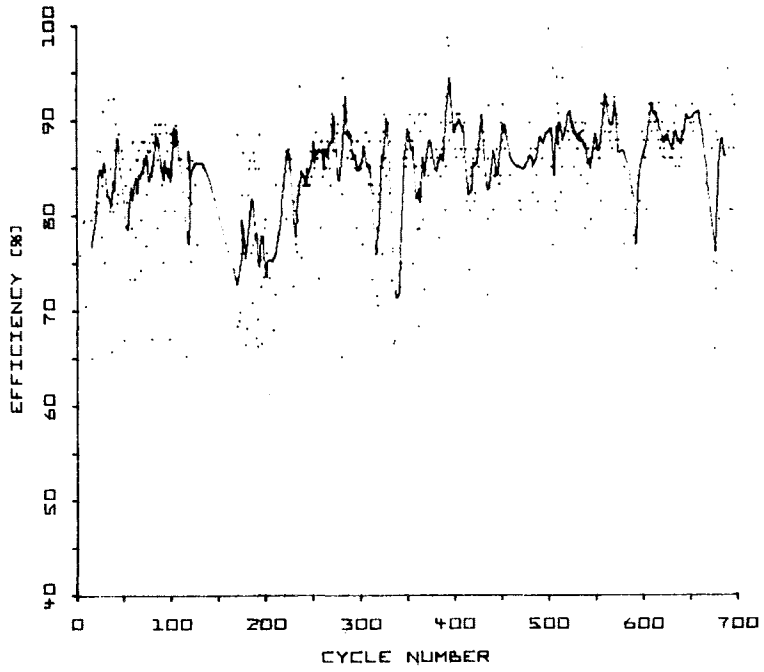

Figure 4.6.10 Energy Efficiency for Full Cell Cyclic Life Test (continuing)

4.7 COST ESTIMATE FOR LMSC MOD 00 ZINC/FERRICYANIDE 20 MW, 100 MWh BATTERY

Prior to the award of the present contract, a preliminary cost estimate for a 10MW, 85 MWh bulk electrical energy storage system was made in a preproposal study, based on the zinc/ferrocyanide electrochemical system. This estimate was modeled after that made previously by Warshaw and Wright (Ref. 57) for the NASA-LeRC flow redox battery, in which external centralized storage of electrolyte was a key feature. In this rough initial capital cost estimate, total system cost and size including a $40/kW allowance for power and conditioning, but not including labor, ROI, taxes, overhead, and without a detailed battery design, was $32.9/kWh. Based on the improved voltaic efficiency achieved with the system since that first estimate, this figure was reduced to $30.0/kWh.

In the present cost estimate these figures are updated and upgraded using the Gould Mod 1 battery (Ref. 58) for a model to incorporate the zinc/ferrocyanide system, since operating voltage and current density are very similar, and a

separator is required. Certain changes in the overall Mod 1 battery design are then necessary. These are as follows:

- Centralized storage of electrolytes external to the battery modules is required for both the zincate and redox electrolytes. For zincate, centralized storage allows recovery, if required, of the sodium ferrocyanide (via procedure outlined in Section 2.2) redox reactant, which may gradually diffuse through the separator with extended cycling. For periodic religation of the redox electrolyte to maintain chemical stability, centralized redox storage is also required.

- Centralized storage is environmentally feasible with this system, due to low toxicities of electrolyte components (compared, for example, to chlorine and bromine).

- Costs for reactants and electrolyte are based on the zinc/ferricyanide system.

- Costs for electrodes and separators are based on electrode areas derived from the Mod 1 battery with both sides of each electrode used. Porous carbon electrodes of the type used in the EDA Mod 4 zinc-chloride battery (Ref. 59) are assumed.

- Costs for tankage, pumps, heat exchangers, and filters are estimated from the NASA-LeRC cost project (Ref. 57) increased by the MWH ratio 100/85. Costs projected for pumps and filters are based on an electrolyte volume equal to the volumes of reactants used, computed as solids. That is, half of the volume of each storage tank is assumed to be electrolyte.*

- Internal plumbing costs are assumed to be 50% of those used in the Gould Mod 1 estimate, due to centralized electrolyte storage.

*This electrolyte volume may be reduced considerably; the minimal volume would be the internal battery volume plus piping volume plus, say, 10% of the tankage volume. The actual minimal value will depend upon dissolution rates of the stored solids relative to conversion rate in the battery.

- Cell diodes for protecting the negative electrode from irreversible modification effects on the event of cell reversal have been eliminated, since graphite electrodes are used.

- Module length has been reduced by 1/3 to 11 feet, since individual electrolyte and bromide storage tanks are not used in the LMSC Mod 00 design.

- Costs for module racks are those for the lower cost design used in the EDA Mod 4 zinc/chlorine system (Ref. 59), adjusted upward by the factor 1.25 to account for the power density difference between the Gould and EDA systems.

These racks would be sectioned into 11-foot truckable lengths (5 feet wide by 6 feet high) to accept one 400-kWh LMSC Mod 00 module per section, which would be factory installed. These sections would be stacked three high on site, and would be bolted together. Two adjacent racks of these sections would constitute a string, and would have electrolyte piping and bus bars centrally located along stacks, running the length of each string. Strings would be 5 modules long.

The overall modular make-up of the LMSC Mod 00 battery would be similar to the Gould Mod 1 design. Stack size would be closely comparable. Electrode area is 0.0929 m^2 (or 1 ft^2) on a side. The Mod 1 20 MW, 100 MWh, battery is structured as indicated in Table 4.7.1.

Thus, the battery consists of 240 421-kWh modules arranged in 16 strings of 15 modules each, or 8 "doubled" strings to accommodate the rack design discussed above. With three tiers per string, each double string would be 55 feet long by 10-1/2 feet wide by 18 feet high. Estimated footprint for the on-site battery layout shown in Fig. 4.7.1 is 8.7 $kWh/ft.^2$*

*This figure is increased to 9 kWh/ft^2 if rectangular-shaped electrolyte storage tanks are used.

Table 4.7.1

LMSC MOD 00 20MW, 100-MWh UTILITY BATTERY COMPONENT RATINGS

Component	Discharge Voltage	Capacity* (kAh)	Stored Energy (kWh)	Number of Units
Electrode Pair	1.74	0.372	0.65	14 negatives, 13 positives in parallel/cell
Cell	1.74	4.84	8.42	5 cells in series/submodule
Submodule	8.70	4.84	42.1	10 submodules in series/module
Module	87.0	4.84	421	15 modules in series/string
String	1305	4.84	6315	16 strings in parallel/battery
Battery	1305	77.4	101,000	

*Negative electrode/loading is assumed to be 2000 Ah/m^2.

The estimated purchased materials and components of the LMSC Mod 00 modular battery in 1978 dollars per kilowatt-hour are summarized in Table 4.7.2. Estimated capital costs of a manufacturing plant capable of producing 25 100-MWh utility energy storage facilities per year are included (Ref. 58, 59). Calculation of these costs follows EPRI guidelines for standardized costing (Ref. 61). Cost computations for individual components are detailed in Appendix I.

To the summation of the individual component costs is then added costs for labor plus overhead, profit and tax, to develop figures for production factory cost and battery selling price. These items are detailed in Table 4.7.3. It is immediately apparent from an inspection of this table that Purchased Materials Costs constitute the major contribution to battery price.

From Table 4.7.2 it is seen that major contributions to Purchased Materials and Components costs derive from:

	(2000 Ah/m^2)	(3000 Ah/m^2)
Redox reagent	21.2%	26.4%
Electrodes	13.0	10.8
Separators	11.9	9.9
Busbars	12.5	10.4
Other cell-related	14.2	11.8
	72.8%	69.3%

(Above figures are computed as percentages of total Purchased Materials and Components Cost.)

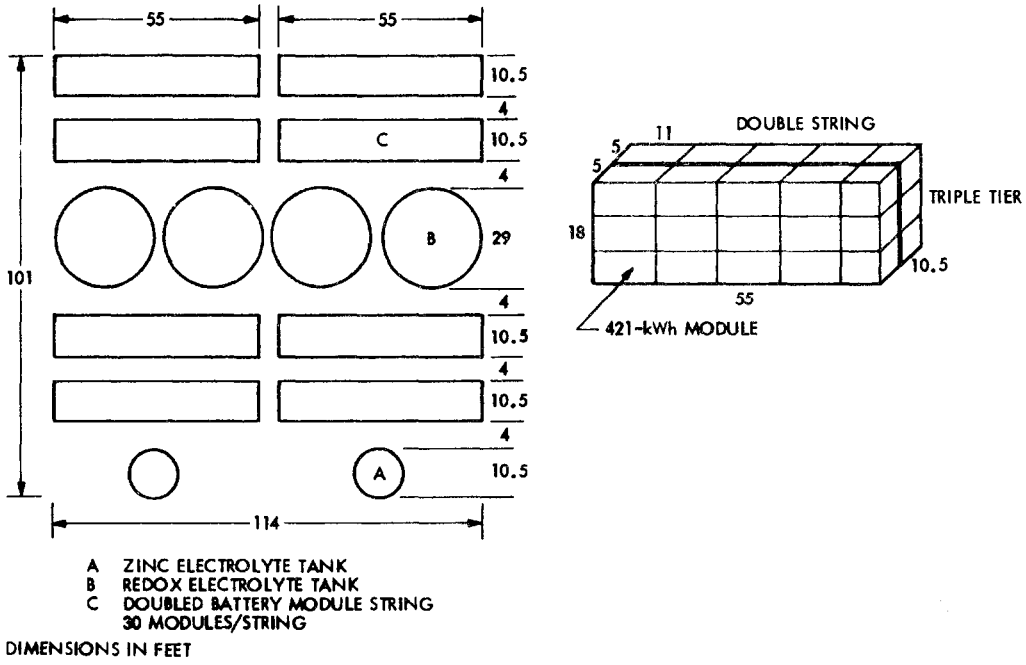

Figure 4.7.1 On-Site Layout of 20 MW, 100-MWh Bulk Electrical Energy Storage Facility

Table 4.7.2

PURCHASED MATERIALS AND COMPONENTS COSTS FOR LMSC MOD 00 BATTERY

($/kWh)

Discharge Capacity (Ah/m^2)	2000	3000
Power Related		
Electrodes		
positive	2.22	1.48
negative	1.33	0.89
Separators	3.24	2.16
Other Cell Components	1.87	1.25
Internal plumbing	2.00	1.33
Busbars	3.41	2.27
Racks and Panels	2.15	1.43
	16.22	10.81
Energy Related		
Reagents		
$Na_4Fe(CN)_6 \cdot 10H_2O$	5.78	5.78
ZnO	0.88	0.88
NaOH	0.43	0.43
Tanks	1.16	1.16
Exterior Plumbing	0.32	0.32
Filter	0.82	0.82
Pumps	1.11	1.11
Heat Exchanger	0.58	0.58
	11.08	11.08
Total Cost	27.30	21.89

Since the cost of the redox reagent, sodium ferrocyanide decahydrate, is 21-26% of the total purchased materials cost, it should be manufactured rather than purchased, unless price discounts substantially larger than 15% can be obtained for 50 kilo ton lots. The salt contains 37% water of crystallization and the chemical components, iron, carbon, and nitrogen are abundant; hence, manufacturing cost should be nominal. Plastic lined, reinforced concrete tanks should be less costly than steel and may be adequate.

It should be more economical to use one large rectangular tank for the redox reactant and two smaller rectangular tanks for the zincate electrolyte. Footprint for this geometry is estimated at 9 kWh/ft^2.

The selection of electrode material has not yet been finalized. An electroformed matte material developed on government contract at LMSC previously for fuel cell research applications should be relatively inexpensive and easier to incorporate into the present design than porous carbon or graphite. Analysis of final costs given in Table 4.7.3 shows that major contributions to capital cost arose from electrode costs in terms of labor and processing equipment costs. With this substitute electrode material, a considerable savings in labor and processing equipment costs should be realized.

The battery selling costs compare well with equivalent costs for the Gould Mod 1 battery, which are \$64/kWh and \$47/kWh for 2000 Ah/m^2 and 3000 Ah/m^2 capacities, respectively.

At the 3000 Ah/m^2 capacity level, the LMSC Mod 00 Zinc/ferrocyanide battery cost at \$31.44 compares favorably with four other utility battery candidates (Ref. 60), Sodium/Sulfur (G.E.) \$35.98; Sodium/Antimony Trichloride (E.S.B.) \$39.60; Lithium/Iron Sulfide (A.T.) \$34.27* and Zinc/Chlorine (EDA) \$34.87.

The present cost estimate lacks the firm basis of a battery module designed specifically for the zinc/ferrocyanide system and therefore can only be considered a first approximation to costs which will be derived from a finalized

*Cell-related costs only

design. It is realized that a bipolar rather than a monopolar battery design would be more cost-effective for the system proposed. These costs, however, are more realistic than those projected in a 1977 ROM preproposal estimate, and serve to identify major cost components. Such an analysis can be used as a guide in the final selection of module and battery design as scale-up proceeds in the development of this electrochemical system.

Table 4.7.3

ESTIMATED MANUFACTURING COST FOR LMSC MOD 00

20 MW, 100 MWh, ZINC/FERRICYANIDE BATTERY

(costs are $/kWh unless noted otherwise)

Discharge Capacity (Ah/m^2)*	2000		3000	
Direct Labor	1.86		1.36	
Labor Overhead @ 150%	2.79		2.04	
Direct Labor + Overhead		4.65		3.40
Purchased Materials & Components	27.30		21.89	
Materials Overhead @ 10%	2.73		2.19	
Materials, Components + Overhead		30.03		24.08
Floor Space Rental (Ref. 3)		0.19		0.13
Equipment Depreciation (Ref 3)		0.58		0.39
Factory Cost		35.45		28.00
Initial Equipment Costs ($)	11.37 M		7.58 M	
Working Capital ($) @ 30% of annual production factory cost	26.59 M		21.00 M	
Initial Invested Capital ($)	37.96 M		28.58 M	
After-Tax Return on Investment @ 15%	5.69 M		4.29 M	
Factory Cost	35.45		28.00	
After-Tax Return on Investment	2.28		1.72	
Taxes	2.28		1.72	
FOB BATTERY SELLING PRICE	40.01		31.44	

*Based on negative electrode area

Section 5
CONCLUSIONS AND RECOMMENDATIONS

This 12-month applied research and development program has been directed primarily to the technical advancement of the rechargeable alkaline zinc/ferricyanide hybrid redox battery. The key technical aspects of this system have been investigated and overall system feasibility has been demonstrated.

This electrochemical system is well suited to utility load leveling and solar voltaic/wind applications, with advantages of high cell voltage, near ambient temperature operation, alkaline electrolyte, low toxicity, low-cost reactant storage, potentially long cycle life and low projected capital costs.

A preliminary economic assessment, updated to include improved performance demonstrated in the current applied research program, suggests that an initial capital cost of $160/kW or $32/kWh are reasonable current figures for a 20-MW (100 MWh) electrically rechargeable bulk energy storage plant, based on this electrochemical system.

The system in its present early state of development demonstrates excellent electrochemical performance. Cell voltages are 1.94 V on charge and 1.78 V on discharge at 35 mA/cm^2. In full-cell cyclic testing at 40^oC, mean energy efficiency stands at 84% after 760 four-hour cycles with energy efficiency currently at 87% , as cycling continues. Mean coulombic and voltaic half-cell efficiencies are 93% coulombic and 91% voltaic for the iron redox electrode and 99% coulombic and 90% voltaic for the zinc electrode. A ferro-ferricyanide redox half cell cyclic test now stands at 1110 four-hour cycles with mean energy efficiency at 86% ; with cyclic testing continuing.

Based upon the results of the above study certain key technical areas have been identified as requiring additional effort. These areas, which are the basis of a follow-on proposal to DOE for a Phase II Study (Ref. 62) are summarized here:

- With the redox electrode, further work is required in two areas. There is a need for a lower cost electrode substrate than the porous nickel plaque now used. Activated porous carbon and carbon felts, as well as nickel-plated porous carbon and a special low-cost nickel electroformed mesh developed previously on government contract in this laboratory, will be evaluated. Additional information is required on the long-term stability of alkaline sodium ferricyanide electrolyte. This will be obtained under appropriate long-term cyclic half-cell testing, using extended charge-discharge cycles. A quantitative technique has now been perfected for measuring the degradation rate of alkaline ferricyanide solutions. Using this technique, concepts for maintaining the long-term capacity of the redox electrode will be evaluated.

- In order to extend long-term cycle life and to meet the zinc electrode loading capacity goal of 2000 Ah/m^2 at 90% energy efficiency, further work is necessary. This work will encompass microscopic studies on the quality of zinc electrodeposition obtained using electrolyte additives and flow rate/flow distribution modification in half-cell cycling. In addition, alternative substrate materials will be evaluated. These include carbon felt, porous carbons and graphites, and an alloy of copper with cadmium, tin, or zinc electrodeposited onto the above or an iron substrate.

- The evaluation of alternative low-cost separator materials, such as uniformly cross-linked and radiation grafted polyethylene and polypropylene will include studies to determine specific resistance, iron and zinc permeation rates, as well as mechanical and chemical stabilities. Attractive separators will be evaluated further under cyclic conditions to determine voltaic losses and mechanical strength. Emphasis will be upon the selection of a low-cost, economical separator having the desired characteristics.

- A mathematical model of the zinc-ferricyanide battery will be developed with the emphasis upon optimizing the system design.

Section 6
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Appendix A
ELECTRONIC INSTRUMENTATION

The instrumentation constructed on this program was based on a National Semiconductor Single Board Computer System model RMC 80/11 with appropriate Input/Output interfacing. The input interfacing consisted of a Burr-Brown model MP8632 8-bit, 32 differential channel analog to digital converter board, a current-to-voltage amplifier section, a hexadecimal (16 key) keypad for operator control and monitoring of cells and cell parameters, and a real-time clock for continuous update of time. The output interfacing consisted of teletype and digital tape cassette storage of reduced cell data transmitted via a RS-232 serial data interface, a 12-digit alphanumeric display enabling operator monitoring of cell operation, setpoints, and cell parameters, and a constant current source to charge and discharge the individual cells.

Current Instrumentation Amplifier

The current-to-voltage amplifier section, circuitry shown in figure A.1, was necessary in order to amplify the mV signal present at the current shunt to a signal level having sufficient resolution for A to D conversion. The current shunt having 150 mV output while passing 3 Amps was amplified 33.3X to provide the A/D with a signal of 4.995 volts. The resolution of the 8-bit converter is $\pm$20 mV, thus inaccuracy is 0.4% instead of 13.3% for the sensed mV potential. The input of the mV signal to the Burr-Brown 3629BP instrumentation amplifier is controlled by the relay logic controlling the constant current source relays because the A/D converter will only recognize a positive input. The OR signal from the E8 port of the microcomputer controls whether or not current is being passed through the current shunt, while the DR signal from the E9 port determines whether the cell is charging or discharging. These signals, via the TTL logic shown, control a relay to invert the shunt input signal upon discharge providing a positive output to the A/D.

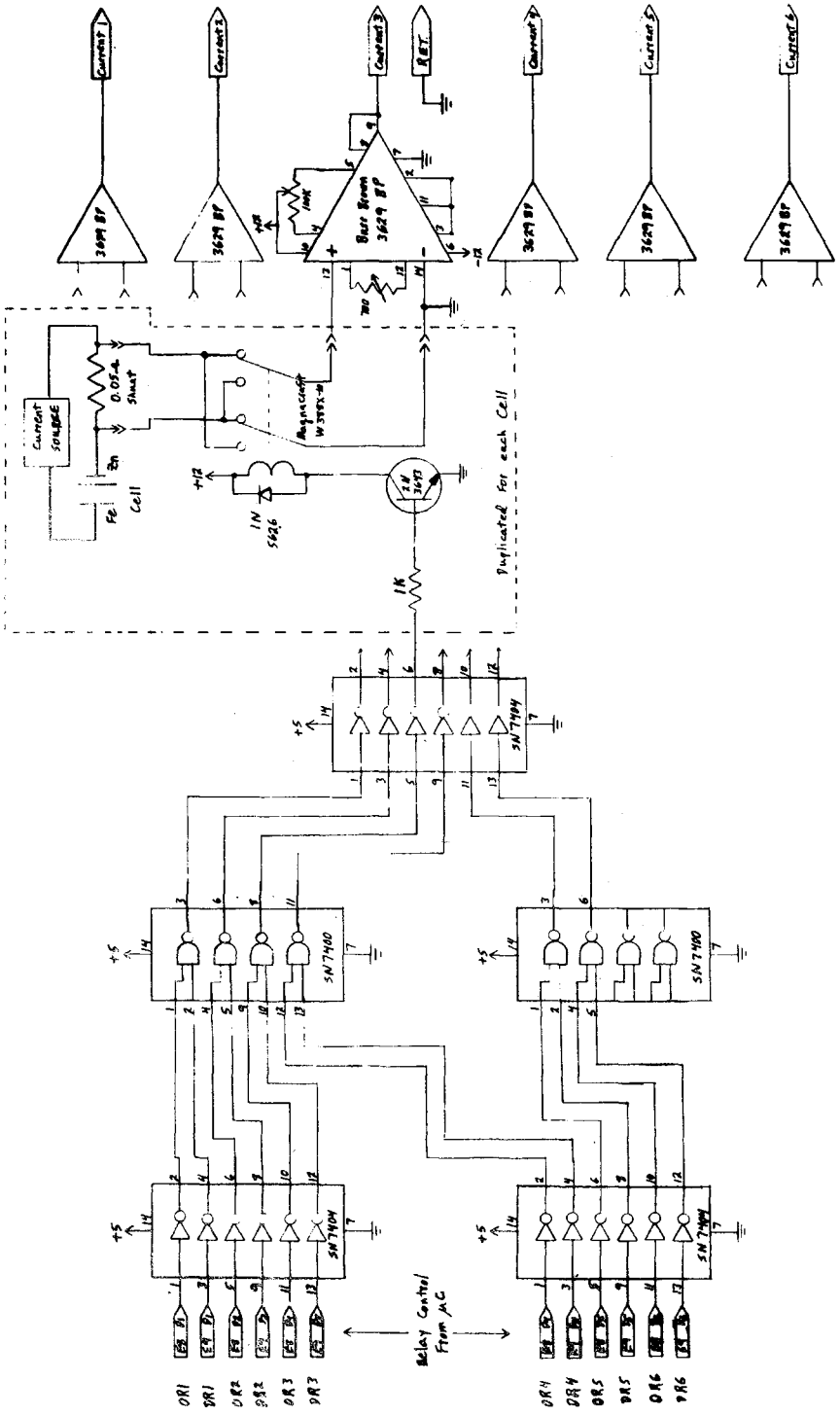

Figure A.1 Current-to-Voltage Instrumentation Amplifier Circuitry

Hexadecimal Keypad

The hexadecimal keypad circuitry shown in figure A.2 is based upon a 16-key, Centralab model M-1650-1 keypad. The SN 74147's and SN 7400 provide BCD coding of the keypad. The output from pin 8 of the SN 7400 signals that a key has been pressed and the SN 7405 and sonalert provide audible reinforcement to the operator. The switch at the bottom provides two choices for the operator. In the normal mode the display is used as a parameter monitor, whereas in the program mode, cell control parameters can be changed, and cell operation can be controlled by the operator. Input to the microcomputer is via the E6 port.

Real-Time Clock Interface

The real-time clock is required for continuous update of elapsed time while the computer performs various operations. The clock, shown in figure A.3, is essentially a frequency divider dividing the 12 VAC 60 Hz signal from the transformer of the μC 12 VDC power supply down to one second periods and inputting to port EA an 8-bit digital code representing one to 255 seconds. As no microcomputer operation takes more than 60 seconds there is sufficient overlap for real-time updating of the microcomputer.

Alphanumeric Display

The monitoring of cell information and control parameters is made possible by a 12-digit alphanumeric display. Based upon three Litronix DL-1416 modules having 4 digits each, the display circuitry, shown in figure A.4, is relatively easy to interface with the microcomputer. The displays consist of seven data lines (D_0-D_6), a chip enable ($\overline{CE}$), a cursor enable ($\overline{CU}$), a write line ($\overline{W}$), and two address lines (A_0,A_1). The data lines,address lines, and write lines are common for each module while each digit is controlled by the cursor and chip enable lines. Overall control of the display is via the Tiny Basic control program (Appendix B) outputting to ports E4 and E5. The SN 7407 hex inverter buffers are required due to the noisy industrial environment.

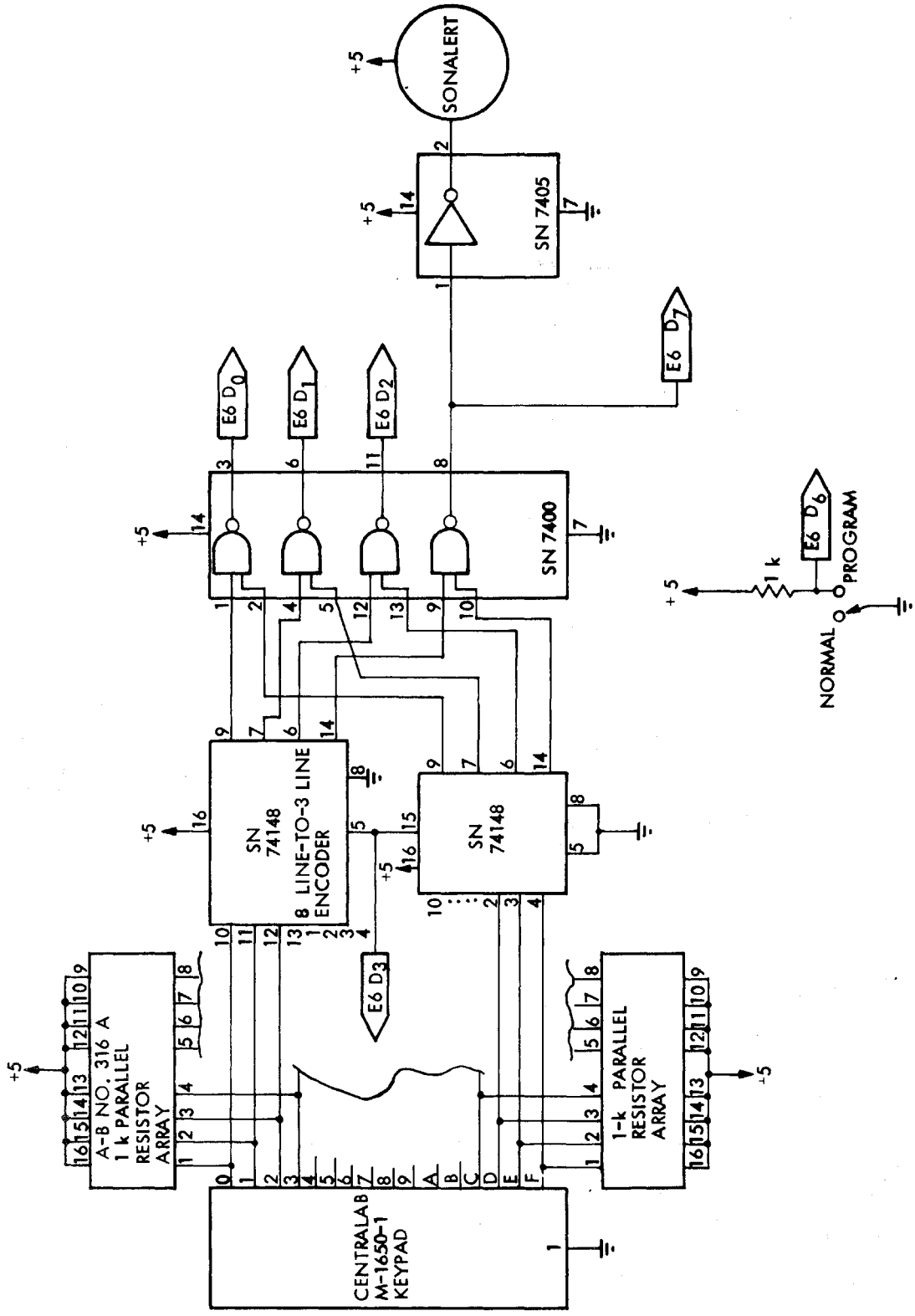

Figure A.2 Hexadecimal Keypad Interface

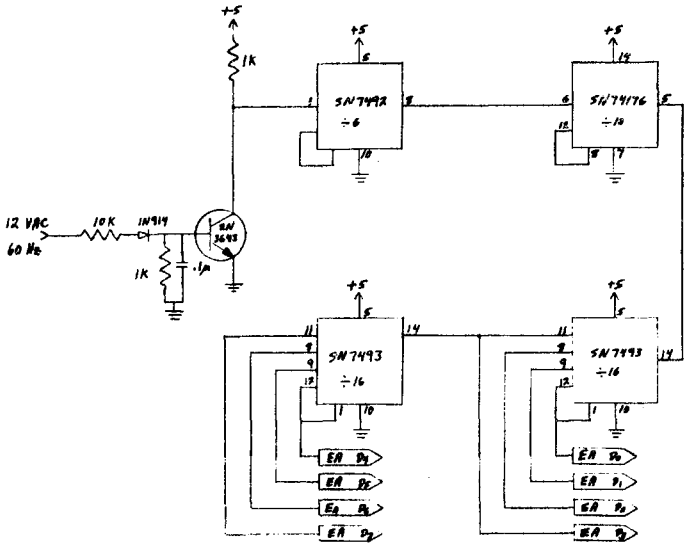

Figure A.3 Real-time clock interface

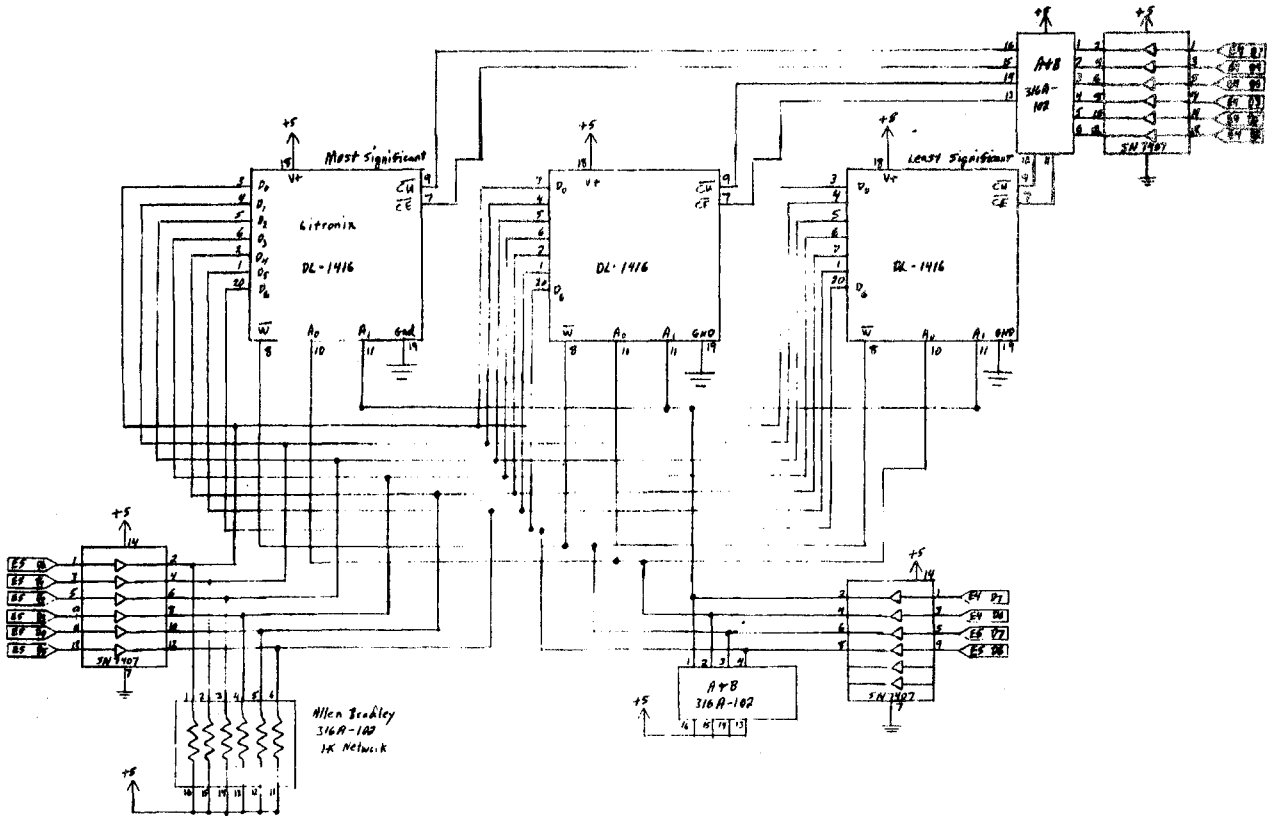

Figure A.4 12-digit Alphanumeric Display circuitry

If they are not installed as close to the displays as physically possible, electrical noise can destroy the CMOS display. During the course of this instrumentation development, six displays costing $30 each were destroyed before remedial action could be devised and implemented.

Constant Current Sources

The constant current sources are the heart of the battery test stand. They are required to charge and discharge the cells at constant current under command of the microcomputer. The microcomputer will command the charge sequence by outputting on port E8 a digital word which turns on the "OR" (open circuit) relay via an optical isolator. The relay allows current to flow from the LM 350 voltage regulator into the cell. The current is maintained constant by a constant voltage drop across the 6Ω variable resistor with current limiting provided by the 0.5Ω resistor. Similarly the discharge sequence is started by having "OR" on and turning "DR" (Direction relay) on via a digital command from the microcomputer on port E9. This action turns on the right-hand discharge circuit. Open circuit periods are controlled by turning "OR" off. Figure A.6 details the circuitry for one of the six current source circuits having common +/- 12V power supplies.

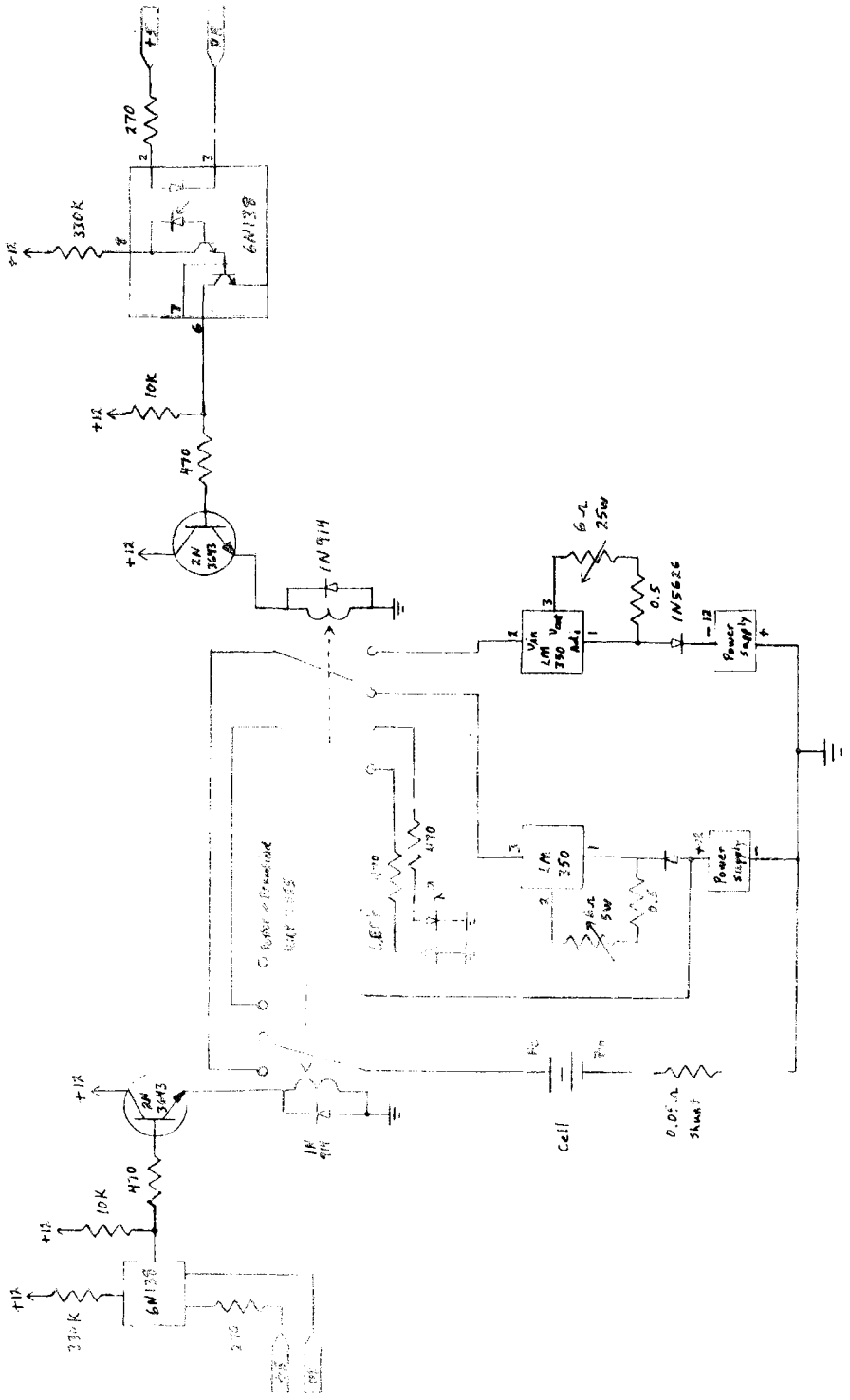

Figure A.5 Constant Current Sources for one cell

Appendix B
"TINY BASIC" CELL CONTROL PROGRAM

The Palo Alto Tiny Basic language is an interpretive language in which each line of code is independently translated to machine language and executed in turn. The assembly language code for this translation is given in Appendix C.

The language is a simplified set of the high order Basic language written and developed by Dr. Li-Chen Wang of LMSC. It was first described in the May 1976 issue of Dr. Dobb's Journal of Computer Calisthenics and Orthodontia. The present program was written for LMSC by Lincoln Semiconductor of Sunnyvale, CA whom we thank for their efforts.

In order to understand the control program it is first necessary to define the limits of the Palo Alto Tiny Basic language.

1. Numbers

All numbers are integers and must be less than 32767. Floating point math is not allowed. Numbers from arithmetic operations in excess of 32767 will result in stoppage of program execution via an error message.

2. Functions

There are three functions in the published language with six additional functions added by Lincoln Semiconductor.

ABS(X)	gives the absolute value of X
RND(X)	gives a random number between 1 and X (inclusive)
SIZE	gives the number of bytes of RAM unused by the program (includes variables of matrixes)
PEEK(X)	gives the value stored at memory location X
POKE(X,Y)	puts the value of Y into memory location X

PUT(X,Y)	Output to port X the value of Y
GET (X)	Input from port X
VOLT (X)	The voltage from A/D converter channel X
AMP(X)	The current from A/D converter channel X (This signal is corrected for shunt and instrumentation amplifier gains.)

3. Arithmetic and Compare Operators

Operation	Function
/	divide
*	multiply
-	subtract
+	add
>	greater than (compare)
<	less than (compare)
=	equal to (compare)
#	not equal to (compare)
>=	greater than or equal to (compare)
<=	less than or equal to (compare)

The +, -, *, and / operations result in a value between -32767 and 32767. All compare operators result in a 1 if true and a 0 if not true.

4. Expressions

The common expressions found in the high order basics are found here, namely:

LET, FOR, NEXT, IF, STOP, RUN, GOTO, GOSUB, LIST, PRINT, INPUT, LIST, REMARK, NEW,RETURN, STEP.

The majority of the above can be truncated such as P. for Print, GOS. for GOSUB, and R. for RETURN. The expression NEW will delete all prior statements.

5. Error Messages

The present Tiny Basic Code has been modified so that upon an error Port E8 is turned off which turns off all cell operations. If this was not done the cells would continue charging or discharging with no control.

The three error conditions in Tiny Basic are What, How, and Sorry.

What?	means it does not understand you and is usually a coding error
How?	means it understands you but does not know how to do it; usually due to arithmetic operation exceeding 32767
Sorry?	means it understands you and knows how to do it but there is not enough memory to do it.

The following listing details the Tiny Basic Control program developed to control the charge/discharge of 6 cells. Table B.1 details the identity of the @(J+X) matrix variable names, Table B.2 details the identity of operator variables, and Table B.3 gives the listing of the control program.

Table B.1 Identity of @(J+X) Matrix Variables

X	Identification	X	Identification
1	S Status	45	TDU Time at T6
2	CN Cycle Number	46	UCU Ah at T6
3	CT Charge Time (h)	47	CPU Cell Pot. at T6
4	OC Overcharge Pot.	48	ZPU Zinc Pot. at T6
5	UC Usable Energy Pot.	49	FPU Iron Pot. at T6
6	ZC Zinc Depletion Pot.	50	CCT A-s Charge
7	FC Iron Depletion Pot.	51	DCT A-s Discharge
8	TAH Accumulated Time (h)	52	TAS Accumulated Time (s)
9	CP Cell Potential	53	TCT Temporary Time
10	ZP Zinc Potential	54	CD Charge Current Density
11	FP Iron Potential	55	DD Discharge Current Density
12	CV Average Charge Pot.	56	VE Voltaic Energy Efficiency
13	DV Average Discharge Pot.	57	UE Usable Coulombic Efficiency
14	+I Charge Current	58	OE Energy Conversion Efficiency
15	CC Charge (Ah)	59	FE Iron Coulombic Efficiency
16	UC Discharge (Ah)	60	ZE Zinc Coulombic Efficiency
17	-I Discharge Current	61	Not Used
18	SSF Secondary Status Flag	62	OCP Open Circuit Pot. Charged
19	V Wait Time OCV	63	OZP OCV Zinc Charged
20	TCC Time for T1	64	OFP OCV Iron Charged
21	CCC Ah at T1	65	O Zero Output
22	CPC Cell Pot. at T1	66	O Zero Output
23	ZPC Zinc Pot. at T1	67	DCP OCV Discharged
24	FPC Iron Pot. at T1	68	DZP OCV-Zinc Discharged
25	TCP Time at T2	69	DFP OCV-Iron Discharged
26	CCP Ah at T2	70	O Zero Output
27	CPP Cell Pot. at T2	71	CCC Ah at T1
28	ZPP Zinc Pot. at T2	72	CCP Ah at T2
29	FPP Iron Pot. at T2	73	UCD Ah at T5
30	TDZ Time for T3	74	UCZ Ah at T3
31	UCZ Ah at T3	75	UCF Ah at T4
32	CPZ Cell Pot. at T3	76	UCU Ah at T6
33	ZPZ Zinc Pot. at T3	77	Current at T1
34	FPZ Iron Pot. at T3	78	Current at T2
35	TDZ Time at T4	79	Current at OCV
36	UCF Ah at T4	80	Current at T3
37	CPF Cell Pot. at T4	81	Current at T4
38	ZPF Zinc Pot. at T4	82	Current at T5
39	FPF Iron Pot. at T4	83	Current at T6
40	TDD Time at T5	84	Ah DCP
41	UCD Ah at T5	85	Ah Discharge
42	CPD Cell Pot. at T5	86	Ah Charge
43	ZPD Zinc Pot. at T5	87	DD Discharge Current Density
44	FPD Iron Pot. at T5	88	TD Time at End Discharge

T1 Test for 30 min for average charge voltage
T2 Test for end of charge (either time or potential controlled)
T3 Test for zinc depletion on discharge
T4 Test for iron depletion on discharge
T5 Test for 30 min for average discharge voltage
T6 Test for usable energy potential

Table B.2
Table of Operator Variables

A	=	Status function
B	=	Base of 1st Battery Array
C	=	Cell number
D	=	Secondary Quotient
E	=	Enter function
F	=	Display function
G	=	Temporary
H	=	N/A
I	=	Temporary Index
J	=	Index to Array
K	=	Key pressed
L	=	Length of array for each cell
M	=	N/A
N	=	N/A
O	=	N/A
P	=	Direction relay bit pattern
Q	=	Temporary
R	=	Open circuit relay bit pattern
S	=	Status of cell
T	=	Timer
V	=	OCV Time
W	=	Temporary
X	=	Temporary
Y	=	N/A
Z	=	Base for A/D

Table B.3

TINY BASIC CONTROL PROGRAM

```
  6 PUT235,137;PUT231,137;PUT232,0;REM INITIALIZE UARTS, OPEN CURRENT
  9 LET B=305,C=1,F=1,L=90,Z=-9*256,V=60
 10 FOR I=1TOB+6*L;LET @(I)=0;NEXT I
 11 @(1)=239;@(2)=238;@(3)=237;@(4)=236;@(5)=247;@(6)=246
 12 @(7)=245;@(8)=244;@(9)=251;@(10)=250;@(11)=249;@(12)=248
 13 GOSUB 1180
 15 FOR I=13TO197;LET @(I)=32;NEXT I
 16 LET @(16)=83;REM F=1
 17 LET @(27)=67,@(28)=78;REM F=2
 18 LET @(39)=67,@(40)=84,@(47)=72,@(48)=82,@(44)=46;REM F=3
 19 LET @(51)=79,@(52)=67,@(55)=46,@(59)=86;REM F=4
 20 LET @(63)=85,@(64)=69,@(67)=46,@(71)=86;REM F=5
 21 LET @(75)=90,@(76)=67,@(79)=46,@(83)=86;REM F=6
 22 LET @(87)=70,@(88)=67,@(91)=46,@(95)=86;REM F=7
 23 LET @(99)=84,@(100)=65,@(104)=46,@(107)=72,@(108)=82;REM F=8
 24 LET @(111)=67,@(112)=80,@(115)=46,@(119)=86;REM F=9
 25 LET @(123)=90,@(124)=80,@(127)=46,@(131)=86;REM F=9
 26 LET @(135)=70,@(136)=80,@(139)=46,@(143)=86;REM F=11
 27 LET @(147)=67,@(148)=86,@(151)=46,@(155)=86;REM F=12
 28 LET @(159)=68,@(160)=86,@(163)=46,@(167)=86;REM F=13
 29 LET @(172)=73,@(175)=46,@(179)=65;REM F=14
 30 LET @(183)=67,@(184)=67,@(188)=46,@(191)=65,@(192)=72;REM F=14
 31 LET @(195)=68,@(196)=67,@(200)=46,@(203)=65,@(204)=72;REM F=15
 32 INPUT"YEAR"@(230),"DAY"@(229),"HR"@(228),"MIN"@(227);@(226)=0
 33 LET @(232)=1
 40 U=GET(234)
 50 FOR J=B TO B+5+LSTEPL;LET @(J+1)=0,@(J+2)=0,@(J+3)=20,@(J+4)=225
 52 LET @(J+5)=145,@(J+6)=80,@(J+7)=30;NEXT J
 60 LET P=126,R=0;PUT233,P
100 T=GET(234);IFT=U GOTO  100
101 IFT<ULET T=T+256
102 LET T=T-U,U=U+T;IFU>=256LET U=U-256
110 LET @(226)=@(226)+T;IF@(226)<60 GOTO  200
120 LET @(226)=@(226)-60,@(227)=@(227)+1;IF @(226)>=60  GOTO  120
125 IF @(227)<60  GOTO  200
130 LET @(227)=@(227)-60,@(228)=@(228)+1;IF@(228)<24 GOTO  200
140 LET @(228)=@(228)-24,@(229)=@(229)+1;IF@(229)<366 GOTO  200
150 LET @(229)=1,@(230)=@(230)+1
200 FOR @(225)=1TO6
202 PUT228,255-@(2);PUT229,170;PUT229,42;PUT229,170
210 LET Q=0,K=GET(230)-48;IFK>=128LET Q=128
212 PUT229,160;PUT229,32;PUT229,160
220 LET K=K-Q;IFK>=64 GOTO  500
```

```
230 IFF<8 GOTO  240
232 LET @(231)=0; GOTO  500
240 IF@#0 GOTO  250
242 IF(@(231)=0)*(F#1) GOTO  3000
244 IFF#1 GOTO  2900
246  GOTO  1000
250 IFK=14 GOTO  400
260 IFK<10 GOTO  270
262 LET @(231)=0; GOTO  500
270 IFF=1 GOTO  330
280 IF@(231)#0 GOTO  290
282 FOR I=1TO12;LET @(204+I)=@(12*F+I);NEXT I;LET @(231)=1
290 LET @(210)=@(211);IF@(211)=46LET @(210)=@(212)
300 IF@(211)=46 GOTO  310
302 LET @(211)=@(212);IF@(212)=46LET @(211)=@(213)
310 IF@(212)=46 GOTO  320
312 LET @(212)=@(213)
320 LET @(213)=K; GOTO  2900
330 LET X=R+L*(C-1);IFK#0 GOTO  340
332 LET @(X+1)=0,@(X+18)=0,@(X+19)=0;GOSUB 354;LET R=R-Q;PUT232,R
334 LET Q=64,W=0;FOR I=6TO1STEP-1;IFP1=0 GOTO  337
335 IFP<0 GOTO  338
336 LET P=P-Q,W=W+Q; GOTO  338
337 IFP>=QLET P=P-Q
338 LET Q=Q/2;NEXT I;LET P=W;PUT233,P; GOTO  1000
340 IF(K#1)*(K#2) GOTO  360
342 IF@(X+1)#0 GOTO  350
344 LET @(X+1)=1,@(X+19)=0;GOSUB 354;LET R=R+Q;PUT232,R; GOTO  1000
350 IF(@(X+1)=4)+(@(X+1)=7)=0 GOTO  3130
351 IF@(X+1)=4 GOTO  356
352 LET @(X+1)=@(X+18),@(X+18)=0;GOSUB 354;LET R=R+Q;PUT 232,R; GOTO  1
000
354 LET Q=1;FOR I=1TOC;LET Q=Q+Q;NEXT I;RETURN
356 LET @(X+1)=@(X+18),@(X+18)=0; GOTO  3130
360 IF@#4 GOTO  364
362 LET @(X+18)=4; GOTO  1000
364 IF@#7 GOTO  370
365 IF(@(X+1)#1)*(@(X+1)#2)*(@(X+1)#16) GOTO  1000
366 LET @(X+18)=@(X+1),@(X+1)=7;GOSUB 354;LET R=R-Q;PUT 232,R; GOTO  10
00
370 IF@#6 GOTO  380
372 INPUT"NEW WAIT TIME"V;LET V=60*V; GOTO  3130
380 IF@#5 GOTO  390
382 LET @=230; GOTO  3002
390 IF@#9 GOTO  3130
```

```
 395 LET Q=292; GOTO  3002
 400 LET @(231)=0
 410 IFF#2 GOTO  420
 412 LET @(B+L*(C-1)+F)=1000*@(210)+100*@(211)+10*@(212)+@(213)
 414  GOTO  1000
 420 LET @(B+L*(C-1)+F)=100*@(210)+@(213)
 430 IF(F#3)*(F#8)#0 GOTO  440
 432 LET @(B+L*(C-1)+F)=@(B+L*(C-1)+F)+10*@(211); GOTO  1000
 440 LET @(B+L*(C-1)+F)=@(B+L*(C-1)+F)+10*@(212); GOTO  1000
 500 IFQ=0 GOTO  1000
 510 IFK>=64LET K=K-64
 520 IFK<10 GOTO  3130
 530  GOTO  530+10*(K-9)
 540 K=GET(230)-48;IFK<192  GOTO  548
 542 PUT 228,255-@(2);PUT 229,193;PUT 229,65;PUT 229,193
 544 K=GET(230)-48;IFK#64 GOTO 544
 545 K=GET(230)-112;IF K=0 GOTO 545
 546 K=K-128;LET F=K+1; GOTO  1000
 548 LET F=1; GOTO  1000
 550 IF@(232)#0 GOTO  552
 551 @(232)=1;PRINT "TAPE READY";GOSUB 8500; GOTO  3130
 552 @(232)=0;PRINT "OK TO REMOVE TAPE"; GOTO  3130
 560 LET C=C+1;IFC>6LET C=1
 562  GOTO  1000
 570 IF@(232)#0GOSUB 7000
 572  GOTO  3130
 580  GOTO  3130
 590 LET F=F+1;IFF>16LET F=1
1000 LET W=12*F,Q=B+L*(C-1),X=@(Q+F),@(W+1)=C;IF F=1  GOTO  1100
1010 IFF=2 GOTO  1200
1020 IF F=15  GOTO  1220
1022 IF F#16  GOTO  1030
1024 LET X=@(Q+85); GOTO  1220
1030 IF(F=3)+(F=8)>0 GOTO  1300
1032 IFF#14 GOTO  1040
1034 LET @(W+5)=32;IF@(Q+1)=2 GOTO  1040
1036 LET @(W+5)=45,X=@(Q+17)
1040 LET @(W+6)=X/100,X=X-100*@(W+6),@(W+8)=X/10,@(W+9)=X-10*@(W+8)
1050  GOTO  3000
1100 IF@(Q+18)=4 GOTO  1170
1102 IF(X=2)+(X=8)+(X=9)+(X=10)+(X=20) GOTO  1112
1104 IF(X=16)+(X=17)+(X=18)+(X=19)+(X=22) GOTO  1120
1105 IFX=3 GOTO  1160
```

```
1106 IFX=7 GOTO  1162
1107 IFX=8 GOTO  1164
1108 IFX=1 GOTO  1130
1109 IFX=4 GOTO  1140
1110 IFX=0 GOTO  1150
1111  GOTO  3130
1112 LET @(18)=67,@(19)=72,@(20)=65,@(21)=82,@(22)=71,@(23)=69; GOTO  30
00
1118 LET @(18)=67,@(19)=72,@(20)=65,@(21)=82,@(22)=71,@(23)=69; GOTO  30
00
1120 LET @(18)=68,@(19)=73,@(20)=83,@(21)=67,@(22)=72,@(23)=71; GOTO  30
00
1130 LET @(18)=73,@(19)=78,@(20)=73,@(21)=84,@(22)=32,@(23)=32; GOTO  30
00
1140 LET @(18)=73,@(19)=78,@(20)=84,@(21)=82,@(22)=69,@(23)=68; GOTO  30
00
1150 LET @(18)=83,@(19)=84,@(20)=79,@(21)=80,@(22)=32,@(23)=32; GOTO  30
00
1160 LET @(18)=80,@(19)=82,@(20)=73,@(21)=78,@(22)=84,@(23)=32; GOTO  30
00
1162 LET @(18)=80,@(19)=65,@(20)=85,@(21)=83,@(22)=69,@(23)=32; GOTO  30
00
1164 LET @(18)=80,@(19)=82,@(20)=73,@(21)=78,@(22)=84,@(23)=32; GOTO  30
00
1170 LET @(18)=73,@(19)=78,@(20)=84,@(21)=82,@(22)=32,@(23)=32; GOTO  30
00
1180 LET @(280)=32,@(281)=32,@(282)=32,@(283)=78,@(284)=65,@(285)=78
1182 @(286)=79,@(287)=32,@(288)=78,@(289)=65,@(290)=78,@(291)=79
1184 LET @(292)=32,@(293)=32,@(294)=32,@(295)=83,@(296)=72,@(297)=65
1186 @(298)=90,@(299)=66,@(300)=79,@(301)=84,@(302)=32,@(303)=63
1187 @(304)=32
1188 RETURN
1200 LET @(30)=X/1000,X=X-1000*@(30),@(31)=X/100,X=X-100*@(31)
1210 LET @(32)=X/10,@(33)=X-10*@(32); GOTO  3000
1220 LET @(W+6)=X/1000,X=X-1000*@(W+6),@(W+7)=X/100,X=X-100*@(W+7)
1230 LET @(W+9)=X/10,@(W+10)=X-10*@(W+9)
1240  GOTO  3000
1300 LET @(W+6)=X/100,X=X-100*@(W+6),@(W+7)=X/10
1310 LET @(W+9)=X-10*@(W+7); GOTO  3000
2900 LET Q=204; GOTO  3002
3000 LET Q=12*F
3002 FOR I=12TO1S.-1
3010 PUT228,255-@(I)
3012 LET W=0;IF@(Q+I)<32LET W=48
3020 PUT229,@(Q+I)+W+128
3030 PUT229,@(Q+I)+W
3040 PUT229,@(Q+I)+W+128
3060 NEXTI
3130 LET J=B+L*(@(225)-1),X=Z+5*(@(225)-1)
3132 LET S=@(J+1);IF(S=0)+(S=3)+(S=4)+(S=7) GOTO  4900
3140 IF@(J+19)>0@(J+19)=@(J+19)-T
3150 IF@(J+19)>0 GOTO  4900
3160 IFS=17 GOTO  3930
```

```
3162 IF(S#1)*(S#2)*(S#16) GOTO  4000
3170 LET @(J+9)=(V.(X+1)+50)/100,@(J+10)=(V.(X+2)+50)/100
3180 LET @(J+11)=(V.(X+3)+50)/100,@(J+17)=(AMP(X+4)+50)/100
3190 LET @(J+14)=(AMP(X+5)+50)/100
3192  GOTO  3230
3195 IF @(225)<=3  GOTO  3200
3197 IF @(J+8)#@(J+3)  GOTO  3230
3198  GOTO  3210
3200 IF @(J+10)#0  GOTO  3230
3210 LET @(J+18)=@(J+1),@(J+1)=7;GOSUB 4510;LET R=R-0;PUT232,R; GOTO  49
00
3230 IFS#1GOTO3400
3232 IF @(225)>=5  GOTO  3240
3234 IF @(225)=2  GOTO  3240
3236 IF @(225)=3  GOTO  3240
3238 IF @(J+11)>@(J+7) GOTO  4900
3239  GOTO  3242
3240 IF@(J+6)<@(J+10)GOTO4900
3242 GOSUB 4510;LET R=R-0;PUT232,R
3250 PRINT "CELL ",#1,@(225)," READY @ ",@(230),"/",@(229)," ",
3252 PRINT #1,@(228),":",@(227),":",@(226)
3260 LET @(J+8)=0,@(J+1)=20,@(J+19)=60
3262 NEXT @(225); GOTO  100
3400 IFS#16GOTO3500
3410 @(J+51)=@(J+51)+T*@(J+17)
3420 IF @(J+51)<0GOTO3540
3430 LET Q=@(J+51)/3600,@(J+85)=@(J+85)+Q,@(J+51)=@(J+51)-3600*Q
3500 IFS=2LET @(J+50)=@(J+50)+T*@(J+14)
3510 IF@(J+50)<=0GOTO3540
3520 LET Q=@(J+50)/3600,@(J+15)=@(J+15)+Q,@(J+50)=@(J+50)-3600*Q
3540 @(J+52)=@(J+52)+T
3550 IF@(J+52)<=0GOTO3600
3552 GOTO 3560
3553 REM LINE 3555 SPEEDS TA CLOCK UP 10X
3554 REM LINE 3552 BYPASSES 10X CLOCK
3555 @(J+52)=@(J+52)-36;@(J+8)=@(J+8)+1;GOTO 3550
3560 LET D=@(J+52)/360,@(J+8)=@(J+8)+D,@(J+52)=@(J+52)-360*D
3600 IFS#2GOTO3700
3610 IF @(J+8)>@(J+3)/2  GOTO  3612
3611 IF @(J+9)<@(J+4)  GOTO  4900
3612 IF@(J+20)#0GOTO3640
3620 @(J+20)=@(J+8);@(J+21)=@(J+15);@(J+22)=@(J+9);@(J+12)=@(J+9)
3630 LET @(J+23)=@(J+10),@(J+24)=@(J+11),@(J+77)=@(J+14),@(J+71)=@(J+15)
3640 IF@(J+9)>@(J+4) GOTO  3650
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3642 IF@(J+8)<@(J+3) GOTO  4900
3650 @(J+25)=@(J+8);@(J+26)=@(J+15);@(J+27)=@(J+9)
3660 LET @(J+28)=@(J+10),@(J+29)=@(J+11),@(J+78)=@(J+14),@(J+86)=@(J+15)
3665 IF @(J+25)<1  GOTO  3210
3670 LET @(J+1)=10,@(J+8)=0,@(J+52)=0,@(J+19)=V;GOSUB 4510;LET R=R-Q;PUT
232,R
3672  GOTO  4900
3700 IFS#16GOTO4000
3702 IF @(J+8)<5  GOTO  3708
3703 IF@(J+40)#0 GOTO  3708
3704 LET @(J+40)=@(J+8),@(J+41)=@(J+85),@(J+42)=@(J+9),@(J+73)=@(J+85)
3706 LET @(J+43)=@(J+10),@(J+44)=@(J+11),@(J+82)=@(J+17)
3707 LET @(J+13)=@(J+9)
3708 IF @(J+9)>@(J+5)  GOTO  3714
3709 IF@(J+45)#0 GOTO  3714
3710 LET @(J+45)=@(J+8),@(J+46)=@(J+85),@(J+47)=@(J+9)
3712 LET @(J+48)=@(J+10),@(J+49)=@(J+11),@(J+76)=@(J+85),@(J+16)=@(J+85)
3714 IF@(J+30)#0 GOTO  3738
3716 IF @(J+10)>@(J+6) GOTO  3739
3720 LET @(J+30)=@(J+8),@(J+31)=@(J+85),@(J+32)=@(J+9),@(J+74)=@(J+85)
3730 LET @(J+33)=@(J+10),@(J+34)=@(J+11),@(J+80)=@(J+17)
3732 IF ((@(225)=5)+(@(225)=6))=0  GOTO  3738
3733 IF @(J+9)>@(J+5) GOTO  3739
3734 IF @(J+35)#0 GOTO  3830
3736  GOTO  3750
3738 IF (@(J+30)#0)*(@(J+35)#0)#0  GOTO  3830
3739 IF @(J+35)#0 GOTO  4900
3740 IF@(J+11)>@(J+7) GOTO  4900
3750 LET @(J+35)=@(J+8),@(J+36)=@(J+85),@(J+37)=@(J+9),@(J+75)=@(J+85)
3760 LET @(J+38)=@(J+10),@(J+39)=@(J+11),@(J+81)=@(J+17)
3765 IF @(J+9)>@(J+5) GOTO  4900
3770 IF @(225)=4  GOTO  3830
3772 IF @(225)=1  GOTO  3830
3780 IF @(J+30)=0 GOTO  4900
3830 LET S=17,@(J+1)=17,@(J+19)=V
3832 GOSUB 4510;LET R=R-Q;PUT232,R
3840 LET @(J+8)=0,@(J+51)=0; GOTO  4900
3930 LET @(J+67)=(V.(X+1)+50)/100,@(J+68)=(V.(X+2)+50)/100
3932 LET @(J+69)=(V.(X+3)+50)/100
3934 LET X=@(J+41),Q=@(J+40);GOSUB 5000;LET X=G,Q=60;GOSUB 5000
3936 LET @(J+87)=G/10,G=G-10*@(J+87);IFG>=5LET @(J+87)=@(J+87)+1
3938 LET X=@(J+26),Q=@(J+25);GOSUB 5000;LET X=G,Q=600;GOSUB 5000
3940 LET @(J+54)=G;IFD/100>5LET @(J+54)=@(J+54)+1
3944 LET X=@(J+42),Q=@(J+22);GOSUB 5000
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3946 LET @(J+56)=10*G+(D+50)/100
3950 LET X=@(J+76),Q=@(J+26);GOSUB 5000
3952 LET @(J+57)=10*G+(D+50)/100
3954 LET X=@(J+56)/10;IF@(J+56)-10*X<=5 GOTO  3958
3956 LET X=X+1
3958 LET Q=@(J+57)/10;IF@(J+57)-10*Q<=5 GOTO  3962
3960 LET Q=Q+1
3962 LET X=X*Q,Q=100;GOSUB 5000
3972 LET @(J+58)=G/10,G=G-10*@(J+58);IFG>5LET @(J+58)=@(J+58)+1
3974 LET X=@(J+75),Q=@(J+26);GOSUB 5000
3976 LET @(J+59)=10*G+(D+50)/100
3980 LET X=@(J+74),Q=@(J+26);GOSUB 5000
3982 LET @(J+60)=10*G+(D+50)/100
3994 LET @(J+30)=0,@(J+35)=0,@(J+40)=0,@(J+45)=0,@(J+50)=0,@(J+51)=0
3995 LET @(J+2)=@(J+2)+1
3996  GOTO  4050
4000 IFS<8GOTO4900
4020 IFS#10 GOTO  4100
4030 IFS=22 GOTO  4050
4034 @(J+62)=(V.(X+1)+50)/100;@(J+63)=(V.(X+2)+50)/100
4036 LET @(J+64)=(V.(X+3)+50)/100
4040 LET @(J+72)=@(J+15),@(J+1)=8,@(J+19)=30
4042  GOTO  4900
4050 LET @(J+84)=@(J+16),@(J+1)=18,@(J+19)=30
4056 GOSUB 8700;IF@(J+1)=3 GOTO  4900
4058 IF@(J+18)#4 GOTO  4900
4060 @(J+18)=@(J+1),@(J+1)=4; GOTO  4900
4100 IFS#8GOTO4200
4110 GOSUB4510
4120 LET P=P+Q;PUT233,P
4130 LET @(J+1)=9,@(J+19)=30
4132  GOTO  4900
4200 IFS#18GOTO4300
4210 GOSUB 4510;LET P=P-Q;PUT233,P
4220 LET @(J+1)=19,@(J+19)=30
4222  GOTO  4900
4300 IFS#9GOTO4400
4310 GOSUB 4510;LET R=R+Q;PUT232,R;REM CLOSE CURRENT RELAY
4320 LET @(J+1)=16,@(J+52)=0
4322  GOTO  4900
4400 IFS#19 GOTO  4430
4410 GOSUB 4510;LET R=R+Q;PUT232,R;REM CLOSE CURRENT RELAY
4420 LET @(J+1)=2;FOR I=8TOL;LET @(J+I)=0;NEXT I
```

```
4422  GOTO  4900
4430 IFS#20 GOTO  4900
4440 LET @(J+84)=@(J+16),@(J+1)=18,@(J+19)=30; GOTO  4900
4500  GOTO  4900
4510 LET Q=1;FOR I=1TO@(225);LET Q=Q+Q;NEXT I;RETURN
4900 NEXT @(225)
4910 GOTO100
5000 IFQ#0 GOTO  5010
5002 LET G=99,D=999;RETURN
5010 LET W=X/Q,X=10*(X-W*Q),G=W,W=X/Q,X=10*(X-W*Q),G=10*G+W,W=X/Q
5020 LET X=10*(X-W*Q),G=10*G+W
5030 LET W=X/Q,X=10*(X-W*Q),D=W,W=X/Q,X=10*(X-W*Q),D=10*D+W,W=X/Q
5040 LET X=10*(X-W*Q),D=10*D+W
5060 RETURN
7000 G=B+L*(C-1)
7002 PRINT
7004 PRINT ;PRINT #1,@(230),"/",@(229),"  ",@(228),":",@(227),":",@(226)
,"  ",
7006 PRINT #2,"CELL #",((G-B)/L)+1,"   CYCLE #",@(G+2)-1
7011 PRINT "          HRS   AMP/HRS  CELL    ZINC    IRON      I"
7012 PRINT "CHARGE";IF@(G+1)#2 GOTO 7074
7014 PRINT "CURRENT ",
7020 LET Q=@(G+8);GOSUB 8600
7030 LET Q=@(G+15);GOSUB 8610
7040 LET Q=@(G+9);GOSUB 8610
7050 LET Q=@(G+10);GOSUB 8610
7060 LET Q=@(G+11);GOSUB 8610
7070 LET Q=@(G+14);GOSUB 8610
7074 PRINT
7080 PRINT "30 MIN  ",;LET Q=@(G+20);GOSUB 8600
7090 LET Q=@(G+71);GOSUB 8610
7100 LET Q=@(G+22);GOSUB 8610
7110 LET Q=@(G+23);GOSUB 8610
7120 LET Q=@(G+24);GOSUB 8610
7130 LET Q=@(G+77);GOSUB 8610
7132 PRINT ;PRINT "END     ",;LET Q=@(G+25);GOSUB 8600;LET Q=@(G+26);GOS
UB 8610
7134 LET Q=@(G+27);GOSUB 8610;LET Q=@(G+28);GOSUB 8610
7136 LET Q=@(G+29);GOSUB 8610
7138 LET Q=@(G+78);GOSUB 8610
7140 PRINT ;PRINT "OCV     ",;LET Q=0;GOSUB 8600
7150 LET Q=@(G+72);GOSUB 8610
7160 LET Q=@(G+62);GOSUB 8610
7170 LET Q=@(G+63);GOSUB 8610
7180 LET Q=@(G+64);GOSUB 8610
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7190 LET Q=@(G+79);GOSUB 8610;PRINT
7200 PRINT "DISCHARGE";IF@(G+1)#16 GOTO  7290
7210 PRINT "CURRENT ",
7230 LET Q=@(G+8);GOSUB 8600
7240 LET Q=@(G+85);GOSUB 8610
7250 LET Q=@(G+9);GOSUB 8610
7260 LET Q=@(G+10);GOSUB 8610
7270 LET Q=@(G+11);GOSUB 8610
7280 LET Q=@(G+12);GOSUB 8610
7290 PRINT
7300 PRINT "30 MIN  ",;LET Q=@(G+40);GOSUB 8600
7310 LET Q=@(G+41);GOSUB 8610
7320 LET Q=@(G+42);GOSUB 8610
7330 LET Q=@(G+43);GOSUB 8610
7340 LET Q=@(G+44);GOSUB 8610
7350 LET Q=@(G+82);GOSUB 8610;PRINT
7360 PRINT "ZINC LIM",;LET Q=@(G+30);GOSUB 8600
7370 LET Q=@(G+74);GOSUB 8610
7380 LET Q=@(G+32);GOSUB 8610
7390 LET Q=@(G+33);GOSUB 8610
7400 LET Q=@(G+34);GOSUB 8610
7410 LET Q=@(G+80);GOSUB 8610;PRINT
7420 PRINT "IRON LIM",;LET Q=@(G+35);GOSUB 8600
7430 LET Q=@(G+75);GOSUB 8610
7440 LET Q=@(G+37);GOSUB 8610
7450 LET Q=@(G+38);GOSUB 8610
7460 LET Q=@(G+39);GOSUB 8610
7470 LET Q=@(G+81);GOSUB 8610;PRINT
7480 PRINT "CELL LIM",;LET Q=@(G+45);GOSUB 8600
7490 LET Q=@(G+76);GOSUB 8610
7500 LET Q=@(G+47);GOSUB 8610
7510 LET Q=@(G+48);GOSUB 8610
7520 LET Q=@(G+49);GOSUB 8610
7530 LET Q=@(G+83);GOSUB 8610;PRINT
7540 PRINT "DCV      ",;LET Q=0;GOSUB 8600
7550 LET Q=0;GOSUB 8610
7560 LET Q=@(G+67);GOSUB 8610
7570 LET Q=@(G+68);GOSUB 8610
7580 LET Q=@(G+69);GOSUB 8610
7590 LET Q=0;GOSUB 8610;PRINT ;RETURN
8500 IF@(233)=0RETURN
8510 LET @(234)=J;FOR J=225TO229;LET @(J+10)=@(J);NEXT J
8520 FOR @(217)=1TO@(233);LET Q=241+6*(@(217)-1),J=B+L*(@(0)-1),@(225)=@
(0)
```

```
8530 LET @(226)=@(Q+1),@(227)=@(Q+2),@(228)=@(Q+3),@(229)=@(Q+4)
8540 LET @(23)=@(Q+5),@(J+1)=@(J+18),@(J+18)=0;GOSUB 8700;NEXT @(217)
8550 FOR J=225TO230;LET @(J)=@(J+10);NEXT J
8560 LET J=@(234),@(233)=0;RETURN
8600 LET W=Q/10,Q=Q-10*W;PRINT #3,W,".",#1,Q,;RETURN
8610 W=Q/100;Q=Q-100*W;PRINT #5,W,".",
8612 IFQ=0 GOTO  8618
8614 IFQ>=10 GOTO  8616
8615 PRINT "0",#1,Q,;RETURN
8616 PRINT #2,Q,;RETURN
8618 PRINT "00",;RETURN
8700 IF @(232)#0 GOTO  8720
8702 IF @(233)>=6RETURN
8704 LET @(233)=@(233)+1,Q=241+6*(@(233)-1)
8706 LET @(Q)=@(225),@(Q+1)=@(226),@(Q+2)=@(227),@(Q+3)=@(228)
8708 LET @(Q+4)=@(229),@(Q+5)=@(230)
8710 LET @(J+18)=@(J+1),@(J+1)=3;RETURN
8720 PRINT ;PRINT #1,@(230),"/",@(229),"  ",@(228),":",@(227),":",@(226)
,
8721 PRINT #1,"    ",@(225),"  ",@(J+2),
8722 LET Q=@(J+25);GOSUB 8950
8723 LET Q=@(J+54);GOSUB 8950
8724 LET Q=@(J+87);GOSUB 8950
8730 LET Q=@(J+56);GOSUB 8950
8740 LET Q=@(J+57);GOSUB 8950
8750 LET Q=@(J+58);GOSUB 8950
8760 LET Q=@(J+60);GOSUB 8950
8770 LET Q=@(J+59);GOSUB 8950;PRINT
8775 LET Q=@(J+23);GOSUB 8900;LET Q=@(J+24);GOSUB 8900
8780 LET Q=@(J+27);GOSUB 8900;LET Q=@(J+62);GOSUB 8900
8790 LET Q=@(J+43);GOSUB 8900;LET Q=@(J+44);GOSUB 8900
8800 LET Q=@(J+48);GOSUB 8900;LET Q=@(J+49);GOSUB 8900
8810 LET Q=@(J+33);GOSUB 8900;LET Q=@(J+34);GOSUB 8900
8820 LET Q=@(J+38);GOSUB 8900;LET Q=@(J+39);GOSUB 8900
8830 LET Q=@(J+67);GOSUB 8900
8880 PRINT ;RETURN
8885 W=Q/100;Q=Q-100*W
8890 PRINT #0,W, GOTO  8920
8900 W=Q/100;Q=Q-100*W
8905 IF Q>=0 GOTO  8910
8907 LET Q=0,W=0
8910 PRINT #3,W,".",
8920 IFQ=0 GOTO  8940
8930 IFQ>=10 GOTO  8938
8932 PRINT "0",#1,Q,;RETURN
8938 PRINT #2,Q,;RETURN
8940 PRINT "00",;RETURN
8950 LET W=Q/10,Q=Q-10*W
8960 PRINT #0,W,".",#1,Q,;RETURN
```

Appendix C

ASSEMBLY LANGUAGE INTERPRETER FOR TINY BASIC

The following listing for an 8080 microcomputer is in assembly language compiled by Lincoln Semiconductor, and is included for report completeness. For an explanation of this listing, the reader is encouraged to consult a microcomputer expert. Key additions to Dr. Li-Chen Wang's Palo Alto Tiny Basic Interpreter with their address are: Open Current Relays (00C0); PEEK (01ED); POKE (01A8); PUT (01B6); GET (01F4); VOLT (01CE);and AMP(01D4).

```
0000          0001  PON
0000 F3       0005  DI
0001 3ECF     0010  MVI A,BAUD+CHRLEN+STOPS
0003 D3ED     0015  OUT COMMND
0005 C3BA00   0020  JMP STO
0008 E3       0025 TSTC XTHL
0009 EF       0030  RST 5
000A BE       0035  CMP M
000B C36800   0036  JMP TC1
000E 3E0D     0040 CRLF MVI A,0DH
0010 F5       0045 OUTC PUSH AF
0011 3A003C   0050  LDA CCSW
0014 B7       0055  ORA A
0015 C36807   0060  JMP OC2
0018 CD9F04   0065 EXPR CALL EXPR2
001B E5       0070  PUSH H
001C C33B04   0075  JMP EXPR1
001F 57       0080  DB 'W'
0020 7C       0085 COMP MOV A,H
0021 BA       0090  CMP D
0022 C0       0095  RNZ
0023 7D       0100  MOV A,L
0024 BB       0105  CMP E
0025 C9       0110  RET
0026 41       0115  DB 'A'
0027 4E       0116  DB 'N'
0028 1A       0120 SS1 LDAX D IGNBLK
0029 FE20     0125  CPI ' '
002B C0       0130  RNZ
002C 13       0135  INX D
002D C32800   0140  JMP SS1
0030 F1       0145 FINISH POP AF
0006          0146 AF EQU P
0031 CDDB05   0150  CALL FIN
0034 C3EE05   0155  JMP QWHAT
0037 47       0160  DB 'G'
0038 EF       0165 TSTV RST 5
0039 D640     0170  SUI '@'
003B D8       0175  RC
003C C25800   0180  JNZ TV1
003F 13       0185  INX D
0040 CD4505   0190  CALL PARN
0043 29       0195  DAD H
0044 DA9F00   0200  JC QHOW
0047 D5       0205  PUSH D
0048 EB       0210  XCHG
0049 CD8705   0215  CALL SIZE
004C E7       0220  RST 4
004D DA1E06   0225  JC ASORRY
0050 21007F   0230  LXI H,VARBGN
0053 CDAA05   0235  CALL SUBDE
0056 D1       0240  POP D
0057 C9       0245  RET
0058 FE1B     0250 TV1 CPI 1BH
005A 3F       0254  CMC
005B D8       0260  RC
005C 13       0265  INX D
005D 21007F   0270  LXI H,VARBGN
0060 07       0275  RLC
0061 85       0280  ADD L
0062 6F       0285  MOV L,A
0063 3E00     0290  MVI A.0
```

```
0065 8C        0295  ADC H
0066 67        0300  MOV H,A
0067 C9        0305  RET
0068 23        0310 TC1 INX H
0069 CA7300    0315  JZ TC2
006C C5        0320  PUSH B
006D 4E        0330  MOV C,M
006E 0600      0335  MVI B,0
0070 09        0340  DAD B
0071 C1        0345  POP B
0072 1B        0350  DCX D
0073 13        0355 TC2 INX D
0074 23        0360  INX H
0075 E3        0365  XTHL
0076 C9        0370  RET
0077 210000    0380 TSTNUM LXI H,0
007A 44        0390  MOV B,H
007B EF        0400  RST 5
007C FE30      0410 TN1 CPI '0'
007E D8        0420  RC
007F FE3A      0430  CPI 3AH
0081 D0        0440  RNC
0082 3EF0      0450  MVI A,0F0H
0084 A4        0460  ANA H
0085 C29F00    0470  JNZ QHOW
0088 04        0480  INR B
0089 C5        0490  PUSH B
008A 44        0500  MOV B,H
008B 4D        0505  MOV C,L
008C 29        0510  DAD H
008D 29        0520  DAD H
008E 09        0530  DAD B
008F 29        0540  DAD H
0090 1A        0550  LDAX D
0091 13        0560  INX D
0092 E60F      0570  ANI 0FH
0094 85        0580  ADD L
0095 6F        0590  MOV L,A
0096 3E00      0600  MVI A,0
0098 8C        0610  ADC H
0099 67        0620  MOV H,A
009A C1        0630  POP B
009B 1A        0635  LDAX D
009C F27C00    0640  JP TN1
009F D5        0645 QHOW PUSH D
00A0 11A600    0650 AHOW LXI D,HOW
00A3 C3F205    0660  JMP ERROR
00A6 48        0662 HOW DB 'H'
00A7 4F        0664  DB 'O'
00A8 57        0666  DB 'W'
00A9 3F        0668  DB '?'
00AA 0D        0669  DB 0DH
00AB 4F        0670 OK DB 'O'
00AC 4B        0671  DB 'K'
00AD 0D        0672  DB 0DH
00AE 57        0673 WHAT DB 'W'
00AF 48        0674  DB 'H'
00B0 41        0676  DB 'A'
00B1 54        0678  DB 'T'
00B2 3F        0680  DB '?'
00B3 0D        0682  DB 0DH
00B4 53        0684 SORRY DB 'S'
00B5 4F        0686  DB 'O'
00B6 52        0688  DB 'R'
00B7 52        0690  DB 'R'
00B8 59        0692  DB 'Y'
00B9 0D        0694  DB 0DH
00BA 3E25      0696 ST0 MVI A,RTS+RXE+TXEN
00BC D3ED      0698  OUT COMMND
00BE 3E89      0700  MVI A,137
00C0 D3EB      0702  OUT 235 OPEN CURRENT RELAYS
00C2 21153C    0703 RSTRT LXI H,TXTBGN
00C5 22133C    0704  SHLD TXTUNF
00C8 3EFF      0705  MVI A,0FFH
00CA 32003C    0706  STA OCSW
00CD 310080    0707 START LXI S,STACK
00D0 210000    0708  LXI H,0
00D3 22113C    0709  SHLD RANPNT
00D6 11AB00    0710  LXI D,OK
00D9 97        0715  SUB A
00DA CD8A06    0720  CALL PRTSTG
00DD 21E400    0725  LXI H,ST2+1
00E0 22013C    0730  SHLD CURRNT
00E3 210000    0735 ST2 LXI H,0
00E6 22073C    0740  SHLD LOPVAR
00E9 22033C    0745  SHLD STKGOS
00EC 3E3E      0750 ST3 MVI A,'>'
00EE CD2406    0755  CALL GETLN
00F1 D5        0760  PUSH D
00F2 11377F    0765  LXI D,BUFFER
00F5 CD7700    0770  CALL TSTNUM
00F8 EF        0780  RST 5
00F9 7C        0790  MOV A,H
00FA B5        0795  ORA L
00FB C1        0800  POP B
00FC CA3B02    0805  JZ DIRECT
00FF 1B        0810  DCX D
0100 7C        0815  MOV A,H
0101 12        0820  STAX D
0102 1B        0825  DCX D
0103 7D        0830  MOV A,L
0104 12        0835  STAX D
```

```
0105 C5       0840  PUSH B
0106 D5       0845  PUSH D
0107 79       0850  MOV A,C
0108 93       0855  SUB E
0109 F5       0860  PUSH AF
010A CD6206   0870  CALL FNDLN
010D D5       0875  PUSH D
010E C22101   0880  JNZ ST4
0111 D5       0885  PUSH D
0112 CD7E06   0890  CALL FNDNXT
0115 C1       0895  POP B
0116 2A133C   0900  LHLD TXTUNF
0119 CD0B07   0905  CALL MVUP
011C 60       0910  MOV H,B
011D 69       0916  MOV L,C
011E 22133C   0920  SHLD TXTUNF
0121 C1       0925 ST4 POP B
0122 2A133C   0930  LHLD TXTUNF
0125 F1       0935  POP AF
0126 E5       0940  PUSH H
0127 FE03     0945  CPI 3
0129 CACD00   0950  JZ START
012C 85       0955  ADD L
012D 6F       0960  MOV L,A
012E 3E00     0965  MVI A,0
0130 8C       0970  ADC H
0131 67       0975  MOV H,A
0132 11007F   0980  LXI D,TXTEND
0135 E7       0985  RST 4
0136 D21D06   0990  JNC QSORRY
0139 22133C   0995  SHLD TXTUNF
013C D1       1000  POP D
013D CD1407   1005  CALL MVDOWN
0140 D1       1010  POP D
0141 E1       1015  POP H
0142 CD0B07   1020  CALL MVUP
0145 C3EC00   1025  JMP ST3
0148          1030 *TABLES * DIRECT * & EXEC
0148          1035 TAB1 DS 0 DIRECT COMMANDS
0148 4C       1036  DB 'L'
0149 49       1038  DB 'I'
014A 53       1040  DB 'S'
014B 54       1042  DB 'T'
014C 80       1043  DB 80H
014D A902     1044  DW LIST
014F 52       1046  DB 'R'
0150 55       1048  DB 'U'
0151 4E       1050  DB 'N'
0152 80       1051  DB 80H
0153 7B02     1052  DW RUN
0155 4E       1054  DB 'N'
0156 45       1056  DB 'E'
0157 57       1058  DB 'W'
0158 80       1059  DB 80H
0159 6C02     1060  DW NEW
015B          1070 TAB2 DS 0 DIRECT/STATEMENT
015B 4E       1072  DB 'N'
015C 45       1074  DB 'E'
015D 58       1076  DB 'X'
015E 54       1078  DB 'T'
015F 80       1079  DB 80H
0160 9103     1080  DW NEXT
0162 4C       1082  DB 'L'
0163 45       1084  DB 'E'
0164 54       1086  DB 'T'
0165 80       1087  DB 80H
0166 5104     1088  DW LET
0168 49       1090  DB 'I'
0169 46       1092  DB 'F'
016A 80       1093  DB 80H
016B E203     1094  DW IF
016D 47       1096  DB 'G'
016E 4F       1098  DB 'O'
016F 54       1100  DB 'T'
0170 4F       1102  DB 'O'
0171 80       1103  DB 80H
0172 9A02     1104  DW GOTO
0174 47       1106  DB 'G'
0175 4F       1108  DB 'O'
0176 53       1110  DB 'S'
0177 55       1112  DB 'U'
0178 42       1114  DB 'B'
0179 80       1115  DB 80H
017A F902     1116  DW GOSUB
017C 52       1118  DB 'R'
017D 45       1120  DB 'E'
017E 54       1122  DB 'T'
017F 55       1124  DB 'U'
0180 52       1126  DB 'R'
0181 4E       1128  DB 'N'
0182 80       1129  DB 80H
0183 1903     1130  DW RETURN
0185 52       1132  DB 'R'
0186 45       1134  DB 'E'
0187 4D       1136  DB 'M'
0188 80       1137  DB 80H
0189 DE03     1138  DW REM
018B 46       1140  DB 'F'
018C 4F       1142  DB 'O'
018D 52       1144  DB 'R'
018E 80       1145  DB 80H
018F 3203     1146  DW FOR
```

```
0191 49        1148  DB 'I'
0192 4E        1150  DB 'N'
0193 50        1152  DB 'P'
0194 55        1154  DB 'U'
0195 54        1156  DB 'T'
0196 80        1157  DB 80H
0197 FB03      1158  DW INPUT
0199 50        1160  DB 'P'
019A 52        1162  DB 'R'
019B 49        1164  DB 'I'
019C 4E        1166  DB 'N'
019D 54        1168  DB 'T'
019E 80        1169  DB 80H
019F C102      1170  DW PRINT
01A1 43        1171  DB 'C'
01A2 41        1172  DB 'A'
01A3 4C        1173  DB 'L'
01A4 4C        1174  DB 'L'
01A5 80        1175  DB 80H
01A6 A807      1176  DW CALL
01A8 50        1177  DB 'P'
01A9 4F        1178  DB 'O'
01AA 4B        1179  DB 'K'
01AB 45        1180  DB 'E'
01AC 80        1181  DB 80H
01AD C507      1182  DW POKE
01AF 53        1183  DB 'S'
01B0 54        1184  DB 'T'
01B1 4F        1185  DB 'O'
01B2 50        1186  DB 'P'
01B3 80        1187  DB 80H
01B4 7502      1188  DW STOP
01B6 50        1189  DB 'P'
01B7 55        1190  DB 'U'
01B8 54        1192  DB 'T'
01B9 80        1194  DB 80H
01BA EB07      1196  DW PUT
01BC 80        1203  DB 80H
01BD 4B04      1204  DW DEFLT
01BF           1206  DS 14
01CD 56        1210 TAB4 DB 'V'
01CE 4F        1211  DB 'O'
01CF 4C        1212  DB 'L'
01D0 54        1213  DB 'T'
01D1 80        1214  DB 80H
01D2 1408      1215  DW VOLT
01D4 41        1216  DB 'A'
01D5 4D        1217  DB 'M'
01D6 50        1218  DB 'P'
01D7 80        1219  DB 80H
01D8 0A08      1220  DW AMP
01DA 52        1221  DB 'R'
01DB 4E        1222  DB 'N'
01DC 44        1223  DB 'D'
01DD 80        1224  DB 80H
01DE 5005      1225  DW RND
01E0 41        1226  DB 'A'
01E1 42        1227  DB 'B'
01E2 53        1228  DB 'S'
01E3 80        1229  DB 80H
01E4 7B05      1230  DW ABS
01E6 53        1231  DB 'S'
01E7 49        1232  DB 'I'
01E8 5A        1233  DB 'Z'
01E9 45        1234  DB 'E'
01EA 80        1235  DB 80H
01EB 8705      1236  DW SIZE
01ED 50        1238  DB 'P'
01EE 45        1239  DB 'E'
01EF 45        1240  DB 'E'
01F0 4B        1241  DB 'K'
01F1 80        1242  DB 80H
01F2 BE07      1243  DW PEEK
01F4 47        1244  DB 'G'
01F5 45        1245  DB 'E'
01F6 54        1246  DB 'T'
01F7 80        1247  DB 80H
01F8 D407      1248  DW GET
01FA 80        1254  DB 80H
01FB 3605      1255  DW XP40
01FD 54        1256 TAB5 DB 'T'
01FE 4F        1257  DB 'O'
01FF 80        1258  DB 80H
0200 4203      1259  DW FR1
0202 80        1260  DB 80H
0203 EE05      1261  DW QWHAT
0205 53        1262 TAB6 DB 'S'
0206 54        1264  DB 'T'
0207 45        1266  DB 'E'
0208 50        1268  DB 'P'
0209 80        1269  DB 80H
020A 4C03      1270  DW FR2
020C 80        1271  DB 80H
020D 5003      1272  DW FR3
020F           1274 TAB8 DS 0
020F 3E        1276  DB '>'
0210 3D        1278  DB '='
0211 80        1279  DB 80H
0212 6104      1280  DW XP11
0214 3D        1282  DB '='
0215 3E        1284  DB '>'
0216 80        1285  DB 80H
```

```
0217 6104       1286  DW XP11
0219 23         1289  DB '#'
021A 80         1289  DB 80H
021B 6704       1290  DW XP12
021D 3E         1292  DB '>'
021E 80         1293  DB 80H
021F 6D04       1294  DW XP13
0221 3D         1296  DB '='
0222 80         1297  DB 80H
0223 7C04       1298  DW XP15
0225 3C         1300  DB '<'
0226 3D         1302  DB '='
0227 80         1303  DB 80H
0228 7404       1304  DW XP14
022A 3D         1306  DB '='
022B 3C         1308  DB '<'
022C 80         1309  DB 80H
022D 7404       1310  DW XP14
022F 3C         1312  DB '<'
0230 80         1313  DB 80H
0231 8204       1314  DW XP16
0233 3C         1316  DB '<'
0234 3E         1318  DB '>'
0235 80         1319  DB 80H
0236 6701       1320  DW XP12
0238 80         1321  DB 80H
0239 8804       1322  DW XP17
023B 214701     1330  DIRECT LXI H,TAB1-1 *** DIRECT ***
023E            1335  EXEC DS 0 *** EXEC ***
023E EF         1340  EX0 RST 5
023F D5         1345  PUSH D
0240 1A         1350  EX1 LDAX D
0241 13         1355  INX D
0242 FE2E       1360  CPI '.'
0244 CA5E02     1365  JZ EX3
0247 23         1370  INX H
0248 BE         1375  CMP M
0249 CA4002     1380  JZ EX1
024C 3E7F       1385  MVI A,7FH
024E 1B         1390  DCX D
024F BE         1395  CMP M
0250 DA6502     1400  JC EX5
0253 23         1405  EX2 INX H
0254 BE         1410  CMP M
0255 D25302     1415  JNC EX2
0258 23         1420  INX H
0259 23         1422  INX H FOR EXTRA BYTE
025A D1         1425  POP D
025B C33E02     1430  JMP EX0
025E 3E7F       1435  EX3 MVI A,7FH
0260 23         1440  EX4 INX H
```

```
0261 BE          1445  CMP M
0262 D26902      1450  JNC EX4
0265 23          1455 EX5 INX H
0266 7E          1460  MOV A,M
0267 23          1465  INX H
0268 66          1470  MOV H,M
0269 6F          1475  MOV L,A
026A F1          1480  POP AF
026B E9          1485  PCHL
026C             1490 * NEW * STOP * RUN (& FRIENDS) * GOTO
026C CDEA05      1495 NEW CALL ENDCHK
026F 21153C      1500  LXI H,TXTBGN
0272 22133C      1505  SHLD TXTUNF
0275 CDEA05      1510 STOP CALL ENDCHK
0278 C3CD00      1515  JMP START
027B CDEA05      1520 RUN CALL ENDCHK
027E 11153C      1525  LXI D,TXTBGN
0281 210000      1530 RUNNXL LXI H,0
0284 CD6A06      1535  CALL FNDLNP
0287 DACD00      1540  JC START
028A EB          1545 RUNTSL XCHG
028B 22013C      1550  SHLD CURRNT
028E EB          1555  XCHG
028F 13          1560  INX D
0290 13          1565  INX D
0291 CD8A07      1570 RUNSML CALL CHKIO
0294 215A01      1575  LXI H,TAB2-1
0297 C33E02      1580  JMP EXEC
029A DF          1585 GOTO RST 3
029B D5          1590  PUSH D
029C CDEA05      1595  CALL ENDCHK
029F CD6206      1600  CALL FNDLN
02A2 C2A000      1605  JNZ AHOW
02A5 F1          1610  POP AF
02A6 C38A02      1615  JMP RUNTSL
02A9 CD7700      1620 LIST CALL TSTNUM
02AC CDEA05      1625  CALL ENDCHK
02AF CD6206      1630  CALL FNDLN
02B2 DACD00      1635 LS1 JC START
02B5 CDF806      1640  CALL PRTLN
02B8 CD8A07      1645  CALL CHKIO
02BB CD6A06      1650  CALL FNDLNP
02BE C3B202      1655  JMP LS1
02C1 0E06        1660 PRINT MVI C,6
02C3 CF          1665  RST 1
02C4 3B          1670  DB ';'
02C5 06          1672  DB PR2-1-$
02C6 CD0E00      1675  CALL CRLF
02C9 C39102      1680  JMP RUNSML
02CC CF          1685 PR2 RST 1
02CD 0D          1690  DB 0DH
```

```
02CB 06          1695  DB PR0-1-$
02CC CD0E00      1700  CALL CRLF
02D2 C38102      1705  JMP RUNNO.
02D5 CF          1710  PR0 RST 1
02D6 22          1715  DB '"'
02D7 05          1720  DB PR1-1-$
02D8 DF          1725  RST 3
02D9 4D          1730  MOV C,L
02DA C3E302      1735  JMP PR3
02DD CD9606      1740  PR1 CALL OUTSTG
02E0 C3E302      1745  JMP PR3
02E3 CF          1750  PR2 RST 1
02E4 2C          1755  DB ','
02E5 06          1760  DB PR6-1-$
02E6 CDDB05      1765  CALL FIN
02E9 C3D502      1770  JMP PR0
02EC CD0E00      1775  PR5 CALL CRLF
02EF F7          1780  RST 6
02F0 DF          1785  PR8 RST 3
02F1 C5          1790  PUSH B
02F2 CD5C06      1795  CALL PRNUM
02F5 C1          1800  POP B
02F6 C3E302      1805  JMP PR3
02F9 CD3F07      1810  GOSUB CALL PUSHA
02FC DF          1815  RST 3
02FD D5          1820  PUSH D
02FE CD6206      1825  CALL FNDLN
0301 C2A000      1830  JNZ AHOW
0304 2A013C      1835  LHLD CURRNT
0307 E5          1840  PUSH H
0308 2A033C      1845  LHLD STKGOS
030B E5          1850  PUSH H
030C 210000      1855  LXI H,0
030F 22073C      1860  SHLD LOPVAR
0312 39          1865  DAD S
0313 22033C      1870  SHLD STKGOS
0316 C38A02      1875  JMP RUNSL
0319 CDEA05      1880  RETURN CALL ENDCHK
031C 2A033C      1885  LHLD STKGOS
031F 7C          1890  MOV A,H
0320 B5          1895  ORA L
0321 CAFE05      1900  JZ QWHAT
0324 F9          1905  SPHL
0325 E1          1910  POP H
0326 22033C      1915  SHLD STKGOS
0329 E1          1920  POP H
032A 22013C      1925  SHLD CURRNT
032D D1          1930  POP D
032E CD2307      1935  CALL POPA
0331 F7          1940  RST 6
0332 CD3607      1945  FOR CALL PUSHA
0335 CDC805      1950  CALL SETVAL
0338 2B          1955  DCX H
0339 22073C      1960  SHLD LOPVAR
033C 21FC01      1965  LXI H,TAB5-1
033F C33F02      1970  JMP EXEC
0342 DF          1975  FR1 RST 3
0343 22063C      1980  SHLD LOPLMT
0346 210402      1985  LXI H,TAB6-1
0349 C33E02      1990  JMP EXEC
034C DF          1995  FR2 RST 3
034D C35303      2000  JMP FR4
0350 210100      2005  FR3 LXI H,1
0353 22093C      2010  FR4 SHLD LOPINC
0356 2A013C      2015  FR5 LHLD CURRNT
0359 220D3C      2020  SHLD LOPLN
035C EB          2025  XCHG
035D 22053C      2030  SHLD LOPPT
0360 010A00      2035  LXI B,10
0363 2A073C      2040  LHLD LOPVAR
0366 EB          2045  XCHG
0367 60          2050  MOV H,B
0368 68          2055  MOV L,B
0369 39          2060  DAD S
036A 3E          2065  DB 3EH
036B 09          2070  FR7 DAD B
036C 7E          2075  MOV A,M
036D 23          2080  INX H
036E B6          2085  ORA M
036F CA8C03      2090  JZ FR8
0372 7E          2095  MOV A,M
0373 2B          2100  DCX H
0374 BA          2105  CMP D
0375 C26303      2110  JNZ FR7
0378 7E          2115  MOV A,M
0379 BB          2120  CMP E
037A C26303      2125  JNZ FR7
037D EB          2130  XCHG
037E 210000      2135  LXI H,0
0381 39          2140  DAD S
0382 44          2145  MOV B,H
0383 4D          2150  MOV C,L
0384 210A00      2155  LXI H,10
0387 19          2160  DAD D
0388 CD1407      2165  CALL NOROOM
038B F9          2170  SPHL
038C 2A0F3C      2175  FR8 LHLD LOPPT
038F EB          2180  XCHG
0390 F7          2185  RST 6
0391 FF          2190  NEXT RST 7
0392 DAEE05      2195  JC QWHAT
0395 220B3C      2200  SHLD LOPVAR
```

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0398 D5       2205 NX0 PUSH D
0399 EB       2210  XCHG
039A 2A073C   2215  LHLD LOPVAR
039D 7C       2220  MOV A,H
039E B5       2225  ORA L
039F CAEF05   2230  JZ AWHAT
03A2 E7       2240  RST 4
03A3 CAB003   2245  JZ NX3
03A6 D1       2250  POP D
03A7 CD2307   2255  CALL POPA
03AA 2A053C   2260  LHLD VARNXT
03AD C39803   2265  JMP NX0
03B0 5E       2270 NX3 MOV E,M
03B1 23       2275  INX H
03B2 56       2280  MOV D,M
03B3 2A093C   2285  LHLD LOPINC
03B6 E5       2290  PUSH H
03B7 19       2295  DAD D
03B8 EB       2300  XCHG
03B9 2A073C   2305  LHLD LOPVAR
03BC 73       2310  MOV M,E
03BD 23       2315  INX H
03BE 72       2320  MOV M,D
03BF 2A0B3C   2325  LHLD LOPLMT
03C2 F1       2330  POP AF
03C3 B7       2335  ORA A
03C4 F2C803   2340  JP NX1
03C7 EB       2345  XCHG
03C8 CDC005   2350 NX1 CALL CKHLDE
03CB D1       2355  POP D
03CC DADA03   2360  JC NX2
03CF 2A0D3C   2365  LHLD LOPLN
03D2 22013C   2370  SHLD CURRNT
03D5 2A0F3C   2375  LHLD LOPPT
03D8 E8       2380  XCHG
03D9 F7       2385  RST 6
03DA CD2307   2390 NX2 CALL POPA
03DD F7       2395  RST 6
03DE 210000   2400 REM LXI H,0
03E1 3E       2405  DB 3EH SKIP NXT INST
03E2 DF       2410 IF RST 3
03E3 7C       2415  MOV A,H
03E4 B5       2420  ORA L
03E5 C29102   2425  JNZ RUNSML
03E8 CD8006   2430  CALL FNDSKP
03EB D28A02   2435  JNC RUNTSL
03EE C3CD00   2440  JMP START
03F1 2A053C   2445 INPERR LHLD STKINP
03F4 F9       2450  SPHL
03F5 E1       2455  POP H
03F6 22013C   2460  SHLD CURRNT
03F9 D1       2465  POP D
03FA D1       2470  POP D
03FB          2475 INPUT DS 0
03FB D5       2480 IP1 PUSH D
03FC CD9606   2485  CALL QTSTG
03FF C30804   2490  JMP IP2
0402 FF       2495  RST 7
0403 DA4304   2500  JC IP4
0406 C31904   2505  JMP IP3
0409 D5       2510 IP2 PUSH D
040A FF       2515  RST 7
040B DAEE05   2520  JC QWHAT
040E 1A       2525  LDAX D
040F 4F       2530  MOV C,A
0410 97       2535  SUB A
0411 12       2540  STAX D
0412 D1       2545  POP D
0413 CD8A06   2550  CALL PRTSTG
0416 79       2555  MOV A,C
0417 1B       2560  DCX D
0418 12       2565  STAX D
0419 D5       2570 IP3 PUSH D
041A EB       2575  XCHG
041B 2A013C   2580  LHLD CURRNT
041E E5       2585  PUSH H
041F 21FB03   2590  LXI H,IP1
0422 22013C   2595  SHLD CURRNT
0425 210000   2600  LXI H,0
0428 39       2605  DAD S
0429 22053C   2610  SHLD STKINP
042C D5       2615  PUSH D
042D 3E3A     2620  MVI A,':'
042F CD2406   2625  CALL GETLN
0432 11377F   2630  LXI D,BUFFER
0435 DF       2635  RST 3
0436 00       2640  NOP
0437 00       2645  NOP
0438 00       2650  NOP
0439 D1       2655  POP D
043A EB       2660  XCHG
043B 73       2675  MOV M,E
043C 23       2680  INX H
043D 72       2685  MOV M,D
043E E1       2690  POP H
043F 22013C   2695  SHLD CURRNT
0442 D1       2700  POP D
0443 F1       2705 IP4 POP AF
0444 CF       2710  RST 1
0445 2C       2715  DB ','
0446 03       2720  DB IP5-1-$
0447 C3FB03   2725  JMP IP1
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044A F7      2730 IP5 RST 6
044B 1A      2735 DEFLT LDAX D
044C FE0D    2740  CPI 0DH
044E CA5A04  2745  JZ LT1
0451 CDC805  2750 LET CALL SETVAL
0454 CF      2755  RST 1
0455 2C      2760  DB ','
0456 03      2765  DB LT1-1-$
0457 C35104  2770  JMP LET
045A F7      2775 LT1 RST 6
045B 210E02  2800 EXPR1 LXI H,TAB8-1
045E C33E02  2810  JMP EXEC
0461 CD8A04  2820 XP11 CALL XP18
0464 D8      2830  RC
0465 6F      2840  MOV L,A
0466 C9      2850  RET
0467 CD8A04  2860 XP12 CALL XP18
046A C8      2870  RZ
046B 6F      2880  MOV L,A
046C C9      2890  RET
046D CD8A04  2900 XP13 CALL XP18
0470 C8      2910  RZ
0471 D8      2920  RC
0472 6F      2930  MOV L,A
0473 C9      2940  RET
0474 CD8A04  2950 XP14 CALL XP18
0477 6F      2960  MOV L,A
0478 C8      2970  RZ
0479 D8      2980  RC
047A 6C      2990  MOV L,H
047B C9      3000  RET
047C CD8A04  3010 XP15 CALL XP18
047F C0      3020  RNZ
0480 6F      3030  MOV L,A
0481 C9      3040  RET
0482 CD8A04  3050 XP16 CALL XP18
0485 D0      3060  RNC
0486 6F      3070  MOV L,A
0487 C9      3080  RET
0488 E1      3090 XP17 POP H
0489 C9      3100  RET
048A 79      3110 XP18 MOV A,C
048B E1      3120  POP H
048C C1      3130  POP B
048D E5      3140  PUSH H
048E C5      3150  PUSH B
048F 4F      3160  MOV C,A
0490 CD9F04  3170  CALL EXPR2
0493 EB      3180  XCHG
0494 E3      3190  XTHL
0495 CDC005  3200  CALL CKHLDE
0498 D1      3210  POP D
0499 210000  3220  LXI H,0
049C 3E01    3230  MVI A,1
049E C9      3240  RET
049F CF      3250 EXPR2 RST 1
04A0 2D      3260  DB '-'
04A1 06      3270  DB XP21-1-$
04A2 210000  3280  LXI H,0
04A5 C3C904  3290  JMP XP26
04A8 CF      3300 XP21 RST 1
04A9 2B      3305  DB '+'
04AA 00      3310  DB XP22-1-$
04AB CDD304  3320 XP22 CALL EXPR3
04AE CF      3330 XP23 RST 1
04AF 2B      3335  DB '+'
04B0 15      3340  DB XP25-1-$
04B1 E5      3350  PUSH H
04B2 CDD304  3360  CALL EXPR3
04B5 EB      3370 XP24 XCHG
04B6 E3      3380  XTHL
04B7 7C      3390  MOV A,H
04B8 AA      3400  XRA D
04B9 7A      3405  MOV A,D
04BA 19      3410  DAD D
04BB D1      3415  POP D
04BC FAAE04  3420  JM XP23
04BF AC      3425  XRA H
04C0 F2AE04  3430  JP XP23
04C3 C39F00  3435  JMP OVOW
04C6 CF      3440 XP25 RST 1
04C7 2D      3445  DB '-'
04C8 83      3450  DB XP42-1-$
04C9 E5      3455 XP26 PUSH H
04CA CDD304  3460  CALL EXPR3
04CD CDB405  3465  CALL CHGSGN
04D0 C3B504  3470  JMP XP24
04D3 CD3005  3475 EXPR3 CALL EXPR4
04D6 CF      3480 XP31 RST 1
04D7 2A      3485  DB '*'
04D8 2C      3490  DB XP34-1-$
04D9 E5      3495  PUSH H
04DA CD3005  3500  CALL EXPR4
04DD 0600    3505  MVI B,0
04DF CDB105  3510  CALL CHKSGN
04E2 EB      3515  XCHG
04E3 E3      3520  XTHL
04E4 CDB105  3525  CALL CHKSGN
04E7 7C      3530  MOV A,H
04E8 B7      3535  ORA A
04E9 CAF204  3540  JZ XP32
04EC 7A      3545  MOV A,D
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04ED B2        3550  ORA D
04EE EB        3555  XCHG
04EF C2A000    3560  JNZ AHOW
04F2 7D        3565 XP32 MOV A,L
04F3 210000    3570  LXI H,0
04F6 B7        3575  ORA A
04F7 CA2205    3580  JZ XP35
04FA 19        3585 XP33 DAD D
04FB DAA000    3590  JC AHOW
04FE 3D        3595  DCR A
04FF C2FA04    3600  JNZ XP33
0502 C32205    3605  JMP XP35
0505 CF        3610 XP34 RST 1
0506 2F        3615  DB '/'
0507 4A        3620  DB XP42-1-$
0509 E5        3625  PUSH H
0509 CDB305    3630  CALL EXPR4
050C 0608      3635  MVI B,0
050E CDB105    3640  CALL CHKSGN
0511 EB        3645  XCHG
0512 E3        3650  XTHL
0513 CDB105    3655  CALL CHKSGN
0516 7A        3660  MOV A,D
0517 B3        3665  ORA E
0518 CAA000    3670  JZ AHOW
051B C5        3675  PUSH B
051C CD9405    3680  CALL DIVIDE
051F 60        3685  MOV H,B
0520 69        3690  MOV L,C
0521 C1        3695  POP B
0522 D1        3700 XP35 POP D
0523 7C        3705  MOV A,H
0524 B7        3710  ORA A
0525 FA9F00    3711  JM QHOW
0528 78        3712  MOV A,B
0529 B7        3713  ORA A
052A FCB405    3715  CM  CHGSGN
052D C3D504    3720  JMP XP31
0530 21CC01    3725 EXPR4 LXI H,TAB4-1
0533 C33E02    3730  JMP EXEC
0536 FF        3735 XP40 RST 7
0537 DA3805    3740  JC XP41
053A 7E        3745  MOV A,M
053B 23        3750  INX H
053C 66        3755  MOV H,M
053D 6F        3760  MOV L,A
053E C9        3765  RET
053F CD7700    3770 XP41 CALL TSTNUM
0542 78        3775  MOV A,B
0543 B7        3780  ORA A
0544 C0        3785  RNZ
0545 CF        3790 PARN RST 1
0546 28        3795  DB '('
0547 05        3800  DB XP43-1-$
0548 DF        3805  RST 3
0549 CF        3810  RST 1
054A 29        3815  DB ')'
054B 01        3820  DB XP43-1-$
054C C9        3825 XP42 RET
054D C3EE05    3830 XP43 JMP QWHAT
0550 CD4505    3835 RND CALL PARN *** RND(EXPR) ***
0553 7C        3840  MOV A,H
0554 B7        3845  ORA A
0555 FA9F00    3850  JM QHOW
0558 B5        3855  ORA L
0559 CA9F00    3860  JZ QHOW
055C D5        3865  PUSH D
055D E5        3870  PUSH H
055E 2A113C    3875  LHLD RANPNT
0561 116408    3880  LXI D,LSTROM
0564 E7        3885  RST 4
0565 DA6B05    3890  JC RA1
0568 210000    3895  LXI H,0
056B 5E        3900 RA1 MOV E,M
056C 23        3905  INX H
056D 56        3910  MOV D,M
056E 22113C    3915  SHLD RANPNT
0571 E1        3920  POP H
0572 EB        3925  XCHG
0573 C5        3930  PUSH B
0574 CD9405    3935  CALL DIVIDE
0577 C1        3940  POP B
0578 D1        3945  POP D
0579 23        3950  INX H
057A C9        3955  RET
057B CD4505    3960 ABS CALL PARN
057E CDB105    3965  CALL CHKSGN
0581 7C        3970  MOV A,H
0582 B4        3975  ORA H
0583 FA9F00    3980  JM QHOW
0586 C9        3985  RET
0587 2A133C    3990 SIZE LHLD TXTUNF
058A D5        3995  PUSH D
058B EB        4000  XCHG
058C 21007F    4005  LXI H,VARBGN
058F CDAA05    4010  CALL SUBDE
0592 D1        4015  POP D
0593 C9        4020  RET
0594 E5        4025 DIVIDE PUSH H
0595 6C        4030  MOV L,H
0596 2600      4035  MVI H,0
0598 CD9F05    4040  CALL DV1
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059B 41       4045  MOV B,C
059C 7D       4050  MOV A,L
059D E1       4055  POP H
059E 67       4060  MOV H,A
059F 0EFF     4065 DV1 MVI C,-1
05A1 0C       4070 DV2 INR C
05A2 CDAA05   4075  CALL SUBDE
05A5 D2A105   4080  JNC DV2
05A8 19       4085  DAD D
05A9 C9       4090  RET
05AA 7D       4095 SUBDE MOV A,L
05AB 93       4100  SUB E
05AC 6F       4105  MOV L,A
05AD 7C       4110  MOV A,H
05AE 9A       4115  SBB D
05AF 67       4120  MOV H,A
05B0 C9       4125  RET
05B1 7C       4130 CHKSGN MOV A,H
05B2 B7       4135  ORA A
05B3 F0       4140  RP
05B4 7C       4145 CHGSGN MOV A,H
05B5 2F       4150  CMA
05B6 67       4155  MOV H,A
05B7 7D       4160  MOV A,L
05B8 2F       4165  CMA
05B9 6F       4170  MOV L,A
05BA 23       4175  INX H
05BB 78       4180  MOV A,B
05BC EE80     4185  XRI 80H
05BE 47       4190  MOV B,A
05BF C9       4195  RET
05C0 7C       4200 CKHLDE MOV A,H
05C1 AA       4205  XRA D
05C2 F2C605   4210  JP CK1
05C5 EB       4215  XCHG
05C6 E7       4220 CK1 RST 4
05C7 C9       4225  RET
05C8 FF       4230 SETVAL RST 7
05C9 DAEE05   4235  JC QWHAT
05CC E5       4240  PUSH H
05CD CF       4245  RST 1
05CE 3D       4250  DB '='
05CF 08       4255  DB SV1-1-$
05D0 DF       4260  RST 3
05D1 44       4265  MOV B,H
05D2 4D       4270  MOV C,L
05D3 E1       4275  POP H
05D4 71       4280  MOV M,C
05D5 23       4285  INX H
05D6 70       4290  MOV M,B
05D7 C9       4295  RET

05D8 C3EE05   4300 SV1 JMP QWHAT
05DB CF       4305 FIN RST 1
05DC 3B       4310  DB ';'
05DD 04       4315  DB FI1-1-$
05DE F1       4320  POP AF
05DF C39102   4325  JMP RUNSML
05E2 CF       4330 FI1 RST 1
05E3 0D       4335  DB 0DH
05E4 04       4336  DB FI2-1-$
05E5 F1       4337  POP AF
05E6 C38102   4340  JMP RUNNXL
05E9 C9       4345 FI2 RET
05EA EF       4350 ENDCHK RST 5
05EB FE0D     4355  CPI 0DH
05ED C8       4360  RZ
05EE D5       4365 QWHAT PUSH D
05EF 11AE00   4370 AWHAT LXI D,WHAT
05F2 97       4375 ERROR SUB A
05F3 D3E8     4376  OUT 232
05F5 CD8A06   4380  CALL PRTSTG
05F8 D1       4385  POP D
05F9 1A       4390  LDAX D
05FA F5       4395  PUSH AF
05FB 97       4400  SUB A
05FC 12       4405  STAX D
05FD 2A013C   4410  LHLD CURRNT
0600 E5       4415  PUSH H
0601 7E       4420  MOV A,M
0602 23       4425  INX H
0603 B6       4430  ORA M
0604 D1       4435  POP D
0605 CACD00   4440  JZ START
0608 7E       4445  MOV A,M
0609 B7       4450  ORA A
060A FAF103   4455  JM INPERR
060D CDF806   4460  CALL PRTLN
0610 1B       4465  DCX D
0611 F1       4470  POP AF
0612 12       4475  STAX D
0613 3E3F     4480  MVI A,'?'
0615 D7       4485  RST 2
0616 97       4490  SUB A
0617 CD8A06   4495  CALL PRTSTG
061A C3CD00   4500  JMP START
061D D5       4505 QSORRY PUSH D
061E 11B400   4510 ASORRY LXI D,SORRY
0621 C3F205   4515  JMP ERROR
0624 D7       4520 GETLN RST 2
0625 11377F   4525  LXI D,BUFFER
0628 CD8A07   4530 GL1 CALL CHKIO
062B CA2806   4535  JZ GL1
062E D7       4540  RST 2
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062F FE0A      4545  CPI 0AH
0631 CA2806    4550  JZ GL1
0634 B7        4555  ORA A
0635 CA2806    4560  JZ GL1
0638 FE7F      4565  CPI 7FH
063A CA4D06    4570  JZ GL3
063D FE7D      4575  CPI 7DH
063F CA5A06    4580  JZ GL4
0642 12        4585  STAX D
0643 13        4590  INX D
0644 FE0D      4595  CPI 0DH
0646 C8        4600  RZ
0647 7B        4605  MOV A,E
0648 FE7F      4610  CPI 7FH
064A C22806    4615  JNZ GL1
064D 7B        4620  GL3 MOV A,E
064E FE37      4625  CPI 37H
0650 CA5A06    4630  JZ GL4
0653 1B        4635  DCX D
0654 3E5C      4640  MVI A,5CH
0656 D7        4645  RST 2
0657 C32806    4650  JMP GL1
065A CD0E00    4655  GL4 CALL CRLF
065D 3E5E      4660  MVI A,5EH
065F C32406    4665  JMP GETLN
0662 7C        4670  FNDLN MOV A,H
0663 B7        4675  ORA A
0664 FA9F00    4680  JM QHOW
0667 11153C    4685  LXI D,TXTBGN
066A           4690  FNDLNP DS 0
066A E5        4695  FL1 PUSH H
066B 2A133C    4700  LHLD TXTUNF
066E 2B        4705  DCX H
066F E7        4710  RST 4
0670 E1        4715  POP H
0671 D8        4720  RC
0672 1A        4725  LDAX D
0673 95        4730  SUB L
0674 47        4735  MOV B,A
0675 13        4740  INX D
0676 1A        4745  LDAX D
0677 9C        4750  SBB H
0678 DA7F06    4755  JC FL2
067B 1B        4760  DCX D
067C B0        4765  ORA B
067D C9        4770  RET
067E           4775  FNDNXT DS 0
067E 13        4780  INX D
067F 13        4785  FL2 INX D
0680 1A        4790  FNDSKP LDAX D
0681 FE0D      4795  CPI 0DH
0683 C27F06    4800  JNZ FL2
0686 13        4805  INX D
0687 C36A06    4810  JMP FL1
068A 47        4815  PRTSTG MOV B,A
068B 1A        4820  PS1 LDAX D
068C 13        4825  INX D
068D B8        4830  CMP B
068E C8        4835  RZ
068F D7        4840  RST 2
0690 FE0D      4845  CPI 0DH
0692 C28B06    4850  JNZ PS1
0695 C9        4855  RET
0696 CF        4860  QTSTG RST 1
0697 22        4865  DB '"'
0698 0F        4870  DB QT3-1-$
0699 3E22      4875  MVI A,'"'
069B CD8A06    4880  QT1 CALL PRTSTG
069E FE0D      4885  CPI 0DH
06A0 E1        4890  POP H
06A1 CA8102    4895  JZ RUNNXL
06A4 23        4900  QT2 INX H
06A5 23        4905  INX H
06A6 23        4910  INX H
06A7 E9        4915  PCHL
06A8 CF        4920  QT3 RST 1
06A9 27        4925  DB 27H
06AA 05        4930  DB QT4-1-$
06AB 3E27      4935  MVI A,27H
06AD C39B06    4940  JMP QT1
06B0 CF        4945  QT4 RST 1
06B1 5F        4950  DB 5FH
06B2 08        4955  DB QT5-1-$
06B3 3E8D      4960  MVI A,8DH
06B5 D7        4965  RST 2
06B6 D7        4970  RST 2
06B7 E1        4975  POP H
06B8 C3A406    4980  JMP QT2
06BB C9        4985  QT5 RET
06BC D5        4990  PRTNUM PUSH D
06BD 110A00    4995  LXI D,10
06C0 D5        5000  PUSH D
06C1 42        5005  MOV B,D
06C2 0D        5010  DCR C
06C3 CDB105    5015  CALL CHKSGN
06C6 F2CC06    5020  JP PN1
06C9 062D      5025  MVI B,'-'
06CB 0D        5030  DCR C
06CC C5        5035  PN1 PUSH B
06CD CD9405    5040  PN2 CALL DIVIDE
06D0 78        5045  MOV A,B
06D1 B1        5050  ORA C
```

```
06D2 CADD06    5055  JZ PN3
06D5 E3        5060  XTHL
06D6 2D        5065  DCR L
06D7 E5        5070  PUSH H
06D8 60        5075  MOV H,B
06D9 69        5080  MOV L,C
06DA C3CD06    5085  JMP PN2
06DD C1        5090  PN3 POP B
06DE 0D        5095  PN4 DCR C
06DF 79        5100  MOV A,C
06E0 B7        5105  ORA A
06E1 FAEA06    5110  JM PN5
06E4 3E20      5115  MVI A,' '
06E6 D7        5120  RST 2
06E7 C3DE06    5125  JMP PN4
06EA 78        5130  PN5 MOV A,B
06EB D7        5135  RST 2
06EC 5D        5140  MOV E,L
06ED 7B        5145  PN6 MOV A,E
06EE FE0A      5150  CPI 0AH
06F0 D1        5155  POP D
06F1 C8        5160  RZ
06F2 C630      5165  ADI '0'
06F4 D7        5170  RST 2
06F5 C3ED06    5175  JMP PN6
06F8 1A        5180  PRTIN LDAX D
06F9 6F        5185  MOV L,A
06FA 13        5190  INX D
06FB 1A        5195  LDAX D
06FC 67        5200  MOV H,A
06FD 13        5205  INX D
06FE 0E04      5210  MVI C,4
0700 CDBC06    5215  CALL PRINUM
0703 3E20      5220  MVI A,' '
0705 D7        5225  RST 2
0706 97        5230  SUB A
0707 CD8A06    5235  CALL PRISTG
070A C9        5240  RET
070B E7        5245  MVUP RST 4
070C C8        5250  RZ
070D 1A        5255  LDAX D
070E 02        5260  STAX B
070F 13        5265  INX D
0710 03        5270  INX B
0711 C30B07    5275  JMP MVUP
0714 78        5280  MVDOWN MOV A,B
0715 92        5285  SUB D
0716 C21C07    5290  JNZ MD1
0719 79        5295  MOV A,C
071A 93        5300  SUB E
071B C8        5305  RZ
071C 1B        5310  MD1 DCX D
071D 2B        5315  DCX H
071E 1A        5320  LDAX D
071F 77        5325  MOV M,A
0720 C31407    5330  JMP MVDOWN
0723 C1        5335  POPA POP B
0724 E1        5340  POP H
0725 22073C    5345  SHLD LOPVAR
0728 7C        5350  MOV A,H
0729 B5        5355  ORA L
072A CA3D07    5360  JZ PP1
072D E1        5365  POP H
072E 22093C    5370  SHLD LOPINC
0731 E1        5375  POP H
0732 220B3C    5380  SHLD LOPLMT
0735 E1        5385  POP H
0736 220D3C    5390  SHLD LOPLN
0739 E1        5395  POP H
073A 220F3C    5400  SHLD LOPPT
073D C5        5405  PP1 PUSH B
073E C9        5410  RET
073F 21A77F    5415  PUSHA LXI H,STKLMT
0742 CDB405    5420  CALL CHGSGN
0745 C1        5425  POP B
0746 39        5430  DAD S
0747 D21D06    5435  JNC QSORRY
074A 2A073C    5440  LHLD LOPVAR
074D 7C        5445  MOV A,H
074E B5        5450  ORA L
074F CA6507    5455  JZ PU1
0752 2A0F3C    5460  LHLD LOPPT
0755 E5        5465  PUSH H
0756 2A0D3C    5470  LHLD LOPLN
0759 E5        5475  PUSH H
075A 2A0B3C    5480  LHLD LOPLMT
075D E5        5485  PUSH H
075E 2A093C    5490  LHLD LOPINC
0761 E5        5495  PUSH H
0762 2A073C    5500  LHLD LOPVAR
0765 E5        5505  PU1 PUSH H
0766 C5        5510  PUSH B
0767 C9        5515  RET
0768 C26D07    5520  OC2 JNZ OC3
076B F1        5525  POP AF
076C C9        5530  RET
076D DBED      5535  OC3 IN STATUS
076F E601      5540  ANI TXRDY
0771 CA6D07    5545  JZ OC3
0774 F1        5550  POP AF
0775 D3EC      5555  OUT DATA
0777 FE0D      5560  CPI 0DH
```

```
0779 C0          5565  RNZ
077A 3E0A        5570  MVI A,0AH
077C D7          5575  RST 2
077D 3E7F        5576  MVI A,7FH
077F D7          5577  RST 2
0780 D7          5578  RST 2
0781 D7          5579  RST 2
0782 D7          5580  RST 2
0783 D7          5581  RST 2
0784 D7          5582  RST 2
0785 D7          5583  RST 2
0786 D7          5584  RST 2
0787 3E0D        5585  MVI A,0DH
0789 C9          5586  RET
078A DBED        5590 CHKIO IN STATUS
078C E602        5595  ANI RXRDY
078E C8          5600  RZ
078F DBEC        5605  IN DATA
0791 E67F        5610  ANI 7FH
0793 FE0F        5615  CPI 0FH
0795 C2A207      5620  JNZ CI1
0798 3A003C      5625  LDA OCSW
079B 2F          5630  CMA
079C 32003C      5635  STA OCSW
079F C38A07      5640  JMP CHKIO
07A2 FE03        5650 CI1 CPI 3
07A4 C0          5655  RNZ
07A5 C3CD00      5660  JMP START
07A8 DF          5670 CALL RST 3 EXPR
07A9 22377F      5680  SHLD BUFFER WHERE
07AC 3EC3        5690  MVI A,0C3H
07AE 32377F      5700  STA BUFFER
07B1 CF          5710  RST 1
07B2 2C          5720  DB ','
07B3 07          5730  DB CQWHAT-1-$
07B4 DF          5740  RST 3 EXPR
07B5 CD377F      5750  CALL BUFFER
07B8 CDCB05      5760  CALL FIN
07BB C3E305      5770 CQWHAT JMP QWHAT
07BE CD4505      5780 PEEK CALL PARN
07C1 6E          5790  MOV L,M
07C2 2600        5800  MVI H,0
07C4 C9          5810  RET
07C5 DF          5820 POKE RST 3 EXPR
07C6 E5          5830  PUSH H WHERE
07C7 CF          5840  RST 1
07C8 2C          5850  DB ','
07C9 07          5860  DB BQWHAT-1-$
07CA D5          5870  RST 3 EXPR
07CB E1          5880  POP H'WHERE'
07CC 77          5890  MOV M,A POKE IT
07CD CDCB05      5910  CALL FIN
07D1 C3E305      5920  JMP QWHAT
07D4 CD4505      7000 GET CALL PARN
07D7 65          7010  MOV H,L
07D8 E5          7040  PUSH H
07D9 21377F      7110  LXI H,BUFFER
07DC 36DB        7120  MVI M,0DBH
07DE 23          7130  INX H
07DF F1          7140  POP AF
07E0 77          7150  MOV M,A PORT ID
07E1 23          7160  INX H
07E2 36C9        7190  MVI M,0C9H RET
07E4 CD377F      7220  CALL BUFFER
07E7 6F          7230  MOV L,A
07E8 2600        7240  MVI H,0
07EA C9          7250  RET
07EB DF          7300 PUT RST 3 EXPR
07EC 65          7310  MOV H,L
07ED E5          7312  PUSH H
07EE CF          7320  RST 1
07EF 2C          7330  DB ','
07F0 15          7340  DB BQWHAT-1-$
07F1 DF          7350  RST 3 EXPR
07F2 65          7352  MOV H,L
07F3 E3          7360  XTHL
07F4 E5          7370  PUSH H
07F5 21377F      7410  LXI H,BUFFER
07F8 36D3        7440  MVI M,0D3H
07FA 23          7450  INX H
07FB F1          7460  POP AF
07FC 77          7470  MOV M,A
07FD 23          7480  INX H
07FE 36C9        7490  MVI M,0C9H RET
0800 F1          7500  POP AF
0801 CD377F      7520  CALL BUFFER
0804 CDCB05      7522  CALL FIN
0807 C3E305      7530 BQWHAT JMP QWHAT
080A CD4505      7540 AMP CALL PARN
080D D5          7552  PUSH D
080E 11[illegible]  7554  LXI D,TABLE
0811 C31808      7556  JMP VOLTA
0814 CD[illegible]  7570 VOLT CALL PARN
0817 D5          7572  PUSH D
0818 11[illegible]  7574  LXI D,TABLE
081B C5          7576 VOLTA PUSH B
081C 4E          7578  MOV C,M
081D 79          7580  MOV A,C
081E 210000      7582  LXI H,0
0821 FE00        7584  CPI 0
0823 CA2608      7585  JZ PSPOPB
0826 E5          7588  PUSH H
```

```
0827 E6          7580  XCHG
0828 0680        7582  MVI B,80H
082A 78          7584  MOV A,B
082B A1          7586 P5ANAC ANA C
082C CA3908      7588  JZ P5INXH
082F 5E          7600  MOV E,M
0830 23          7602  INX H
0831 56          7604  MOV D,M
0832 23          7606  INX H
0833 E3          7608  XTHL
0834 19          7610  DAD D
0835 E3          7612  XTHL
0836 C33B08      7614  JMP P5MVAB
0839 23          7616 P5INXH INX H
083A 23          7618  INX H
083B 78          7620 P5MVAB MOV A,B
083C 0F          7622  RRC
083D 47          7624  MOV B,A
083E D22B08      7626  JNC P5ANAC
0841 E1          7628  POP H
0842 C1          7630 P5POPB POP B
0843 D1          7632  POP D
0844 C9          7634  RET
0845 A861        7650 TABL5 DW 25000
0847 D430        7652  DW 12500
0849 6818        7654  DW 6250
084B 350C        7656  DW 3125
084D 1A06        7658  DW 1562
084F 0D03        7660  DW 781
0851 8601        7662  DW 390
0853 C300        7664  DW 195
0855 983A        7666 TABL3 DW 15000
0857 4C1D        7668  DW 7500
0859 A60E        7670  DW 3750
085B 5307        7672  DW 1875
085D AA03        7674  DW 938
085F B701        7676  DW 439
0861 EA00        7678  DW 234
0863 7500        7680  DW 117
0864             8999 LSTADR EQU $-1
3C00             9000  ORG 3C00H
3C00 FF          9005 OCRW DB 0FFH
3C01 0000        9010 CURRNT DW 0
3C03 0000        9015 STKSAV DW 0
3C05             9020 VARNXT DS 0
3C05 0000        9025 STKIMP DW 0
3C07 0000        9030 LOPVAR DW 0
3C09 0000        9035 LOPINC DW 0
3C0B 0000        9040 LOPLMT DW 0
3C0D 0000        9045 LOPLN DW 0
3C0F 0000        9050 LOPPT DW 0
3C11 0000        9055 NXTSTK DW 0
3C13 153C        9060 EXPTAB DW EXPSTK
3C15             9065 TXTBGN DS 0
7F00             9075  ORG 7F00H
7F00             9080 VARBGN DS 54
7F00             9082 TXTEND EQU VARBGN
7F36             9085        DS 1
7F37             9090 BUFFER DS 73
7F7F             9095 BUFEND DS 0
7F7F             9100        DS 40
7FA7             9105 STKLMT DS 0
8000             9110  ORG 8000H
8000             9115 STACK DS 0
8000             9120 *PORT DEFINITIONS
00ED             9122 STATUS EQU 0EDH
00ED             9124 COMMND EQU 0EDH
00EC             9126 DATA EQU 0ECH
8000             9128 *MODE DEFINITIONS
0003             9130 BAUD EQU 3
000C             9132 CHRLEN EQU 0CH
00C0             9134 STOPS EQU 0C0H
8000             9136 *COMMAND DEFINITIONS
0020             9138 RTS EQU 20H
0004             9140 RXE EQU 4
0001             9142 TXEN EQU 1
0002             9144 DTR EQU 2
8000             9146 *STATUS DEFINITIONS
0001             9148 TXRDY EQU 1
0002             9150 RXRDY EQU 2
0004             9152 TXE EQU 4
```

Appendix D

DATA SORTING PROGRAM

The following program is written in TYMBASIC for use on a TYMSHARE system IBM 360 computer. The program will sort the preliminary data stored on the tape cassette unit from random cell records into specific cell record files.

```
10 PRINT DATE
20 OPEN "R1",OUTPUT,1
30 OPEN "R2",OUTPUT,2
40 OPEN "R3",OUTPUT,3
50 OPEN "R4",OUTPUT,4
60 OPEN "R5",OUTPUT,5
70 OPEN "R6",OUTPUT,6
80 STRING A
90 DIM A2(1000),A3(1000),A4(1000),A5(1000),A6(1000),A7(1000)
100 DIM A8(1000),A9(1000),B1(1000),B2(1000),B3(1000),B4(1000),B5(1000)
110  DIM B6(1000),B7(1000),B8(1000),B9(1000),C1(1000),C2(1000),C3(1000)
120 DIM C4(1000),C5(1000),C6(1000)
130 TEXT A1(1000)
140 A="16% 23(#)/"
150 OPEN "D248",INPUT,7
160 FOR I=1 TO 1000
170 ON ENDFILE(7) GO TO 220
180 ON ERROR GO TO 290
190 INPUT FROM 7 IN FORM A:A1(I),A2(I),A3(I),A4(I),A5(I),A6(I),A7(I),A8(
I),A9(I),B1(I),B2(I),B3(I),B4(I),B5(
**I),B6(I),B7(I),B8(I),B9(I),C1(I),C2(I),C3(I),C4(I),C5(I),C6(I)
200 J=I
210 NEXT I
220 PRINT DATE
230 FOR I=1 TO J
240 WRITE ON A2(I) IN FORM A:A1(I),A2(I),A3(I),A4(I),A5(I),A6(I),A7(I),A
8(I),A9(I),B1(I),B2(I),B3(I),B4(I),B
**5(I),B6(I),B7(I),B8(I),B9(I),C1(I),C2(I),C3(I),C4(I),C5(I),C6(I)
250 NEXT I
260 PRINT DATE
270 CLOSE 1,2,3,4,5,6,7
280 GO TO 300
290 PRINT I,A1(I)
300 PRINT
```

Appendix E
DATA REPORT PROGRAM

The following program, written in TYMBASIC, is for generation of reports on the performance of individual cells. The program first computes a statistical mean for the cyclic energy efficiency. Any cycle having an energy efficiency that is more than one standard deviation from the mean is denoted and ignored for a second calculation of statistical means. This allows for a rejection of cyclic data in which reference electrode, thermal, or electronic malfunctions occur. This data is marked with a * on the report output. The second calculation of statistical means and standard deviations is outputted at the end of the report and individual cycle data is marked if it is one standard deviation (S) or two standard deviations (D) from the mean energy efficiency.

The program generates two reports, the first is a cycle-by-cycle efficiency report while the second gives a cycle-by-cycle report of voltages (cell, iron, and zinc) at several points in the charge/discharge cycle.

The last function of this program is to generate a data file from which data can be plotted.

```
10 OPEN "RD1",INPUT,1
20 STRING CL
30 INPUT IN IMAGE "INPUT CELL TEST CONFIGURATION : FULL,REDOX OR ZINC :
#":CL
40 CL=LEFT(CL,1)
50 DIM CELL(1000),CYCLE(1000),CT(1000),CD(1000),DD(1000),VE(1000)
60 DIM UE(1000),OE(1000),ZE(1000),FE(1000),FPT1(1000),ZPT1(1000)
70 DIM CPT2(1000),FPT3(1000),ZPT3(1000),FPT4(1000),ZPT4(1000)
80 DIM FPT5(1000),ZPT5(1000),FPT6(1000),ZPT6(1000),CPT1(1000)
90 DIM CPT3(1000),CPT4(1000),CPT5(1000),CPT6(1000),OCV(1000),DCV(1000),F
(10)
100 TEXT DCODE(1000),TCODE(1000),PD(1000)
110 STRING R,S,T,U,V,W
120 R="16% 23(#)/"
130 S="# # # # # # # # # # # #/"
140 FOR I=1 TO 1000
150 ON ENDFILE (1) GO TO 190
160 INPUT FROM 1 IN FORM R:DCODE(I),CELL(I),CYCLE(I),CT(I),CD(I),DD(I),V
E(I),UE(I),OE(I),ZE(I),FE(I),ZPT1(I)
**,FPT1(I),CPT2(I),OCV(I),ZPT5(I),FPT5(I),ZPT6(I),FPT6(I),ZPT3(I),FPT3(I
),ZPT4(I),FPT4(I),DCV(I)
170 J=I
180 NEXT I
190 FF=0
200 FOR L=1 TO 6
210 FOR K=1 TO J
220 C=CELL(K)
230 IF C#L THEN GO TO 270
240 IF FF=L THEN GO TO 280
250 FF=L
260 F(L)=1
270 NEXT K
280 NEXT L
290 FOR L =1 TO 6
300 FA=0
310 A=0
320 SOE=0
330 DOE=0
340 IF L#1 THEN GO TO 430
350 IF F(L)#1 THEN GO TO 2670
360 IF FA#0 THEN GO TO 870
370 OPEN "REFF1",OUTPUT,2
380 OPEN "RV1",OUTPUT,3
390 FA=1
400 GOSUB 2700
410 L=1
420 GO TO 870
```

```
470 OPEN "RV2",OUTPUT,3
480 FA=1
500 L=2
530 IF F(L)#1 THEN GO TO 2670
540 IF FA#0 THEN GO TO 870
550 OPEN "REFF3",OUTPUT,2
560 OPEN "RV3",OUTPUT,3
570 FA=1
580 GOSUB 2700
590 L=3
600 GO TO 870
770 L=5
780 GO TO 870
```

```
850 L=6
870  T="%%%%%%%N %%%%%%%%P %%%%    7(BB%%%%.%)/"
880  V="%%%%%% %%.% %.%% %%%% %%%%.% %%%%.% %%%%.% %%%%.% %%%%.% %%%%.%
%%%%.% %"
890  U="%%%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%%
 %.%%"
900  W="%%%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%% %.%%
 %.%%"
910 FOR K=1 TO J
920 C=CELL(K)
930 IF C#L THEN GO TO 1560
940 TCODE(K)=RIGHT(DCODE(K),8)
950 DCODE(K)=LEFT(DCODE(K),6)
960 DI=VAL(RIGHT(DCODE(K),3))
970 IF DI=113 THEN GO TO 1360
980 IF DI=313 THEN GO TO 1010
990 IF SUBSTR(TCODE(K),2,1)="S" THEN GO TO 1010
1000 IF VAL(LEFT(TCODE(K),2))#10 THEN GO TO 1360
1010 IF ZPT1(K)<FPT1(K) THEN GO TO 1060
1020 ZP=FPT1(K)
1030 FPT1(K)=ZPT1(K)-FPT1(K)
1040 ZPT1(K)=ZP
1050 GO TO 1080
1060 ZP=ZPT1(K)-FPT1(K)
1070 FPT1(K)=0
1080 IF ZPT3(K)<FPT3(K) THEN GO TO 1130
1090 ZP=FPT3(K)
1100 FPT3(K)=ZPT3(K)-FPT3(K)
1110 ZPT3(K)=ZP
1120 GO TO 1150
1130 ZP=ZPT3(K)-FPT3(K)
1140 FPT3(K)=0
1150 IF ZPT4(K)<FPT4(K) THEN GO TO 1200
1160 ZP=FPT4(K)
1170 FPT4(K)=ZPT4(K)-FPT4(K)
1180 ZPT4(K)=ZP
1190 GO TO 1220
1200 ZP=ZPT4(K)-FPT4(K)
1210 FPT4(K)=0
1220 IF ZPT5(K)<FPT5(K) THEN GO TO 1270
1230 ZP=FPT5(K)
1240 FPT5(K)=ZPT5(K)-FPT5(K)
1250 ZPT5(K)=ZP
1260 GO TO 1280
1270 ZPT5(K)=FPT5(K)
1280 FPT5(K)=0
```

```
1290 IF ZPT5(K)<FPT6(K) THEN GO TO 1360
1300 TP=FPT6(K)
1310 FPT6(K)=ZPT5(K)+FPT6(K)
1320 ZPT6(K)=TP
1330 GO TO 1360
1340 ZPT6(K)=FPT6(K)
1350 FPT6(K)=0
1360 A=A+1
1370 CPT1(K)=ZPT1(K)+FPT1(K)
1380 CPT3(K)=ZPT3(K)+FPT3(K)
1390 CPT4(K)=ZPT4(K)+FPT4(K)
1400 CPT5(K)=ZPT5(K)+FPT5(K)
1410 CPT6(K)=ZPT6(K)+FPT6(K)
1420 IF CL="R" THEN GO TO 1450
1430 IF CL="F" THEN GO TO 1540
1440 GO TO 1500
1450 VE(K)=(FPT5(K)/FPT1(K))*100
1460 TE(K)=FE(K)
1470 CPT5(K)=FPT3(K)
1480 CE(K)=(VE(K)*UE(K))/100
1490 GO TO 1560
1500 VE(K)=(ZPT5(K)/ZPT1(K))*100
1510 TE(K)=FE(K)
1520 ZPT6(K)=ZPT3(K)
1530 CE(K)=(VE(K)*UE(K))/100
1540 SUE=SUE+CE(K)
1550 SUE2=SUE2+CE(K)**2
1560 NEXT K
1570 MUE=SUE/A
1580 SIGE=SQRT((SUE2-((SUE**2)/A))/(A-1))
1590 N=0
1600 S7=0
1610 S8=0
1620 S9=0
1630 S10=0
1640 S11=0
1650 S12=0
1660 D0=0
1670 D1=0
1680 D2=0
1690 D3=0
1700 D4=0
1710 FOR K=1 TO J
```

```
1720 C=CELL(K)
1730 IF C#L THEN GO TO 1880
1740 IF ABS(OE(K)-MOE)<1*SDOE THEN GO TO 1770
1750 PD(K)="*"
1760 GO TO 1880
1770 SV=SV+VE(K)
1780 SU=SU+UE(K)
1790 XO=XO+OE(K)
1800 SIC=SIC+CD(K)
1810 SID=SID+DD(K)
1820 DV=DV+VE(K)**2
1830 DU=DU+UE(K)**2
1840 XD=XD+OE(K)**2
1850 DIC=DIC+CD(K)**2
1860 DID=DID+DD(K)**2
1870 A=A+1
1880 NEXT K
1890 MV=SV/A
1900 MU=SU/A
1910 MO=XO/A
1920 MC=SIC/A
1930 MD=SID/A
1940 TDVE=SQRT(ABS((DV-((SV**2)/A))/(A-1)))
1950 TDUE=SQRT(ABS((DU-((SU**2)/A))/(A-1)))
1960 TDOE=SQRT(ABS((XD-((XO**2)/A))/(A-1)))
1970 TDC=SQRT(ABS((DIC-((SIC**2)/A))/(A-1)))
1980 TDD=SQRT(ABS((DID-((SID**2)/A))/(A-1)))
1990 FOR K=1 TO J
2000 C=CELL(K)
2010 IF C#L THEN GO TO 2350
2020 M=M+1
2030 IF M<35 THEN GO TO 2110
2040 PRINT IN FORM "3/"
2050 PRINT "...."
2060 PRINT IN FORM "3/"
2070 GOSUB 3050
2080 N=12
2090 M=-16
2100 FA=0
2110 IF CL="R" THEN GO TO 2140
2120 IF CL="F" THEN GO TO 2230
2130 GO TO 2190
2140 VE(K)=(FPTS(K)/FPT1(K))*100
```

```
2150 UE(K)=FE(K)
2160 CPT6(K)=FPT3(K)
2170 OE(K)=(VE(K)*UE(K))/100
2180 GO TO 2230
2190 VE(K)=(ZPT5(K)/ZPT1(K))*100
2200 UE(K)=ZE(K)
2210 CPT6(K)=ZPT3(K)
2220 OE(K)=(VE(K)*UE(K))/100
2230 IF PD(K)="*" THEN GO TO 2310
2240 IF ABS(OE(K)-MO)<TDOE THEN GO TO 2300
2250 IF ABS(OE(K)-MO)<2*TDOE THEN GO TO 2280
2260 PD(K)="D"
2270 GO TO 2310
2280 PD(K)="S"
2290 GO TO 2310
2300 PD(K)=" "
2310 PRINT IN IMAGE V;DCODE(K),CT(K),CPT6(K),CYCLE(K),CD(K),DD(K),VE(K),
UE(K),OE(K),ZE(K),FE(K),PD(K)
2320 IF PD(K)="*" THEN GO TO 2350
2330 IF PD(K)="D" THEN GO TO 2350
2340 WRITE ON 2    IN FORM T:DCODE(K),TCODE(K),CYCLE(K),CD(K),DD(K),VE(K)
,UE(K),OE(K),ZE(K),FE(K)
2350 NEXT K
2360 CLOSE 2,3
2370 PRINT IN FORM "3/"
2380 PRINT IN IMAGE "STATISTICAL MEAN          %%.%    %%.%    %%.%    %%.%
 %%.% ":MC,MD,MV,MU,MO
2390 PRINT
2400 PRINT IN IMAGE "STANDARD DEVIATION        %%.%    %%.%    %%.%    %%.%
 %%.% ":TDC,TDD,TDVE,TDUE,TDOE
2410 FOR X=1 TO (46-N-M)
2420 PRINT
2430 NEXT X
2440 PRINT"...."
2450 PRINT IN FORM "3/"
2460 PRINT"...."
2470 GOSUB 3150
2480 M=0
2490 FOR K=1 TO J
2500 C=CELL(K)
2510 IF C#L THEN GO TO 2610
2520 M=M+1
2530 IF M<50 THEN GO TO 2600
2540 PRINT IN FORM "3/"
2550 PRINT "...."
2560 PRINT IN FORM "3/"
2570 GOSUB 3150
```

```
2580 N=4
2590 M=1
2600 PRINT IN IMAGE U:CYCLE(K),CPT1(K),ZPT1(K),FPT1(K),CPT2(K),OCV(K),CP
T5(K),ZPT5(K),FPT5(K),CPT6(K),ZPT6(K
**),FPT6(K),CPT3(K),DCV(K)
2610 NEXT K
2620 FOR X=1 TO (61-M-N)
2630 PRINT
2640 NEXT X
2650 PRINT "...."
2660 PRINT IN FORM "3/"
2670 NEXT L
2680 CLOSE 1
2690 GO TO 3110
2700 PRINT IN IMAGE"CELL = #":L
2710 STRING DA,INI,TEMP,FLOW,FEANL,FEOH,ZNANL,ZNOH,MEMB,IR,ZN
2720 INPUT IN IMAGE"INITIALS : #":INI
2730 INPUT IN IMAGE"DATE     : #":DA
2740 INPUT IN IMAGE"TEMPERATURE : #":TEMP
2750 INPUT IN IMAGE "FACE VELOCITY : #":FLOW
2760 INPUT IN IMAGE "MEMBRANE : #":MEMB
2770 INPUT IN IMAGE "FE ELECTRODE : #":IR
2780 INPUT IN IMAGE "   ANALYSIS : #":FEANL
2790 INPUT IN IMAGE "   OH ANLYSIS : #":FEOH
2800 INPUT IN IMAGE "ZN ELECTRODE : #":ZN
2810 INPUT IN IMAGE "   ANALYSIS : #":ZNANL
2820 INPUT IN IMAGE "   OH ANALYSIS : #":ZNOH
2830 PRINT "...."
2840 PRINT
2850 PRINT
2860 PRINT
2870 PRINT
2880 PRINT"                          **HYBRID REDOX BATTERY**"
2890 PRINT
2900 PRINT
2910 PRINT
2920 PRINT
2930 PRINT IN IMAGE "BATTERY CONSTRUCTION (# )":L
2940 PRINT "*************************************************************
**********"
2950 PRINT
2960 PRINT IN IMAGE"# * [# FE(2+):# NAOH] * # * [# ZNO:# NAOH] * #":IR,F
EANL,FEOH,MEMB,ZNANL,ZNOH,ZN
2970 PRINT
2980 PRINT "*************************************************************
**********"
2990 PRINT
```

```
3000 PRINT IN IMAGE"INITIALS  %%%       DATE  %%%%%%%%      TEMPERATURE  %
%.% C":INI,DA,TEMP
3010 PRINT
3020 PRINT IN IMAGE"FLOW RATE # CM/SEC":FLOW
3030 PRINT
3040 PRINT
3050 PRINT " DATE  C.T. C.P. CYCLE   +        -       VOLT    COUL   ENERGY
ZN      FE"
3060 PRINT "        HRS   E    NO.    C.D.    C.D.    EFF     EFF     EFF
EFF     EFF"
3070 PRINT "                                MA/CM2        %       %       %
 %       %"
3080 PRINT "------  --- ---- ----   ----   ----   ----   ----   ----    -
---    ----"
3090 PRINT
3100 RETURN
3110 PRINT
3120 PRINT
3130 PRINT
3140 GO TO 3230
3150 PRINT IN FORM "3/"
3160 PRINT IN IMAGE "CELL UNDER TEST (# )":L
3170 PRINT
3180 PRINT" CN    CP    ZP    FP    CP    CP    CP    ZP    FP    CP    ZP    FP
CP    CP"
3190 PRINT"   #       30 MIN       END  OCV      30 MIN          USABLE
ZN    OCV"
3200 PRINT"---- -------------- ---- ---- ------------- ------------- -
--- ----"
3210 PRINT
3220 RETURN
3230 PRINT
```

Appendix F
REDUCED DATA REPORT

The following listing details the typical output from the Data Report Program (Appendix E). The data presented is for the full cell cycle life test which is still in progress. The output for the first section is self-explaining except for C.P. E which is the usable energy cell potential, nominally set by the operator at 1.45 volts. Deviations from this value are indicative of various malfunctions. The second set of data gives the cycle number, CN, the voltages at half-way into charge, the cell potential at the end of charge, the charged OCV, the average discharge voltages, the voltages when the cell potential was 1.45 (usable energy point), the cell potential when the zinc potential was 0.80 vs Hg/HgO (zinc depletion), and the open circuit potential (OCV) of the discharged cell. Both OCV potentials are recorded after one minute at OCV to allow for attainment of equilibrium.

[illegible] PROOF BATTERY**

BATTERY CONSTRUCTION (6)

FE + (SAT'D FE(2+):5 NAOH) * W-114 * (SAT'D ZNO:5 NAOH) * CD/FE

INITIALS IPH   DATE 9/26/79   TEMPERATURE 40 C

FLOW RATE 10 CM/SEC

DATE	C.T. HRS	C.P. V	CYCLE NO.	+ C.D. MA/CM2	- C.D. MA/CM2	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %	
79/142	2.0	1.41	1	36.1	35.7	92.4	70.4	64.4	95.6	59.8	D
79/142	2.0	1.46	2	36.3	35.7	90.4	67.7	61.2	94.7	55.5	D
79/142	2.0	1.54	3	37.3	35.7	92.5	83.5	76.4	97.1	6.3	
79/143	2.0	1.33	4	41.2	37.7	89.9	35.4	31.5	71.1	5.5	*
79/143	.5	1.54	5	29.7	36.7	0.0	123.6	0.0	279.8	24.7	*
79/143	2.0	1.85	6	36.4	35.0	3.6	24.7	1.0	85.6	4.5	*
79/143	2.0	1.47	7	23.5	35.3	94.4	84.8	79.9	91.8	62.1	
79/143	2.0	1.31	8	39.3	36.0	91.5	88.1	80.1	91.7	16.9	
79/143	2.0	1.29	9	36.4	28.7	91.5	77.6	71.0	96.3	6.6	S
79/144	2.0	1.46	10	37.7	35.0	91.5	58.3	52.8	93.2	5.7	D
79/144	1.8	1.50	11	43.2	36.0	86.3	40.3	34.4	87.2	25.9	*
79/144	2.0	1.45	12	37.8	35.3	90.1	67.6	61.2	84.6	7.9	D
79/144	2.0	1.45	14	36.2	35.3	88.2	61.4	53.7	96.6	[illegible]	D
79/144	2.0	1.44	15	35.2	35.7	91.0	88.4	80.1	94.8	[illegible]	
79/145	2.0	1.56	16	37.2	40.7	91.5	71.8	65.5	106.9	[illegible]	S
79/145	2.0	1.46	17	35.1	35.3	90.1	55.6	50.4	[illegible]	36.9	D
79/145	2.0	1.51	18	41.0	38.7	83.9	55.1	46.2	85.4	19.4	D
79/145	2.0	1.46	19	39.7	35.0	91.0	88.6	81.0	96.7	[illegible]	
79/146	2.0	2.43	20	43.0	37.3	91.5	119.6	109.2	129.1	[illegible]	D
79/146	2.0	1.41	21	20.9	37.0	89.4	93.2	82.8	94.2	[illegible]	
79/146	2.0	1.42	22	25.7	36.7	91.4	95.6	87.4	97.1	[illegible]	
79/146	2.0	1.44	23	25.0	36.3	92.4	88.7	81.9	92.7	[illegible]	
79/147	2.0	1.47	24	25.2	36.7	89.9	69.2	62.1	90.1	8.2	D
79/147	2.0	1.43	25	24.7	37.3	90.0	97.0	87.3	99.7	[illegible]	
79/147	2.0	1.44	26	[illegible]	37.3	88.1	89.3	78.3	[illegible]	[illegible]	
79/147	2.0	1.46	27	[illegible]	36.7	91.4	92.5	83.7	95.1	[illegible]	
79/147	.6	1.40	28	38.3	39.0	87.8	103.6	91.5	108.0	[illegible]	
79/147	1.4	1.35	29	37.4	37.3	89.9	84.4	75.6	86.8	[illegible]	
79/147	2.0	[illegible]	30	37.8	35.3	91.0	69.7	63.7	98.4	[illegible]	D
79/148	2.0	1.43	31	41.2	38.7	87.2	47.5	40.9	92.3	[illegible]	
79/148	2.0	1.36	32	37.3	37.3	88.2	58.9	51.9	100.2	[illegible]	D
79/148	2.0	1.35	33	37.3	37.7	90.1	69.2	62.1	98.7	[illegible]	S
79/148	2.0	1.40	34	27.6	37.3	90.1	103.3	92.7	106.7	93.5	
79/148	2.0	1.46	35	41.7	38.0	[illegible]	[illegible]	81.0	[illegible]	[illegible]	

WAFER	CYCLE	CAPACITY	CYCLES	+	-	VOLTAGE	CAPACITY	ENERGY	EFFICIENCY	
	NO.	%	NO.	C.D.	C.D.	RATIO	RATIO	RATIO	RATIO	
				MA/CM2		%	%	%	%	
79/148	2.0	1.44	36	39.7	37.0	91.0	93.4	83.5	95.3	
79/149	2.0	1.43	37	37.5	37.0	98.5	92.0	86.8	93.8	
79/149	2.0	1.27	38	42.1	40.7	91.1	93.4	87.3	93.5	
79/149	2.0	1.45	39	40.2	40.7	91.1	89.2	81.0	90.8	
79/149	2.0	1.03	40	26.8	28.7	91.1	101.5	92.2	100.4	
79/149	2.0	1.41	41	42.7	40.7	91.1	95.3	86.8	92.9	
79/149	2.0	1.47	42	41.8	39.7	92.1	93.2	86.2	93.9	
79/150	2.0	1.39	43	22.8	22.3	96.7	97.2	94.0	99.4	
79/150	2.0	1.44	44	35.7	36.7	91.1	91.1	83.2	92.0	
79/150	2.0	1.44	45	38.2	36.7	96.2	99.1	92.1	100.1	
79/150	2.0	1.47	46	35.2	36.7	95.6	93.4	87.6	94.1	
79/150	2.0	1.33	47	22.1	21.7	95.3	109.1	102.0	107.4	
79/151	2.0	1.46	48	39.3	38.0	96.1	95.6	87.4	96.8	
79/151	2.0	1.39	49	25.4	25.7	96.3	92.1	85.3	94.4	
79/151	2.0	1.37	50	32.6	32.7	95.3	91.4	83.6	91.6	
79/151	2.0	1.43	51	37.8	36.0	95.4	109.3	104.6	110.1	
79/151	2.0	1.41	52	40.9	39.7	91.1	91.9	83.1	91.7	
79/151	2.0	1.44	53	37.8	37.3	91.1	89.8	81.9	90.3	
79/151	1.2	1.44	54	43.0	39.3	85.9	89.8	76.6	85.5	
79/152	2.0	1.43	55	36.8	35.7	90.9	95.7	86.4	100.3	
79/152	2.0	1.27	56	34.2	36.3	93.2	91.1	84.8	101.2	
79/152	2.0	1.38	57	33.7	36.3	89.9	96.3	85.4	97.0	
79/152	2.0	1.52	58	37.7	36.3	87.4	90.7	79.2	92.7	
79/152	2.0	1.47	59	34.4	36.7	90.2	90.5	81.2	93.5	
79/152	2.0	1.46	60	35.7	36.6	91.2	97.0	85.3	96.6	
79/153	2.0	1.23	61	36.6	36.3	90.2	82.4	73.8	95.5	
79/153	2.0	1.33	62	35.7	36.3	91.2	86.5	78.3	99.4	
79/153	2.0	1.47	63	36.8	36.3	91.2	94.6	86.4	96.4	
79/153	2.0	1.47	64	35.5	37.7	91.2	95.5	86.4	95.9	
79/153	2.0	1.47	65	36.0	36.0	91.2	95.4	86.4	97.2	
79/153	2.0	1.47	66	35.8	35.7	92.1	94.9	87.4	96.7	
79/154	2.0	1.27	67	36.0	36.3	90.2	82.1	74.7	97.2	
79/154	2.0	1.27	68	35.5	36.7	91.2	83.4	76.1	97.7	
79/154	2.0	1.47	69	35.7	35.7	91.2	97.4	88.8	99.8	
79/154	2.0	1.43	70	35.4	36.7	91.2	97.4	88.8	99.8	
79/154	2.0	1.45	71	35.7	36.3	90.2	97.2	88.3	98.8	
79/154	2.0	1.47	72	35.7	36.3	91.2	97.0	88.3	99.1	
79/155	2.0	1.38	73	35.5	36.3	91.2	83.4	76.1	97.2	
79/155	2.0	1.48	74	35.4	35.3	91.2	90.6	82.6	95.8	
79/155	2.0	1.46	75	35.6	36.3	91.2	96.4	87.8	97.6	
79/155	2.0	1.41	76	31.8	36.0	86.2	38.4	82.2	100.5	
79/155	2.0	1.47	77	36.7	36.3	91.1	95.4	86.2	100.0	
79/155	2.0	1.44	78	36.7	36.3	90.2	96.1	87.3	99.5	
79/156	2.0	1.45	79	35.5	36.0	90.2	75.1	67.5	97.5	
79/156	2.0	1.44	80	26.3	36.0	91.2	89.5	80.1	101.0	
79/156	2.0	1.47	81	36.3	36.7	90.3	95.4	86.1	100.3	
79/156	2.0	1.45	82	35.9	35.1	90.3	97.9	88.2	99.1	
79/156	2.0	1.47	83	34.4	35.1	91.2	96.6	88.1	100.5	
79/157	2.0	1.47	84	36.4	36.7	91.2	96.4	87.8	99.1	
79/157	2.0	1.31	85	26.9	25.7	91.2	87.5	79.8	96.4	
79/157	2.0	1.35	86	26.1	25.7	91.2	90.9	82.8	99.6	

DATE	C.T. HRS	C.P. E	CYCLE NO.	A C.D. MA/CM2	C.D.	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %	
79/157	2.0	1.33	87	36.0	35.7	91.2	98.6	90.1	100.2	98.6	
79/157	2.0	1.48	88	36.0	35.3	90.2	98.6	89.1	100.0	99.8	
79/157	2.0	1.45	89	35.7	35.7	91.2	98.8	90.1	100.2	100.2	
79/158	2.0	1.25	90	36.0	35.7	90.2	93.1	85.7	98.6	93.1	
79/158	2.0	1.27	91	36.2	36.7	90.2	83.7	75.6	101.5	83.9	
79/158	2.0	1.42	92	36.0	35.3	91.2	94.4	85.5	98.4	94.4	
79/158	2.0	1.31	93	36.0	35.7	90.2	89.6	81.0	98.6	89.6	
79/158	2.0	1.47	94	35.7	35.3	91.2	98.6	90.1	100.9	100.9	
79/158	2.0	1.45	95	35.4	35.3	91.2	97.6	89.0	99.1	99.1	
79/159	2.0	1.47	96	35.6	35.3	90.2	96.7	87.3	98.1	98.1	
79/159	2.0	1.48	97	35.3	35.3	89.2	96.2	85.4	97.9	65.6	
79/159	2.0	1.46	98	35.3	35.3	90.2	74.9	67.5	96.2	96.2	S
79/159	2.0	1.49	99	35.0	35.7	90.2	98.6	89.1	100.2	100.2	
79/159	2.0	1.45	100	34.9	35.3	90.2	98.1	88.5	99.3	99.3	
79/159	2.0	1.47	101	35.1	35.3	91.1	97.6	89.2	99.0	99.0	
79/160	2.0	1.45	102	35.1	35.3	91.1	97.1	88.3	98.8	98.8	
79/160	2.0	1.41	103	35.0	35.3	90.2	90.0	81.0	98.1	89.8	
79/160	2.0	1.48	104	34.8	35.3	90.2	70.3	63.0	97.1	70.1	D
79/160	2.0	1.45	105	34.8	35.3	90.2	100.2	90.0	102.2	102.2	
79/160	2.0	1.43	106	35.5	35.3	92.1	96.9	89.2	98.1	98.1	
79/160	2.0	1.43	107	35.6	35.7	92.1	96.5	88.8	97.7	97.7	
79/161	2.0	1.47	108	35.5	35.7	92.2	96.5	88.4	97.1	97.1	
79/161	2.0	1.44	109	35.3	35.7	91.1	95.5	86.4	97.6	95.9	
79/161	2.0	1.46	110	35.3	35.7	92.2	95.2	88.2	97.6	97.7	
79/161	2.0	0.00	111	35.2	35.3	92.2	0.0	0.0	0.0	0.0	S
79/161	2.0	0.00	112	35.1	1.7	0.0	0.0	0.0	5.0	5.0	S
79/161	2.0	1.68	113	35.1	35.3	85.2	228.7	201.5	248.7	5.0	S
79/162	2.0	1.68	114	35.0	35.3	90.1	55.1	49.5	97.4	5.0	D
79/162	2.0	1.66	115	35.1	35.3	90.2	70.4	63.7	97.9	5.0	S
79/162	2.0	1.41	117	35.2	35.3	90.2	95.5	85.5	98.1	5.0	
79/162	2.0	1.76	118	34.9	35.7	89.7	96.1	412.4	168.5	6.4	
79/162	2.0	1.80	119	35.2	35.3	89.1	87.7	78.3	93.1	89.7	
79/163	2.0	1.58	120	35.2	36.0	88.2	86.3	76.7	96.4	86.3	
79/163	2.0	1.54	121	35.0	35.0	86.2	94.8	81.2	98.3	95.4	
79/163	2.0	1.41	122	35.0	36.0	89.1	96.4	86.3	98.6	96.4	
79/163	1.5	1.50	123	36.1	35.3	88.1	60.7	56.2	71.7	6.5	D
79/163	2.0	1.57	124	35.1	35.3	89.1	114.5	101.5	116.8	5.0	S
79/163	2.0	1.56	125	35.2	35.3	89.1	94.1	83.7	96.7	5.0	
79/164	2.0	1.62	126	35.2	36.0	89.1	68.5	60.5	97.6	5.0	D
79/164	2.0	1.52	127	35.5	36.0	89.1	86.6	76.4	96.9	86.8	
79/171	2.0	1.41	169	35.0	35.7	86.4	89.4	68.8	101.7	89.4	S
79/171	2.0	1.46	170	35.2	35.7	89.1	100.2	89.0	104.5	104.5	
79/171	2.0	1.46	171	35.3	35.7	89.1	78.8	69.4	95.1	78.8	S
79/172	2.0	1.38	172	35.4	35.7	89.1	79.5	70.3	98.8	79.1	
79/172	2.0	1.36	173	35.2	35.7	89.1	82.1	73.5	98.1	82.1	
79/172	2.0	1.42	174	35.3	36.0	88.2	89.8	79.2	99.1	90.1	
79/172	2.0	1.44	175	35.1	35.3	88.2	94.5	82.7	100.2	94.8	
79/172	2.0	1.46	176	35.2	36.0	88.2	99.1	87.1	100.9	100.9	
79/172	2.0	1.46	177	35.2	35.3	89.1	80.0	72.5	99.5	82.5	
79/173	2.0	1.36	178	35.3	36.3	88.2	70.3	62.9	97.2	70.2	S
79/173	2.0	1.38	179	35.2	36.0	88.2	78.4	68.6	98.6	78.7	S

DATE	C.T. HRS	C.P. E	CYCLE NO.	+ C.D. MA/CM2	- C.D.	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %	
79/173	2.0	1.46	180	35.1	36.0	88.2	88.1	77.4	99.5	88.4	
79/173	2.0	1.46	181	35.2	36.0	88.2	94.5	82.7	99.3	94.8	
79/173	2.0	1.46	182	35.2	35.7	88.2	97.2	85.4	99.1	99.1	
79/173	2.0	1.46	183	35.2	35.7	89.1	97.2	86.3	98.8	98.3	
79/174	2.0	1.38	184	35.2	36.0	89.1	85.6	76.5	99.3	85.6	
79/174	2.0	1.44	185	35.3	35.7	88.2	80.9	71.3	99.5	81.8	S
79/174	2.0	1.46	186	35.1	36.0	89.1	86.9	77.4	98.8	87.2	
79/174	2.0	1.46	187	34.9	36.7	88.2	98.8	87.1	100.5	99.5	
79/174	2.0	1.44	188	35.1	36.3	88.2	97.9	86.2	99.5	99.3	
79/174	2.0	1.42	189	35.2	36.0	89.1	96.5	85.4	98.3	97.2	
79/175	2.0	1.44	190	35.3	36.3	89.1	76.4	67.6	99.8	76.9	S
79/175	2.0	1.44	191	35.4	36.3	87.3	80.0	69.6	99.3	80.5	S
79/175	2.0	1.46	192	35.5	36.3	89.1	75.4	66.7	96.5	76.1	S
79/175	2.0	1.42	193	35.2	36.3	88.2	97.4	85.4	99.1	98.1	
79/175	2.0	1.40	194	35.2	36.7	89.1	99.8	89.0	101.7	101.2	
79/175	2.0	1.48	195	35.4	36.0	89.1	82.4	73.0	98.4	82.8	S
79/176	2.0	1.42	196	35.4	36.0	87.2	76.7	67.0	98.4	76.9	S
79/176	2.0	1.42	197	35.2	36.0	87.2	72.8	63.5	98.6	73.5	D
79/176	2.0	1.43	198	35.2	36.3	86.3	85.6	74.0	99.3	85.6	S
79/176	2.0	1.48	199	35.6	35.7	88.2	90.2	79.2	92.5	92.0	
79/176	2.0	1.46	200	35.4	35.7	89.1	89.6	80.1	92.5	91.8	
79/176	2.0	1.46	201	35.2	36.3	89.1	86.5	76.5	90.1	87.9	
79/177	2.0	1.48	202	35.3	36.3	88.2	68.2	59.8	97.4	69.3	D
79/177	2.0	1.47	203	35.3	36.0	86.3	63.0	54.2	102.1	63.0	D
79/177	2.0	1.44	204	35.2	36.0	88.2	83.7	73.9	91.5	85.1	S
79/177	1.3	1.23	205	36.0	1.7	0.0	7.3	0.0	31.0	7.8	*
79/178	2.0	1.40	207	34.7	36.7	89.2	118.2	105.0	124.0	118.5	D
79/178	2.0	1.31	208	35.6	36.3	90.2	76.1	68.4	101.2	75.9	S
79/179	2.0	1.29	209	35.7	36.0	89.2	61.0	54.3	97.7	61.0	D
79/179	2.0	1.33	210	35.7	36.0	88.3	82.1	72.2	92.5	82.1	S
79/179	2.0	1.43	211	35.2	36.0	89.2	94.1	83.7	100.0	94.1	
79/179	0.0	0.00	217	1.6	1.7	0.0	100.0	0.0	100.0	100.0	*
79/179	2.0	1.51	222	36.4	36.0	91.2	88.1	80.1	89.2	89.2	
79/179	2.0	1.47	223	36.0	36.0	90.2	97.2	87.3	98.4	98.4	
79/180	2.0	1.53	224	35.9	35.7	91.1	95.1	86.4	97.0	97.0	
79/180	2.0	1.49	225	36.0	35.7	91.2	96.3	87.4	97.7	97.7	
79/180	2.0	1.51	226	36.0	36.3	89.2	96.1	85.4	97.7	97.7	
79/180	2.0	1.51	227	35.9	35.7	90.3	96.1	86.4	97.5	97.5	
79/180	.1	1.49	228	238.3	46.0	89.1	141.3	125.5	144.1	144.1	D
79/181	2.0	1.52	229	35.7	35.7	89.2	82.3	73.0	84.6	84.6	S
79/181	2.0	1.50	230	36.1	36.3	89.3	91.7	81.9	96.5	96.5	
79/182	2.0	1.49	231	35.9	36.0	87.6	91.6	81.0	97.0	97.0	
79/182	2.0	1.49	232	36.1	36.0	85.7	90.5	77.4	94.0	94.0	
79/182	2.0	1.45	233	35.5	33.0	86.7	88.5	76.6	92.7	92.7	
79/182	2.0	1.47	234	36.0	19.0	86.7	91.7	80.0	94.2	94.2	
79/182	2.0	1.49	235	35.9	34.7	88.4	95.4	83.6	97.4	97.4	
79/182	2.0	1.47	236	35.1	35.7	88.4	93.6	82.7	96.0	96.0	
79/183	2.0	1.47	237	27.1	25.3	94.6	98.8	94.0	102.8	102.8	S
79/183	2.0	1.31	238	2.4	3.7	100.0	75.9	76.0	96.6	96.6	
79/183	2.0	1.31	239	5.7	1.7	0.0	87.0	0.0	88.4	88.4	*
79/183	2.0	1.47	240	35.5	35.3	88.4	95.5	83.6	97.4	97.4	

DATE	C.T. HRS	C.P. E	CYCLE NO.	+ C.D. MA/CM2	- C.D. MA/CM2	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %	
79/183	2.0	1.49	241	35.4	35.0	87.6	95.1	83.6	97.6	97.6	
79/183	2.0	1.47	242	36.1	35.0	89.4	94.7	84.5	96.8	96.8	
79/184	2.0	1.48	243	35.8	35.3	87.6	96.3	84.5	97.9	97.9	
79/184	2.0	1.47	244	36.0	35.3	87.7	94.7	83.6	96.8	96.8	
79/184	2.0	1.47	245	35.7	36.0	87.7	96.5	84.5	98.1	98.1	
79/184	2.0	1.49	246	36.0	35.3	87.7	95.4	83.6	97.2	97.2	
79/184	2.0	1.48	247	35.9	35.7	87.6	94.9	83.6	97.0	97.0	
79/184	2.0	1.41	248	36.0	35.7	89.4	98.4	87.2	100.2	100.2	
79/185	2.0	1.47	249	36.0	35.3	88.4	96.1	84.5	97.7	97.7	
79/185	2.0	1.47	250	35.9	35.7	88.6	97.0	86.3	98.6	98.6	
79/185	2.0	1.43	251	35.7	35.3	88.6	97.2	86.3	98.4	98.4	
79/185	2.0	1.47	252	35.7	35.3	88.6	96.0	85.4	97.7	97.7	
79/185	2.0	1.48	253	35.8	35.3	90.4	97.0	87.3	98.6	98.6	
79/185	2.0	1.45	254	35.7	35.7	91.3	97.7	89.2	98.8	98.8	
79/186	2.0	1.39	255	35.4	35.7	90.4	96.5	86.4	97.6	97.6	
79/186	2.0	1.33	256	35.5	35.3	90.4	82.4	73.8	84.0	84.0	S
79/186	2.0	1.47	257	35.7	35.3	92.2	111.4	102.1	115.2	115.2	S
79/186	2.0	1.47	258	35.3	35.7	91.2	87.3	79.2	93.9	93.9	
79/186	2.0	1.47	259	35.8	35.3	90.4	97.9	88.2	99.8	99.8	
79/186	2.0	1.43	260	36.0	35.3	91.3	96.8	88.3	98.6	98.6	
79/187	2.0	1.47	261	35.7	35.3	88.4	95.8	84.5	98.1	98.1	
79/187	2.0	1.46	262	35.7	35.3	89.4	95.8	85.4	98.1	98.1	
79/187	2.0	1.46	263	35.5	35.7	88.4	96.7	85.4	98.8	98.8	
79/187	2.0	1.47	264	35.8	35.7	89.3	96.5	85.4	98.1	98.1	
79/187	2.0	1.47	265	35.8	36.0	91.2	96.3	87.4	98.1	98.1	
79/187	2.0	1.47	266	35.8	36.0	91.2	97.2	88.3	98.8	98.8	
79/188	2.0	1.48	267	35.7	36.0	90.3	96.0	86.4	98.4	98.4	
79/188	2.0	1.46	268	35.6	35.7	89.3	96.3	85.4	98.6	98.6	
79/188	2.0	1.46	269	35.5	35.7	88.3	95.5	83.6	97.2	97.2	
79/188	2.0	1.43	270	35.6	35.7	90.3	99.8	90.0	101.2	101.2	
79/188	2.0	1.45	271	35.8	35.3	93.2	98.1	91.1	99.8	99.8	
79/188	2.0	1.47	272	35.8	35.3	90.2	96.7	87.3	97.9	97.9	
79/189	2.0	1.47	273	35.8	35.3	90.2	97.4	87.3	99.1	99.1	
79/189	2.0	1.45	274	35.7	35.3	90.3	97.4	87.3	98.6	98.6	
79/189	2.0	1.45	275	36.8	38.0	106.2	98.2	103.9	99.3	99.3	D
79/189	2.0	1.47	276	35.8	36.0	90.3	98.6	89.1	99.8	99.8	
79/189	2.0	1.45	277	35.7	35.7	91.2	99.5	90.1	100.5	100.5	
79/189	2.0	1.47	278	34.7	36.0	87.0	45.3	39.1	57.6	57.6	*
79/190	2.0	1.48	279	35.0	35.3	77.1	82.4	63.1	92.1	92.1	D
79/190	2.0	1.48	280	35.0	35.3	79.4	83.3	65.6	94.3	94.3	S
79/190	2.0	1.46	281	35.3	35.3	89.3	93.4	82.8	101.2	101.2	
79/190	2.0	1.46	282	36.3	15.7	94.2	100.7	94.9	105.7	105.7	S
79/190	2.0	1.44	283	36.4	36.0	92.2	100.0	92.0	102.5	102.5	
79/191	2.0	1.45	284	36.4	36.0	92.1	100.5	92.0	102.1	102.1	
79/191	2.0	1.46	285	36.3	36.0	90.3	98.6	89.1	100.7	100.7	
79/191	2.0	1.44	286	36.5	35.7	91.2	97.7	89.2	99.1	99.1	
79/191	2.0	1.46	287	36.5	36.0	92.1	94.5	86.5	98.6	94.5	
79/192	2.0	1.45	288	36.2	36.0	91.1	98.2	89.2	99.5	99.5	
79/192	2.0	1.45	289	36.2	35.3	91.2	98.4	89.2	99.5	99.5	
79/192	2.0	1.46	290	36.1	35.7	90.3	97.5	87.3	98.8	98.8	
79/192	2.0	1.46	291	36.1	35.7	91.2	95.2	86.4	98.6	95.8	

DATE	C.T. HRS	C.P. E	CYCLE NO.	+ C.D. MA/CM2	- C.D. MA/CM2	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %	
79/192	2.0	1.48	292	36.6	36.0	91.2	97.5	88.3	98.9	98.9	
79/193	2.0	1.48	294	36.8	35.7	90.3	96.4	86.4	98.4	98.4	
79/193	2.0	1.46	295	36.7	36.0	89.3	96.4	85.4	98.6	88.4	
79/193	2.0	1.46	296	36.5	36.0	88.3	90.4	79.2	93.4	91.3	
79/193	2.0	1.46	297	36.6	35.7	91.2	97.3	88.3	99.8	98.9	
79/193	2.0	1.44	298	36.7	36.0	91.1	97.3	88.3	99.1	99.1	
79/194	2.0	1.48	301	36.5	36.0	89.2	96.1	85.4	99.1	95.7	
79/194	2.0	1.44	302	36.3	36.0	87.2	89.0	77.4	92.7	87.4	
79/195	2.0	1.48	305	34.8	36.7	90.4	201.7	181.8	206.5	206.2	*
79/195	2.0	1.46	306	37.2	36.0	92.1	96.9	89.2	98.9	97.3	
79/195	2.0	1.46	307	37.1	36.3	92.1	97.1	89.2	98.7	98.7	
79/195	2.0	1.48	308	37.2	36.7	92.1	93.1	85.6	96.6	79.9	
79/195	2.0	1.48	309	37.2	36.7	91.0	92.2	83.7	94.6	92.4	
79/195	2.0	1.48	310	37.3	36.3	92.1	96.2	88.3	97.5	97.5	
79/197	2.0	1.47	312	37.0	35.7	91.5	80.9	73.7	86.9	79.5	S
79/197	2.0	1.45	313	37.1	36.3	92.1	91.5	83.7	96.9	89.0	
79/197	2.0	1.47	314	37.2	36.7	91.1	90.8	82.8	95.5	89.0	
79/201	2.0	1.48	316	36.3	35.7	91.5	84.2	76.4	101.6	4.8	
79/201	2.0	1.47	317	35.7	36.0	90.4	80.1	72.0	99.5	6.1	S
79/201	2.0	1.47	318	36.0	35.7	91.0	78.2	71.0	98.8	76.4	S
79/201	2.0	1.47	319	36.0	35.3	92.5	88.9	81.9	98.1	88.6	
79/201	2.0	1.47	320	36.2	35.3	91.5	90.8	82.8	97.2	91.5	
79/202	2.0	1.46	321	36.4	35.3	91.5	92.0	83.7	94.5	94.5	
79/202	2.0	1.46	322	36.3	35.7	91.0	97.2	88.3	101.4	101.4	
79/202	2.0	1.49	323	36.1	36.0	91.5	84.3	76.4	96.8	85.5	
79/202	2.0	1.45	324	36.1	35.3	91.5	93.8	85.5	99.1	94.0	
79/202	2.0	1.48	325	36.4	32.7	92.6	96.3	89.3	99.1	98.4	
79/202	2.0	1.40	326	36.7	33.0	92.6	98.4	91.1	99.8	99.8	
79/203	2.0	1.31	327	36.7	33.0	93.5	93.2	86.5	98.0	93.2	
79/203	2.0	1.43	328	36.8	32.0	92.6	91.4	84.6	95.9	91.6	
79/203	2.0	1.46	329	36.7	32.0	93.6	96.4	90.2	99.1	98.2	
79/203	2.0	1.42	330	36.3	32.0	93.6	95.9	90.2	97.2	97.2	
79/203	2.0	1.45	331	36.2	32.0	92.6	89.2	82.8	95.9	89.6	
79/203	2.0	1.47	332	36.1	32.3	92.6	94.9	88.3	98.4	96.1	
79/204	2.0	1.48	333	36.1	32.3	92.1	80.1	73.6	84.5	82.2	S
79/204	2.0	1.46	334	35.6	32.3	82.2	31.1	25.4	109.4	34.9	*
79/204	2.0	1.33	335	36.2	32.7	86.6	77.0	67.0	100.2	77.0	S
79/204	2.0	1.47	336	37.1	32.0	91.1	73.7	67.3	95.5	75.3	S
79/204	2.0	1.41	337	36.9	32.0	89.1	72.2	64.1	97.5	72.2	D
79/205	2.0	1.47	338	36.7	32.3	89.2	66.2	58.7	97.5	66.9	D
79/285	2.0	1.47	340	36.5	32.7	87.3	62.1	53.9	99.3	62.6	D
79/205	2.0	1.46	341	36.7	33.0	89.1	82.1	73.0	93.2	87.8	S
79/205	2.0	1.50	342	36.8	32.7	90.1	83.9	75.6	92.3	90.7	
79/205	2.0	1.46	343	37.2	32.3	91.0	83.0	75.5	92.6	86.4	
79/206	2.0	1.46	344	37.2	33.0	91.0	87.2	79.2	94.2	91.3	
79/206	2.0	1.47	345	37.0	33.0	91.0	89.9	81.9	97.1	91.2	
79/206	2.0	1.48	346	37.1	33.0	92.1	91.7	84.6	95.3	95.3	
79/206	2.0	1.46	347	37.2	33.3	92.1	93.7	86.5	97.1	97.1	
79/206	2.0	1.48	348	37.2	33.0	92.1	93.9	86.5	96.9	96.9	
79/207	2.0	1.46	349	37.0	33.0	92.6	92.1	85.6	96.6	93.5	
79/207	2.0	1.48	350	37.1	33.0	92.6	92.6	86.5	95.5	93.5	

DATE	C.T. HRS	C.P. E	CYCLE NO.	+ C.D. MA/CM2	- C.D.	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %	
79/207	2.0	1.42	351	37.0	32.7	92.1	94.8	87.4	96.8	96.8	
79/207	2.0	1.44	352	37.2	33.0	92.6	95.1	88.3	96.9	96.9	
79/207	2.0	1.46	353	36.8	33.3	92.1	97.5	89.2	99.5	99.3	
79/207	2.0	1.46	354	36.7	33.0	92.6	98.2	91.1	99.8	99.8	
79/208	2.0	1.46	355	36.8	33.3	92.6	94.8	88.3	97.3	97.1	
79/208	2.0	1.47	356	36.8	33.7	92.1	82.4	75.4	95.7	82.6	
79/208	2.0	1.42	357	36.5	33.7	93.1	94.7	88.3	98.2	97.5	
79/208	2.0	1.46	358	35.7	33.3	92.1	92.8	85.6	97.2	93.9	
79/208	2.0	1.39	359	35.9	33.3	93.6	96.3	90.2	98.4	96.3	
79/208	2.0	1.45	360	35.7	33.0	92.6	91.8	85.6	95.8	92.1	
79/209	2.0	1.49	361	35.9	33.3	92.6	84.9	79.0	93.3	85.2	
79/209	2.0	1.43	362	35.6	32.7	93.1	74.0	68.8	92.0	74.5	S
79/209	2.0	1.47	363	35.9	33.0	92.1	86.3	79.1	93.5	87.5	
79/209	2.0	1.44	364	35.0	33.0	93.1	97.9	91.1	101.0	101.0	
79/209	2.0	1.46	365	37.2	33.0	92.6	95.7	89.3	98.0	97.5	
79/210	2.0	1.45	366	36.9	33.3	92.6	91.6	85.6	96.8	92.1	
79/210	2.0	1.47	367	36.9	32.3	92.1	87.4	80.0	94.1	89.2	
79/210	2.0	1.47	368	36.9	33.0	92.1	79.0	72.7	94.4	79.9	S
79/210	2.0	1.47	369	36.4	32.7	92.1	70.9	65.3	95.4	71.2	D
79/210	2.0	1.46	370	36.5	32.7	93.1	97.7	91.1	103.7	21.0	
79/210	2.0	1.46	371	35.4	33.0	93.1	97.9	91.1	99.8	37.2	
79/211	2.0	1.60	372	35.9	32.7	93.6	92.1	86.5	95.8	4.4	
79/211	2.0	1.46	373	35.5	33.0	93.1	91.5	84.6	94.8	12.2	
79/211	2.0	0.00	374	35.4	1.7	0.0	0.0	0.0	21.6	4.5	*
79/211	.6	1.48	375	35.5	33.0	92.1	345.3	317.4	356.3	356.3	*
79/211	2.0	1.44	376	36.6	33.3	92.1	93.6	86.5	97.5	94.8	
79/211	2.0	1.31	377	36.0	34.7	93.1	28.5	26.0	33.8	28.5	*
79/292	2.0	1.52	378	36.4	35.7	93.2	155.6	145.1	159.5	139.8	*
79/212	1.6	.92	379	39.0	1.7	0.0	5.6	0.0	5.9	5.6	*
79/213	.9	1.87	380	37.2	1.7	0.0	10.4	8.0	23.9	10.4	*
79/213	2.0	1.46	381	35.7	36.3	91.3	188.1	971.1	198.1	189.5	*
79/213	2.8	1.46	382	35.5	37.0	92.6	96.4	87.4	98.8	98.8	
79/214	2.0	1.46	383	35.5	37.8	92.6	93.4	86.5	97.7	97.7	
79/214	2.0	1.47	384	35.5	36.7	92.6	84.3	78.1	114.1	85.0	
79/214	2.0	1.48	386	35.7	37.0	91.1	93.5	84.6	98.4	98.4	
79/214	2.0	1.46	387	35.7	37.0	92.1	98.4	90.2	102.1	102.1	
79/214	2.0	1.44	388	34.9	37.0	92.1	95.0	87.4	98.1	98.1	
79/215	2.0	1.46	389	35.6	37.7	92.9	96.0	88.3	98.8	98.4	
79/215	2.0	1.45	390	35.6	37.3	93.1	94.6	87.4	100.0	96.0	
79/215	2.0	1.47	391	35.7	37.7	92.1	87.6	81.0	97.4	90.0	
79/215	2.0	1.45	392	35.4	37.7	92.1	93.4	85.6	99.8	94.6	
79/215	2.0	1.44	393	36.1	38.0	93.1	99.5	92.9	102.5	102.3	
79/215	2.0	1.44	394	35.6	36.7	92.1	98.6	99.1	180.7	100.5	S
79/216	2.0	1.48	395	35.7	37.3	92.1	98.4	98.2	100.5	100.2	S
79/216	2.0	1.44	396	35.2	37.0	92.1	95.7	88.3	98.8	98.8	
79/216	2.0	1.31	397	34.4	37.3	92.6	97.3	90.2	100.5	97.3	
79/216	2.0	1.42	398	34.7	37.0	92.6	99.3	92.1	100.7	100.7	
79/216	2.0	1.39	399	36.0	36.7	92.6	98.1	91.1	100.2	99.3	
79/216	2.0	1.44	400	36.2	37.0	92.6	96.3	89.3	98.8	98.8	
79/217	2.0	1.43	401	35.7	37.0	92.1	97.0	89.2	99.3	97.4	
79/217	2.0	1.45	402	35.7	36.7	92.1	95.1	87.4	99.5	97.0	

			CLE							
				MA/CM2						
79/213	2.0	1.46	401	37.8	37.9	92.1	94.2	86.5	97.7	95.3
79/214	2.0	1.46	404	37.8	37.0	92.1	93.8	91.1	101.4	101.3
79/215	2.0	1.46	405	37.8	37.3	92.1	93.8	91.1	100.5	100.5
79/216	2.0	1.46	406	37.8	38.7	92.1	93.8	90.2	99.5	99.3
79/217	2.0	1.45	407	37.8	37.3	92.1	93.7	91.1	99.5	99.3
79/218	2.0	1.46	408	38.7	37.7	92.1	94.2	87.4	96.7	95.1
79/218	2.0	1.45	409	34.9	36.2	92.1	95.8	87.4	99.5	95.5
79/218	2.0	1.46	410	37.8	36.0	93.1	96.5	89.3	97.6	97.6
79/218	2.0	1.45	411	33.0	36.2	92.1	93.5	86.5	97.9	5.2
79/218	2.0	1.44	412	37.8	37.2	92.1	93.8	90.2	98.6	95.6
79/218	2.0	2.71	413	37.8	37.0	92.1	95.1	87.4	102.1	95.2
79/219	2.0	2.79	414	33.2	35.7	90.1	93.8	81.9	290.5	46.0
79/219	2.0	1.43	416	35.5	36.7	85.1	87.1	74.7	96.9	83.1
79/219	2.0	1.46	417	38.8	37.3	84.5	86.0	81.0	94.0	90.1
79/220	1.0	1.47	418	35.5	37.3	91.0	92.1	84.6	95.5	93.7
79/220	2.0	1.46	419	37.8	37.3	91.0	93.1	85.5	97.8	96.0
79/220	2.0	1.47	420	38.1	37.7	91.0	93.5	85.5	98.3	94.3
79/220	2.0	2.83	421	34.6	38.0	91.0	94.7	86.4	138.3	62.2
79/220	2.0	1.47	422	37.8	37.7	91.0	93.1	81.9	95.5	83.8
79/220	2.0	1.47	423	37.8	37.7	91.0	91.1	82.8	98.4	86.5
79/221	2.0	1.47	424	38.1	38.2	91.0	93.7	87.4	99.1	94.1
79/221	2.0	1.45	425	36.4	38.0	91.0	95.2	86.4	99.8	92.2
79/221	2.0	1.43	426	35.4	38.7	91.0	95.3	87.4	101.1	16.5
79/221	2.0	1.43	427	37.1	37.0	91.0	93.8	85.5	98.7	92.4
79/221	2.0	1.45	428	38.1	38.1	91.0	95.3	87.4	100.0	93.0
79/222	2.0	1.47	429	34.6	38.5	92.0	93.6	89.3	101.4	93.9
79/222	2.0	1.43	430	37.1	38.0	92.0	94.8	90.2	98.9	97.3
79/252	2.0	1.39	431	36.1	39.0	92.1	96.4	90.2	100.5	97.9
79/252	2.0	1.45	432	35.4	38.0	92.1	96.6	89.2	98.9	96.1
79/292	2.0	1.44	433	35.5	38.7	92.1	95.7	88.3	98.6	93.8
79/292	2.0	2.66	434	35.4	38.7	92.1	91.6	84.6	219.4	89.1
79/292	2.0	1.45	435	33.2	39.7	89.9	85.8	72.1	95.6	78.5 S
79/292	2.0	1.45	436	35.7	39.3	90.1	89.0	80.1	99.8	86.0
79/292	2.0	1.44	437	36.0	39.7	91.1	95.0	85.4	97.9	6.3
79/292	2.0	1.86	438	37.6	40.1	79.1	91.5	92.9	155.4	74.3
79/292	2.0	1.47	442	37.2	39.7	90.1	92.1	91.0	0.0	84.3
79/293	2.0	1.45	443	37.2	38.3	91.1	93.3	84.6	97.3	92.4
79/293	2.0	1.47	444	38.1	37.7	92.1	93.8	86.6	97.7	90.5
79/234	2.0	1.45	445	36.2	39.7	91.1	92.9	84.6	0.0	90.6
79/293	2.0	1.49	446	38.6	40.7	91.1	93.4	87.4	100.7	94.4
79/293	2.0	1.49	448	38.9	39.7	90.1	90.7	83.7	99.8	5.3
79/295	2.0	1.46	449	37.7	39.3	92.1	91.2	83.7	97.1	90.5
79/295	2.0	1.43	450	37.0	38.0	92.1	92.1	84.6	99.5	5.4
79/295	2.0	1.47	451	36.6	40.3	93.1	97.0	90.2	100.0	5.5
79/226	2.0	1.43	452	36.5	40.0	93.1	95.0	86.3	97.5	5.5
79/226	2.0	1.47	453	36.5	40.6	93.1	96.3	92.1	103.0	5.5
79/226	2.0	1.46	454	36.3	39.7	92.1	97.2	89.2	101.4	5.5
79/226	2.0	1.44	455	36.7	39.7	93.1	94.3	87.4	100.0	83.9
79/227	2.0	1.45	460	36.8	40.3	92.1	92.3	84.6	0.0	20.4
79/229	2.0	1.47	469	38.2	38.3	92.1	92.6	85.6	0.0	91.5
79/229	2.0	1.37	470	36.7	36.7	91.0	90.2	81.9	0.0	86.1

DATE	C.T. HRS	C.P. E	CYCLE NO.	+ C.D. MA/CM2	- C.D. MA/CM2	VOLT EFF %	[illegible] EFF %	ENERGY EFF %	DI %	RE %	
79/229	2.0	2.42	471	37.1	35.3	91.0	[illegible]	[illegible]	0.0	[illegible]	
79/231	2.0	1.44	481	16.2	37.0	94.4	95.9	90.2	104.1	99.3	
79/231	2.0	1.46	482	36.7	34.0	91.5	96.4	87.4	100.7	97.8	
79/231	2.0	1.45	483	37.1	36.3	91.5	94.8	[illegible]	[illegible]	[illegible]	
79/231	2.0	1.47	484	36.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/232	2.0	1.46	487	36.9	36.0	91.0	95.9	87.4	104.5	94.6	
79/232	2.0	1.48	488	36.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/232	2.0	1.45	489	36.9	35.3	92.6	97.8	81.8	96.6	86.5	
79/233	2.0	1.48	494	36.6	37.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/234	2.0	1.46	501	36.8	34.3	86.7	[illegible]	100.0	0.0	117.7	S
79/234	2.0	1.37	502	36.3	34.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/235	2.0	1.49	504	36.2	41.0	90.1	[illegible]	[illegible]	[illegible]	[illegible]	
79/235	2.0	1.43	505	36.4	41.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/235	2.0	1.45	506	36.3	31.7	92.6	[illegible]	[illegible]	[illegible]	[illegible]	S
79/236	2.0	1.46	507	36.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/236	2.0	1.44	508	36.3	31.3	92.6	[illegible]	[illegible]	[illegible]	[illegible]	
79/236	2.0	1.47	509	36.3	30.7	[illegible]	[illegible]	[illegible]	0.0	[illegible]	
79/236	2.0	1.46	510	36.4	30.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	S
79/236	2.0	1.46	511	36.4	29.0	93.6	97.9	92.1	98.9	[illegible]	
79/236	2.0	1.44	512	36.5	29.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/237	2.0	1.47	513	36.4	27.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/237	2.0	1.48	514	36.2	28.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/237	2.0	1.46	515	36.2	29.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/237	2.0	1.46	516	36.2	29.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	S
79/238	2.0	1.35	522	36.0	28.0	[illegible]	[illegible]	[illegible]	0.0	[illegible]	
79/238	2.0	1.46	523	36.3	34.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/238	2.0	1.46	524	36.5	35.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/238	2.0	1.30	525	36.5	34.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/239	2.0	1.42	526	36.5	39.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/239	2.0	1.48	527	36.5	40.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/239	2.0	1.48	528	36.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/239	2.0	1.47	529	36.4	34.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/239	2.0	1.44	530	36.6	32.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/239	2.0	1.46	531	36.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/240	2.0	1.48	532	36.7	39.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/240	2.0	1.46	533	36.6	39.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/240	2.0	1.46	534	36.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/240	2.0	1.47	535	36.7	37.0	[illegible]	[illegible]	[illegible]	0.0	[illegible]	
79/240	2.0	1.42	536	36.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/240	2.0	1.46	537	36.8	29.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/241	2.0	1.46	538	36.7	33.3	[illegible]	[illegible]	[illegible]	0.0	[illegible]	
79/241	2.0	1.45	539	36.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/241	2.0	1.46	540	36.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/241	2.0	1.41	541	36.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/241	2.0	1.46	542	37.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/241	2.0	1.46	543	37.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/242	2.0	1.46	544	36.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/242	2.0	1.46	545	36.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/242	2.0	1.44	546	36.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/242	2.0	1.47	547	36.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
79/242	2.0	1.42	548	37.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

DATE	C.D. HRS	C.B. E	CYCLE NO.	I C.D. MA/CM2	C C.D. MA/CM2	VOLT EFF %	COUL EFF %	ENERGY EFF %	EN EFF %	CE EFF %	
79/243	2.0	1.44	549	37.3	41.3	91.5	96.0	87.8	98.9	96.9	
79/243	2.0	1.44	550	36.7	40.3	91.0	97.3	88.3	98.4	98.4	
79/243	2.0	1.46	551	36.7	37.3	92.1	95.0	87.4	97.7	94.3	
79/243	2.0	1.42	552	36.5	38.7	91.5	97.5	88.3	96.4	95.4	
79/243	2.0	1.44	553	37.2	40.3	91.5	95.7	87.5	95.6	95.6	
79/243	2.0	1.40	554	37.4	38.7	91.5	93.5	86.6	94.0	96.0	
79/244	2.0	1.48	555	37.3	42.0	91.0	95.3	88.4	96.7	94.8	
79/244	2.0	1.01	556	36.7	40.7	91.5	89.6	81.7	93.8	93.9	
79/244	2.0	1.46	557	36.6	34.7	92.6	98.6	99.1	102.2	96.3	
79/244	2.0	1.46	558	36.8	35.3	92.6	99.5	92.1	101.1	101.3	
79/245	2.0	1.42	559	36.4	36.0	92.1	100.0	92.0	100.7	100.7	
79/245	2.0	1.38	560	36.4	36.0	92.1	99.1	91.1	100.2	100.3	
79/245	2.0	1.46	561	36.7	36.0	92.1	96.6	89.2	98.3	98.3	
79/245	2.0	1.46	562	36.4	38.0	91.5	102.5	92.5	104.5	104.3	
79/245	2.0	1.46	563	36.5	37.3	92.6	99.3	92.1	102.9	101.1	
79/245	2.0	1.45	564	37.2	37.7	91.0	100.7	91.9	102.5	63.9	
79/246	2.0	1.49	565	36.5	37.3	90.1	99.3	89.1	103.0	100.0	
79/246	2.0	1.49	566	36.9	37.7	90.1	98.0	88.2	100.7	98.4	
79/246	2.0	1.44	567	37.2	37.7	91.0	98.4	89.2	102.0	99.8	
79/246	2.0	1.45	568	37.3	37.0	91.0	96.4	87.4	99.1	96.7	
79/246	2.0	1.39	569	37.2	38.7	91.0	99.1	90.1	100.7	99.6	
79/246	2.0	1.44	570	37.2	38.7	91.5	101.3	91.9	103.7	102.5	
79/247	2.0	1.43	571	37.0	38.7	91.5	101.6	92.6	102.9	102.0	
79/247	2.0	1.45	572	36.8	38.7	91.0	97.1	88.3	100.0	97.5	
79/247	2.0	1.47	573	36.8	38.7	91.0	100.5	91.0	103.3	5.4	
79/247	2.0	1.64	574	37.4	38.7	90.1	100.0	90.0	101.6	5.1	
79/248	2.0	1.82	575	36.7	37.0	92.1	95.7	88.3	496.1	93.0	
79/249	2.0	1.46	580	36.8	36.7	90.4	86.2	77.4	93.0	96.0	
79/249	2.0	1.48	581	36.7	36.7	90.4	94.8	85.5	96.4	96.4	
79/249	2.0	1.46	582	36.7	37.0	91.5	88.6	81.0	94.3	91.1	
79/249	2.0	1.46	583	34.8	36.7	91.5	111.0	101.0	113.2	110.9	S
79/250	2.0	1.44	589	35.9	36.7	89.9	99.3	82.8	103.9	99.0	
79/250	2.0	1.47	590	37.9	36.0	90.4	87.5	78.3	98.4	90.0	
79/251	2.0	1.46	591	35.8	36.7	88.9	87.7	78.3	90.5	88.4	
79/251	2.0	1.44	592	36.2	39.0	88.9	87.3	77.4	92.5	90.3	
79/251	2.0	1.47	593	35.9	38.3	88.9	84.2	74.8	90.3	91.0	
79/251	2.0	1.44	594	35.7	38.3	90.4	90.4	81.6	95.6	93.2	
79/251	2.0	1.45	595	36.9	38.3	91.5	92.1	83.7	100.9	98.3	
79/251	2.0	1.31	596	37.4	38.3	90.4	94.2	84.6	98.4	94.2	
79/251	2.0	1.44	597	37.2	38.3	90.4	90.6	81.9	96.8	91.5	
79/252	2.0	1.46	600	37.1	37.0	91.0	97.8	89.2	99.3	96.0	
79/252	2.0	1.48	601	39.3	37.0	92.6	114.1	105.9	117.3	112.0	D
79/252	2.0	1.42	602	37.6	36.3	91.5	97.1	85.3	98.8	97.3	
79/253	2.0	1.43	603	37.5	36.7	91.5	95.3	86.4	98.7	95.3	
79/253	2.0	1.41	604	37.1	36.7	91.5	89.2	81.0	94.7	93.2	
79/253	2.0	1.46	605	37.4	36.7	91.5	96.8	88.3	99.7	97.7	
79/253	2.0	1.46	607	36.7	36.3	92.6	98.0	91.1	98.6	98.5	
79/253	2.0	1.46	608	35.7	35.7	92.6	98.9	92.1	99.5	99.5	
79/254	2.0	1.41	609	37.2	36.7	92.6	97.5	90.2	98.2	98.2	
79/254	2.0	1.43	610	36.9	36.7	91.5	96.4	88.8	98.8	98.3	
79/254	2.0	1.44	611	36.7	36.7	92.6	98.6	91.1	99.1	98.1	

DATE	C.T. HRS	C.P. E	CYCLE NO.	+ C.D. MA/CM2	- C.D.	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %	
79/254	2.0	1.46	612	37.0	37.0	91.5	96.9	91.1	98.6	98.6	
79/254	2.0	1.48	613	37.1	37.0	90.6	97.3	90.2	97.8	97.8	
79/254	2.0	1.44	614	37.2	36.7	92.3	97.3	90.2	97.8	97.8	
79/255	2.0	1.46	615	36.7	36.7	92.6	97.8	91.1	99.1	99.1	
79/255	2.0	1.46	616	36.7	37.0	92.3	96.9	93.3	98.6	98.3	
79/255	2.0	1.43	617	36.9	37.3	91.5	95.1	87.5	98.6	98.3	
79/255	2.0	1.47	618	27.7	0.0	92.7	94.4	88.2	100.0	97.5	
79/255	2.0	1.46	619	36.5	37.0	91.5	94.9	87.4	97.5	97.3	
79/256	2.0	1.40	620	36.3	37.7	91.5	96.1	88.3	97.5	97.5	
79/256	2.0	1.48	621	36.2	36.9	91.6	95.1	90.2	98.4	96.8	
79/256	2.0	1.42	622	36.2	35.7	92.6	93.3	86.5	98.4	93.8	
79/256	2.0	1.46	623	36.0	36.3	91.5	96.1	87.4	98.1	98.1	
79/256	2.0	1.44	624	35.4	37.7	91.5	95.5	86.4	96.7	96.7	
79/256	2.0	1.40	625	35.6	36.9	91.5	97.1	88.3	97.9	97.9	
79/257	2.0	1.34	626	35.6	38.3	91.5	97.1	88.3	97.7	97.7	
79/257	2.0	1.30	627	35.7	38.7	91.5	97.1	88.2	98.5	98.5	
79/257	2.0	1.44	628	36.4	36.7	91.5	97.1	89.2	98.4	98.4	
79/257	2.0	1.44	629	35.9	36.3	91.5	96.9	88.4	98.1	98.1	
79/257	2.0	1.46	630	36.0	36.7	91.0	95.4	86.4	97.7	97.7	
79/257	2.0	1.48	631	36.2	36.5	91.5	95.5	87.4	97.7	97.7	
79/257	2.0	1.46	632	36.2	40.0	91.5	97.3	86.4	97.7	97.7	
79/258	2.0	1.44	633	36.2	39.3	91.5	97.1	87.4	96.8	96.8	
79/258	2.0	1.46	634	36.2	39.0	91.5	99.1	90.1	100.2	100.2	
79/258	2.0	1.48	635	36.1	39.6	90.4	94.9	85.5	98.8	98.8	
79/258	2.0	1.48	636	36.2	39.0	91.5	101.1	91.9	102.5	102.5	
79/258	2.0	1.46	637	36.2	39.5	91.5	97.5	88.3	98.6	98.6	
79/258	2.0	1.48	638	36.2	39.4	91.0	97.3	88.5	98.2	98.2	
79/259	2.0	1.48	639	36.0	38.7	90.4	94.3	85.5	96.8	96.8	
79/259	2.0	1.46	640	36.0	39.3	91.0	97.0	88.3	98.1	98.1	
79/259	2.0	1.44	641	35.9	40.6	91.6	95.6	86.4	96.5	96.3	
79/259	2.0	1.46	642	36.0	40.1	91.5	98.8	89.2	100.2	100.2	
79/259	2.0	1.46	643	36.3	40.0	91.0	97.3	88.3	99.1	99.1	
79/260	2.0	1.48	651	36.3	40.4	90.6	97.1	90.2	100.0	100.0	
79/260	2.0	1.44	652	36.3	40.4	91.5	99.6	90.1	100.5	100.5	
79/261	2.0	1.44	653	36.2	40.2	91.5	97.1	88.1	99.8	99.8	
79/261	2.0	1.42	654	36.3	40.1	91.5	98.1	89.2	99.3	99.3	
79/261	2.0	1.46	655	36.3	39.4	92.6	95.8	90.2	97.7	97.7	
79/263	2.0	1.44	668	36.4	40.2	91.5	98.3	89.7	98.8	98.8	
79/264	2.0	1.46	673	36.2	39.8	91.0	100.1	91.0	102.9	101.4	
79/264	2.0	1.48	674	36.2	39.3	91.0	95.5	87.4	97.5	97.5	
79/264	2.0	1.45	675	36.2	39.1	91.0	83.8	75.5	102.5	83.4	
79/265	2.0	1.33	676	36.2	40.1	91.0	78.9	66.4	99.5	72.9	S
79/265	2.0	1.41	677	36.2	40.0	92.1	78.6	72.7	99.3	78.6	S
79/265	2.0	1.46	678	36.2	39.9	92.1	82.5	75.4	99.3	82.7	
79/265	2.0	1.45	679	36.2	39.6	92.1	97.5	89.2	98.6	98.6	
79/265	2.0	1.46	680	36.2	39.6	92.1	96.3	88.3	98.6	98.6	
79/265	2.0	1.43	681	36.3	39.7	92.1	87.4	80.0	98.4	87.6	
79/267	2.0	1.48	691	36.3	37.8	93.1	102.8	95.8	103.2	103.7	S
79/267	2.0	1.82	692	36.3	35.9	91.1	96.8	87.4	96.9	96.3	
79/267	2.0	1.46	693	36.4	37.8	92.1	88.1	81.0	101.7	88.6	
79/268	2.0	1.46	694	36.4	39.4	92.1	91.5	74.5	97.9	91.7	S

DATE	C.T. HRS	C.P. E	CYCLE NO.	+ C.D. MA/CM2	- C.D.	VOLT EFF %	COUL EFF %	ENERGY EFF %	ZN EFF %	FE EFF %
79/268	2.0	1.42	695	36.4	38.1	92.1	87.9	81.0	94.1	88.3
79/268	2.0	1.44	696	36.3	37.4	93.1	99.8	93.0	103.0	100.2
79/268	2.0	1.46	697	36.5	36.6	92.1	94.7	87.4	180.2	95.2
79/268	2.0	1.46	698	36.4	35.6	92.1	100.0	92.0	182.7	102.7
STATISTICAL MEAN				36.3	36.0	91.0	92.3	83.9		
STANDARD DEVIATION				9.3	3.5	2.0	9.5	9.2		

CELL UNDER TEST (6)

CM #	CP	ZP 30 MIN	FP	CP END	CP OCV	CP	ZP 30 MIN	FP	CP	ZP USABLE	FP	CP ZN	CP OCV
1	1.88	1.45	.43	1.88	1.82	1.74	1.31	.43	1.41	1.27	.14	.80	1.62
2	1.89	1.46	.43	1.91	1.80	1.72	1.29	.43	1.46	1.23	.23	.96	1.74
3	1.88	1.45	.43	1.91	1.82	1.76	1.33	.43	1.54	1.25	.29	.80	1.74
4	1.89	1.46	.43	1.91	1.82	1.78	1.33	.45	1.33	1.33	0.00	.76	.37
5	2.33	1.88	.45	2.32	1.84	1.54	1.54	0.00	1.54	1.54	0.00	0.00	.63
6	2.24	1.48	.76	2.19	1.91	1.25	1.25	0.00	1.25	1.25	0.00	.74	.18
7	1.80	1.41	.39	1.89	1.80	1.74	1.31	.43	1.47	1.43	.04	.80	1.56
8	1.89	1.46	.43	1.89	1.80	1.76	1.31	.45	1.31	1.21	.10	.80	1.74
9	1.90	1.45	.45	1.89	1.82	1.74	1.31	.43	1.29	1.29	0.00	.74	1.64
10	1.90	1.45	.45	1.89	1.80	1.74	1.31	.43	1.46	1.25	.21	.78	1.70
11	1.98	1.43	.55	2.91	1.80	1.70	1.25	.45	1.50	1.27	.23	.80	1.76
12	1.93	1.46	.47	1.91	1.82	1.74	1.29	.45	1.45	1.27	.18	.80	1.72
13	1.97	1.46	.51	1.89	1.80	1.72	1.31	.41	1.45	1.25	.20	.76	1.74
14	1.93	1.46	.47	1.89	1.82	1.74	1.31	.43	1.44	1.23	.21	.80	1.72
15	1.90	1.45	.45	1.89	1.82	1.76	1.35	.41	1.56	1.29	.27	.80	1.70
16	1.93	1.46	.47	1.91	1.82	1.76	1.33	.43	1.46	1.25	.21	.80	1.70
17	2.11	1.48	.63	1.91	1.82	1.72	1.31	.41	1.51	1.33	.18	.76	1.76
18	1.94	1.45	.49	1.89	1.82	1.74	1.31	.43	1.46	1.21	.25	.80	1.72
19	1.91	1.48	.43	1.91	1.82	1.78	1.35	.43	2.42	2.42	0.00	0.00	1.11
20	1.90	1.86	.04	1.88	1.80	1.70	1.37	.33	1.41	1.02	.39	1.17	1.35
21	1.88	1.45	.43	1.88	1.80	1.68	1.33	.35	1.42	1.05	.37	1.17	1.35
22	1.89	1.43	.43	1.86	1.80	1.72	1.33	.39	1.44	1.19	.25	.76	1.70
23	1.92	1.45	.47	1.88	1.80	1.70	1.31	.39	1.47	1.31	.16	.80	1.74
24	1.88	1.45	.43	1.89	1.82	1.72	1.31	.41	1.43	1.23	.20	.76	1.72
25	1.95	1.45	.51	1.88	1.80	1.74	1.31	.43	1.44	1.11	.33	.88	1.74
26	1.88	1.43	.45	1.91	1.82	1.72	1.31	.41	1.46	1.19	.27	.78	1.74
27	1.92	1.45	.47	2.66	1.72	1.66	1.27	.39	1.40	1.05	.35	1.05	1.37
28	1.93	1.46	.47	2.79	1.80	1.70	1.31	.39	1.35	1.21	.14	.76	1.72
29	1.90	1.45	.45	1.91	1.82	1.74	1.33	.41	1.29	1.29	0.00	.72	1.74
30	1.99	1.46	.53	1.93	1.82	1.68	1.29	.39	1.43	1.27	.16	.80	.68
31	1.97	1.46	.51	1.93	1.82	1.76	1.31	.45	1.46	1.25	.21	.80	.55
32	1.94	1.45	.49	1.97	1.84	1.74	1.31	.43	1.35	1.25	.10	.80	.76
33	1.94	1.45	.49	1.99	1.86	1.74	1.31	.43	1.43	1.00	.43	1.21	1.64
34	1.93	1.43	.49	1.97	1.84	1.76	1.33	.43	1.46	1.05	.41	1.19	1.37
35	1.92	1.45	.47	1.97	1.84	1.74	1.31	.43	1.44	1.05	.39	1.17	1.37
36	1.94	1.45	.49	1.97	1.84	1.76	1.33	.43	1.43	1.25	.18	.78	.64
37	1.92	1.41	.51	1.97	1.86	1.76	1.31	.45	1.27	1.27	0.00	.80	.68
38	1.94	1.43	.51	1.97	1.86	1.74	1.29	.45	1.48	1.23	.25	.80	1.35
39	1.94	1.45	.49	1.97	1.86	1.76	1.31	.45	1.43	1.02	.41	1.15	1.56
40	1.92	1.45	.47	1.97	1.86	1.78	1.33	.45	1.41	1.00	.41	1.19	1.46
41	1.96	1.43	.53	1.97	1.86	1.78	1.33	.45	1.47	1.04	.43	1.19	1.39
42	1.92	1.49	.43	1.93	1.82	1.72	1.29	.43	1.35	.92	.43	1.19	1.39
43	1.94	1.45	.49	1.97	1.86	1.74	1.31	.43	1.44	1.21	.23	.74	.82
44	1.94	1.45	.49	1.97	1.86	1.76	1.31	.45	1.44	1.21	.23	.80	1.76
45	1.86	1.39	.47	1.91	1.84	1.76	1.31	.45	1.47	1.02	.45	1.13	1.41
47	1.94	1.43	.49	1.82	1.82	1.82	1.37	.45	1.33	.90	.43	1.23	1.37
48	1.90	1.41	.49	1.91	1.84	1.76	1.35	.41	1.48	1.05	.43	1.11	1.41
49	1.86	1.39	.47	1.93	1.82	1.72	1.31	.41	1.39	.94	.45	1.05	1.37
50	1.92	1.43	.49	1.93	1.84	1.86	1.39	.47	1.37	1.27	.10	.78	.61

CELL UNDER TEST (6)

CN #	CP	ZP	FP	CP	CP	CP	ZP	FP	CP	ZP	FP	CP	CP
	30 MIN			END	OCV	30 MIN			USABLE			ZR	OCV
51	1.84	1.39	.45	1.91	1.82	1.70	1.27	.43	1.43	1.04	.39	1.11	1.26
52	1.94	1.45	.49	1.97	1.86	1.76	1.33	.43	1.41	1.00	.41	1.13	1.41
53	1.92	1.45	.47	1.95	1.84	1.74	1.33	.41	1.44	1.21	.23	.76	.65
54	1.94	1.45	.49	2.52	1.84	1.70	1.31	.39	1.44	1.17	.27	.80	1.78
55	1.94	1.45	.49	1.99	1.86	1.74	1.31	.43	1.43	1.23	.20	.78	.61
56	1.96	1.45	.51	1.97	1.88	1.78	1.33	.45	1.27	1.27	0.00	0.00	0.00
57	1.97	1.89	.08	1.97	1.86	1.76	1.56	.20	1.38	1.05	.33	1.03	1.78
58	1.97	1.54	.43	1.97	1.86	1.76	1.33	.43	1.52	1.05	.47	1.17	1.76
59	1.95	1.46	.49	1.95	1.86	1.76	1.33	.43	1.47	1.04	.43	1.15	1.41
60	1.95	1.46	.49	1.95	1.86	1.78	1.33	.45	1.46	1.05	.41	1.17	1.43
61	1.97	1.46	.51	1.97	1.88	1.76	1.33	.43	1.23	1.23	0.00	.80	.43
62	1.95	1.46	.49	1.97	1.88	1.78	1.33	.45	1.33	1.15	.18	.80	.41
63	1.94	1.45	.49	1.97	1.88	1.78	1.33	.45	1.47	1.04	.43	1.13	1.43
64	1.95	1.46	.49	1.97	1.88	1.78	1.33	.45	1.47	1.04	.43	1.19	1.72
65	1.94	1.45	.49	1.95	1.86	1.78	1.33	.45	1.47	1.04	.43	1.23	1.66
66	1.94	1.45	.49	1.95	1.86	1.78	1.33	.45	1.47	1.04	.43	1.17	1.43
67	1.94	1.45	.49	1.97	1.88	1.76	1.31	.45	1.27	1.27	0.00	.80	.55
68	1.96	1.45	.51	1.97	1.88	1.78	1.33	.45	1.27	1.25	.02	.80	.41
69	1.96	1.45	.51	1.97	1.88	1.78	1.33	.45	1.47	1.04	.43	1.17	1.84
70	1.94	1.45	.49	1.99	1.88	1.80	1.33	.47	1.49	1.04	.45	1.21	1.87
71	1.96	1.45	.51	1.95	1.86	1.78	1.33	.45	1.45	1.02	.43	1.23	1.81
72	1.94	1.45	.49	1.95	1.86	1.78	1.33	.45	1.47	1.04	.43	1.17	1.43
73	1.95	1.46	.49	1.97	1.88	1.76	1.33	.43	1.38	1.17	.21	.78	.63
74	1.98	1.45	.53	1.97	1.86	1.76	1.33	.43	1.48	1.23	.25	.78	.40
75	1.95	1.46	.49	1.97	1.88	1.74	1.33	.41	1.46	1.15	.31	.78	1.58
76	1.97	1.46	.51	1.97	1.88	1.76	1.31	.45	1.41	.98	.43	1.11	1.70
77	1.97	1.46	.51	1.97	1.88	1.76	1.31	.45	1.47	1.04	.43	1.13	1.70
78	1.97	1.46	.51	1.99	1.88	1.76	1.31	.45	1.44	1.19	.25	.80	.70
79	1.96	1.45	.51	1.99	1.86	1.76	1.31	.45	1.45	1.25	.20	.80	.43
80	1.97	1.46	.51	2.01	1.88	1.76	1.31	.45	1.44	1.11	.33	.78	1.11
81	1.97	1.46	.51	1.99	1.88	1.78	1.33	.45	1.47	1.04	.43	1.19	1.72
82	1.96	1.45	.51	1.99	1.88	1.76	1.31	.45	1.45	1.02	.43	1.21	1.66
83	1.96	1.45	.51	1.97	1.88	1.76	1.31	.45	1.47	1.04	.43	1.19	1.85
84	1.96	1.45	.51	1.97	1.88	1.78	1.33	.45	1.47	1.04	.43	1.21	1.87
85	1.97	1.46	.51	1.99	1.88	1.78	1.31	.47	1.31	1.31	0.00	.78	.61
86	1.96	1.45	.51	1.99	1.88	1.76	1.31	.45	1.33	1.27	.06	.80	.39
87	1.96	1.45	.51	1.97	1.86	1.78	1.33	.45	1.33	1.15	.18	.80	1.25
88	1.97	1.46	.51	1.97	1.86	1.76	1.31	.45	1.48	1.07	.41	.88	1.69
89	1.96	1.45	.51	1.95	1.86	1.76	1.31	.45	1.45	1.02	.43	1.23	1.79
90	1.96	1.45	.51	1.97	1.86	1.76	1.31	.45	1.25	1.23	.02	.80	.47
91	1.96	1.45	.51	2.13	2.03	1.78	1.33	.45	1.27	1.27	0.00	.80	.65
92	1.96	1.45	.51	1.97	1.86	1.78	1.33	.45	1.42	1.17	.25	.80	.61
93	1.97	1.46	.51	1.97	1.86	1.78	1.33	.45	1.31	1.31	0.00	.80	.35
94	1.94	1.43	.51	1.97	1.86	1.78	1.33	.45	1.47	1.04	.43	1.21	1.80
95	1.96	1.45	.51	1.97	1.86	1.78	1.33	.45	1.45	1.04	.41	1.23	1.43
96	1.96	1.45	.51	1.95	1.86	1.78	1.33	.45	1.47	1.02	.45	1.23	1.43
97	1.97	1.46	.51	1.95	1.86	1.78	1.33	.45	1.44	1.07	.37	.76	1.52
98	1.96	1.45	.51	1.95	1.86	1.76	1.31	.45	1.46	1.25	.21	.80	.43
99	1.96	1.45	.51	1.97	1.86	1.80	1.33	.47	1.49	1.04	.45	1.23	1.72

CELL UNDER TEST (6)

CN #	CP	ZP	FP	CP	CP	CP	ZP	FP	CP	ZP	FP	CP	CP
	30 MIN			END	OCV	30 MIN			USABLE			ZN	OCV
100	1.96	1.45	.51	1.97	1.86	1.78	1.33	.45	1.45	1.00	.45	1.23	1.54
101	1.96	1.45	.51	1.97	1.86	1.78	1.33	.45	1.47	1.04	.43	1.19	1.39
102	1.94	1.43	.51	1.95	1.86	1.78	1.33	.45	1.45	1.02	.43	1.17	1.41
103	1.96	1.45	.51	1.97	1.86	1.78	1.33	.45	1.41	1.25	.16	.80	.39
104	1.96	1.45	.51	1.97	1.86	1.78	1.33	.45	1.48	1.27	.21	.80	.45
105	1.96	1.45	.51	1.97	1.88	1.78	1.33	.45	1.45	1.02	.43	1.13	1.41
106	1.96	1.45	.51	1.95	1.88	1.78	1.33	.45	1.43	1.00	.43	1.19	1.39
107	1.94	1.45	.49	1.95	1.86	1.78	1.33	.45	1.43	1.00	.43	1.23	1.41
108	1.94	1.43	.51	1.95	1.86	1.76	1.31	.45	1.47	1.04	.43	1.19	1.41
109	1.94	1.43	.51	1.97	1.88	1.76	1.31	.45	1.44	1.07	.37	.78	1.45
110	1.96	1.45	.51	1.95	1.86	1.76	1.31	.45	1.46	1.09	.37	.76	1.70
111	1.96	1.45	.51	1.95	1.86	2.56	2.56	0.00	0.00	0.00	0.00	1.78	1.84
112	2.44	2.44	0.00	1.99	1.88	0.00	0.00	0.00	0.00	0.00	0.00	1.78	1.88
113	2.01	1.89	.12	2.01	1.89	1.78	1.74	.04	1.68	1.68	0.00	.80	.41
114	1.96	1.88	.08	1.93	1.84	1.74	1.72	.02	1.68	1.68	0.00	.80	.33
115	1.96	1.88	.08	1.95	1.84	1.76	1.72	.04	1.66	1.66	0.00	.72	.41
117	1.95	1.70	.25	1.95	1.86	1.76	1.74	.02	1.41	1.37	.04	.74	1.60
118	2.07	1.95	.12	1.97	1.84	2.21	1.70	.51	1.76	1.43	.33	.80	0.00
119	1.96	1.86	.10	1.95	1.84	2.13	1.68	.45	1.83	1.50	.33	.68	.37
120	2.45	1.88	.57	1.95	1.84	2.17	1.70	.47	1.68	1.56	.12	.72	.33
121	2.35	1.88	.47	1.95	1.84	2.09	1.72	.37	1.64	1.58	.06	.80	.21
122	1.98	1.88	.10	1.95	1.84	1.76	1.72	.04	1.41	1.39	.02	0.00	1.39
123	1.96	1.86	.10	2.29	1.88	1.72	1.72	0.00	1.50	1.50	0.00	.80	1.76
124	1.98	1.88	.10	1.97	1.86	1.76	1.72	.04	1.57	1.41	.16	0.00	1.70
125	2.15	1.86	.29	1.95	1.84	1.76	1.72	.04	1.56	1.46	.10	.78	1.72
126	1.98	1.84	.14	1.95	1.84	1.76	1.72	.04	1.62	1.58	.04	.76	.37
127	2.00	1.88	.12	1.97	1.86	1.91	1.66	.25	1.62	1.48	.14	.80	.37
169	2.01	1.46	.55	1.97	1.86	1.74	1.31	.43	1.41	1.23	.18	.80	.45
170	2.04	1.45	.59	1.97	1.86	1.74	1.31	.43	1.46	1.05	.41	9.11	1.66
171	1.96	1.45	.51	1.95	1.84	1.74	1.31	.43	1.46	1.13	.33	.80	.43
172	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.38	1.15	.23	.78	.45
173	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.38	1.15	.23	.80	.43
174	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.42	1.11	.31	.80	.39
175	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.44	1.15	.29	.80	.45
176	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.46	1.05	.41	1.05	1.68
177	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.46	1.13	.33	.78	.41
178	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.36	1.13	.23	.80	.47
179	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.38	1.17	.21	.80	.47
180	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.46	1.17	.29	.78	.41
181	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.46	1.19	.27	.78	.43
182	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.46	1.07	.39	1.05	1.70
183	1.96	1.45	.51	1.97	1.84	1.74	1.31	.43	1.46	1.09	.37	.64	1.68
184	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.38	1.15	.23	.80	.41
185	1.96	1.43	.53	1.97	1.84	1.74	1.31	.43	1.44	1.13	.31	.74	.39
186	1.96	1.45	.51	1.97	1.86	1.74	1.31	.43	1.46	1.25	.21	.80	.41
187	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.46	1.13	.33	.78	1.72
188	1.98	1.45	.53	1.97	1.84	1.74	1.31	.43	1.44	1.11	.33	.70	1.68
189	1.96	1.45	.51	1.97	1.84	1.74	1.31	.43	1.42	1.13	.29	.72	1.72
190	1.96	1.45	.51	1.97	1.84	1.74	1.31	.43	1.44	1.17	.27	.80	.47

CN #							ZP	FP	CP	ZP	FP	CP	CP
							30 MIN			USABLE		ZM	OCV
191	1.[illegible]	[illegible]5	.53	1.[illegible]7	[illegible]	[illegible]	.31	.41	1.44	1.15	.29	[illegible]	[illegible]
192	1.[illegible]	[illegible]3	[illegible]	1.97	1.[illegible]	1.[illegible]	.31	.43	1.46	1.23	[illegible]	[illegible]	[illegible]
193	1.[illegible]	1.45	.53	[illegible]	[illegible]	[illegible]	1.31	.43	1.42	1.09	.33	8.78	[illegible]
194	1.98	1.45	.53	[illegible]	[illegible]	1.74	1.31	.43	1.40	1.05	.35	.90	1.78
195	1.99	1.45	.53	1.97	[illegible]	[illegible]	[illegible]	.43	1.48	1.19	.29	.90	.41
196	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.42	1.15	.27	.80	.45
197	1.95	1.46	.53	[illegible]	[illegible]	1.72	1.31	.41	1.42	1.11	.31	.78	.43
198	1.99	1.46	.53	1.97	1.86	1.74	1.31	.43	1.43	1.25	.18	.80	.45
199	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.48	1.11	.37	.94	1.76
200	1.96	1.45	.51	1.97	1.86	1.74	1.31	.43	1.46	1.13	.33	.92	1.76
201	1.98	1.45	.53	1.97	1.84	1.72	1.31	.41	1.46	1.15	.31	.80	1.76
202	1.98	1.45	.53	1.97	1.86	1.72	1.31	.41	1.48	1.21	.27	.90	.45
203	1.99	1.45	.53	1.97	1.86	1.72	1.31	.41	1.47	1.27	.20	.80	.45
204	1.98	1.45	.53	1.97	1.86	1.74	1.31	.43	1.44	1.13	.31	.80	.43
205	2.07	1.48	.57	2.07	1.91	.00	0.00	0.00	1.23	1.23	0.00	.78	.41
207	1.98	[illegible]3	[illegible]	2.01	[illegible]	1.76	1.31	.45	1.40	1.13	.27	.82	1.76
208	1.96	1.45	.51	1.95	1.86	1.76	1.31	.45	1.31	1.31	0.00	.78	.41
209	1.98	1.45	.53	[illegible]	[illegible]	.76	1.31	.45	1.29	1.29	0.00	.80	.41
210	2.00	[illegible]5	.55	1.99	[illegible]	[illegible]	1.31	.45	1.33	1.33	0.00	.80	.41
211	2.00	1.45	.55	1.97	1.84	1.76	1.31	.45	1.43	1.29	.14	.80	.45
217	3.22	[illegible]3	2.[illegible]	3.20	[illegible]	[illegible]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
222	1.99	[illegible]6	.53	1.93	1.84	[illegible]	1.31	.51	1.51	1.04	.47	1.23	[illegible]
223	2.[illegible]	[illegible]3	[illegible]	[illegible]	[illegible]	[illegible]	.29	.51	[illegible]	1.00	.47	1.25	1.72
224	1.[illegible]	[illegible]	[illegible]	2.[illegible]	[illegible]	[illegible]	.29	.51	[illegible]	1.02	.51	[illegible]	1.74
225	2.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.31	.53	[illegible]	1.02	.47	[illegible]	1.68
226	2.[illegible]	[illegible]	.53	1.99	[illegible]	[illegible]	1.31	.53	1.51	1.02	.49	1.29	1.70
227	2.[illegible]	.48	.53	[illegible]	[illegible]	[illegible]	1.31	.51	1.51	[illegible]	.49	1.25	[illegible]
228	2.01	1.48	[illegible]	1.97	[illegible]	[illegible]	1.29	.45	[illegible]	1.02	.47	[illegible]	1.43
229	1.99	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.31	.49	[illegible]	1.03	.47	[illegible]	[illegible]
230	2.07	1.52	.59	[illegible]	[illegible]	[illegible]	1.31	.55	[illegible]	1.05	.43	[illegible]	[illegible]
231	2.11	[illegible]	[illegible]	2.[illegible]	[illegible]	[illegible]	1.31	.53	1.49	1.04	.45	[illegible]	[illegible]
232	2.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.31	.53	1.49	[illegible]	.45	[illegible]	[illegible]
233	2.03	[illegible]	.53	1.97	[illegible]	[illegible]	1.31	.51	[illegible]	[illegible]	.41	[illegible]	[illegible]
234	2.09	[illegible]	[illegible]3	[illegible]	[illegible]	[illegible]	1.31	.51	[illegible]	1.02	.45	[illegible]	[illegible]
235	2.01	[illegible]	.49	[illegible]	[illegible]	[illegible]	1.31	.47	1.49	1.04	.45	[illegible]	[illegible]
236	2.01	[illegible]	.49	[illegible]	[illegible]	[illegible]	1.31	.47	[illegible]	[illegible]	.43	[illegible]	[illegible]
237	[illegible]	[illegible]	.47	[illegible]	[illegible]	[illegible]	[illegible]	.47	[illegible]	[illegible]	.47	[illegible]	[illegible]
238	[illegible]	[illegible]	.49	[illegible]	[illegible]	[illegible]	[illegible]	.49	[illegible]	.84	.47	[illegible]	[illegible]
239	[illegible]	[illegible]	.49	[illegible]	[illegible]	[illegible]	0.00	0.00	[illegible]	.84	.47	[illegible]	[illegible]
230	2.01	[illegible]	.51	[illegible]	[illegible]	[illegible]	1.31	.47	[illegible]	[illegible]	.43	[illegible]	[illegible]
241	2.03	[illegible]	.51	[illegible]	[illegible]	[illegible]	1.31	.49	[illegible]	[illegible]	.45	[illegible]	[illegible]
242	2.01	[illegible]	.51	[illegible]	[illegible]	[illegible]	1.31	.47	[illegible]	[illegible]	.43	[illegible]	[illegible]
243	2.01	[illegible]	.49	[illegible]	[illegible]	[illegible]	1.31	.45	[illegible]	[illegible]	.43	[illegible]	[illegible]
244	2.[illegible]	[illegible]	.47	[illegible]	[illegible]	[illegible]	1.31	.47	[illegible]	[illegible]	.43	[illegible]	[illegible]
245	2.03	[illegible]	.51	[illegible]	[illegible]	[illegible]	1.31	.49	[illegible]	[illegible]	.43	[illegible]	[illegible]
246	2.03	[illegible]	.51	[illegible]	[illegible]	[illegible]	1.31	.49	[illegible]	[illegible]	.45	[illegible]	[illegible]
247	2.03	[illegible]	.49	[illegible]	[illegible]	[illegible]	1.31	.47	[illegible]	[illegible]	.43	[illegible]	[illegible]
248	[illegible]	[illegible]	.47	[illegible]	[illegible]	[illegible]	1.31	.49	[illegible]	[illegible]	.43	[illegible]	[illegible]
249	2.01	[illegible]	.47	1.91	[illegible]	1.78	1.31	.47	1.47	[illegible]	.43	1.17	[illegible]

CELL UNDER TEST (6)

CN #	CP	ZP	FP	CP	CP	CP	ZP	FP	CP	ZP	FP	CP	CP
	30 MIN			END	OCV	30 MIN			USABLE			20	OCV
250	2.03	1.54	.49	1.93	1.86	1.80	1.31	.49	1.47	1.04	.43	1.21	1.43
251	2.01	1.52	.49	1.95	1.86	1.78	1.31	.47	1.43	1.00	.43	1.15	1.41
252	2.05	1.54	.51	1.93	1.86	1.80	1.31	.49	1.47	1.04	.43	1.17	1.41
253	1.99	1.50	.49	1.93	1.86	1.80	1.31	.49	1.48	1.05	.43	1.19	1.43
254	1.97	1.48	.49	1.93	1.86	2.15	1.58	.57	1.45	1.02	.43	1.15	1.41
255	1.99	1.50	.49	1.93	1.86	1.80	1.31	.49	1.39	.96	.43	1.21	1.78
256	1.88	1.39	.49	1.95	1.86	1.80	1.35	.45	1.33	.98	.35	1.11	1.78
257	1.94	1.45	.49	1.95	1.88	1.68	1.31	.47	1.47	1.04	.43	1.19	1.45
258	1.95	1.46	.49	1.97	1.88	1.78	1.31	.47	1.47	1.04	.43	1.21	1.50
259	1.97	1.50	.47	1.93	1.86	1.78	1.31	.47	1.47	1.04	.43	1.21	1.43
260	1.97	1.48	.49	1.93	1.86	1.78	1.31	.47	1.43	1.00	.43	1.17	1.43
261	1.99	1.50	.49	1.93	1.86	1.78	1.31	.47	1.47	1.04	.43	1.15	1.43
262	1.99	1.50	.49	1.95	1.86	1.78	1.31	.47	1.46	1.05	.41	1.11	1.43
263	2.03	1.52	.51	1.95	1.88	1.80	1.37	.43	1.45	1.09	.37	1.09	1.43
264	1.99	1.52	.47	1.95	1.88	1.78	1.31	.47	1.47	1.04	.43	1.11	1.43
265	1.98	1.46	.49	1.93	1.86	1.78	1.31	.47	1.47	1.04	.43	1.15	1.43
266	1.95	1.46	.49	1.95	1.86	1.78	1.31	.47	1.41	1.04	.43	1.15	1.43
267	1.97	1.52	.45	1.95	1.86	1.78	1.33	.45	1.48	1.07	.41	1.11	1.50
268	1.99	1.52	.47	1.95	1.86	1.76	1.37	.39	1.46	1.09	.37	1.07	1.43
269	1.99	1.52	.47	1.99	1.85	1.74	1.29	.45	1.46	1.05	.41	1.13	1.64
270	1.97	1.48	.49	1.93	1.84	1.78	1.31	.47	1.43	1.02	.41	1.19	1.39
271	1.87	1.46	.41	1.91	1.84	1.80	1.33	.47	1.45	1.02	.43	1.13	1.39
272	1.95	1.48	.47	1.93	1.84	1.78	1.31	.47	1.47	1.02	.45	1.23	1.39
273	1.95	1.48	.47	1.93	1.84	1.78	1.31	.47	1.47	1.04	.43	1.21	1.39
274	1.97	1.48	.49	1.91	1.84	1.78	1.35	.43	1.45	1.02	.43	1.19	1.39
275	1.97	1.52	.45	2.23	2.15	1.78	1.33	.45	1.45	1.02	.43	1.21	1.39
276	1.95	1.48	.47	1.89	1.84	1.80	1.33	.47	1.47	1.04	.45	1.23	1.58
277	1.93	1.46	.47	1.91	1.84	1.80	1.33	.47	1.45	1.00	.45	1.15	1.47
278	1.90	1.43	.47	2.13	1.86	1.63	1.23	.45	1.47	1.04	.43	1.21	1.58
279	2.23	1.75	.49	2.03	1.86	1.74	1.27	.47	1.48	1.05	.43	1.21	1.86
280	2.11	1.62	.49	2.01	1.88	1.70	1.31	.39	1.40	1.07	.41	1.19	1.58
281	1.98	1.52	.47	1.93	1.86	1.78	1.33	.45	1.46	1.07	.39	1.17	1.70
282	1.96	1.48	.47	1.93	1.86	1.82	1.35	.47	1.46	1.05	.41	1.19	1.70
283	1.93	1.48	.47	1.93	1.84	1.80	1.31	.47	1.44	1.05	.39	1.19	1.64
284	1.95	1.46	.47	1.93	1.84	1.80	1.31	.47	1.43	1.04	.41	1.17	1.58
285	1.93	1.43	.51	1.91	1.84	1.80	1.33	.47	1.46	1.05	.41	1.09	1.51
286	1.94	1.45	.49	1.93	1.84	1.78	1.33	.45	1.44	1.05	.39	1.11	1.56
287	1.90	1.43	.47	1.93	1.84	1.76	1.33	.43	1.46	1.19	.27	.98	1.47
288	1.92	1.43	.49	1.95	1.84	1.76	1.31	.43	1.43	1.01	.41	1.19	1.39
289	1.88	1.39	.49	1.91	1.84	1.76	1.31	.43	1.43	1.04	.41	1.05	1.41
290	1.90	1.41	.49	1.91	1.84	1.76	1.31	.43	1.45	1.07	.39	1.13	1.41
291	1.88	1.41	.47	1.91	1.84	1.78	1.31	.45	1.46	1.11	.35	1.09	1.43
292	1.90	1.41	.49	1.91	1.84	1.78	1.31	.45	1.46	1.11	.35	1.09	1.43
293	1.92	1.43	.49	1.91	1.84	1.78	1.33	.45	1.46	1.11	.35	1.03	1.39
294	1.94	1.45	.49	1.93	1.86	1.76	1.33	.43	1.48	1.11	.33	.97	1.56
295	1.97	1.48	.49	1.91	1.84	1.78	1.31	.45	1.48	1.21	.27	.72	1.52

CELL UNDER TEST (6)

CN #	CP	ZP	FP	CP	CP	CP	ZP	FP	CP	ZP	FP	CP	CP
	30 MIN			SNL	OCV	30 MIN			USABLE			ZN	OCV
302	1.97	1.56	.51	1.93	1.86	1.72	1.31	.41	1.45	1.23	.21	.78	1.64
305	1.97	1.56	.53	2.01	1.89	1.78	1.31	.47	1.48	1.13	.35	1.07	1.70
306	1.91	1.46	.45	1.89	1.82	1.75	1.33	.43	1.46	1.13	.33	.93	1.60
307	1.91	1.48	.43	1.89	1.82	1.76	1.33	.43	1.46	1.13	.33	.90	1.50
308	1.91	1.46	.45	1.89	1.82	1.76	1.33	.43	1.48	1.17	.31	.94	1.52
309	1.89	1.46	.43	1.91	1.82	1.74	1.31	.43	1.48	1.17	.31	1.07	1.56
310	1.91	1.46	.45	1.89	1.82	1.76	1.33	.43	1.48	1.13	.35	1.07	1.52
312	1.90	1.45	.45	1.91	1.82	1.74	1.33	.41	1.47	1.27	.20	.74	1.68
313	1.92	1.45	.47	1.95	1.84	1.74	1.31	.43	1.45	1.29	.16	.76	1.68
314	1.92	1.45	.47	1.93	1.84	1.76	1.33	.43	1.47	1.27	.20	.80	1.66
316	1.89	1.58	.31	1.91	1.82	1.71	1.46	.25	1.48	1.46	.02	.74	.31
317	1.89	1.62	.27	1.91	1.82	1.71	1.50	.21	1.47	1.43	.04	.80	1.02
318	1.93	1.48	.45	1.93	1.82	1.74	1.31	.43	1.47	1.27	.20	.78	1.31
319	1.90	1.45	.45	1.93	1.84	1.78	1.33	.45	1.47	1.29	.18	.78	1.52
320	1.90	1.45	.45	1.91	1.84	1.76	1.33	.43	1.47	1.27	.20	.80	1.48
321	1.90	1.45	.45	1.93	1.84	1.74	1.31	.43	1.46	1.15	.31	1.01	1.68
322	1.91	1.46	.45	1.95	1.84	1.74	1.31	.43	1.46	1.21	.25	.86	1.66
323	1.90	1.45	.45	1.93	1.84	1.76	1.33	.43	1.49	1.31	.18	.78	1.62
324	1.90	1.43	.47	1.95	1.84	1.76	1.33	.43	1.45	1.29	.16	.78	1.66
325	1.90	1.43	.47	1.93	1.84	1.78	1.33	.45	1.48	1.19	.29	.74	1.66
326	1.88	1.43	.45	1.91	1.84	1.76	1.33	.43	1.40	1.15	.25	.78	1.64
327	1.88	1.43	.45	1.91	1.82	1.78	1.33	.45	1.31	1.31	0.00	.72	1.50
328	1.90	1.43	.47	1.93	1.84	1.76	1.33	.43	1.43	1.31	.12	.68	1.50
329	1.88	1.43	.45	1.93	1.84	1.78	1.33	.45	1.48	1.19	.27	.68	1.58
330	1.88	1.43	.45	1.93	1.84	1.78	1.33	.45	1.42	1.11	.31	1.09	1.46
331	1.90	1.45	.45	1.95	1.88	1.76	1.33	.43	1.45	1.29	.16	.74	1.58
332	1.88	1.43	.45	1.95	1.86	1.78	1.33	.45	1.47	1.27	.20	.68	1.60
333	1.92	1.45	.47	1.97	1.86	1.76	1.31	.45	1.48	1.13	.35	.76	1.74
334	1.97	1.50	.47	2.01	1.88	1.80	1.33	.39	1.46	1.23	.23	.70	1.82
335	2.03	1.48	.55	1.95	1.86	1.76	1.33	.43	1.33	1.31	.02	.80	.27
336	1.91	1.46	.45	2.03	1.89	1.76	1.31	.45	1.47	1.27	.20	.80	.21
337	1.86	1.43	.43	1.93	1.81	1.74	1.31	.43	1.41	1.33	.08	.80	.20
338	1.97	1.48	.49	2.03	1.89	1.76	1.31	.45	1.47	1.31	.16	.78	.26
340	1.93	1.46	.51	2.03	1.84	1.74	1.31	.43	1.47	1.33	.14	.78	.16
341	2.03	1.50	.53	1.91	1.82	1.72	1.31	.41	1.46	1.31	.00	.80	1.64
342	1.91	1.48	.43	1.91	1.82	1.74	1.31	.41	1.50	1.19	.31	.80	1.68
343	1.83	1.43	.41	1.91	1.82	1.74	1.31	.41	1.48	1.31	.09	.80	1.60
344	1.84	1.46	.45	1.91	1.82	1.72	1.31	.41	1.38	1.25	.13	.80	1.72
345	1.90	1.46	.45	1.91	1.84	1.76	1.33	.43	1.43	1.23	.20	.80	1.70
346	1.90	1.45	.45	1.89	1.79	1.74	1.31	.43	1.48	1.19	.29	.88	1.72
347	1.92	1.45	.47	1.89	1.82	1.76	1.33	.43	1.46	1.19	.27	.92	1.72
348	1.90	1.43	.47	1.89	1.82	1.76	1.33	.43	1.48	1.17	.31	.98	1.72
349	1.92	1.45	.47	1.93	1.86	1.78	1.33	.45	1.48	1.23	.21	.80	1.68
350	1.92	1.45	.47	1.89	1.82	1.74	1.31	.43	1.48	1.21	.27	.86	1.72
351	1.90	1.45	.45	1.89	1.82	1.76	1.33	.43	1.42	1.13	.29	8.86	1.72
352	1.90	1.45	.45	1.89	1.82	1.76	1.33	.43	1.44	1.13	.31	.98	1.72
353	1.90	1.45	.45	1.89	1.82	1.76	1.33	.43	1.46	1.19	.27	.74	1.68
354	1.90	1.45	.45	1.89	1.82	1.76	1.33	.43	1.46	1.17	.29	.82	1.70
355	1.90	1.45	.45	1.89	1.82	1.78	1.35	.43	1.46	1.21	.25	.74	1.70

CELL UNDER TEST (6)

CN #	CP	ZP	FP	CP END	CP OCV	RP	ZP	FP	CP	ZP	FP	CP 2M	CP OCV
	30 MIN					30 MIN			VSABLE				
356	1.88	1.43	.45	1.89	1.82	1.76	1.32	.43	1.47	1.25	.12	.80	1.66
357	1.92	1.45	.47	1.89	1.82	1.80	1.35	.45	1.42	1.17	.25	.76	1.71
358	1.92	1.45	.47	1.89	1.82	1.78	1.33	.45	1.46	1.25	.21	.80	1.74
359	1.90	1.43	.47	1.89	1.82	1.76	1.33	.43	1.39	1.21	.18	.74	1.70
360	1.90	1.43	.47	1.89	1.82	1.76	1.33	.43	1.45	1.31	.14	.78	1.62
361	1.92	1.45	.47	1.89	1.82	1.76	1.33	.43	1.49	1.33	.16	.80	1.64
362	1.92	1.45	.47	1.89	1.82	1.78	1.33	.45	1.43	1.29	.14	.80	1.60
363	1.93	1.46	.47	1.91	1.84	1.80	1.35	.45	1.47	1.27	.20	.80	1.72
364	1.92	1.45	.47	1.89	1.84	1.78	1.33	.45	1.44	1.15	.29	.90	1.74
365	1.92	1.45	.47	1.89	1.82	1.76	1.33	.43	1.46	1.23	.23	.72	1.72
366	1.90	1.43	.47	1.89	1.82	1.76	1.33	.43	1.45	1.29	.16	.80	1.70
367	1.90	1.45	.45	1.89	1.82	1.76	1.33	.43	1.47	1.27	.20	.78	1.76
368	1.92	1.45	.47	1.89	1.82	1.78	1.33	.45	1.47	1.33	.14	.80	1.64
369	1.92	1.43	.47	1.91	1.84	1.78	1.33	.45	1.47	1.35	.12	.80	1.54
370	1.92	1.45	.47	1.89	1.84	2.99	2.99	0.00	1.46	1.13	.33	.96	1.74
371	1.91	1.46	.45	1.89	1.82	1.78	1.37	.41	1.46	1.17	.29	.68	1.66
372	1.92	1.45	.47	1.89	1.82	2.75	2.75	0.00	1.60	1.60	0.00	.80	1.58
373	1.91	1.46	.45	1.89	1.84	1.76	1.33	.43	1.46	1.21	.25	.76	1.74
374	1.92	1.84	.08	1.91	1.84	0.00	0.00	0.00	0.00	0.00	0.00	1.74	1.82
375	1.94	1.43	.51	1.89	1.84	1.80	1.33	.47	1.43	1.15	.28	.82	1.74
376	1.94	1.45	.49	1.91	1.84	1.80	1.33	.47	1.44	1.21	.23	.76	1.70
377	1.94	1.45	.49	1.91	1.84	1.78	1.33	.45	1.41	1.31	0.00	.78	.95
378	1.93	1.45	.48	1.91	1.84	1.78	1.33	.45	1.58	1.58	0.00	1.58	1.82
379	1.92	1.45	.49	8.89	1.84	0.00	0.00	0.00	.91	.52	0.00	1.56	.45
380	2.07	1.46	.61	2.34	1.91	0.00	0.00	0.00	.93	1.06	.88	.76	.81
381	1.98	1.45	.51	1.97	1.89	1.82	1.36	.46	1.46	1.20	.23	.80	1.74
382	1.96	1.45	.45	1.88	1.80	1.76	1.35	.41	1.48	1.41	.33	1.01	1.78
383	1.91	1.46	.45	1.89	1.82	1.78	1.33	.43	1.46	1.19	.24	.92	1.76
384	1.90	1.45	.45	1.89	1.82	1.76	1.33	.43	1.47	1.31	.16	.85	1.68
385	1.91	1.46	.45	1.93	1.84	1.78	1.31	.47	1.48	1.13	.35	1.07	1.76
387	1.92	1.45	.47	1.93	1.84	1.78	1.31	.47	1.46	1.17	.29	.90	1.74
388	1.90	1.45	.45	1.91	1.82	1.76	1.31	.45	1.44	1.15	.29	.86	1.76
389	1.90	1.45	.45	1.89	1.84	1.78	1.33	.45	1.46	1.25	.21	1.54	1.76
390	1.92	1.45	.47	1.89	1.84	1.76	1.31	.45	1.45	1.25	.20	.80	1.74
391	1.92	1.45	.47	1.99	1.84	1.78	1.33	.45	1.47	1.29	.18	.78	1.74
392	1.91	1.46	.45	1.91	1.84	1.78	1.33	.45	1.45	1.27	.18	.80	1.74
393	1.90	1.45	.45	1.91	1.84	1.76	1.31	.45	1.44	1.15	.29	.80	1.74
394	1.93	1.45	.48	1.89	1.82	1.76	1.31	.45	1.44	1.15	.29	.68	1.72
395	1.90	1.45	.45	1.89	1.80	1.74	1.31	.43	1.38	1.19	.20	.80	1.74
396	1.90	1.45	.45	1.89	1.82	1.76	1.31	.45	1.44	1.23	.21	.68	1.74
397	1.88	1.45	.43	1.89	1.80	1.76	1.31	.45	1.41	1.35	.06	.84	1.74
398	1.90	1.45	.45	1.89	1.84	1.77	1.31	.46	1.44	1.07	.35	.97	1.72
399	1.90	1.45	.45	1.89	1.82	1.76	1.31	.45	1.39	1.21	.18	.49	1.65
400	1.90	1.45	.45	1.91	1.84	1.78	1.33	.45	1.44	1.19	.25	.75	1.78
401	1.90	1.45	.45	1.91	1.82	1.76	1.31	.45	1.43	1.23	.20	.72	1.74
402	1.92	1.45	.47	1.91	1.82	1.76	1.31	.45	1.45	1.33	.12	.78	1.74
403	1.92	1.45	.47	1.91	1.86	1.76	1.31	.45	1.42	1.33	.09	.61	1.74
404	1.92	1.45	.47	1.91	1.84	1.76	1.31	.45	1.44	1.37	.07	1.00	1.74
405	1.92	1.45	.47	1.91	1.84	1.78	1.31	.47	1.48	1.37	.12	1.03	1.72

CELL UNDER TEST (6)

CN #	CP	ZP 30 MIN	FP	CP END	CP OCV	CP	ZP 30 MIN	FP	CP	ZP USABLE	FP	CP ZN	CP OCV
406	1.92	1.45	.47	1.89	1.84	1.78	1.33	.45	1.38	1.11	.27	.84	1.74
407	1.90	1.43	.47	1.91	1.84	1.76	1.31	.45	1.46	1.21	.25	.83	1.70
408	1.90	1.43	.47	1.89	1.84	1.76	1.31	.45	1.48	1.25	.21	.80	1.76
409	1.92	1.45	.47	1.91	1.84	1.76	1.31	.45	1.45	1.27	.18	.70	1.72
410	1.92	1.45	.47	1.91	1.84	1.78	1.33	.45	1.46	1.09	.37	1.03	1.72
411	1.88	1.43	.45	1.91	1.84	2.71	2.71	0.00	1.45	1.31	.14	.72	1.70
412	1.89	.70	1.19	1.91	1.84	1.78	1.33	.45	1.44	1.11	.33	.79	1.72
413	1.92	1.43	.49	1.91	1.84	1.76	1.33	.43	2.71	2.71	0.00	.14	1.54
414	1.91	1.46	.45	1.95	1.84	1.74	1.29	.45	2.79	2.79	0.00	0.00	0.00
416	1.93	1.46	.47	1.93	1.82	1.72	1.33	.39	1.43	1.35	.08	.78	1.62
417	1.90	1.43	.47	1.91	1.82	1.72	1.31	.41	1.46	1.23	.23	.70	1.72
418	1.90	1.45	.45	1.91	1.84	1.74	1.31	.43	1.47	1.27	.20	.78	1.72
419	1.92	1.45	.47	1.91	1.84	1.74	1.31	.43	1.44	1.19	.25	.76	1.74
420	1.92	1.45	.47	1.93	1.84	1.74	1.31	.43	1.47	1.29	.18	.70	1.72
421	1.92	1.45	.47	1.91	1.84	1.74	1.33	.41	2.83	2.83	0.00	0.00	.80
422	1.92	1.45	.47	1.93	1.82	1.74	1.31	.43	1.47	1.35	.12	.80	1.66
423	1.92	1.45	.47	1.91	1.82	1.74	1.31	.43	1.47	1.35	.12	.80	1.66
424	1.92	1.43	.49	1.93	1.84	1.72	1.31	.41	1.47	1.27	.20	.80	1.66
425	1.90	1.43	.47	1.93	1.84	1.74	1.31	.43	1.45	1.31	.14	.78	1.62
426	1.90	1.43	.47	1.93	1.84	2.70	2.70	0.00	1.45	1.33	.12	.76	1.60
427	1.90	1.43	.47	1.93	1.84	1.74	1.31	.43	1.41	1.27	.14	.78	1.64
428	1.90	1.43	.47	1.93	1.84	1.74	1.33	.41	1.45	1.33	.12	.80	1.62
429	1.92	1.43	.49	1.93	1.84	1.74	1.33	.41	1.47	1.33	.14	.80	1.64
430	1.90	1.43	.47	1.93	1.84	1.76	1.31	.45	1.42	1.13	.29	.78	1.62
431	1.92	1.43	.49	1.93	1.84	1.74	1.31	.43	1.39	1.25	.14	.80	1.60
432	1.90	1.43	.47	1.93	1.84	1.76	1.33	.43	1.45	1.29	.16	.78	1.56
433	1.90	1.43	.47	1.93	1.84	1.74	1.31	.43	1.41	1.31	.10	.74	1.56
434	1.92	1.43	.49	1.93	1.84	1.76	1.33	.43	2.66	2.66	0.00	0.00	0.00
435	1.91	1.50	.41	1.93	1.82	1.72	1.31	.41	1.45	1.27	.18	.78	1.54
436	1.93	1.46	.47	1.93	1.84	1.72	1.31	.41	1.45	1.29	.16	.74	1.70
437	1.93	1.46	.47	1.93	1.84	1.86	1.86	0.00	1.44	1.15	.29	.80	1.72
438	1.91	1.46	.45	1.93	1.84	1.74	1.39	.35	1.86	1.86	0.00	.78	0.00
442	1.93	1.50	.43	1.95	1.84	1.74	1.35	.39	1.47	1.29	.18	0.00	1.70
443	1.93	1.58	.35	1.95	1.86	1.76	1.35	.41	1.45	1.27	.18	.72	1.68
444	1.92	1.45	.47	1.95	1.86	1.74	1.31	.43	1.47	1.29	.18	.80	1.70
445	1.92	1.45	.47	1.95	1.86	1.74	1.31	.43	1.45	1.29	.16	0.00	1.72
446	1.92	1.45	.47	1.95	1.86	1.74	1.31	.43	1.48	1.27	.21	.80	1.70
448	1.90	1.43	.47	1.93	1.86	1.74	1.64	.10	1.45	1.27	.18	.74	1.68
449	1.92	1.43	.49	1.93	1.86	1.76	1.31	.45	1.46	1.25	.21	.78	1.68
450	1.92	1.43	.49	1.95	1.86	1.76	1.74	.02	1.43	1.41	.02	.78	1.76
451	1.91	1.89	.02	1.95	1.86	1.78	1.76	.02	1.47	1.45	.02	.86	1.76
452	1.91	1.89	.02	1.95	1.86	1.78	1.76	.02	1.43	1.41	.02	.70	1.78
453	1.91	1.89	.02	1.95	1.88	1.78	1.76	.02	1.47	1.45	.02	.78	1.72
454	1.93	1.91	.02	1.93	1.88	1.78	1.76	.02	1.46	1.25	.21	.80	1.78
455	1.92	1.45	.47	1.93	1.86	1.78	1.33	.45	1.44	1.23	.21	.80	1.76
460	1.92	1.31	.61	1.91	1.84	2.01	2.01	0.00	1.45	1.25	.20	0.00	1.76
469	1.92	1.45	.47	1.91	1.82	1.76	1.33	.43	1.47	1.29	.18	0.00	1.72
470	1.92	1.45	.47	1.91	1.82	1.76	1.33	.43	1.37	1.33	.04	0.00	1.56
471	1.91	1.27	.64	1.89	1.82	1.74	1.70	.04	2.42	2.42	0.00	0.00	1.56

CELL UNDER TEST (6)

CN #	CP	ZP 30 MIN	FP	CP END	CP OCV	CP	ZP 30 MIN	FP	CP	ZP USABLE	FP	CP ZN	CP OCV
481	1.80	1.37	.43	1.88	1.78	1.70	1.31	.39	1.44	1.19	.25	.80	1.72
482	1.88	1.43	.45	1.89	1.82	1.76	1.33	.43	1.46	1.25	.21	.80	1.70
483	1.92	1.45	.47	1.91	1.82	1.80	1.31	.49	1.45	1.27	.18	.76	1.70
484	1.92	1.45	.47	1.91	1.82	1.74	1.31	.43	1.47	1.27	.20	0.00	1.70
487	1.92	1.45	.47	1.91	1.82	1.74	1.31	.43	1.46	1.21	.25	.76	1.70
488	1.92	1.45	.47	1.93	1.82	1.74	1.31	.43	1.48	1.17	.31	.80	1.72
489	1.90	1.43	.47	1.91	1.82	1.74	1.31	.43	1.46	1.19	.27	.78	1.72
494	1.93	1.46	.47	1.95	1.84	1.76	1.31	.45	1.48	1.13	.35	1.07	1.66
501	2.03	1.54	.49	1.93	1.84	1.78	1.33	.45	1.46	1.09	.37	0.00	1.76
502	1.94	1.45	.49	1.89	1.82	1.78	1.33	.45	1.37	1.27	.10	0.00	1.76
504	1.92	1.43	.49	1.91	1.82	1.76	1.31	.45	1.49	1.29	.20	.80	1.43
505	1.90	1.43	.47	1.91	1.82	1.72	1.29	.43	1.43	1.31	.12	1.11	1.74
506	1.90	1.43	.47	1.89	1.82	1.76	1.31	.45	1.45	1.04	.41	1.21	1.54
507	1.90	1.43	.47	1.89	1.82	1.76	1.31	.45	1.46	1.15	.31	1.09	1.72
508	1.90	1.43	.47	1.91	1.82	1.74	1.31	.43	1.44	1.05	.39	1.19	1.74
509	1.90	1.43	.47	1.91	1.82	1.76	1.31	.45	1.47	1.27	.20	0.00	1.74
510	1.92	1.43	.49	1.89	1.82	1.78	1.33	.45	1.46	1.05	.41	1.17	1.74
511	1.90	1.43	.47	1.89	1.82	1.78	1.33	.45	1.46	1.05	.41	1.21	1.70
512	1.88	1.43	.45	1.89	1.82	1.76	1.31	.45	1.44	1.23	.21	.74	1.64
513	1.90	1.43	.47	1.89	1.82	1.76	1.31	.45	1.47	1.27	.20	.78	1.62
514	1.93	1.46	.47	1.91	1.82	1.76	1.31	.45	1.48	1.13	.35	1.07	1.76
515	1.92	1.45	.47	1.89	1.82	1.76	1.31	.45	1.46	1.13	.33	1.01	1.70
516	1.92	1.45	.47	1.91	1.82	1.76	1.31	.45	1.46	1.07	.39	1.19	1.68
522	1.94	1.45	.49	1.91	1.84	1.78	1.31	.47	1.35	1.29	.06	0.00	1.66
523	1.94	1.45	.49	1.89	1.84	1.74	1.31	.43	1.46	1.21	.25	1.09	1.72
524	1.92	1.43	.49	1.89	1.82	1.76	1.31	.45	1.46	1.15	.31	1.09	1.68
525	1.90	1.43	.47	1.89	1.82	1.78	1.33	.45	1.30	1.05	.25	.96	1.70
526	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.42	1.21	.21	.72	1.58
527	1.90	1.41	.49	1.89	1.82	1.74	1.31	.43	1.48	1.19	.29	.84	1.70
528	1.94	1.45	.49	1.91	1.82	1.76	1.31	.45	1.48	1.19	.29	.76	1.76
529	1.92	1.43	.49	1.91	1.82	1.74	1.31	.43	1.47	1.29	.18	.78	1.64
530	1.94	1.45	.49	1.91	1.82	1.78	1.33	.45	1.44	1.23	.21	1.09	1.66
531	1.92	1.43	.49	1.89	1.82	1.74	1.31	.43	1.46	1.19	.27	.84	1.56
532	1.92	1.43	.49	1.89	1.82	1.74	1.31	.43	1.48	1.15	.33	.92	1.60
533	1.92	1.43	.49	1.89	1.82	1.72	1.29	.43	1.46	1.13	.33	1.05	1.62
534	1.92	1.43	.49	1.89	1.82	1.74	1.31	.43	1.46	1.07	.39	1.15	1.68
535	1.92	1.43	.49	1.89	1.82	1.74	1.31	.43	1.47	1.31	.16	0.00	1.58
536	1.90	1.43	.47	1.91	1.82	1.74	1.31	.43	1.42	1.07	.35	1.03	1.52
537	1.92	1.43	.49	1.91	1.82	1.76	1.33	.43	1.46	1.05	.41	1.09	1.56
538	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.21	.25	0.00	1.70
539	1.92	1.45	.47	1.91	1.82	1.76	1.31	.45	1.45	1.29	.16	0.00	1.70
540	1.92	1.45	.47	1.91	1.82	1.76	1.31	.45	1.46	1.13	.33	.80	1.64
541	1.92	1.45	.47	1.89	1.82	1.74	1.31	.43	1.41	1.23	.18	.72	1.52
542	1.90	1.43	.47	1.91	1.82	1.74	1.31	.43	1.46	1.25	.21	.80	1.56
543	1.92	1.43	.49	1.93	1.84	1.72	1.29	.43	1.46	1.07	.39	1.17	1.74
544	1.93	1.46	.47	1.93	1.84	1.72	1.29	.43	1.46	1.09	.37	.76	1.45
545	1.92	1.45	.47	1.93	1.84	1.76	1.31	.45	1.46	1.25	.21	0.00	1.74
546	1.93	1.46	.47	1.91	1.82	1.76	1.31	.45	1.44	1.21	.23	0.00	1.70
547	1.90	1.43	.47	1.91	1.82	1.74	1.31	.43	1.47	1.27	.20	.78	1.60

CELL UNDER TEST (6)

CN #	CP	ZP 30 MIN	FP	CP END	CP OCV	CP	ZP 30 MIN	FP	CP	ZP USABLE	FP	CP ZN	CP OCV
548	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.42	1.05	.37	1.13	1.72
549	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.44	1.07	.37	1.01	1.72
550	1.92	1.45	.47	1.89	1.82	1.74	1.31	.43	1.44	1.07	.37	.99	1.74
551	1.92	1.45	.47	1.89	1.82	1.74	1.31	.43	1.46	1.19	.27	.76	1.72
552	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.42	1.11	.31	.47	1.64
553	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.44	1.13	.31	.87	1.64
554	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.40	1.05	.35	.77	1.72
555	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.48	1.23	.25	.02	1.60
556	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.31	1.31	0.00	.53	1.48
557	1.90	1.43	.47	1.89	1.82	1.78	1.33	.45	1.46	1.25	.21	.53	1.58
558	1.92	1.43	.49	1.89	1.82	1.74	1.31	.43	1.46	1.17	.29	.96	1.68
559	1.92	1.45	.47	1.89	1.82	1.74	1.31	.43	1.42	1.05	.37	1.09	1.72
560	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.38	1.15	.23	.97	1.68
561	1.92	1.45	.47	1.89	1.82	1.76	1.33	.43	1.46	1.15	.31	.96	1.74
562	1.92	1.43	.49	1.89	1.82	1.74	1.33	.41	1.46	1.11	.35	1.05	1.74
563	1.90	1.43	.47	1.89	1.82	1.76	1.33	.43	1.46	1.21	.25	.76	1.62
564	1.92	1.43	.49	1.91	1.82	1.76	1.60	.16	1.45	1.27	.18	.78	1.56
565	1.94	1.39	.55	1.91	1.82	1.76	1.39	.37	1.49	1.31	.18	.78	1.48
566	1.92	1.39	.53	1.95	1.84	1.72	1.37	.35	1.49	1.31	.18	.80	1.60
567	1.92	1.41	.51	1.91	1.82	1.74	1.37	.37	1.44	1.23	.21	.78	1.72
568	1.90	1.39	.51	1.89	1.82	1.74	1.37	.37	1.45	1.29	.16	.76	1.72
569	1.92	1.41	.51	1.91	1.82	1.74	1.37	.37	1.39	1.21	.18	.76	1.72
570	1.90	1.39	.51	1.89	1.82	1.74	1.35	.39	1.44	1.23	.21	.51	1.58
571	1.92	1.41	.51	1.89	1.82	1.74	1.37	.37	1.43	1.27	.16	.80	1.62
572	1.90	1.39	.51	1.89	1.82	1.74	1.37	.37	1.45	1.29	.16	.80	1.74
573	1.92	1.39	.53	1.89	1.82	1.76	1.39	.37	1.47	1.33	.14	.80	1.58
574	1.93	1.25	.68	1.91	1.82	1.84	1.84	0.00	1.64	1.64	0.00	.70	1.64
575	1.92	1.45	.47	1.89	1.82	2.52	2.52	0.00	1.82	1.82	0.00	.76	0.00
580	1.88	1.43	.45	1.89	1.80	1.72	1.31	.41	1.46	1.19	.27	.80	1.72
581	1.88	1.43	.45	1.89	1.80	1.72	1.31	.41	1.48	1.19	.29	.80	1.74
582	1.88	1.43	.45	1.89	1.80	1.72	1.31	.41	1.46	1.21	.25	.80	1.72
583	1.90	1.43	.47	1.89	1.82	1.72	1.31	.41	1.46	1.17	.29	.76	1.70
589	1.92	1.45	.47	1.89	1.80	1.70	1.31	.39	1.44	1.21	.23	.80	1.52
590	1.90	1.43	.47	1.89	1.80	1.70	1.31	.39	1.47	1.31	.16	.78	1.50
591	1.90	1.43	.47	1.91	1.80	1.70	1.31	.39	1.46	1.19	.27	.80	1.66
592	1.90	1.43	.47	1.91	1.80	1.70	1.31	.39	1.44	1.17	.27	.80	1.72
593	1.90	1.43	.47	1.91	1.80	1.70	1.31	.39	1.47	1.27	.20	.80	1.70
594	1.88	1.43	.45	1.89	1.80	1.72	1.31	.41	1.44	1.17	.27	.78	1.72
595	1.88	1.43	.45	1.89	1.80	1.72	1.31	.41	1.45	1.31	.14	.80	1.58
596	1.88	1.43	.45	1.89	1.82	1.72	1.31	.41	1.31	1.31	0.00	.78	1.62
597	1.88	1.43	.45	1.89	1.80	1.72	1.31	.41	1.44	1.19	.25	.80	1.54
600	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.11	.35	1.01	1.76
601	1.90	1.43	.47	1.89	1.82	1.75	1.52	.23	1.48	1.19	.29	.70	1.54
602	1.87	1.23	.64	1.89	1.82	1.71	1.50	.21	1.43	1.23	.20	.76	1.50
603	1.87	1.23	.64	1.89	1.80	1.71	1.50	.21	1.43	1.31	.12	.80	1.43
604	1.87	1.23	.64	1.89	1.80	1.72	1.52	.20	1.41	1.37	.04	.80	1.62
606	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.13	.33	1.01	1.70
607	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.46	1.07	.39	1.13	1.66
608	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.09	.37	1.15	1.68

CELL UNDER TEST (6)

CN #	CP	ZP	FP	CP	CP	CP	ZP	FP	CP	ZP	FP	CP	CP
	30 MIN			END	OCV	30 MIN			USABLE			ZN	OCV
609	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.41	1.04	.37	1.03	1.60
610	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.35	.98	.37	1.13	1.70
611	1.90	1.43	.47	1.89	1.82	1.76	1.31	.45	1.41	1.04	.37	1.15	1.70
612	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.09	.37	.94	1.60
613	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.48	1.13	.35	1.07	1.68
614	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.44	1.09	.35	1.13	1.70
615	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.46	1.17	.29	1.09	1.70
616	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.46	1.23	.23	.61	1.56
617	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.43	1.23	.20	.72	1.39
618	1.90	1.43	.47	1.80	1.89	1.82	1.37	.45	1.47	1.27	.20	.76	1.54
619	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.46	1.17	.29	.61	1.56
620	1.88	1.43	.45	1.88	1.82	1.74	1.31	.43	1.40	1.11	.29	.68	1.70
621	1.88	1.43	.45	1.88	1.82	1.76	1.31	.45	1.48	1.25	.23	.74	1.64
622	1.88	1.43	.45	1.88	1.82	1.72	1.29	.43	1.42	1.21	.21	.74	1.54
623	1.90	1.43	.47	1.88	1.82	1.74	1.31	.43	1.46	1.15	.31	1.01	1.60
624	1.88	1.43	.45	1.88	1.82	1.74	1.31	.43	1.44	1.11	.33	.78	1.72
625	1.88	1.43	.45	1.88	1.82	1.74	1.31	.43	1.40	1.05	.35	.99	1.72
626	1.88	1.43	.45	1.88	1.82	1.74	1.31	.43	1.34	1.07	.27	1.01	1.72
627	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.30	1.05	.25	.90	1.72
628	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.44	1.07	.37	1.09	1.72
629	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.44	1.07	.37	1.13	1.72
630	1.92	1.45	.47	1.91	1.82	1.74	1.31	.43	1.46	1.13	.33	1.11	1.72
631	1.90	1.45	.45	1.89	1.82	1.74	1.31	.43	1.48	1.11	.37	1.13	1.74
632	1.88	1.43	.45	1.89	1.82	1.72	1.31	.41	1.46	1.11	.35	1.11	1.74
633	1.88	1.43	.45	1.88	1.82	1.74	1.31	.43	1.44	1.09	.35	1.13	1.74
634	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.46	1.11	.35	1.09	1.74
635	1.90	1.45	.45	1.89	1.82	1.72	1.29	.43	1.48	1.11	.37	1.13	1.74
636	1.90	1.43	.47	1.88	1.82	1.74	1.31	.43	1.48	1.11	.37	1.11	1.72
637	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.09	.37	1.13	1.72
638	1.93	1.46	.47	1.89	1.82	1.72	1.29	.43	1.48	1.11	.37	1.13	1.72
639	1.92	1.45	.47	1.97	1.84	1.72	1.29	.43	1.48	1.11	.37	1.13	1.74
640	1.92	1.45	.47	1.89	1.82	1.74	1.31	.43	1.46	1.09	.37	1.13	1.72
641	1.92	1.45	.47	1.91	1.82	1.74	1.31	.43	1.44	1.09	.35	.72	1.74
642	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.09	.37	1.11	1.72
643	1.90	1.43	.47	1.89	1.82	1.74	1.31	.43	1.46	1.09	.37	1.07	1.72
651	1.90	1.43	.47	1.89	1.82	1.74	1.33	.41	1.48	1.09	.39	1.15	1.74
652	1.92	1.45	.47	1.89	1.82	1.74	1.33	.41	1.44	1.07	.37	1.15	1.74
653	1.88	1.43	.45	1.89	1.82	1.76	1.33	.43	1.44	1.07	.37	1.13	1.72
654	1.90	1.43	.47	1.89	1.82	1.74	1.33	.41	1.42	1.05	.37	1.11	1.74
655	1.92	1.45	.47	1.89	1.82	1.76	1.31	.45	1.46	1.09	.37	1.13	1.74
668	1.88	1.43	.45	1.89	1.82	1.74	1.31	.43	1.44	1.11	.33	.96	1.74
673	1.92	1.45	.47	1.91	1.84	1.74	1.29	.45	1.46	1.19	.27	.80	1.60
674	1.92	1.45	.47	1.91	1.82	1.74	1.29	.45	1.48	1.09	.39	.88	1.76
675	1.92	1.45	.47	1.89	1.82	1.74	1.29	.45	1.45	1.27	.18	.80	1.23
676	1.92	1.45	.47	1.89	1.82	1.74	1.29	.45	1.33	1.25	.08	.78	.80
677	1.90	1.43	.47	1.89	1.82	1.74	1.29	.45	1.41	1.25	.16	.80	.64
678	1.94	1.45	.49	1.91	1.84	1.76	1.29	.47	1.46	1.25	.21	.80	.74
679	1.96	1.45	.51	1.91	1.84	1.74	1.29	.45	1.45	1.02	.43	1.11	1.76
680	1.92	1.45	.47	1.89	1.82	1.76	1.31	.45	1.46	1.05	.41	1.23	1.76

CELL UNDER TEST (6)

CN #	CP	ZP	FP	CP	CP	CP	ZP	FP	CP	ZP	FP	CP	CP
	30 MIN			END	OCV	30 MIN			USABLE			ZN	OCV
681	1.90	1.43	.47	1.89	1.82	1.76	1.31	.45	1.43	1.27	.16	.88	1.48
691	1.94	1.43	.51	1.91	1.84	1.80	1.31	.49	1.48	1.23	.25	.74	1.64
692	1.94	1.43	.51	1.91	1.84	1.84	1.33	.51	1.82	.80	1.02	1.68	1.78
693	1.94	1.45	.49	1.89	1.84	1.78	1.31	.47	1.46	1.25	.21	.76	.78
694	1.92	1.43	.49	1.89	1.84	1.78	1.31	.47	1.46	1.25	.21	.78	.82
695	1.92	1.43	.49	1.91	1.84	1.76	1.29	.47	1.42	1.17	.25	.80	1.68
696	1.94	1.43	.51	1.91	1.84	1.78	1.31	.47	1.44	1.15	.29	.80	1.70
697	1.90	1.43	.47	1.89	1.84	1.76	1.31	.45	1.46	1.19	.27	.80	1.64
698	1.92	1.45	.47	1.89	1.84	1.76	1.31	.45	1.46	1.05	.41	1.17	9.74

Appendix G
PROGRAM FOR DATA SMOOTHING AND GRAPHICS

The following program, written in TYMBASIC, applies a data smoothing routine (5, 7, or 11 point - Ref.63)which eliminates data noise caused by reference electrode, thermal, or electronic malfunctioning. The program outputs a data file which is comprised of a cycle number and an efficiency in the following data block order.

Voltaic efficiency
Voltaic data smoothing
Coulombic efficiency
Coulombic data smoothing
Energy efficiency
Energy data smoothing

```
10 STRING PLOT
20 DIM NP(2000),NDATA(2000),MDATA(2000),NC(2000),CDATA(2000)
30 DIM CYCLE(2000),CD(2000),DD(2000),VE(2000)
40 DIM UE(2000),OE(2000),ZE(2000),FE(2000)
50 TEXT DCODE(2000),TCODE(2000)
60 INPUT IN IMAGE "CELL NUMBER ?  #":L
70 IF L#1 THEN GO TO 130
80 OPEN "REFF1",INPUT,4
90 OPEN "PLOT1",OUTPUT,5
100 GOSUB 430
110 L=1
120 GO TO 420
130 IF L#2 THEN GO TO 190
140 OPEN "REFF2",INPUT,4
150 OPEN "PLOT2",OUTPUT,5
160 GOSUB 430
170 L=2
180 GO TO 420
190 IF L#3 THEN GO TO 250
200 OPEN "REFF3",INPUT,4
210 OPEN "PLOT3",OUTPUT,5
220 GOSUB 430
230 L=3
240 GO TO 420
250 IF L#4 THEN GO TO 310
260 OPEN "REFF4",INPUT,4
270 OPEN "PLOT4",OUTPUT,5
280 GOSUB 430
290 L=4
300 GO TO 420
310 IF L#5 THEN GO TO 370
320 OPEN "REFF5",INPUT,4
330 OPEN "PLOT5",OUTPUT,5
340 GOSUB 430
350 L=5
360 GO TO 420
370 IF L#6 THEN GO TO 420
380 OPEN "REFF6",INPUT,4
390 OPEN "PLOT6",OUTPUT,5
400 GOSUB 430
410 L=6
420 GO TO 1040
430 STRING W,Y
```

```
440 DIM CP(2000)
450 W="6%B 8%B # # # # # # # #/"
460 Y="2(12#)/"
470 FOR I=1 TO 1000
480 ON ENDFILE (4) GO TO 520
490 INPUT FROM 4 IN FORM W:DCODE(I),TCODE(I),CYCLE(I),CD(I),DD(I),VE(I),
UE(I),OE(I),ZE(I),FE(I)
500 G=I
510 NEXT I
520 PRINT IN IMAGE "NO. DATA POINTS : #":G
530 INPUT IN IMAGE "5 OR 7 POINT SMOOTHING ? #":P
540 FOR J=1 TO G
550 WRITE ON 5 IN FORM Y:CYCLE(J),VE(J)
560 NDATA(J)=VE(J)
570 NEXT J
580 WRITE ON 5:"9999.,0."
590 GOSUB 740
600 FOR J=1 TO G
610 WRITE ON 5 IN FORM Y:CYCLE(J),UE(J)
620 NDATA(J)=UE(J)
630 NEXT J
640 WRITE ON 5:"9999.,0."
650 GOSUB 740
660 FOR J=1 TO G
670 WRITE ON 5 IN FORM Y:CYCLE(J),OE(J)
680 NDATA(J)=OE(J)
690 NEXT J
700 WRITE ON 5:"9999.,0."
710 GOSUB 740
720 CLOSE 4,5
730 RETURN
740 B=G-P-1
750 FOR AK=2 TO P
760 JK=AK-1
770 NP(AK)=NDATA(JK)
780 NC(AK)=CYCLE(JK)
790 NEXT AK
800 FOR K=1 TO B
810 JK=K+P-1
820 FOR KK=1 TO P-1
830 KA=KK+1
840 NP(KK)=NP(KA)
850 NC(KK)=NC(KA)
860 NEXT KK
```

```
870 NP(P)=NDATA(JK)
880 NC(P)=CYCLE(JK)
890 IF P=7 THEN GO TO 950
900 NSUM=17*NP(3)+12*(NP(2)+NP(4))-3*(NP(1)+NP(5))
910 NCSUM=17*NC(3)+12*(NC(2)+NC(4))-3*(NC(1)+NC(5))
920 MDATA(K)=NSUM/35
930 CDATA(K)=NCSUM/35
940 GO TO 990
950 NSUM=7*NP(4)+6*(NP(3)+NP(5))+3*(NP(2)+NP(6))-2*(NP(1)+NP(7))
960 NCSUM=7*NC(4)+6*(NC(3)+NC(5))+3*(NC(2)+NC(6))-2*(NC(1)+NC(7))
970 MDATA(K)=NSUM/21
980 CDATA(K)=NCSUM/21
990 WRITE ON 5 IN FORM Y:CDATA(K),MDATA(K)
1000 NEXT K
1010 WRITE ON 5:"9999.,0."
1020 PRINT
1030 RETURN
1040 PRINT
```

Appendix H
EZPLOT PROGRAM FOR GRAPHICS GENERATION

The following program, written in THMSHARE Editor, is an EZPLOT program for generating a plot of cyclic data by the Tymshare computer. The program takes the data file generated by the Data Smoothing program, Appendix G, and plots the data. The particular listing generates a plot for voltaic, coulombic, and energy efficiencies for a cell having less than 600 cycles. Simple modification to the first INCREMENT of each plot allows for scaling of plot to the number of cycles.

```
ROTATE TO 270
MOVE TO 3,1
TYPE "OPEN DATA FILE"
PAUSE
X SCALE
     START=0
     INCREMENT =100
Y SCALE
     START=60
     INCREMENT=10
X AXIS
     LENGTH=6
     SPACING=.5,1
     FORMAT="%%%"
     LABEL="CYCLE NUMBER"
     LSIZE=.1
Y AXIS
     LENGTH=6
     SPACING=.5,1
     FORMAT="%%%"
     LABEL="EFFICIENCY (%)"
     LSIZE=.1
DATA
PLOT
     SYMBOL=25
     SIZE=.1
EXECUTE
SUPRESS X AXIS
SUPRESS Y AXIS
DELETE PLOT
DATA
PLOT
     LINES
     SIZE=.1
TITLE 1
     LOC=2,6
     TEXT="VOLTAIC EFFICIENCY"
     SIZE=.1
EXECUTE
DELETE PLOT
MOVE TO 0,8.5
SUPPRESS TITLE 1
X SCALE
```

```
     START=0
     INCREMENT =100
Y SCALE
     START=60
     INCREMENT=10
X AXIS
     LENGTH=6
     SPACING=.5,1
     FORMAT="%%%"
     LABEL="CYCLE NUMBER"
     LSIZE=.1
Y AXIS
     LENGTH=6
     SPACING=.5,1
     FORMAT="%%%"
     LABEL="EFFICIENCY (%)"
     LSIZE=.1
DATA
PLOT
     SYMBOL=25
     SIZE=.1
EXECUTE
SUPRESS X AXIS
SUPRESS Y AXIS
DELETE PLOT
DATA
PLOT
     LINES
     SIZE=.1
TITLE 2
     LOC=2,6
     TEXT="COULOMBIC EFFICIENCY"
     SIZE=.1
EXECUTE
DELETE PLOT
MOVE TO 0,8.5
SUPPRESS TITLE 2
X SCALE
     START=0
     INCREMENT =100
Y SCALE
     START=40
     INCREMENT=10
```

```
X AXIS
     LENGTH=6
     SPACING=.5,1
     FORMAT="%%%"
     LABEL="CYCLE NUMBER"
     LSIZE=.1
Y AXIS
     LENGTH=6
     SPACING=.5,1
     FORMAT="%%%"
     LABEL="EFFICIENCY (%)"
     LSIZE=.1
DATA
PLOT
     SYMBOL=25
     SIZE=.1
EXECUTE
SUPRESS X AXIS
SUPRESS Y AXIS
DELETE PLOT
DATA
PLOT
     LINES
     SIZE=.1
TITLE 3
     LOC=2,6
     TEXT="ENERGY EFFICIENCY"
     SIZE=.1
EXECUTE
MOVE TO -3,7.5
```

Appendix I

COST ESTIMATES FOR COMPONENTS OF THE LMSC
MOD 00 ZINC/FERROCYANIDE 20 MW, 100 MWh BATTERY

1. COST BASES

The following cost bases were used in these computations:

Reagent Costs

- The unit price for sodium ferrocyanide decahydrate was taken as $0.69 kg based on (1) a price quotation* of $0.37/lb in 24,000 lb lots and (2) that for 50,000 ton lots it was conservatively assumed that it could be obtained at a 15% discount from this quotation. Using EPRI cost estimating guidelines (ref 61), this cost was further reduced by 24.8%, which is the present percentage value of the salvaged reagent using a 15% per annum discount rate on the 100% value over 10 years. The 100% figure has not been adjusted for inflation. It is assumed that any slow decomposition of the ferrocyanide salt has been reversed periodically by religation over the 10-year period.

- Zinc was priced as zinc oxide at $1.23/kg**. The salvage value is also taken as 24.8%, as described above.

- Sodium hydroxide was priced at $0.24/kg (100% basis) as the 73% solution.**

Electrode Costs

- The negative electrode substrate is selected as Union Carbide CS graphite, at a cost of $1.98/kg and a cutting efficiency of 0.514 and a thickness of 0.050 inch (ref 61). Density is 1.76 g/cc.

*American Cyanamid Co., Sept. 1979
**Chemical Marketing Reporter, May 28, 1979

- For positive electrode substrate, Airco Speer grade 37G porous carbon, at $5.08/kg was selected. Following the electrode design used in the EDA zinc/chlorine battery, a cutting efficiency of 0.563 and electrode thickness of 0.050 inch were assumed (ref. 59). Density is 1.35 g/cm^3.

Separator Costs

- Separator material was assumed to be an RAI Research Corp. grafted, cross-linked polyethylene or polypropylene material having essentially the same physical properties and pore size distribution as their teflon-based material, which we found to be satisfactory, except for cost and tear strength. For sales volume at the million square feet per year level, RAI Research Corp. projects a price of $1.00/ft^2 for this material.*

Bus Bar Costs

The Gould figure of $3.80/kWh is used for fabricated copper bus bars (ref. 58); after reduction by the ratio of the number of modules in the LMSC Mod 00 battery to that in the Mod 1 Gould battery (240/250). This gives a unit price of $3.65/kWh. This price was reduced for the salvage value of the copper involved, $300 \times \frac{240}{250} = 288$ kg/module. At $1.43/kg, salvage value is 288 x $1.43 x .248 = $102./module or $0.24/kWh. This gives a reduced cost of $3.41/kWh.

2. COMPONENT COSTS

Electrodes

Referring to Table 4.7.1, negative electrode area is: 14 (plates/cell) x .0929 (m^2/plate) x 5 (cells/submodule) x 10 (submodule/module) x 15 (modules/string) x 16(strings/battery) = 1.56 x 10^4m^2.

*Private communication. R. Facciola, RAI Research Corp., May 1979

Total Cost:

$$15{,}600\ (m^2/\text{battery}) \times 0.05\ (\text{inch thickness}) \times 2.54\ (\text{cm/in.}) \times \frac{10{,}000\ (cm^2/m^2)}{1000\ (\text{g/kg})} \times \frac{1.76\ (\text{g/cc})}{0.514\ (\text{cutting efficiency})} = 67{,}840\ \text{kg graphite required}$$

$67{,}840 \times \$1.98 = \underline{\$134{,}300}$ (negative electrode substrate)

Positive electrode area is:

$$13\ (\text{plates/cell}) \times 0.0929(m^2/\text{plate}) \times 12{,}000\ (\text{cells/battery}) = 1.45 \times 10^4 m^2$$

Weight of porous carbon required:

$$1.45 \times 10^8 (cm^2) \times \frac{1.35\ (\text{g/cc}) \times 0.05\ (\text{inch}) \times 2.54\ (\text{cm/in})}{1000\ (\text{g/kg}) \times 0.563\ \text{cutting efficiency}}$$

$$= 44{,}157\ \text{kg porous carbon required}$$

$44{,}160 \times \$5.08 = \$224{,}300$ (positive electrode substrate)

Total cost for all electrode material is: $\underline{\$358{,}600}$

or: \$3.55/kWh

Separator

Separator material cost is $\$1.00/ft^2$ or $\$10.76/m^2$. Assume area of a separator is 5% larger than that of an electrode. Total area is: $0.0975\ m^2$

$26(\text{separators/cell}) \times 0.0975/m^2/\text{separator} \times 12{,}000\ (\text{cells/battery}) = 30{,}420\ m^2$

Cost is: $30{,}420 \times \$10.76 - \underline{\$327{,}300}$ or \$3.24/kWh

Reagents

Cell voltage is 1.74 V, and turnaround coulombic efficiencies are 96% and 95%, for redox and zinc electrodes, respectively. Assume 3% excess capacity for each electrode.

- Sodium ferrocyanide decahydrate

$$1.03 \text{ (excess capacity)} \times \frac{1.01 \times 10^8 \text{(watthrs/battery)} \times 484.0 \text{ (g/equiv)} \times 0.69 \text{ (\$/kg)}}{1.74 \text{ (V/cell)} \times 0.96 \text{ (eff.)} \times 26.8 \text{ (Ah/equiv)} \times 1000 \text{ (g/kg)}}$$

$$= \$776.100$$

This cost is reduced by 24.8% for salvage value.

$\$776,100 \times 0.752 =$ 583,600 redox reactant cost or $5.78/kWh

- Zinc Oxide

$$1.03 \text{ (excess capacity)} \times \frac{1.01 \times 10^8 \text{(watts/battery)} \times 40.7 \text{ (g/equiv)} \times 1.23 \text{ (\$/kg)}}{1.74 \text{ (V/cell)} \times 0.95 \text{ (eff.)} \times 26.8 \text{ (Ah/equiv.)} \times 1000 \text{ (g/kg)}}$$

$$= \$117,600$$

This cost is reduced by 24.8% for salvage value.

$\$117,600 \times 0.752 =$ $88,400 or 0.88 kWh

- Sodium Hydroxide

Assume electrolyte volume is battery cell volume plus piping volume plus 50% of electrolyte storage tank volume. Assume a 5N NaOH electrolyte (See below storage tanks for volume estimation).

Cell electrolyte volume is: 0.35 (cm/interelectrode gap) (Ref. 58) x 0.0929(m^2/electrode)
x 26 (interelectrode gap/cell) x 10^4(cm^2/m^2)
= 8454 cm^3/cell

$$\frac{8454\ (cm^3) \times 12{,}000\ \text{cells/battery}}{10^6(cm^3/m^3)} = 101.4\ m^3/\text{battery}$$

Piping contains 12.5 m^3
Half of Tankage Volume is 797.0 m^3

$$\text{Cost is: } \frac{910.9\ (m^3) \times 10^3(1/m^3) \times 5\ (\text{equiv/l}) \times 40\ \text{g/equiv}) \times 0.24\ (\$/kg)}{1000\ (g/kg)}$$

= \$43,720 or \$0.43/kWh

Reactant Tanks

- Catholyte Tank

Compute volume of solid $Na_4Fe(CN)_6 \cdot 10\ H_2O$ used:

$$\frac{776{,}100\ (\$/\text{batt}) \times 454\ (g/lb)}{0.31\ (\$/lb) \times 10^6(cm^3/m^3) \times 1.458\ (g/cm^3)} = 779.6\ m^3$$

In crystal form, assume 50% porosity. Then need tank volume of 2 x 780 = 1560 m^3. Half of this volume would be electrolyte. Assume four cylindrical tanks, 20 feet tall. Diameter is:

$$((1560)\ (20 \times \pi \times 0.30455)^{-1})^{1/2}$$

= 9.03 m or 29.7 ft.

$$\text{Area of tank} = \frac{2\pi d^2}{4} + \pi dh$$

$$= \frac{2\pi(9.03)^2}{4} + \pi(9.03)(20)(0.30455) = 300.9\ m^2$$

Four tanks have total area: $1204\ m^2$

Anolyte Tank

Volume is $$\frac{117{,}600\ (\$/batt) \times 454\ (g/lb)}{0.56\ (\$/lb) \times 1000\ (cm^3/l) \times 5.47\ (g/cm^3)}$$

$$= 17{,}430\ \ell \text{ or } \underline{17.4\ m^3}$$

Double this for 50% solids porosity and double again for two tanks (one empty)

$$17.4 \times 4 = 69.6\ m^3 \text{ total volume}$$

Diameter of each tank is taken as 10 ft; with a corresponding height of 14.9 ft.

Tankage area is: $2(\frac{2\pi d^2}{4} + \pi dh)$

$$= 2(\frac{2\pi(3.05)^2}{4} + (3.05\pi)\ (4.57)) = 116.8\ m^2$$

Total tankage area: $1204 + 117 = 1321\ m^2$

Using structural carbon steel at \$0.47/kg with a 3/8 inch wall thickness, cost is:

$$\frac{2.54\ (cm/in)\ 0.47\ (\$/kg) \times 1321\ (m^2) \times 0.375\ (in) \times 10^4/cm^2m^2) \times 7.87\ (g/cm^3)}{1000\ (g/kg)}$$

$$= \$46{,}540$$

Tanks will be lined with sulfonated polyethylene lining at $\$53.80/m^2$ (ref. 57). Hence, add: $\$53.80 \times 1321 = \$71{,}070$ for a total cost of \$117,600 or \$1.16/kWh.

Filters, Heat Exchangers, and Pumps

These costs are taken as those given in the NASA-LeRC Cost Estimate (ref. 57) increased by the factor 100/85 to account for increased energy stored in a 100 MWh plant.

Filters ($0.48\ m^3/sec$)	$82,500	or	$0.82/kWh
Heat Exchangers (stainless steel tubes at $\$43/m^2$)	$58,800	or	0.58/kWh
Pumps @ $48,000/96.9 kW in stainless steel			
4 @ 50 kW and 2 @ 5kW	$112,000	or	$1.11 kWh

Racks

EDA (ref. 59) Costs (adjusted upward by the power density ratio for the two systems, 1.25) were used for the racks upon which the battery modules are mounted, each string being three tiers high by five modules long. Two such strings are placed adjacent to each other for a double string, with electrolytes piped to each doubled string. Strings are 55 feet long by five feet wide by 18 feet in height.

These costs are:	Materials	Labor
Rack structure	$148,500	
Rack Assembly		$54,000
Weatherproof panels (@ $\$2.00/ft^2$ est.)	68,700	
Panel Assembly (est.)		4,000
	$217,200	$58,000
	$2.15 kWh	$0.57/kWh

Miscellaneous Costs — 2000 Ah/m^2 basis

	Materials ($/kWh)	Labor ($/kWh)
Internal plumbing (ref. 58)	2.00	-
Cell Components (other than electrodes and separators (ref. 58)	1.87	-
Cell Assembly (ref. 58)	-	0.36
Cell Stack Assembly (ref. 58)	-	0.27
Module Assembly (ref. 58)	-	0.30
External Plumbing (racks) Pipe and valves (est.)	0.32	0.10
Tanks (fabrication and erection) (est.)		0.25
Rack and Panel Assembly (ref. 59)	-	0.58
Process Equipment (for Electrode fab) (ref. 59)	4.55	
Physical Plant (ref. 59)	1.25	
Floor Space Rental (ref. 59)	0.19	

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