DESIGN AND COST STUDY FOR NICKEL ZINC BATTERY MANUFACTURE ELECTRIC VEHICLE PROPULSION BATTERIES

CONTRACT NO. 31-109-38-3542

EAGLE-PICHER INDUSTRIES, INC.
ELECTRONICS DIVISION
COUPLES DEPARTMENT
JOPLIN, MISSOURI
64801

EAGLE EP PICHER

DISCLAIMER

DISCLAIMER

TASK A
DESIGN AND COST STUDY FOR NICKEL/ZINC BATTERY MANUFACTURE
ELECTRIC VEHICLE PROPULSION BATTERIES

CONTRACT NUMBER 31-109-38-3542

PREPARED FOR

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ABSTRACT

For satisfying the 25 KWH energy requirement necessary for vehicle propulsion, a 700 pound nickel-zinc battery was configured. Containing 64 individual cells, the unit was selected for minimum weight from computed packaging possibilities. Unit volume was projected to be 4.77 cubic feet. Capacity of the cells delivering 100+ volts was set at 245 ampere hours. Selection was made primarily because of the compatibility with expressed vehicle requirements of a lower current system. Manufacturing costs were computed for a unit using sintered positive electrodes at $86/KWH, Pilot Plant Rate and $78/KWH, Production Plant Rate. Based on a lower than anticipated cost differential between sintered and non-sintered positive electrodes and certain other performance differences, the sintered electrode was chosen for the battery design. Capital expenditures for a production rate of 10,000 batteries per year are estimated to be $2,316,500. Capital expenditure for demonstrating production rates in a pilot plant facility is approximately $280,000, sharing the use of some available equipment.

1.0 INTRODUCTION

This Design and Cost Study is submitted to complete the requirements of Argonne National Laboratories Contract No. 31-109-38-3545. The Study is directed toward verification of current nickel-zinc battery capabilities and optimization of this capability. Based upon present production posture, manufacturing processes are discussed for the purposes of establishing direct costs in a most efficient and economical fashion. Capital investments in equipment are estimated for both a pilot and a production manufacturing rate. The major and underlying goals of this effort are the reduction of manufacturing costs, the increase of battery cycle life and the improvement of energy density.

Both sintered and non-sintered methods of manufacturing the positive electrode were studied, with the resulting selection of the sintered electrode. This decision was based on the lower than expected cost differential and the inferior performance of the non-sintered electrode. Eagle-Picher does not believe the projected cost differential between the two electrodes justifies the risk and development expense of trying to improve non-sintered electrode performance to match that of the sintered electrode.

An optimum configuration has been established and characterized with three successive design generations. The Baseline Design represents the state-of-the-art, while Designs #2 and #3 represent potential future improvements. The Baseline Design was used to generate the performance data, manufacturing processes, manufacturing equipment, and cost projections.

We believe that Eagle-Picher offers the best available engineering expertise, manufacturing experience and sincere desire to develop, operate and deliver as required by the statement of work. Eagle-Picher's effort will be willingly coordinated with ANL and the vehicle designers to provide the team effort necessary to achieve program goals.

2.0 DESIGN CONFIGURATION

2.1 Optimization

The optimized cell configuration and ultimately the minimized weight and volume battery was approached by devising a computer program which would consider all elements of cell design. The program essentially designs a cell based upon inputs of energy required, active material efficiencies, material loading and densities and separator characteristics. To establish the design on a comparative basis, several additional features are included as follows:

1) Internal Case Dimensions - Fixed allowance values
2) Cell Case Wall Thickness - Varies with capacity
3) Cell Cover - Varies with cell wall thickness and footprint area
4) Plate Tab - Varies with electrode weight
5) Interplate Connections - Varies with cell thickness and discharge current
6) Intercell Connections - Varies with cell width and discharge current

To limit the calculations, a range of electrode areas was established and incremental ratios of electrode length-to-height were used. Other basic inputs were electrolyte specific gravity and electrode grid weights. A 10 millivolt drop allowance was fixed for the computation of material necessary to perform the interplate/intercell connection functions.

The object of the calculations was to yield an accurate and unbiased comparison of a large number of possible configurations from which the lightest weight or volume might be selected. The program was to increment on number of cells. A total weight and volume for the battery was computed at each increment. Weight and volume of the cell components was also computed along with its respective contribution (percentage) to the total. From the electrode size limitations, the number and size of the electrode for each cell was determined.

At current densities established by the positive electrode loading, material efficiencies are considered to be constant. Thus for the fixed energy requirement, active material does not vary and does not affect the comparative picture. Variations observed in the computed totals are a function of cell case/cover, electrolyte filled void and intercell/interplate connections. Cell case and void decrease as the number of cells decrease while the current carrying connector increase. From computed results over the range of 4 to 90 cells in four-cell increments, the minimum weight battery was obtained for twelve cells. The minimum weight configuration electrode has a lenght-to-width ratio of 1.75. Incrementing in the range as previously described, minimum volume for the battery was obtained at eight cells.

Three basic designs were generated through use of the computer program. These designs are summarized below.

Baseline Design

This configuration represents the current state-of-the-art production nickel-zinc batteries. Weight and volume are calculated using typical values for input design variables. The weights and volumes shown for this design are those that could reasonably be expected to be delivered today.

Design No. 2

The second design is the result of selecting all input design variables within their known operating limits, but at the values that result in minimum weight and volume. This design is intended to establish the upper limit of energy density possible with state-of-the-art limits of design variables.

Design No. 3

Design number three is a projection of future improvements. This design results in significantly lower weight and volume primarily from an increase in positive electrode active material loading. This increase results in a lower cell surface area with a resulting decrease in separator, current collectors and substrates, and electrolyte to fill the voids in these materials. The increase in active material loading is based on the projected capability of loading nickel plaque to a level of 2.0 gm/in^2 and then placing two of the resulting electrodes back-to-back. An electrode assembly is then obtained with an effective active material loading of 4.0 gm/in^2. This loading level is considered to be the highest permissible with the given power requirements.

A comparison of the three designs is shown below.

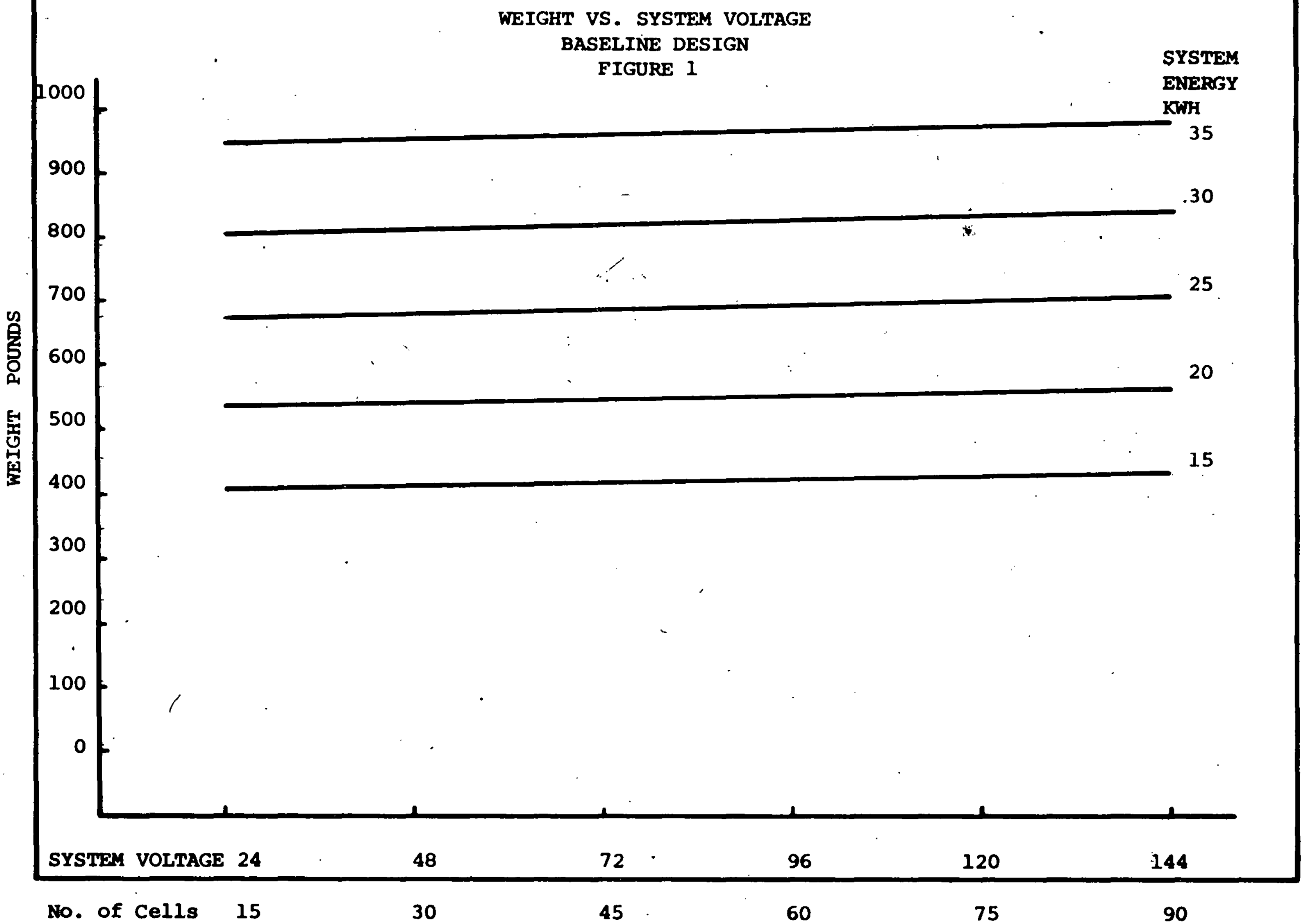
COMPUTER OPTIMUM CONFIGURATION STUDIES

	Baseline Design	Design No. 2	Design No. 3
Separator	Cellophane	Polypropylene	Polypropylene
Positive Active Material Loading	2.0 gm/in^2	2.0 gm/in^2	4.0 gm/in^2
Ratio Neg/Pos Ampere-Hours	3/1	2.75/1	2.75/1
Negative Density	40 gm/in^3	55 gm/in^3	55 gm/in^3
Energy Density	80 WH/Kg	100 WH/Kg	120 KW/Kg

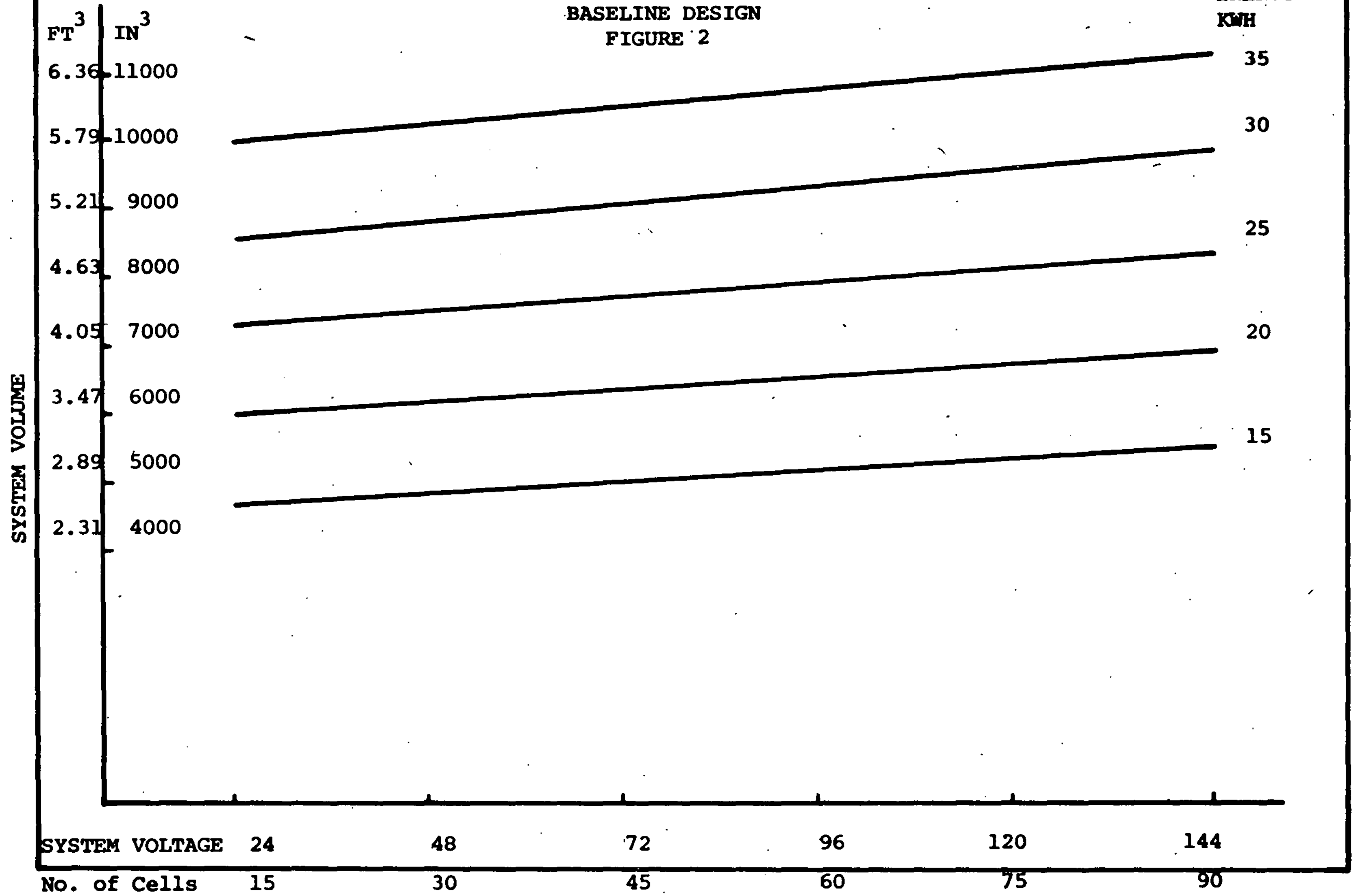
Weights and volumes for designs 1, 2 and 3 are presented in Figures 1 - 6 for system voltages from 24 to 144 volts and system energy levels of 15 to 35 KWH. Also shown in Figure 7 is a weight/volume plot comparing the three designs at the 96 volt level over the range of system energy.

Figures 1 - 6 show that for any of the three designs, a change in voltage over the range of 24 to 144 volts represents a weight change of approximately 4% and a volume change of approximately 15%. However, a shift from the baseline design to the projected improved design (No. 3)

BATTERY SYSTEM TRADE OFF STUDIES

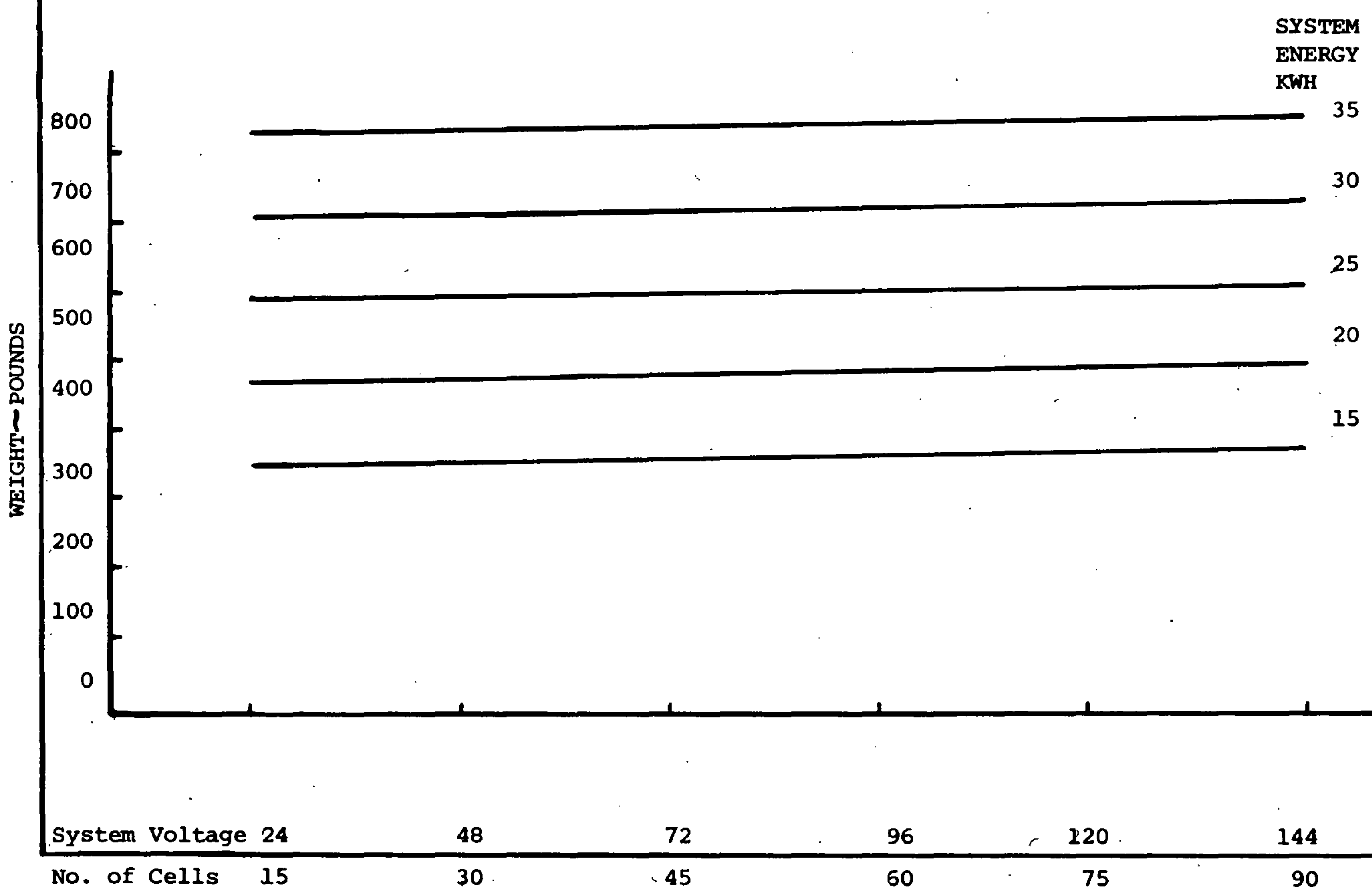


BATTERY SYSTEM TRADE OFF STUDIES
VOLUME VS. SYSTEM VOLTAGE
BASELINE DESIGN
FIGURE 2



BATTERY SYSTEM TRADE OFF STUDIES

BATTERY WEIGHT VS. SYSTEM VOLTAGE
DESIGN #2
FIGURE 3

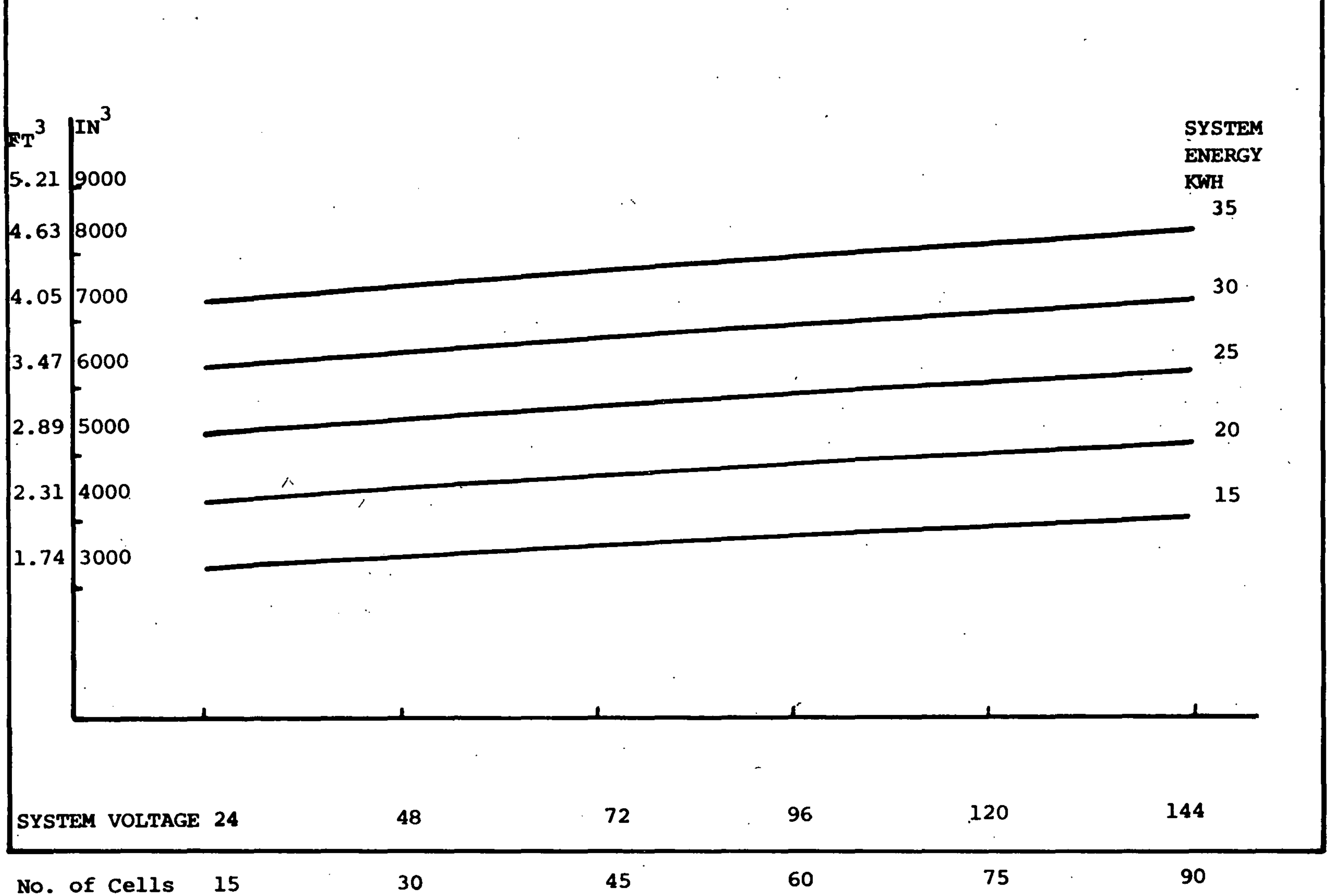


BATTERY SYSTEM TRADE OFF STUDIES

VOLUME VS. SYSTEM VOLTAGE

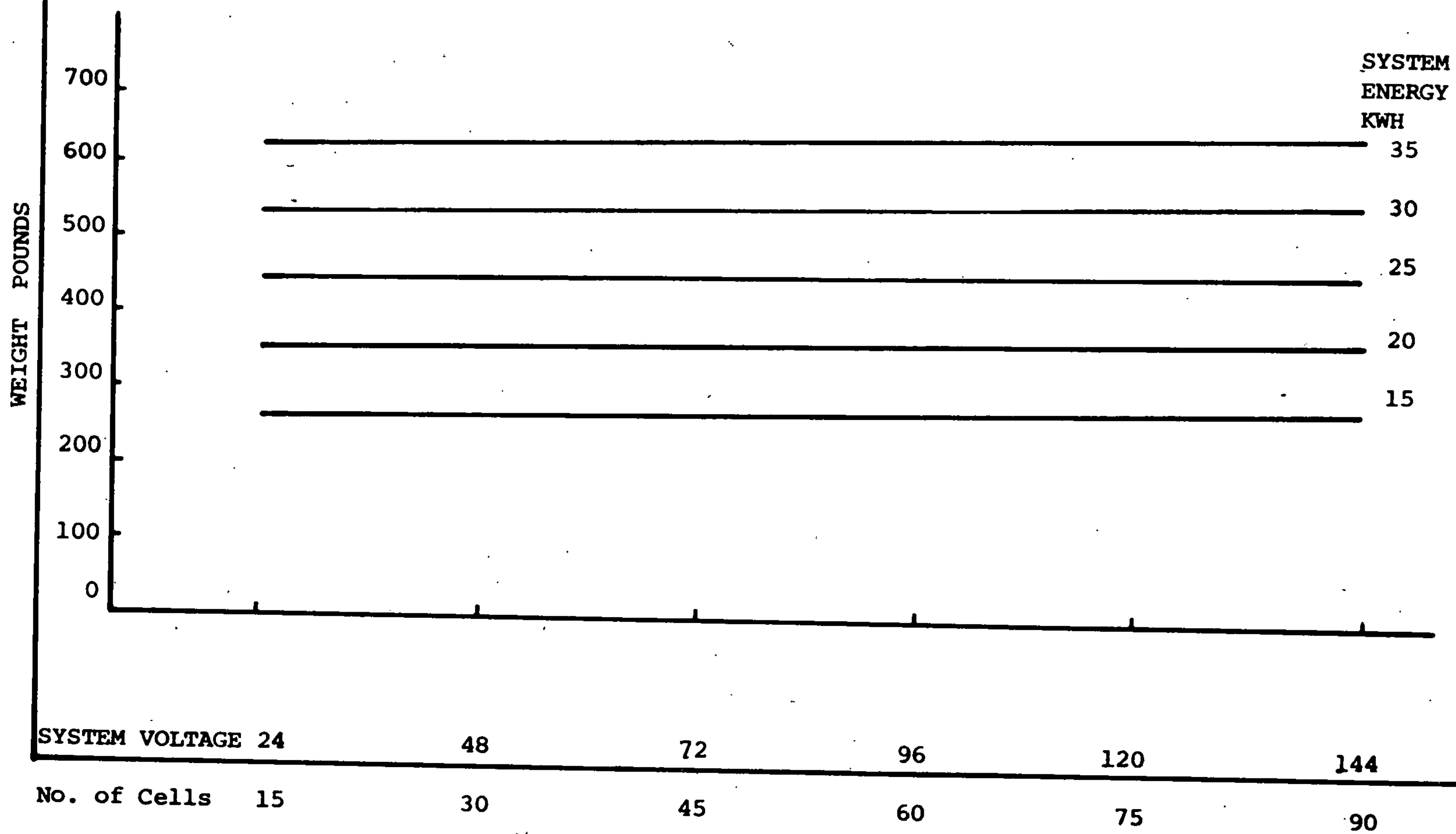
DESIGN #2

FIGURE 4



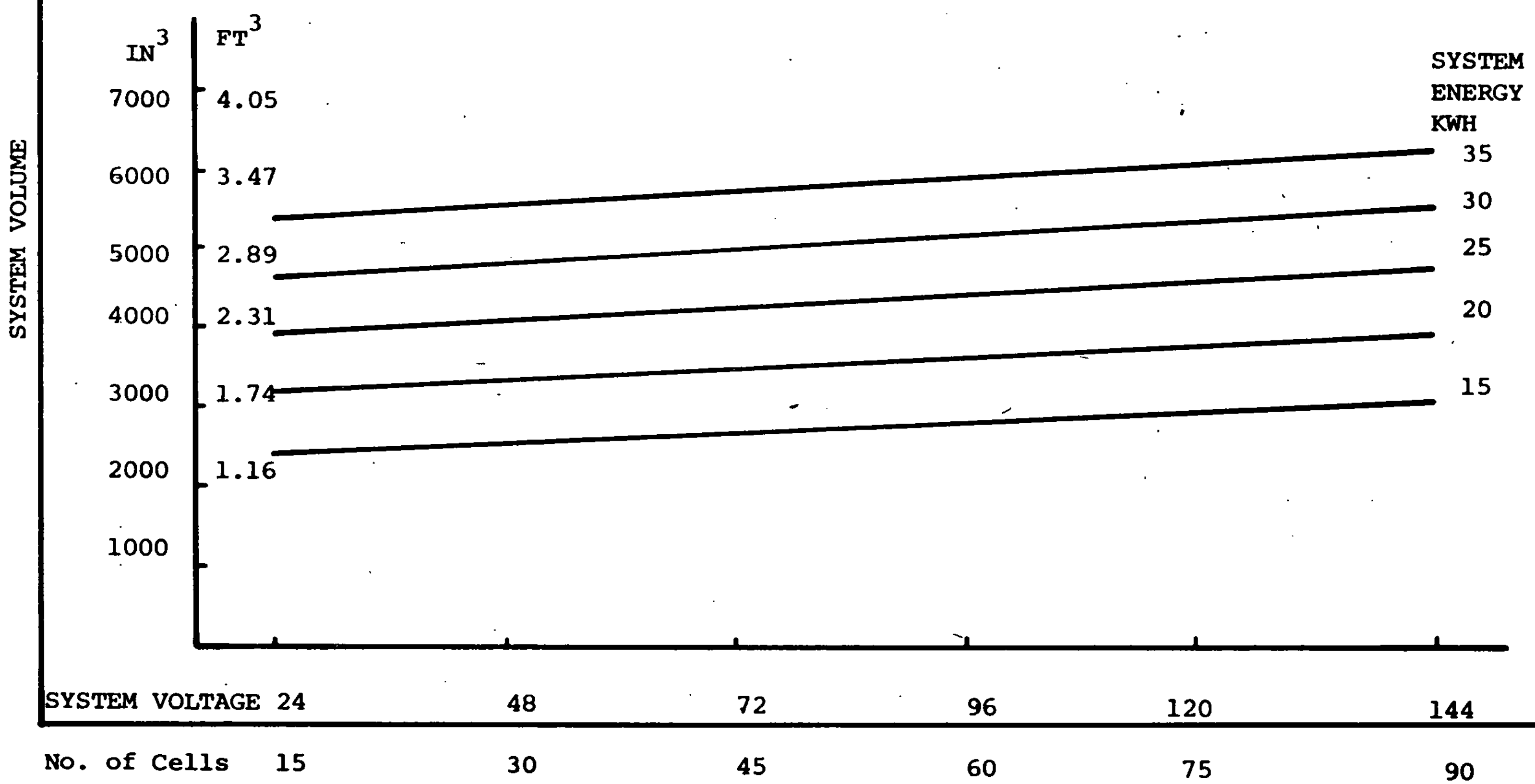
BATTERY SYSTEM TRADE OFF STUDIES

WEIGHT VS. SYSTEM VOLTAGE
DESIGN #3
FIGURE 5

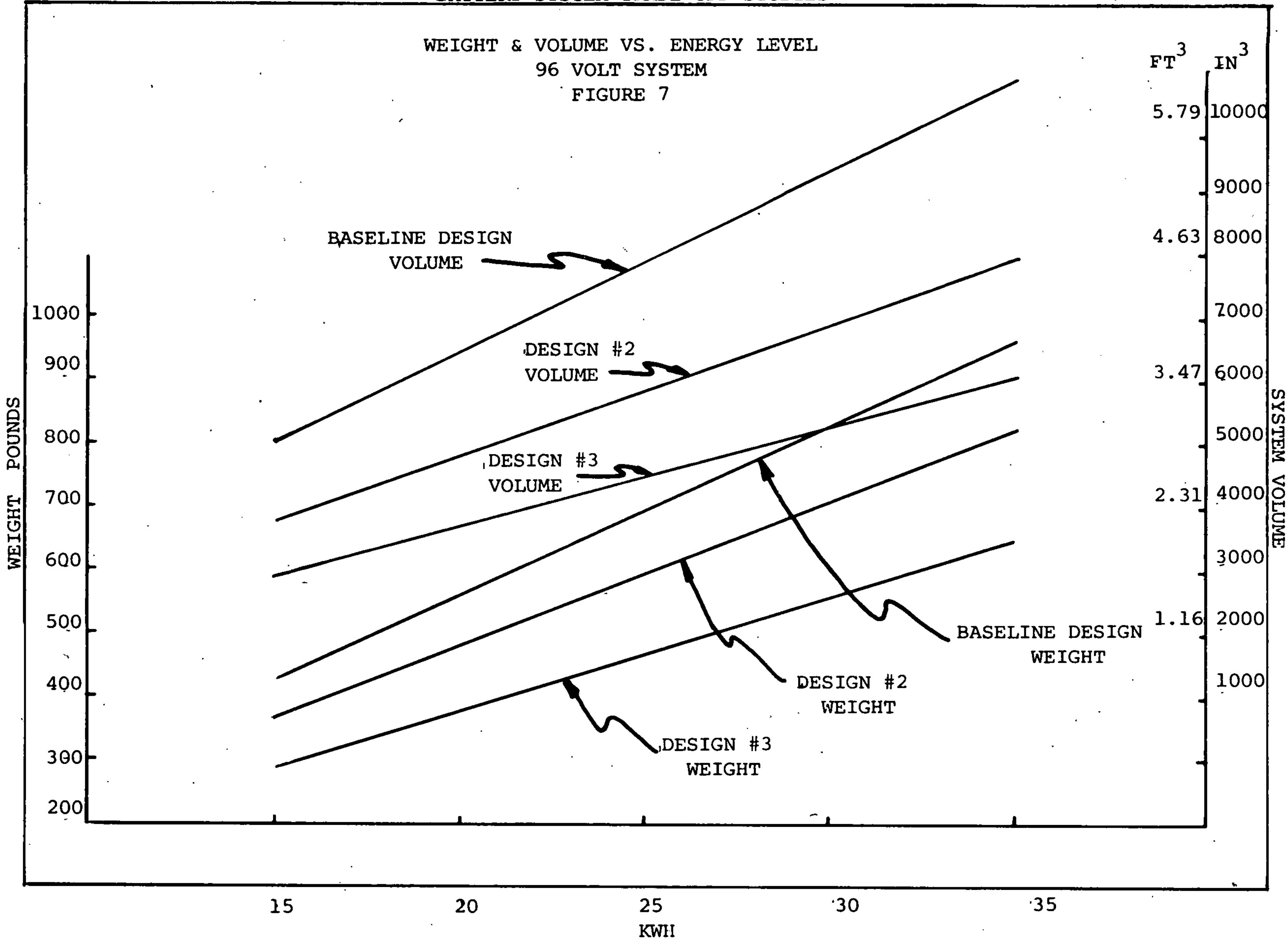


BATTERY SYSTEM TRADE OFF STUDIES

VOLUME VS. SYSTEM VOLTAGE
DESIGN #3
FIGURE 6



BATTERY SYSTEM TRADE OFF STUDIES

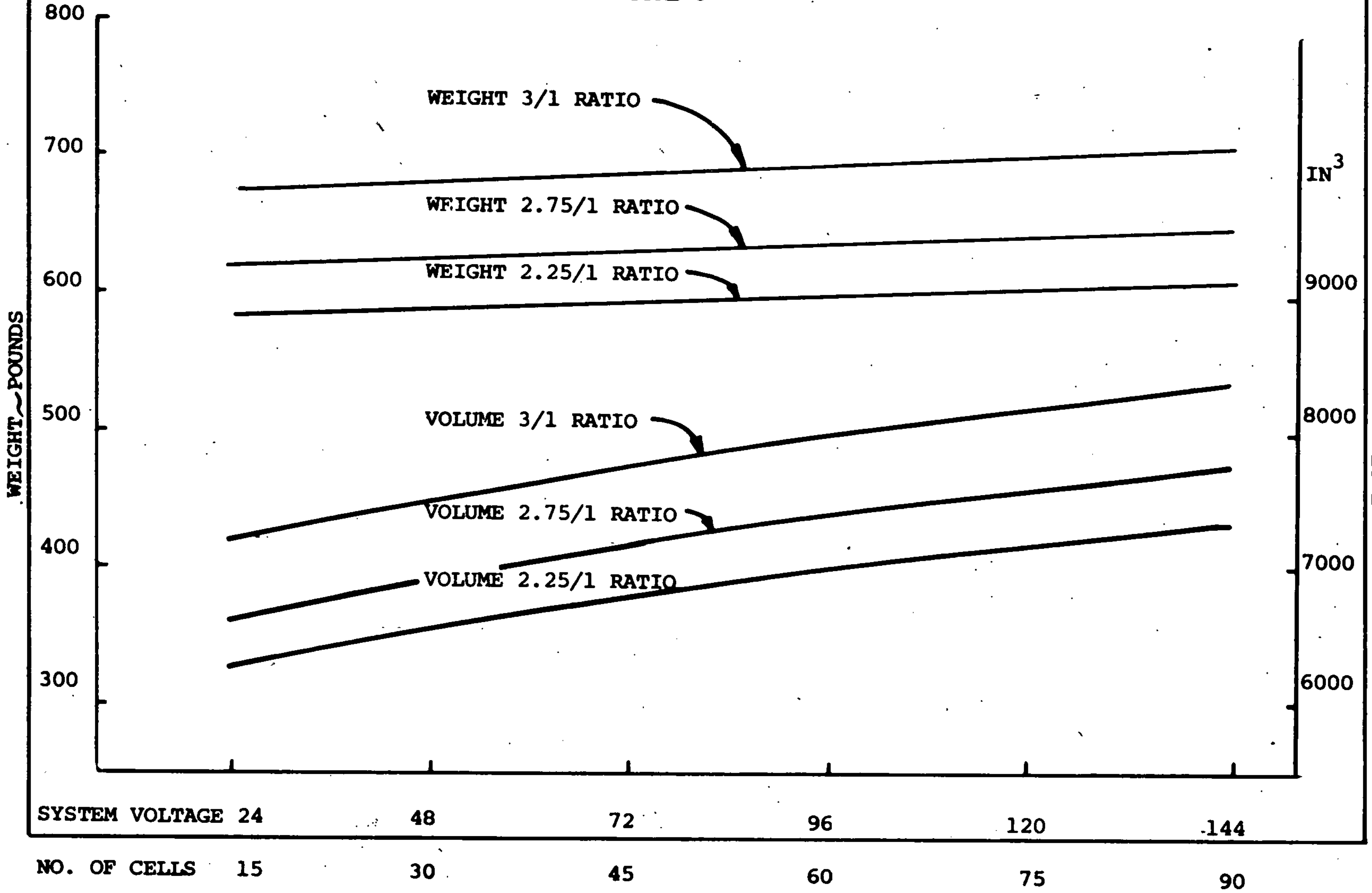


represents a weight savings of 33% and a volume savings of 50%. It is evident that the impact of system weight and volume due to the selection of various voltage levels is considerably less than the potential weight and volume savings of the improved design. There is an obvious trend toward lower battery weight and volume at the lower voltage levels, but because of the relatively small improvements, a certain amount of selection flexibility can be exercised. The range of cell capacities dictated by combinations of voltages from 24 to 144 volts and energy levels from 15 to 35 KWH is from approximately 100AH at 144 volts and 15 KWH to approximately 1500AH at 24 volts and 35 KWH. This range of cell sizes is familiar to Eagle-Picher, considering that Eagle-Picher has previously produced numerous small size cells and is presently developing cells of 300,850 and 4000 AH capacity.

In order to establish the individual effects of various design variables, calculations were made comparing the baseline design to that obtained by individually substituting an improved separator system, lower negative/positive active material ratio, and higher postitve electrode active material loading. Evaluation of Figures 8, 9 and 10 reveal that higher positive electrode active material loading option offers the greatest potential for weight and volume reduction. For a 96 volts, 25 KWH system, a 21% weight reduction and a 22% volume reduction could be realized with the higher loading level. Lowering the negative to positive

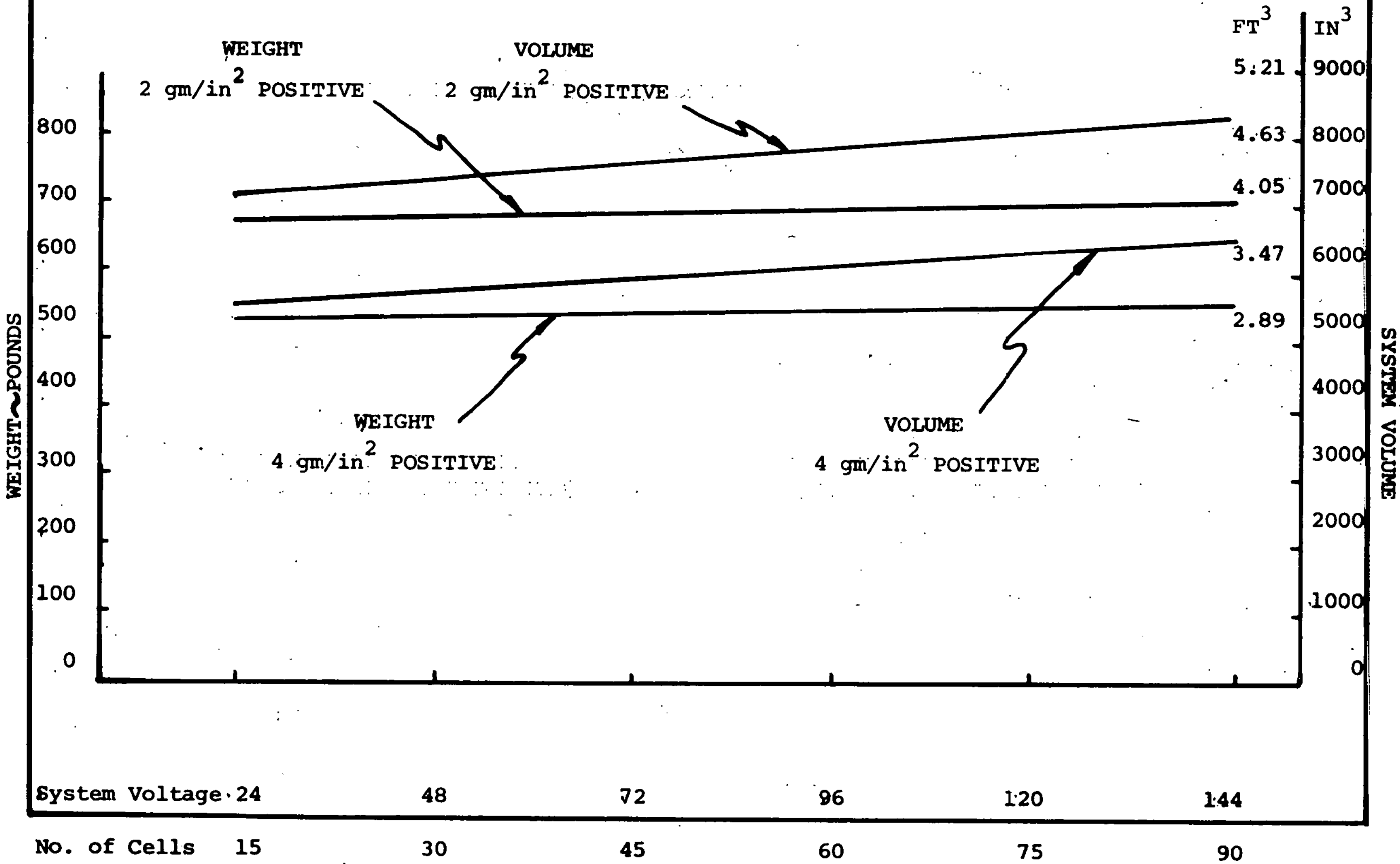
BATTERY SYSTEM TRADE OFF STUDIES

BASELINE DESIGN
EFFECT OF RATIO NEGATIVE/POSITIVE ACTIVE MATERIAL
SYSTEM ENERGY 25 KWH.
FIGURE 8



BATTERY SYSTEM TRADE OFF STUDIES

BASELINE DESIGN
POSITIVE ELECTRODE ACTIVE MATERIAL LOADING
SYSTEM ENERGY 25 KWH
FIGURE 9



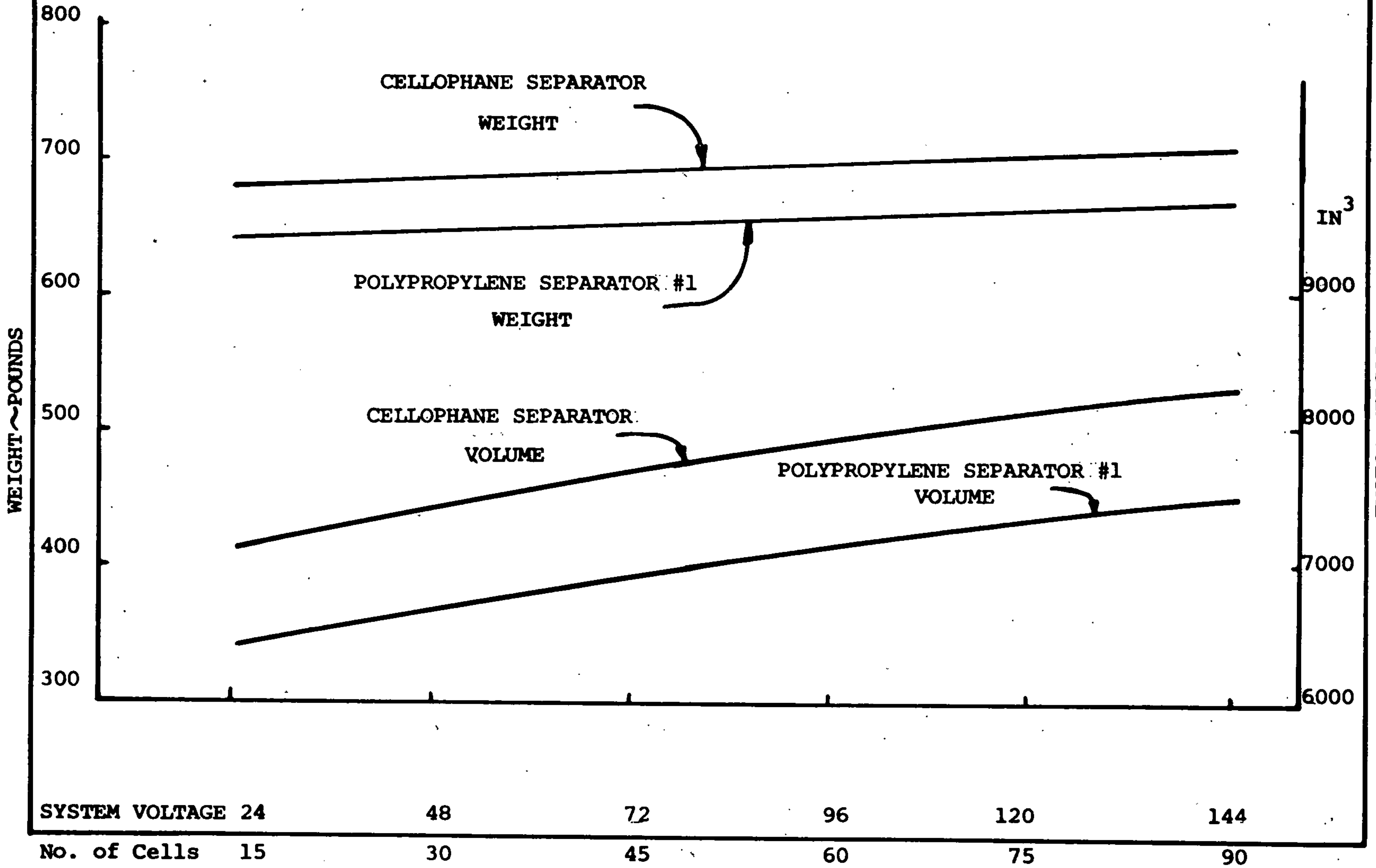
BATTERY SYSTEM TRADE OFF STUDIES

BASELINE DESIGN

EFFECT OF SEPARATOR SYSTEM ON BATTERY WEIGHT & VOLUME

SYSTEM ENERGY 25 KWH.

FIGURE 10



active material ratio offers a 14% weight reduction and a 13% volume reduction. Incorporation of the optional separator system offers a 5% weight reduction and a 10% volume reduction. The optional separator system and the lower negative to positive ratio are considered to be feasible today, while the conversion to the higher positive loading level represents the greatest challenge.

After considerable review of the configuration possibilities as a function of system voltage, the decision was made to select the optimized configuration at a voltage level of approximately 100 volts for the purposes of this design and cost study. Flexibility still remains in this decision since variation of system voltage does not effect the total amount of electrode materials processed for any given energy requirement. Selection of the 100 volt, 64 cell arrangement was made principally because of its practicality and compatibility with lower current vehicular systems being considered. It should be noted that a 25 volt (16) cell change in system voltage results in approximately a 1.7 change in system weight and a 5% change in volume. The larger number of cells allows flexibility in locating the battery in the vehicle and, if required, provides the capability for more efficient battery thermal control.

From a battery standpoint, the selected arrangement is the optimum size considering electrode size and the required packaging. The minimum weight cell case and conductor hardware was selected. Also, minimum weight "free void" electrolyte is included in the selected configuration. The resulting cell is of the size comparable with currently manufactured cells of several types. The selected electrode is also a more commonly handled size. This similarity with currently manufactured cells provided credibility to equipment and labor estimates used in other sections of this study. It is not difficult however, to observe that the fewer number of cells required to package the energy, the lower the manufacturing cost. This is evident in both the labor and component part costs principally in the area of the individually defined electrode and cell assembly. Estimates place the maximum reduction of cost due to minimizing number of cells in the range of 5 to 7 percent. Other considerations as functions of the number of cells are maintenance and possible cell balance charging requirements. All of these factors including weight and volume direct the overall improvement trend for the battery to the lower number of cells system. This trend presently appears to be in opposition to vehicle system considerations such that the design selected for this study may well emerge as the best compromise.

The following cell and system characteristics were established for purposes of this design and cost study.

BATTERY SYSTEM

64 Cells 102 Volt 25 KWH

245 Ampere Hour Cells

4 Modules per Battery

4 Submodules per Module

4 Cells per Submodule

Total Weight - 699 Pounds Total Volume - 4.77 Cubic Feet

CELL CHARACTERISTICS

Positive Active Material 939 grams

20 Electrodes - 5.93 x 3.96 x 0.070

Active Material Loading = 2.0 grams per square inch

Negative Active Material 1408 grams

20 Electrodes - 5.93 x 3.96 x 0.075

Active Material Loading - 3.0 grams per square inch

Separation System

2504K Pellon - Cellophane 193 - 2504K Pellon

Electrolyte - 1.300 Potassium Hydroxide

Cell Dimensions - 4.29 x 7.64 x 3.92

This configuration is the Baseline Design previously described, and as such is considered to be the state-of-the-art nickel-zinc system deliverable today. Possible future improvements to this design are reflected in Design No. 2 and 3.

2.2 Design Drawings/Performance Data

2.2.1 Battery Drawings

Figures 11, 12, 13 and 14 are presented as detailed drawings of the proposed design. Figure 11 depicts details of the cell design including the electrode size and cell case arrangement. It is envisioned that a submodule or four cell monoblock arrangement would be used as the lowest replaceable item in the battery (shown in Figure 12). This submodule is of a size and weight comparable to the common automotive type, electrical system battery. Figure 13 combines the submodules into a module package of delivery size including module support and intersubmodule connections. An alternate arrangement of submodules is shown in Figure 14. Four modules would be required for a complete 25 KWH battery. Also shown in Figure 15 is a sketch of a typical electric vehicle with the 25 KWH battery installed. This figure shows the relative volume relationship between vehicle and battery.

2.2.2 Performance Data

Figures 16 through 18 present some projected performance data for the proposed battery. This projected performance is based on test data obtained in Eagle-Picher laboratories on nickel-zinc cells of 7.0 to 300 ampere-hour size. Figure 16 shows battery voltage for various rates of discharge at a temperature of 75°F. Figure 17 is a plot of battery voltage as a function of temperature at the four hour rate. Capacity retention as

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

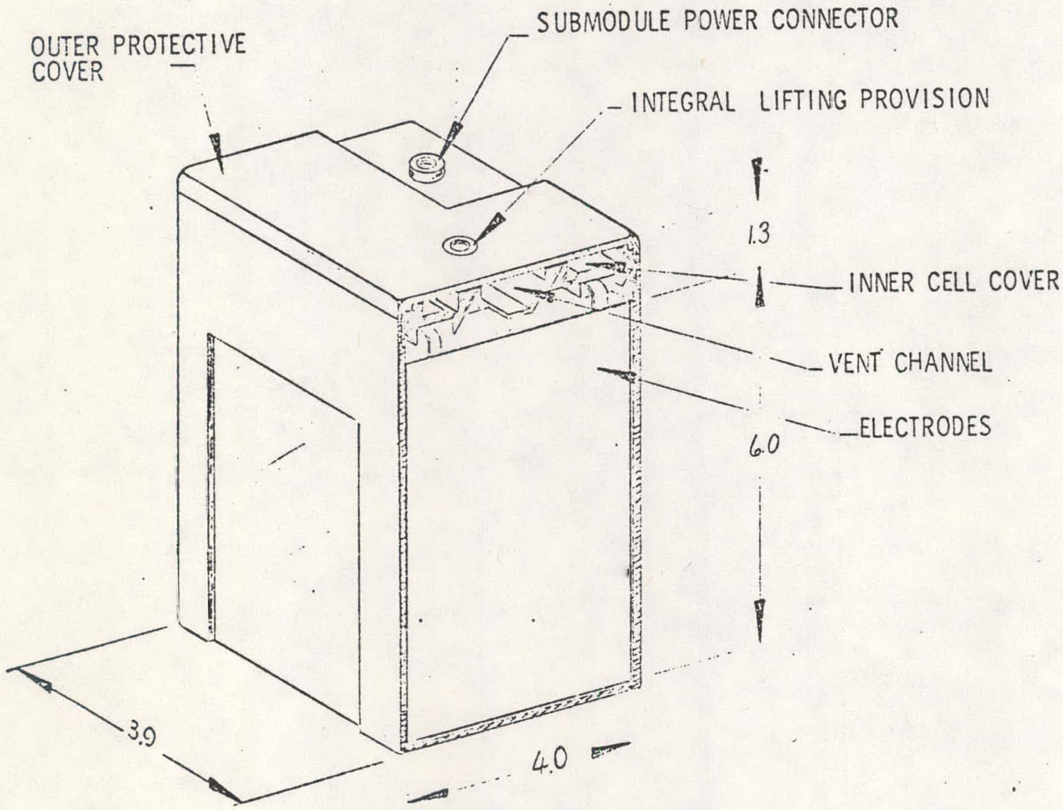


FIGURE 11

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON FRACTIONS DECIMALS ANGLES
±1/32 2 PL ±.03 3 PL ±.010 ±2°

MATERIAL:

CONTRACT NO.

DATE

PREPARED
CHECKED
ENGINEER

EAGLE PICHER INDUSTRIES, INC.
COUPLES DEPARTMENT
JOPLIN, MISSOURI

CELL DESIGN DETAIL

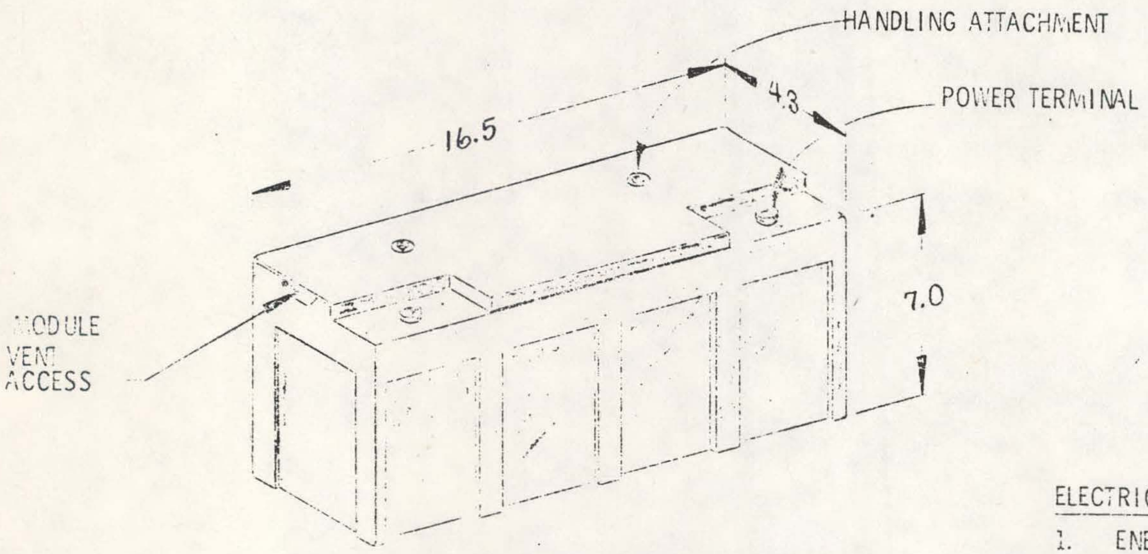
SIZE B CODE IDENT NO. 81855 006209

SCALE 1/2 SHEET

NEXT ASSY USED ON
APPLICATION

5	4	3	2	1

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

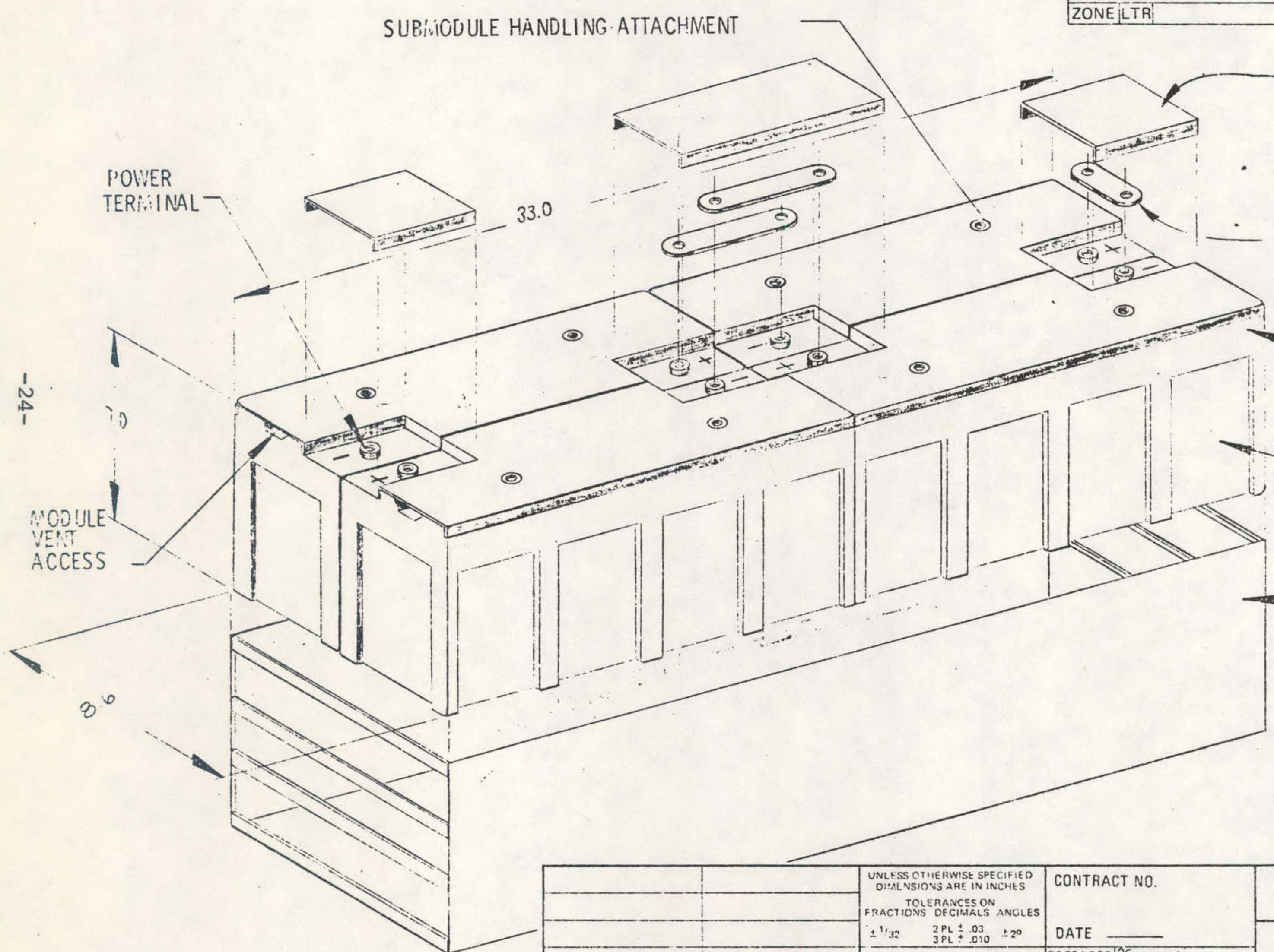


ELECTRICAL/PHYSICAL CHARACTERISTICS

1.	ENERGY	1.56 KWH
2.	VOLTAGE	6.4 V NOMINAL
3.	VOLUME	.3 CUBIC FEET
4.	WEIGHT	44 POUNDS

FIGURE 12

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES ± 1/32 2 PL ± .03 ±2° 3 PL ± .010	CONTRACT NO.	EAGLE PICHER INDUSTRIES, INC. COUPLES DEPARTMENT JOPLIN, MISSOURI	
MATERIAL:	DATE PREPARED CHECKED ENGINEER	FOUR (4) CELL SUB MODULE DESIGN	
NEXT ASSY / USED ON		SIZE B	CODE IDENT NO. 81855 / 006211
APPLICATION		SCALE	SHEET



ELECTRICAL/PHYSICAL CHARACTERISTICS

1.	ENERGY	6.25 KWH
2.	VOLTAGE	25.6 NOMINAL
3.	VOLUME	1.2 CUBIC FEET
4.	WEIGHT	176 POUNDS

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON FRACTIONS DECIMALS ANGLES
±1/32 2 PL ± .03 3 PL ± .010 ±2°

MATERIAL:

CONTRACT NO.

DATE

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EAGLE PICHER INDUSTRIES, INC.
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JOPLIN, MISSOURI

6.25 KWH MODULE DESIGN

SIZE B | CODE IDENT NO. 81855 | 006208
SCALE | SHEET

FIGURE 13

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

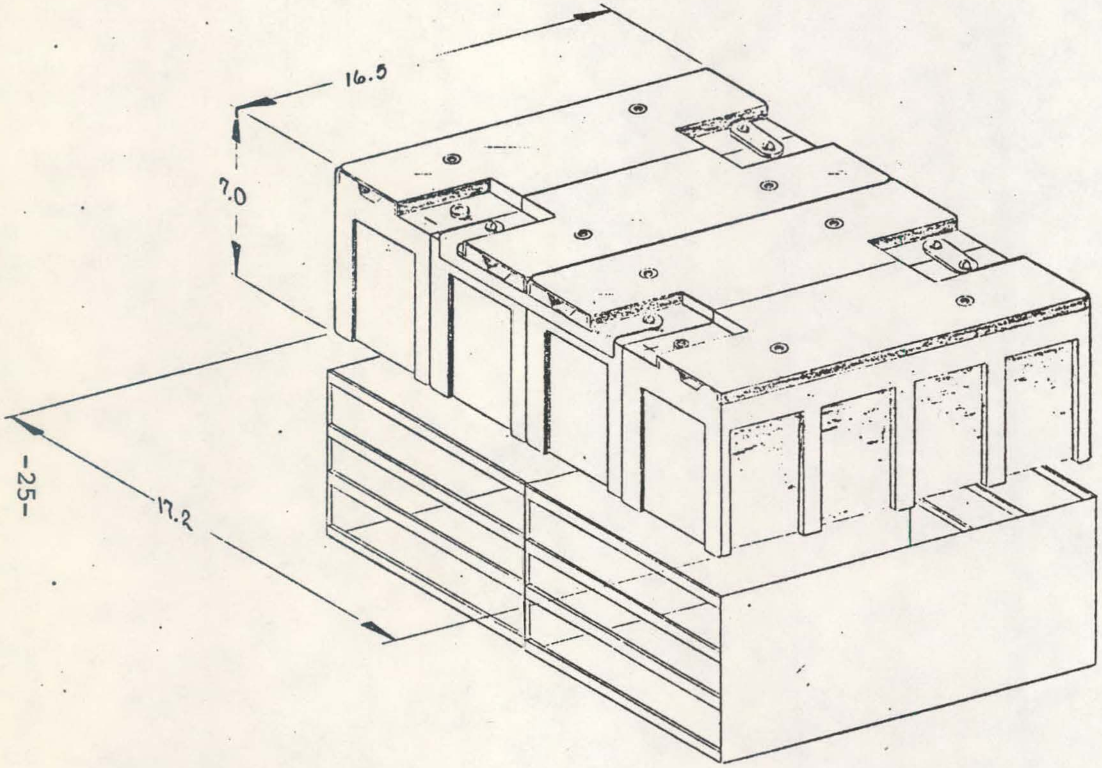

FIGURE 14

FIND NO.	QTY REQD.	CODE IDENT.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	SPEC	MATERIAL OR NOTE	EP NO.

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS DECIMALS ANGLES
± 1/32 2 PL ± .03 3 PL ± .010 ± 2°

MATERIAL:

CONTRACT NO.

DATE
PREPARED
CHECKED
ENGINEER

NEXT ASSY | USED ON
APPLICATION

EAGLE PICHER INDUSTRIES, INC.
COUPLES DEPARTMENT
JOPLIN, MISSOURI

6.25 KWH MODULE DESIGN
(ALTERNATE ARRANGEMENT)

SIZE C | CODE IDENT NO. 81855 | 006210

SCALE | SHEET

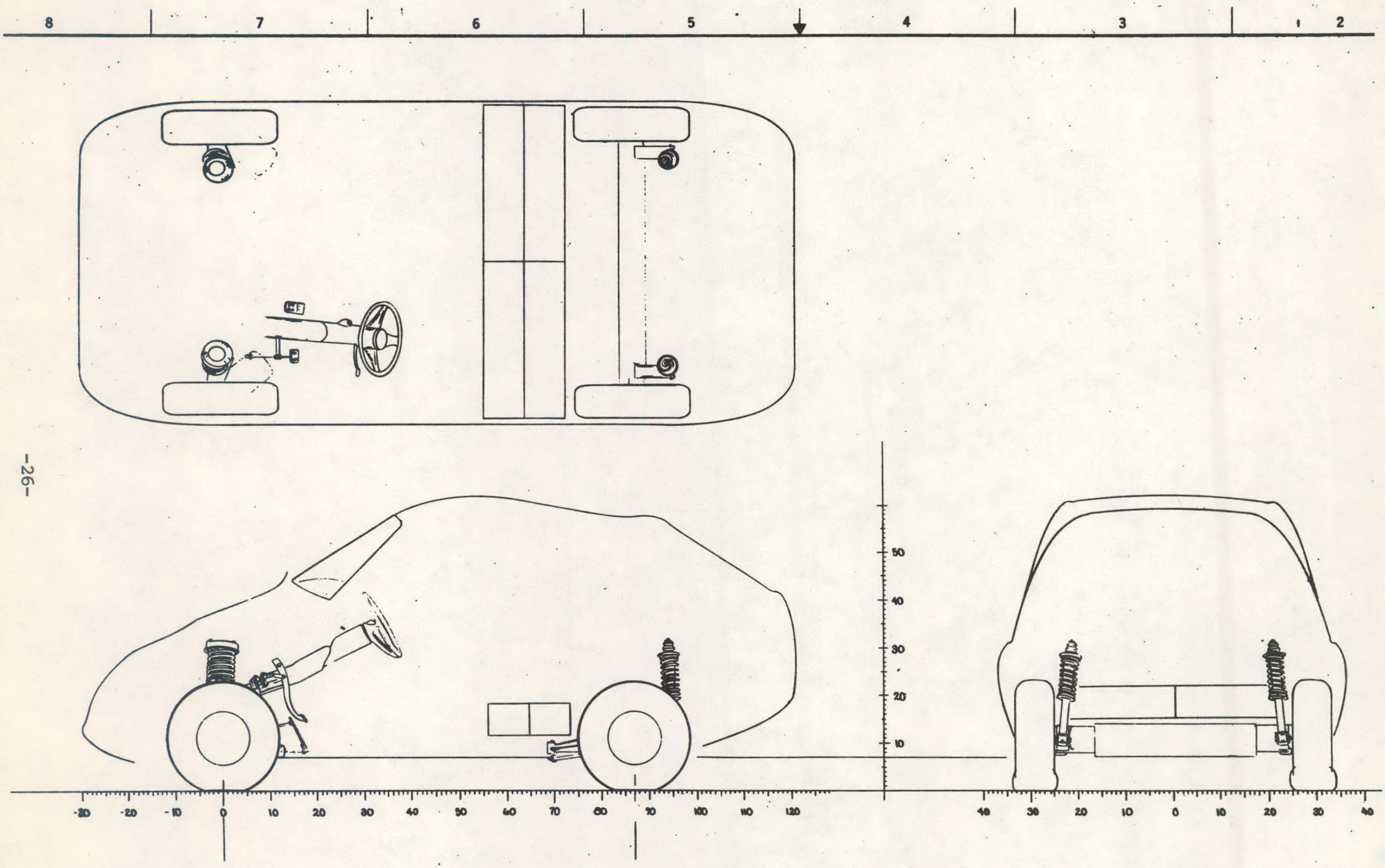
8
7
6
5
4
3
2
50
40
30
20
10
-20
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
40
30
20
10
0
10
20
30
40

FIGURE 15

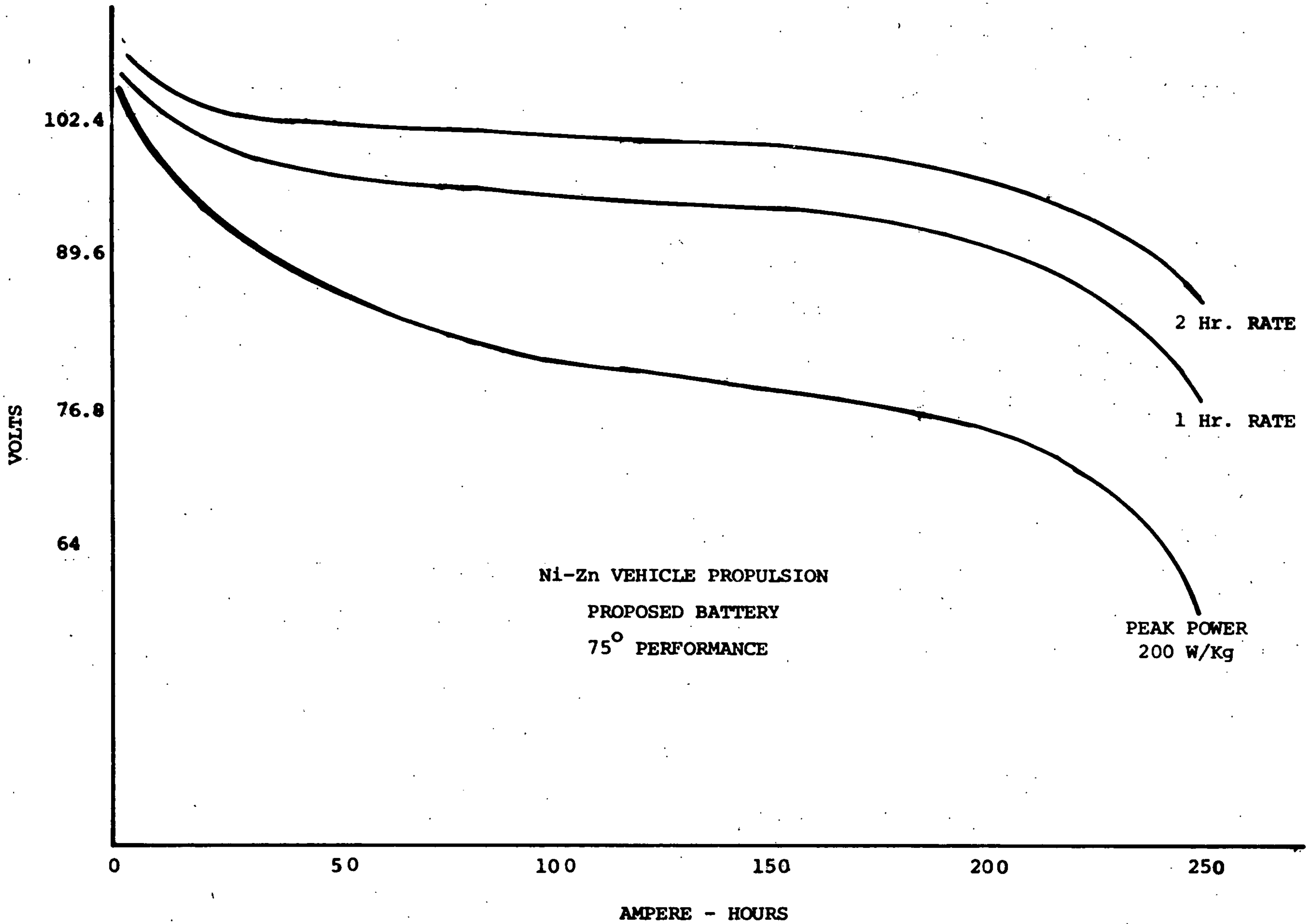
VOLTS
102.4
89.6
76.8
64
0
50
100
150
200
250
AMPERE - HOURS
2 Hr. RATE
1 Hr. RATE
PEAK POWER
200 W/Kg
Ni-Zn VEHICLE PROPULSION
PROPOSED BATTERY
75° PERFORMANCE

FIGURE 16

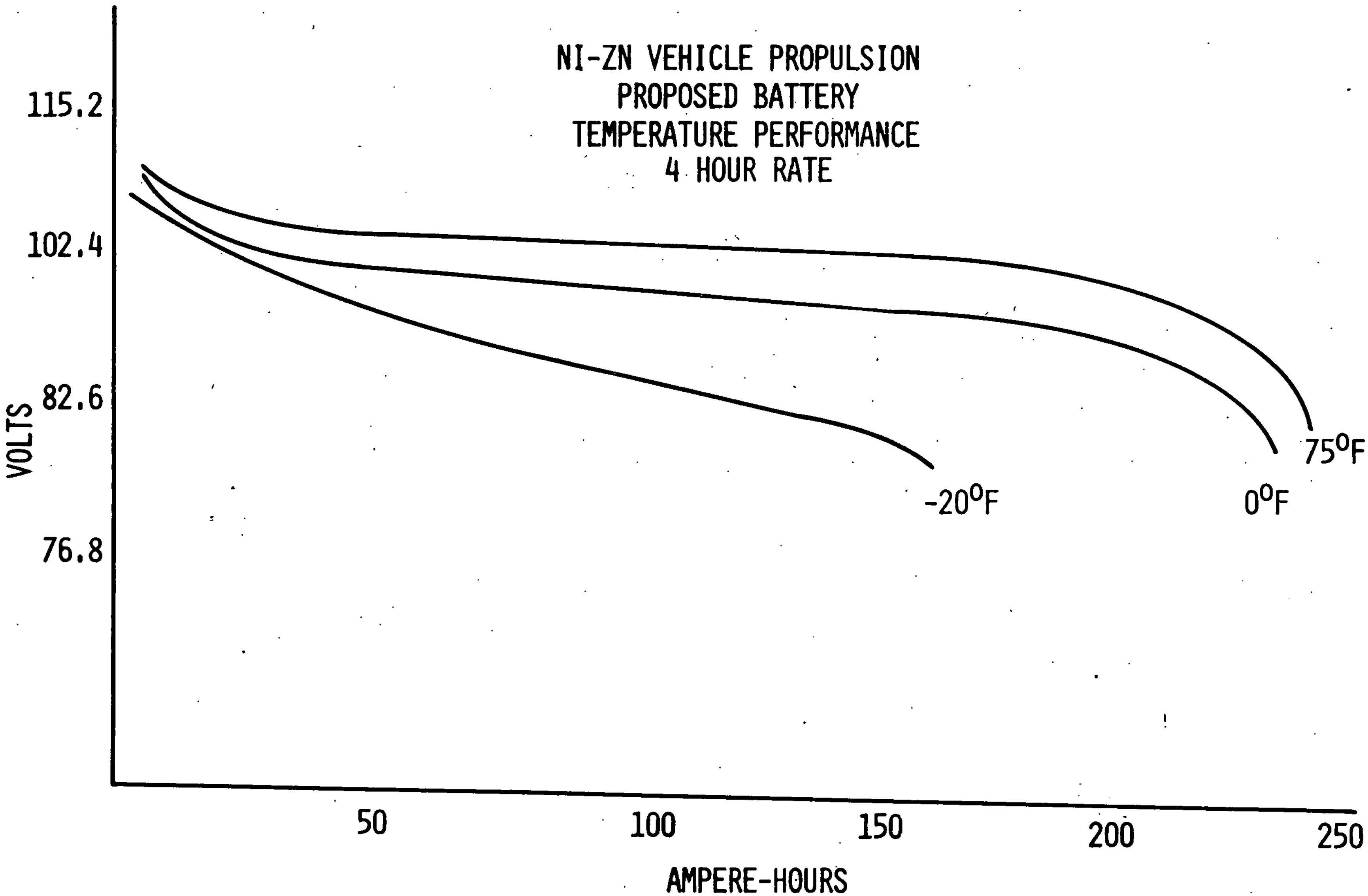
NI-ZN VEHICLE PROPULSION
PROPOSED BATTERY
TEMPERATURE PERFORMANCE
4 HOUR RATE
115.2
102.4
82.6
76.8
VOLTS
-20^{0}F
0^{0}F
75^{0}F
50
100
150
200
250
AMPERE-HOURS

FIGURE 17

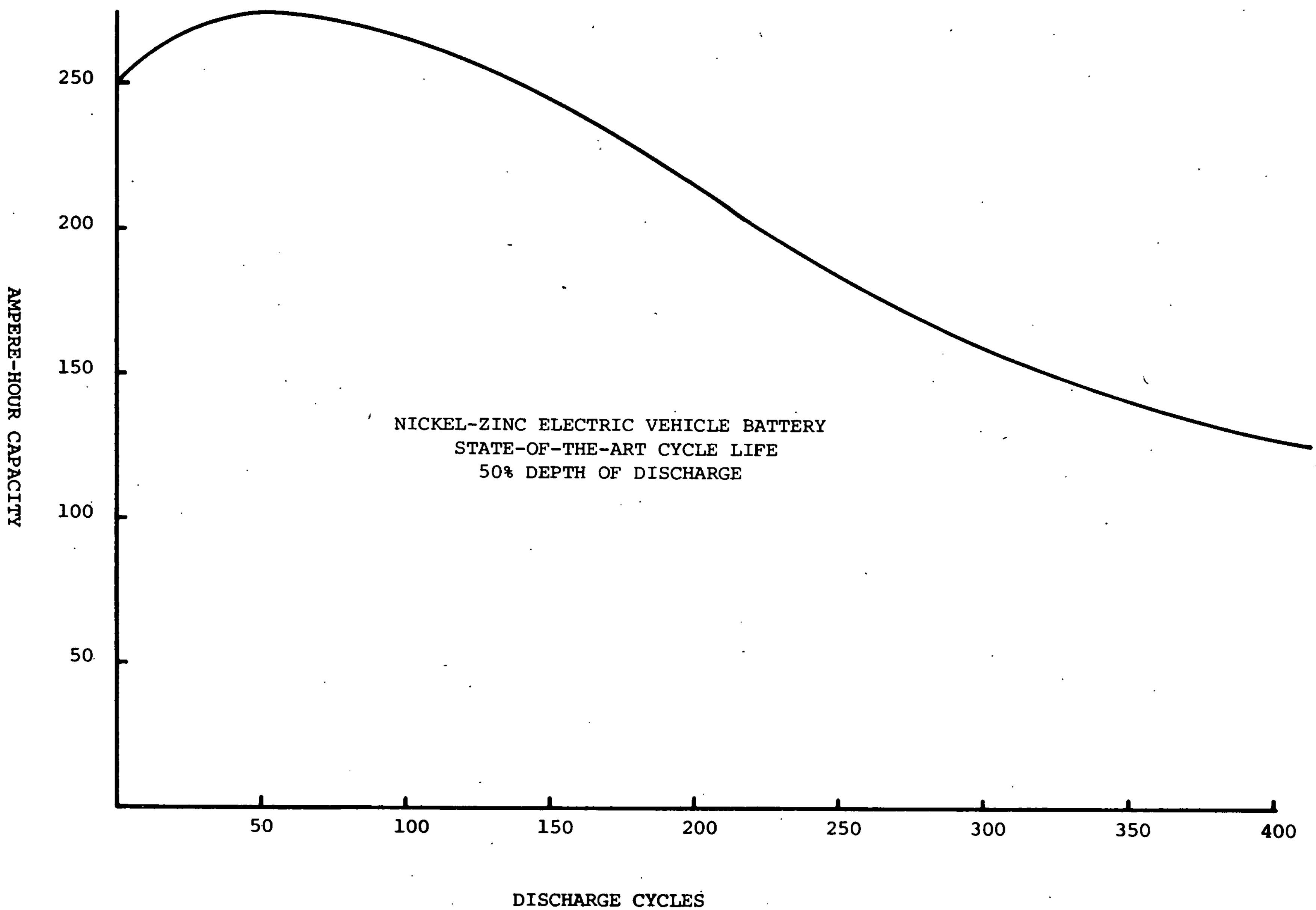
NICKEL-ZINC ELECTRIC VEHICLE BATTERY
STATE-OF-THE-ART CYCLE LIFE
50% DEPTH OF DISCHARGE
AMPERE-HOUR CAPACITY
250
200
150
100
50
50
100
150
200
250
300
350
400
DISCHARGE CYCLES

FIGURE 18

a function of cycling is shown in Figure 18. This cycle life is what could reasonably be expected for a deep discharge duty cycle (60 - 80%). The performance presented in these figures is applicable for the proposed battery configuration (Baseline Design) with sintered positive electrodes. This performance is strictly state-of-the-art with no allowance made for potential improvements. It is referred to as projected only because it has been demonstrated in laboratory tests (7.0 to 300 AH cells) but not in the specific configuration of the proposed propulsion battery.

2.2.3 Power Capability

An analysis of the power capability of the proposed battery has been prepared, with the following results. This analysis included both sintered and non-sintered nickel electrodes and resulted in a significant differentiation between the two electrodes. The following table shows the maximum power output for the proposed battery with both sintered and non-sintered electrode. Power is limited by the current density maximum of $.25A/in^2$ for non-sintered electrodes and $1.77A/in^2$ for sintered electrodes. The non-sintered electrode current density is the maximum obtainable. The sintered electrode will operate at current densities above $1.77A/in^2$, but this limit was selected to avoid thermal complications. Power output can be calculated, given the cell surface area (dictated by the active material loading), the current density, and the voltage vs. current density relationship. These values are shown below.

POWER CAPABILITY - BASELINE DESIGN

	Sintered Electrodes	Non-Sintered Electrodes
Positive Active Material Loading	2.0 gm/in^2	2.0 gm/in^2
Cell Surface Area	916 in^2	916 in^2
Maximum Current Density	1.77 A/in^2	.25 A/in^2
Power Output	2000 Watts/cell	355 Watts/cell
Peak Power Requirement (200 Watts/Kg x 5 Kg/cell)	1000 Watts/cell	1000 Watts/cell
Energy Density (c/5 Rate)	80 WH/Kg	80 WH/Kg

The significance of this analysis is that the sintered electrode battery has twice the required power capability in the Baseline Design, while the non-sintered electrode battery has only one-third the required power capability. The sintered electrode design can be modified by increasing the active material loading, which lowers the cell surface area and total output current at a fixed current density, until the output power is reduced from 2000 Watts/cell to 1000 Watts/cell. This level is obtained at an active material loading of 4.0 gm/in^2. This is the modification that was performed to obtain the previously discussed Design No. 3 and its resulting energy density of 120 WH/Kg. The same type of modification, but in reverse, can be performed on the non-sintered electrode design. In order for this design to deliver 1000 Watts/cell, active material loading must be reduced to .72 gm/in^2 and a corresponding energy density of 55 WH/Kg is obtained.

2.2.4 Thermal Analysis

It is anticipated that thermal considerations will significantly influence both the battery design and the battery/vehicle interface. An elementary thermal analysis, as shown below, predicts a significant temperature rise if no provision is made for removing the heat from the battery.

Assumed System Characteristics: 64 cells
245 AH Capacity
25 KWH system energy
1.6 volts/cell load voltage
700 lbs.
75% depth of discharge

Composite Specific Heat: 0.2 BTU/lb-^{O}F

The internal heat generation can be calculated as:

64 cells (open circuit voltage - load voltage)(discharge capacity)

64 (1.75-1.6)(245)(.75)

= 1764 Watt-hours

=6020 BTU

This results in a temperature rise of:

$$(6020\ \text{BTU})\left(\frac{\text{lb-}^{O}\text{F}}{.2\ \text{BTU}}\right)\left(\frac{1}{700\ \text{lbs.}}\right) = 43^{O}\text{F temperature rise}$$

This calculated value of temperature rise does not account for heat dissipated from the battery through convection, conduction, or radiation. In fact, these are the means that must be employed in order to prevent the realization of the potential temperature. To do this, the battery has been designed with integral thermal spaces to allow good thermal conduction from the cell stacks to a vehicle heat sink. Also, the battery/vehicle interface design must include certain factors; such as flow-through ventilation, maximum heat sink material, and separated physical arrangement, in order to maximize battery cooling.

Excessive battery heating will be manifested in dramatically shortened battery life, reduced discharge and charge efficiencies, and failure to accept charge until cooled to room temperature. Attempts to charge the battery while at an elevated temperature will cause loss of electrolyte, excessive gassing and zinc dendrite shorting.

2.2.5 Charging Methods

With respect to preferred charging procedures, Eagle-Picher employs a current limited - constant potential charge at 1.88 volts per cell. This procedure will charge a fully discharged cell to 90% capacity in 2 hours and full capacity in 3 hours. It will also limit the overcharge to 5 - 10%, which is extremely important in maximizing the cells' cycle life. This charging method has been used in Eagle-Picher laboratory testing on battery level tests containing up to 10 series cells and demonstrating cycle life in excess of 400 cycles. Considering the specified duty cycle charge of 4 - 8 hours, Eagle-Picher has demonstrated state-of-the-art quick charging methods beyond the goal requirements.

2.2.6 Goals Vs. Performance Summary

A summary of the anticipated performance and capability of the proposed Baseline Design, the ANL goals, and some projected potential improvements is shown below.

GOALS & CAPABILITIES FOR NICKEL-ZINC
ELECTRIC VEHICLE BATTERY

	ANL GOALS	Current Technology Baseline Design	Projected
Duty Cycle	2-4 Hr. Discharge	1 Hr. Discharge (60-80% DOD) 3 Hr. Charge	1 Hr. Discharge (60-80% DOD) 3 Hr. Charge
Energy Efficiency	60%	75%	75%
Cycle Life	1000	250-300	750-1000
Cost	$50/KWH	$600-800/KWH	$78/KWH
Specific Energy	110 WH/Kg	80 WH/Kg	120 WH/Kg*
Specific Power Sustaining	50 W/Kg	100 W/Kg	50 W/Kg*
Peak	200 W/Kg	400 W/Kg	200 W/Kg*

*These projections assume sacrificing existing power capability in order to achieve higher energy density.

3.0 CURRENT DEVELOPMENT PROBLEMS

The following paragraphs contain what is considered to be the major problem areas that must be engaged during the nickel zinc development. These areas are discussed in order of their relative importance. Assessment is made qualitatively based upon the major factors of cost, cycle life and energy density.

Generally, it can be stated that the actual use cost of the system varies proportionally with any of the major factors which affect cell performance. For example, if the cycle life is doubled, actual use cost is reduced by one-half. On the other hand, a manufacturing cost reduction, for example, reducing the cost of the positive electrode by one-half, only reflects in actual use cost to the extent that the positive electrode contributes to the total cost of the system. The impact would be something less than a one-half reduction.

Since the negative electrode is the cycle life "limiter" of the current nickel-zinc design, any improvement is directly converted into a proportional reduction in actual use cost. Cycle life of the negative electrode is the cycle life of the cell. If the (Specified) cycle life goal of 1,000 cycles can be attained, primarily through negative electrode improvements, a cost impact would be realized which would exceed any achieved through modification of the positive electrode design and processing. And this reduction of cost could be realized without compromising an already proven, highly efficient, dimensionally stable and structurally sound electrode. The creation of a new developmental problem would also be eliminated.

3.1 Negative Electrode

Improving the cycle life capability of the negative electrode emerges as the major technical obstacle requiring considerable attention. Capacity degradation and subsequently cycle life is primarily a function of the negative electrode efficiency or the increasing unavailability of active zinc material. Specifically, zinc electrode inefficiency is manifested by the shape change phenomona, dendritic formations and hydrogen gas evolution. Hydrogen gas liberation or self-discharge only appears to be a problem in extended stand situations and is not considered to be of major concern. Dendritic formations can be attacked at the cause by use of certain additives or tolerated by proper selection of separator materials which are resistant to dendrite growth. Major concern thus becomes the effort required to reduce, retard or eliminate shape change. Improvements in this area not only could yield the desired additional cycles but also achieve a payoff in energy density by improving zinc efficiency. Cost would also be slightly effected due to the reduction in zinc material.

In terms of cost for the negative electrode, reduction of cost would be well served by replacing the grid structure of silver with a suitable substitute material, such as copper, zinc, or zinc coated copper. More importantly, eliminating silver as the negative electrode grid structure is considered mandatory for this application. Several materials or combinations of materials are currently being evaluated. Although solution to this problem is very important costwise, finding an acceptable substitute is not expected to be a technically difficult task. Elimination of silver from the zinc electrode also eliminates a source of gas evolution due to the contact of dissimilar metals in common electrolyte.

3.2 Positive Electrode

Primary concern regarding the positive electrode is in the area of cost. To produce a dimensionally stable electrode with a relatively inert structure capable of extensive cycling can involve several wet processes. Processing costs become a major consideration when compared to the more easily processed negative electrode. These processing costs coupled with relatively expensive materials yield an expensive component. It should be noted that cost history has been based upon production rates and quality levels required by aerospace and aircraft applications. At the required production rates, new experience may be gained which will generate the feedback necessary for cost optimization. Certainly costs will reduce based upon the higher production rates required. Further reduction in cost may be in the area of the substrate and its manipulation for cost and energy density effectiveness. Energy density improvement would be an added payoff with any reduction in substrate requirements.

Reduction in positive electrode manufacturing costs are anticipated from the incorporation of the new electrochemical methods of impregnation. These methods involve fewer steps and significantly reduced time as compared to classical impregnation methods. This will be described in Paragraph 4.1.

3.3 Separation System

The separation system generates a considerable amount of interest during the development of any secondary cell. Cellulosic types are being used extensively in present day cells including nickel zinc. These types, cellophane, FSC, etc. are still subject to degradation by oxidation. To provide the necessary separation scheme for long cycle life, it is necessary to use multiple layers of cellulosics which contribute to increasing cell volume. Most importantly, in the nickel zinc system, the resistance of the separator material to penetration due to zinc dendrite growth is a necessary attribute. As the cycle life of the zinc electrode itself demonstrates developed improvement, the role of the separation system will become increasingly important. The interaction between the type, configuration and quantity of separation material and the shape change of the negative electrode also requires specific attention and evaluation. Thus, the search for the ideal system must continue involving the evaluation of new materials becoming available. Developments in the separation system area must be tempered by mass production considerations and must not ignore costs. And, compounding the already complex requirements placed upon the separator system, the system is required to yield adequate, efficient electrical performance. Continuing interest in the separator system should be maintained to keep abreast of any developments in active material capabilities.

3.4 Electrolyte

Electrolyte should also be considered as a potential area of improvement. Currently, a 30% solution of potassium hydroxide is specified. Interactions between the electrolyte and the negative electrode efficiency appear to be most important. Evaluations are being made concerning varying specific gravity and the use of additives. A reduction in gas evolution as well as improvement in cycle life may be expected. And, it should not be overlooked that the electrolyte is an important element in the negative electrode shape change condition.

4.0 MANUFACTURING PROCESSES

Figure 19 shows the general layout of the battery manufacturing processes and includes reference figure numbers for the detailed breakdown. Fabrication of the active material electrodes is the critical sequence of the process. Once the electrodes are complete, the remaining operations are strictly assembly in nature adapting to an assembly line.

The following sections contain a brief description of the manufacturing process steps. Each detailed figure is discussed individually.

4.1 Positive Electrode (Figure 20)

The positive electrode of the nickel zinc battery must be trouble free and reliable to produce a stable battery due to the inherent problems of the negative electrode. The production proven, dependable nickel hydroxide electrode manufactured on a sintered nickel substrate can be reduced in cost to make it more competitive with the non-sintered and pocket electrode manufacturing techniques on a cost-per-cycle basis. This plaque manufacturing technique is described containing several cost savings modifications to the process. The major features are the formation of a 0.070 inch thick sintered plaque by the dry process and completing the impregnation and formation of the active material in a single batch process tank system. Impregnation will be accomplished using an electrochemical deposition technique that has been developed by Eagle-Picher as a

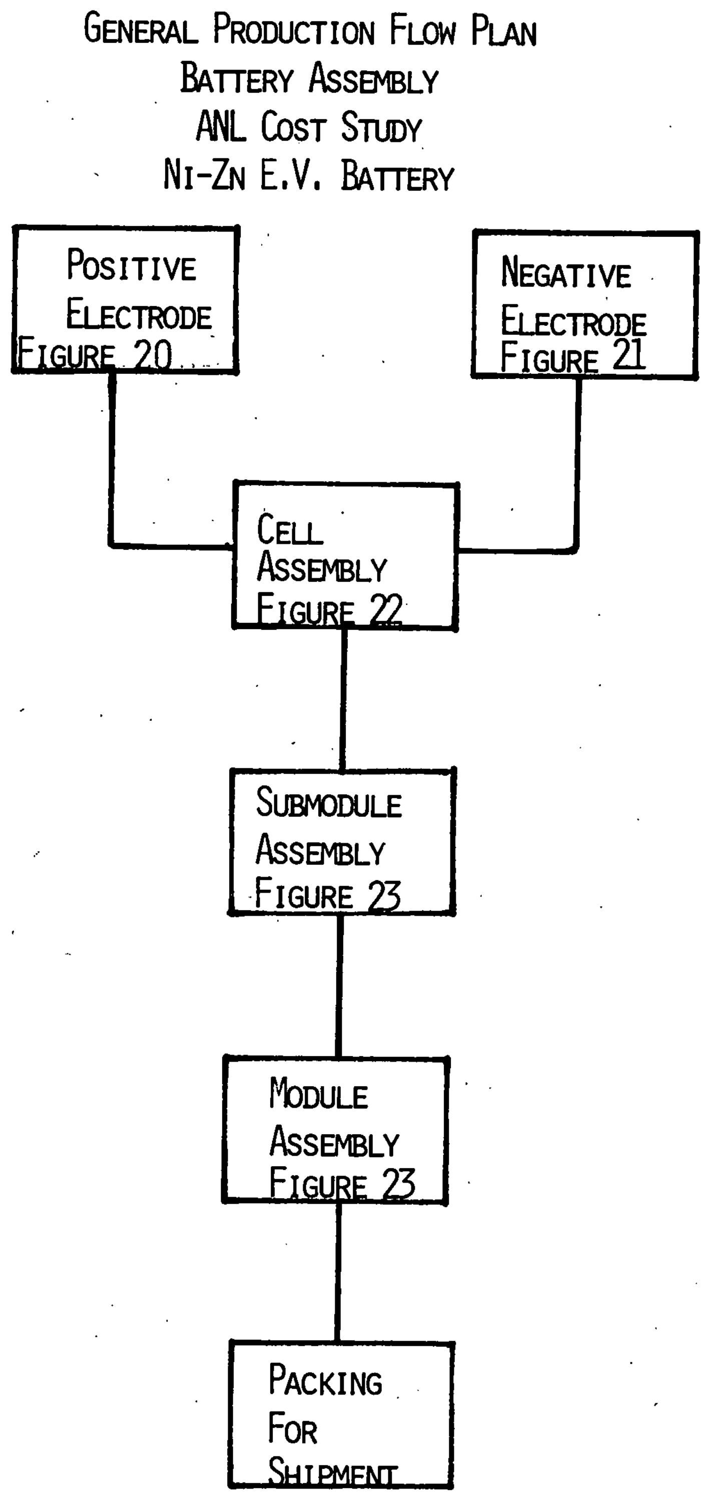
GENERAL PRODUCTION FLOW PLAN
BATTERY ASSEMBLY
ANL COST STUDY
NI-ZN E.V. BATTERY
POSITIVE ELECTRODE FIGURE 20
NEGATIVE ELECTRODE FIGURE 21
CELL ASSEMBLY FIGURE 22
SUBMODULE ASSEMBLY FIGURE 23
MODULE ASSEMBLY FIGURE 23
PACKING FOR SHIPMENT

FIGURE 19

POSITIVE ELECTRODE PROCESSING
ANL COST STUDY
NI-ZN E.V. BATTERY

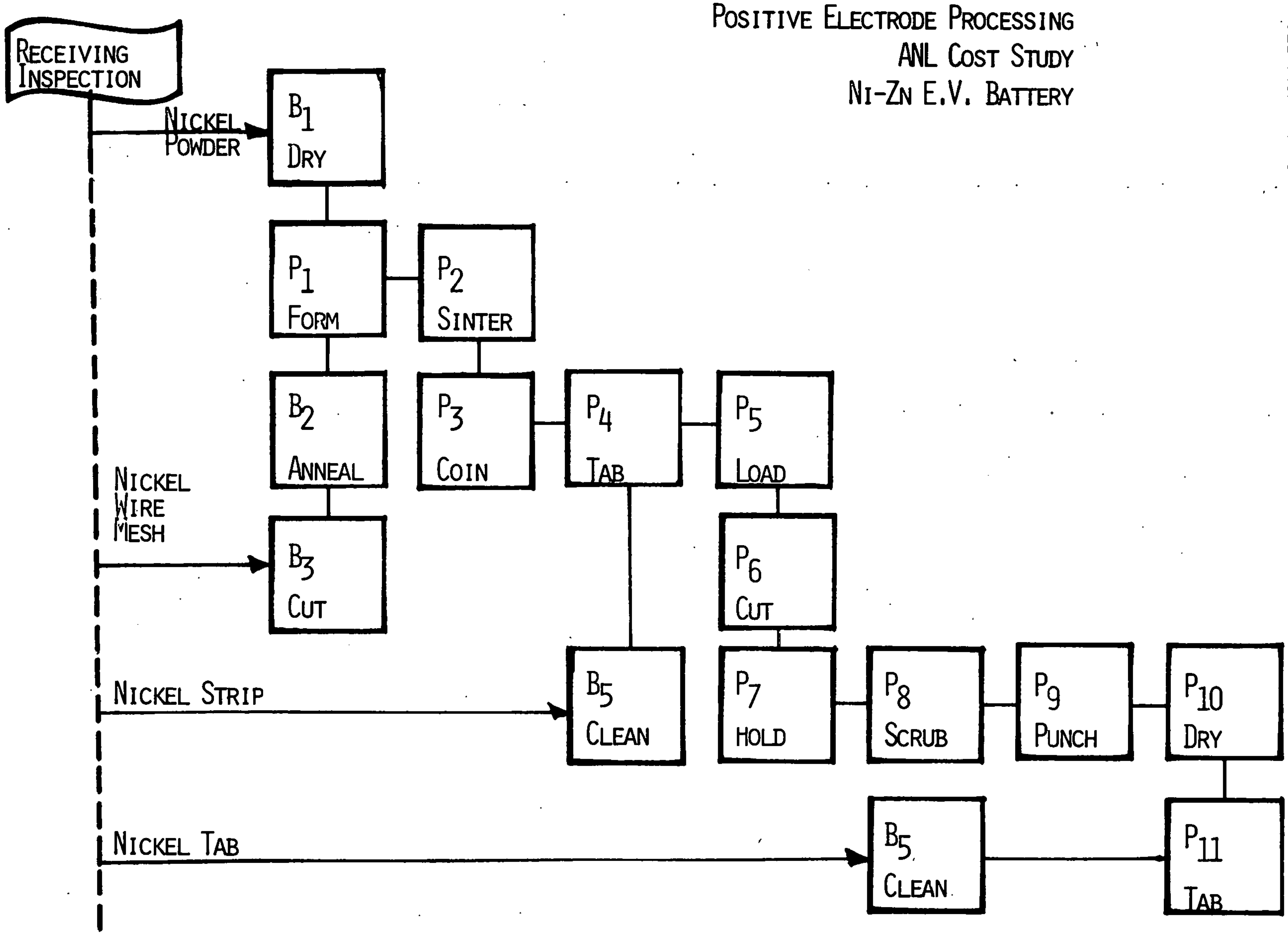

FIGURE 20

modification of the classical impregnation method used for many years. Eagle-Picher is familiar with Western Electric and Air Force patents on electrochemical deposition and has permission to use both patents. The Eagle-Picher process does not infringe either patent and is presently being submitted for patent.

In the final processing, the use of a semiautomated scrubbing machine gives the operator time for a visual examination of the electrode during the feeding handling. Use of conveyors can eliminate all manual handling between the final process steps. As all parameters and variables are recognized from present production and research, no significant variable will be introduced into the techniques discussed herein.

P_1 Form - Nickel plaque is formed by laying a woven wire screen in a shallow mold, filling the mold with pure, dry nickel powder and leveling to the desired height. A carrier platen is clamped to the top of the mold and the mold is inverted. The platen with the molded plaque is placed on the furnace belt for sintering.

P_2 Sinter - Molded plaque material travels through a continuous furnance with an established heat profile for desired results. A three zone furnace with a reducing atmosphere is necessary to perform this operation. Plaque and carrier platen are separated as they emerge from the cooling zones in the furnace. Carrier platens are returned to the forming process and plaque material is stacked in lot batches.

P_3 Coin - Sintered plaque is coined on both sides to outline the desired electrode pattern. An indexing notch is also formed for use during the electrode punching operation.

P_4 Tab - Nickel strip to be used for making plaque connections to processing bus bars are welded to each plaque along two edges.

P_5 Load - Plaques are suspended by the tabs from input bus bars between the counterelectrodes of the processing tank. Impregnation solution is brought into the tank, the deposition process completed and the solution removed. Potassium hydroxide is brought into the tank for the formation charge/discharge cycle. KOH is removed after the formation cycle and the plaques are rinsed with hot, demineralized water. Two additional rinse cycles are performed, followed by a final rinse using deionized water. Water is agitated during all rinsing. Plaques are now ready for removal from tank.

P_6 Cut - This operation removes the nickel strip that was welded on in P_4. A power shear is used.

P_7 Hold - Impregnated and formed plaques are placed in a hold/soak tank of deionized water awaiting final processing.

P_8 Scrub - Plaques are removed from the hold tank and fed through a machine which simultaneously scrubs both sides of the plaque with stiff bristle brushes while continually rinsing the plaque in deionized water.

P_9 Punch - The clean plaque continues on to the punch press for blanking into the final electrode size. Indexing is via the notches cut during the coining operation, P_3.

P_{10} Dry - The punch-through die drops the finished electrode onto a conveyor which enters a drying chamber.

P_{11} Tab - Preformed tabs are resistance welded to the finished electrode in the coined area formed for this purpose. The electrode is now ready for cell assembly.

4.2 Negative Electrode -(Figure 21)

The negative electrode can be processed by means of a vacuum deposition method. Because of a newly developed binder system, a water slurry method was selected, a method with a continuous deposition of slurry feature. The slurry deposition is very similar to the technique used by Eagle-Picher in secondary zinc plate manufacture with the exception of the continuous feature.

N_1 Weigh - Deposition ingredients are measured on a batch basis for addition to the blender.

N_2 Blend - Batch blender blends zinc oxide and binder system at a rate capable of providing slurry to the continuous process.

N_3 Deposit - A continuous roll of grid material is passed through the slurry box depositing a uniform amount of blend. The strip is subjected to a vacuum to aid in bonding the material to the grid and to remove excess water.

NEGATIVE ELECTRODE PROCESSING
ANL COST STUDY
NI-ZN E.V. BATTERY

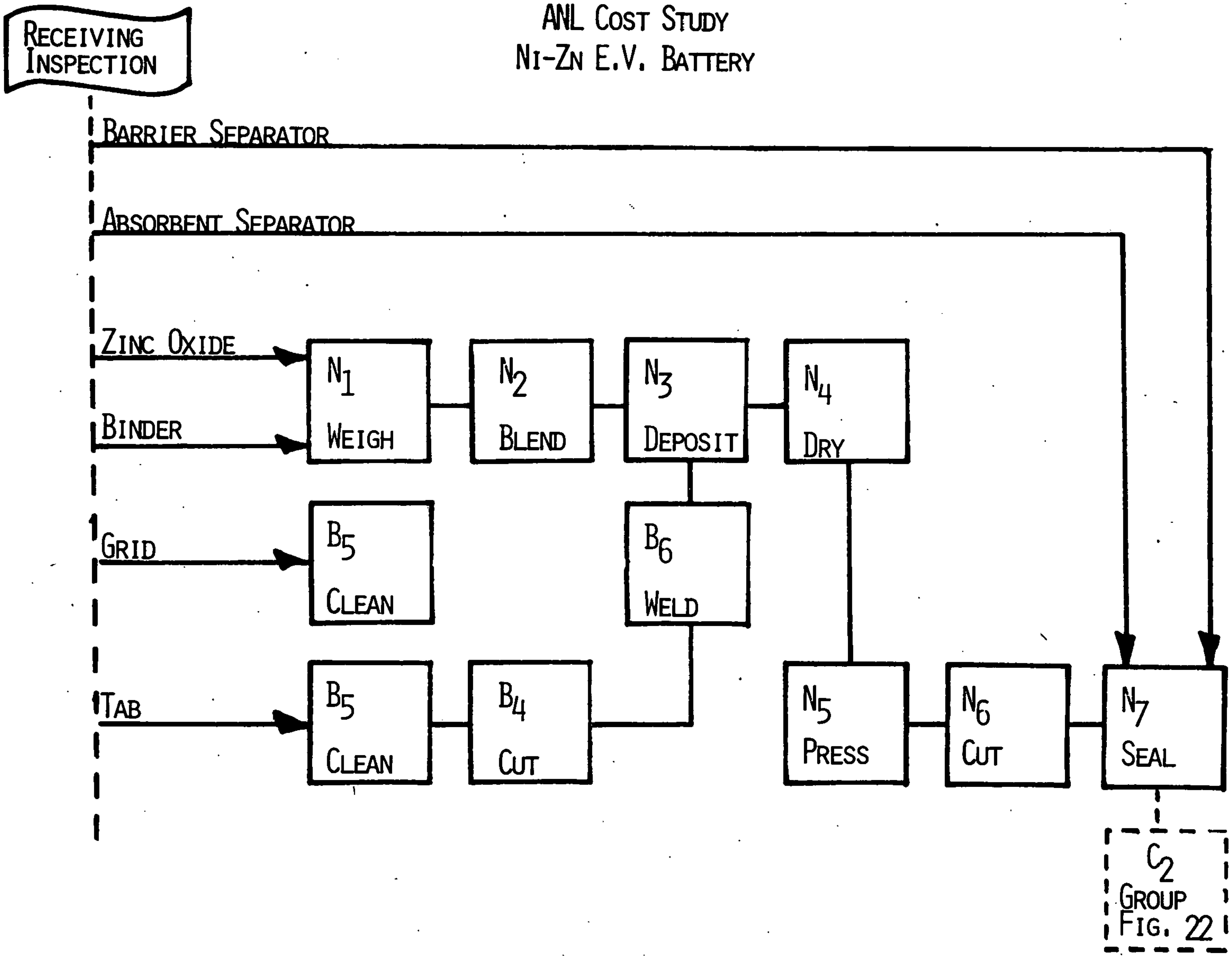

FIGURE 21

N_4 Dry - The material continues through an electric furnace for drying.

N_5 Press - The material is dry prossed to the desired final electrode density.

N_6 Cut - Press with cutting dies is used to blank out individual electrodes while coining the electrode edges.

N_7 Seal - Individual electrodes are transfered to a sealing machine that positions the electrode between layers of separation material and heat seals a separator bag cutting the materials to length from continuous rolls. The negative electrode/separator assembly is now ready for cell assembly.

4.3 Cell Assembly - (Figure 22)

Subsequent to grouping the electrodes into the cell pack, key features of the cell assembly are the fixtures designed to cut electrode tabs to final length and welding tabs to cell terminals. Cell assembly is made up otherwise by a series of simple assembly operations.

C_1 Group - Collect and identify the proper number of positive electrodes for cell assembly.

C_2 Group - Collate and identify the proper number of negative electrodes for cell assembly.

C_3 Group - Collate the positive and negative electrodes to form the cell pack. Insert pack into container with tab manipulation fixture. Form electrode tabs into position for subsequent cutting and welding. Set device.

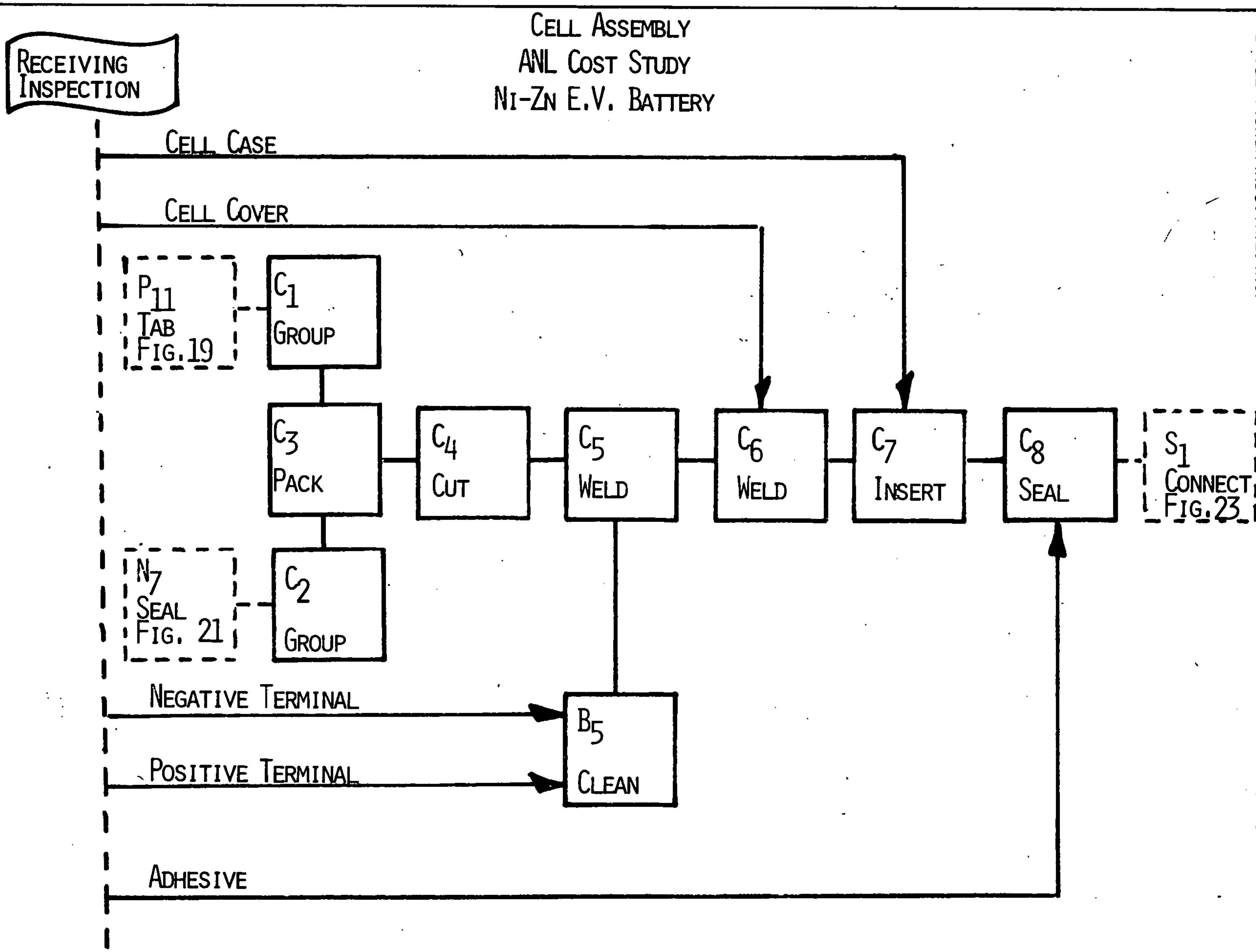

FIGURE 22

EAGLE-PICHER INDUSTRIES INC. — ELECTRONICS DIVISION

C_4 Cut - Place cell pack with fixture in position and cut electrode tabs to final length using powershear.

C_5 Weld - Place cell pack with fixture in position and weld cell terminals to tabs with resistance welder. Remove cell pack from fixture.

C_6 Weld - Locate cell cover on cell terminals and weld using ultrasonic welding equipment.

C_7 Insert - Cell pack with terminals and cover are lifted and inserted into the cell case using simple mechanical apparatus designed to complete the operations.

C_8 Seal - Adhesive material is dispersed to seal the cell cover to the cell case. Cell is ready to proceed to submodule/module assembly.

4.4 Submodule/Module Assembly - (Figure 23)

Continuing from cell assembly, the following final assembly steps are requried.

S_1 Connect - Submodule intercell connectors are positioned and welded to cell terminals.

S_2 Seal - Potting material is dispensed to encapsulate intercell connectors and provide additional sealing around cell terminals.

S_3 Install - Vent assemblies are installed into individual cells using band tools.

S_4 Install - Submodule cover is snapped into position.

SUBMODULE/MODULE ASSEMBLY
ANL COST STUDY
NI-ZN E.V. BATTERY

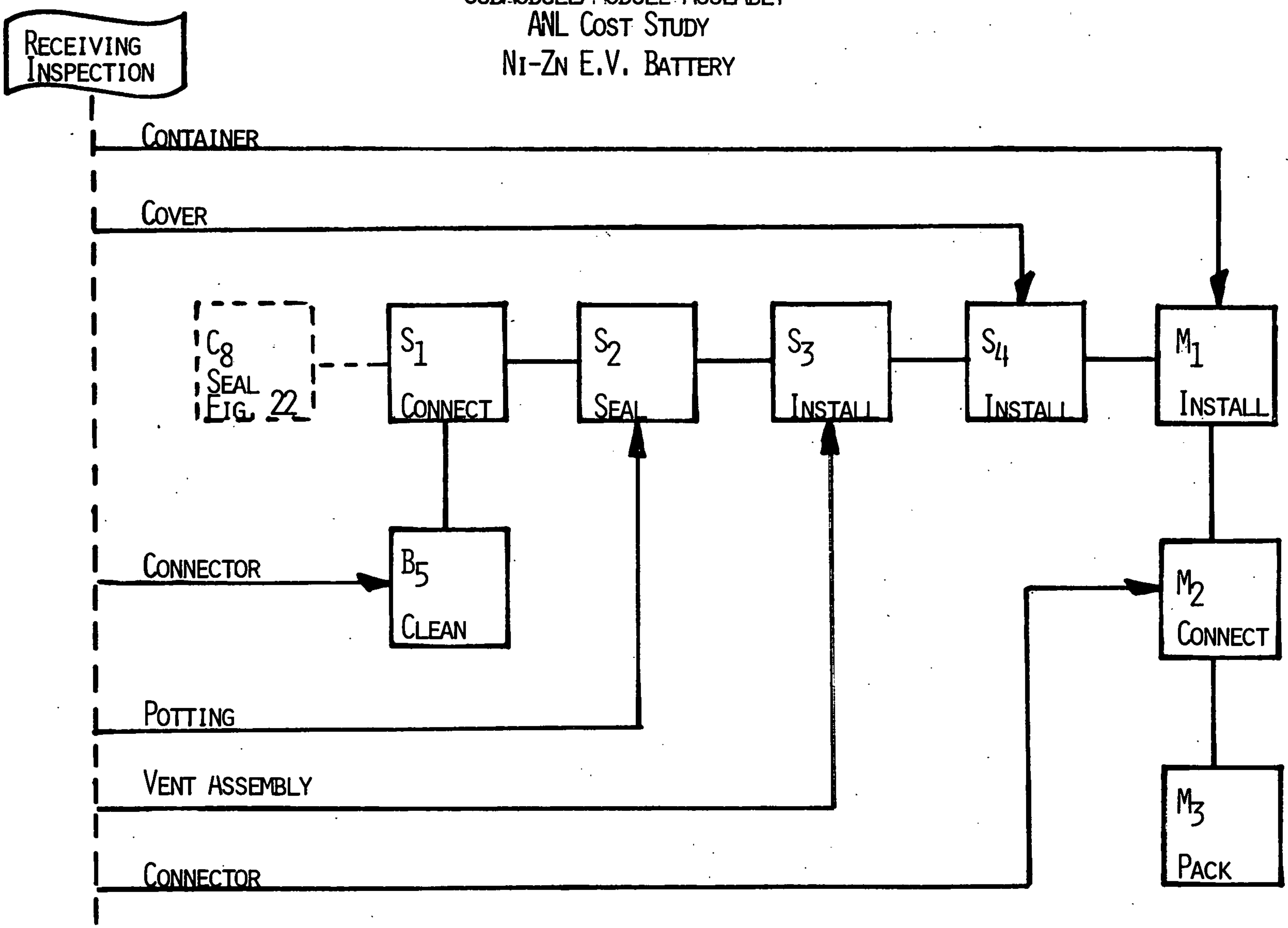

FIGURE 23

EAGLE-PICHER INDUSTRIES INC. — ELECTRONICS DIVISION

M_1 Install - Submodules are placed into module container using suitable lifting apparatus.

M_2 Connect - Intersubmodule connectors are positioned and fastened using hand tolls.

M_3 Pack - Module is placed into packaging for shipment using available lifting apparatus.

4.5 Support Processes

Not described in the proceeding sections were several processes involved in preparing parts or materials for use in the main process flow. These processes appear in the flow diagram figures and are described briefly as follows:

B_1 Dry - Nickel powder may require drying to improve its flow characteristics or may be used as received if bulk density is correct.

B_2 Anneal - Nickel wire screen must be annealed to a dead soft condition before placement in the forming molds. This is necessary so that they will lie flat in the mold. Cleaning is also accomplished while annealing in a reducing atmosphere.

B_3 Cut - Powershear used to cut grid wire or metal sheet (tab) materials.

B_4 Cut - Automatic equipment set to cut electrode tabs to length from strip material on rolls.

B_5 Clean - Vapor degreasing of metal parts to be processed or welded.

B_6 Weld - Resistance welder set to perform tab-to-grid welding.

4.6 Quality Assurance

All materials and parts received will be subjected to incoming inspection based upon established parts and material specifications. The required level of sampling will dictate the extent of the receiving inspection effort.

In process inspection will require the majority of the quality assurance effort. Positive electrode processing (sintered) will require testing of the sintered plaque for strength, porosity and thickness. The plaque will be visually inspected for flaws and imperfections with particular attention paid to material produced at the beginning of a run. Periodic checks will be necessary to maintain consistency verification. Tests will be performed to verify active material loading level. During all processing, key process parameters will be monitored continuously or automatically if necessary.

Inspections will be conducted throughout the processing of the negative electrode on a sample basis, including verification of blend consistancy and uniformity of the deposited material. The final electrode will be inspected for weight and thickness conformity. Separator bagging operation will require verification of adequacy.

In the cell assembly, orientation of electrodes will be of prime concern and a test will be devised for checking the terminal-to-cover and cover-to-case seals. Insulation resistance testing of each cell may be performed to verify separation adequacy.

Sample pull tests will be required on all welded joints as established by machine and sampling requirements. This will include grid-to-tab joints, tab-to-terminal joints and terminal-to-intercell connector joints. Throughout all processing, cleanliness and workmanship would be emphasized. Weight statistics may be compiled at various stages of assembly to monitor produce consistency and pinpoint variations. Final inspection of the completed module assembly would complete the over-all scheme of quality verification.

4.7 Plant Layout

A drawing of the over-all pilot plant floor plan is shown in Figure 24.

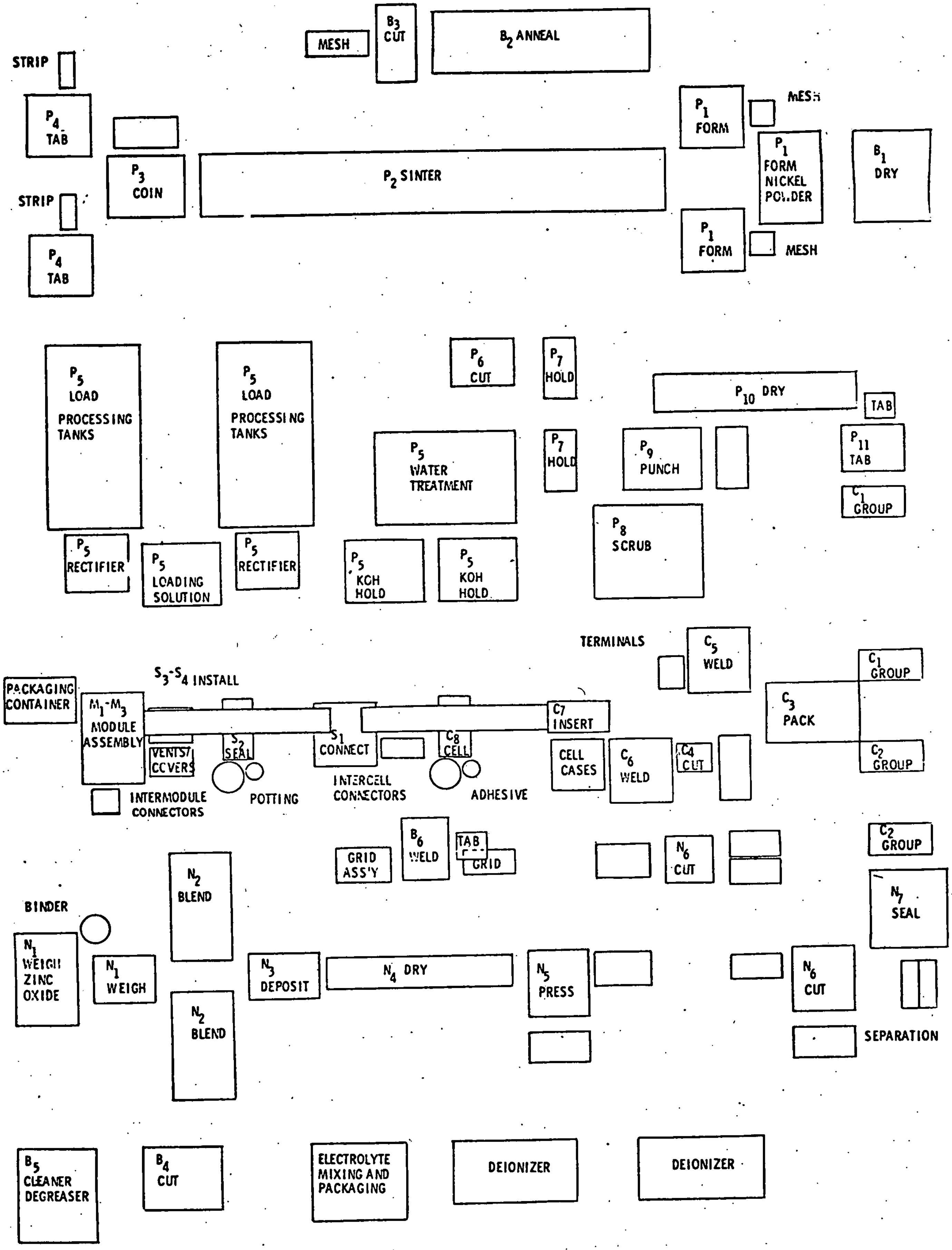

FIGURE 24
PILOT PLANT FLOOR PLAN

5.0 CAPITAL INVESTMENTS

5.1 Plant and Equipment

The following tables, Tables I - IV, are an equipment breakdown listing for the process areas discussed in the previous Paragraph 4.0. Process indentification numbers are used in the listing for reference to the flow diagrams. Equipment is tabulated for the 1000, 2000 and 10,000 battery per year rates. The 10,000 batteries per year rate was established for the production facility since it appeared that this rate maximized the output of several pieces of key equipment with their associated support equipment. To produce at rates higher than 10,000 units per year would require investing multiples of the 10,000 rate.

For the pilot plant rate, 1000 batteries per year was also tabulated as a method of indicating the investment that Eagle-Picher considers necessary to verify the rate capability of the process capability. The reason for this is that Eagle-Picher presently owns a portion of this equipment and can demonstrate the rates without additional outlay of monies. For instance, the 1000 rate can be demonstrated in the nickel sintered plaque area on present equipment.

A final Table V summarizes total costs including estimates for plant support and buildings/grounds.

TABLE I
MANUFACTURING EQUIPMENT
POSITIVE ELECTRODE

Process Step	Type Equipment Required	Manufacturing Rate - Batteries per Year: 1000 No.	1000 Total Cost	2000 No.	2000 Total Cost	10,000 No.	10,000 Total Cost
P_1 Form	Mold System w/Carrier Platens	1	5,700	2	11,400	4	25,600
P_2 Sinter	Furnace 3 Zone w/Gas Gen.	1	32,000	2	64,000	4	160,000
P_3 Coin	Press w/Coining Dies	1	9,300	1	9,300	2	18,600
P_4 Tab	Resistance Welder	1	7,500	2	15,000	4	30,000
P_5 Load	Process Tank System	2	190,000	4	380,000	4	600,000
P_6 Cut	Powershear	1	3,500	1	3,500	2	7,000
P_7 Hold	Tank	1	1,000	2	2,000	5	5,000
P_8 Scrub	Brush Scrubber/Spray Rinse	1	25,000	1	25,000	5	125,000
P_9 Punch	Press w/Cutting Dies	1	10,000	1	10,000	2	20,000
P_{10} Dry	Furnace	1	7,500	1	7,500	2	15,000
P_{11} Tab	Resistance Welder (Spot)	1	7,500	1	7,500	2	15,000
	TOTAL - Positive Electrode		$299,000		$535,200		$1,021,000

TABLE II
MANUFACTURING EQUIPMENT
NEGATIVE ELECTRODE

Process Step	Type Equipment Required	Manufacturing Rate - Batteries per Year					
		1000		2000		10,000	
		No.	Total Cost	No.	Total Cost	No.	Total Cost
N_1 Weigh	Scales	1	500	1	500	2	1,000
N_2 Blend	Blender	1	2,500	2	5,000	2	16,200
N_3 Deposit	Continuous Slurry Processor	1	5,000	2	10,000	8	40,000
N_4 Dry	Electric Furnace	1	10,000	1	10,000	2	15,000
N_5 Press	Press (100T) w/Die Set	1	77,000	1	77,000	2	154,000
N_6 Cut	Press w/Die Set	1	12,000	1	12,000	2	30,000
N_7 Seal	Sealing Machine	1	20,000	1	20,000	1	20,000
	TOTAL - Negative Electrode		$127,000		$134,500		$276,200

TABLE III
MANUFACTURING EQUIPMENT
CELL/SUBMODULE/MODULE ASSEMBLY

Process Step	Type Equipment Required	Manufacturing Rate - Batteries per Year					
		1000		2000		10,000	
		No.	Total Cost	No.	Total Cost	No.	Total Cost
C_1 Group	Divider/Containers	60	100	120	200	600	1,000
C_2 Group	Divider/Containers	60	100	120	200	600	1,000
C_3 Pack	Containers/Fixtures	2	800	4	1,600	10	4,000
C_4 Cut	Powershear	1	3,500	1	3,500	1	3,500
C_5 Weld	Resistance Welder	1	1,800	1	1,800	1	1,800
C_6 Weld	Ultrasonic Welder/Fix.	1	4,500	1	4,500	1	4,500
C_7 Insert	Lifting/Handling Device	1	600	1	600	1	600
C_8 Seal	Adhesive Dispenser	1	3,000	1	3,000	2	6,000
S_1 Connect	Resistance Welder	1	1,800	1	1,800	2	3,600
S_2 Seal	Potting Dispenser	1	2,700	1	2,700	2	5,400
S_3 Install	Hand/Power Tool	1	200	1	200	2	400
S_4 Install	None	-	-	-	-	-	-
M_1 Install	Lifting/Handling Device	1	600	1	600	2	1,200
M_2 Connect	Hand/Power Tool	1	200	1	200	2	400
M_3 Package	Lifting/Handling Device	-	-	-	-	-	-
	TOTAL		$19,900		$20,900		$33,400

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TABLE IV
MANUFACTURING EQUIPMENT
PARTS/MATERIALS PREPARATION/HANDLING

Process Step	Type Equipment Required	Manufacturing Rate - Batteries per Year: 1000 No.	Total Cost	2000 No.	Total Cost	10,000 No.	Total Cost
B_1 Dry	Stationary Oven	1	1,500	2	3,000	4	9,600
B_2 Anneal	Conveyor Furnace	1	7,500	2	15,000	4	30,000
B_3 Cut	Powershear	1	3,500	1	3,500	2	7,000
B_4 Cut	Automatic Cutter w/Die Set	1	2,500	1	2,500	2	5,000
B_5 Clean	Degreaser	1	2,500	1	2,500	2	5,000
B_6 Weld	Resistance Welder	1	1,800	1	1,800	2	3,600
Support Equip.	Mixing (KOH)	1	1,000	1	1,000	1	1,500
	Deionizers	2	12,000	2	12,000	3	36,000
	Conveyors	6	7,200	9	10,800	24	28,800
	Weighing/Identification	1	1,000	1	1,000	4	4,000
	Storage Bins	4	2,000	4	2,000	4	6,000
	TOTAL		$42,500		$55,100		$136,500

TABLE V

CAPITAL INVESTMENTS

AREA	PRODUCTION RATE BATTERIES PER YEAR 1,000	2,000	10,000
Sintered Positive Electrode	299,000	535,200	1,021,200
Negative Electrode	127,000	134,500	276,200
Cell/Submodule/Module Assembly	19,900	20,900	33,400
Parts/Materials Preparation/Handling	42,500	55,100	136,500
Quality Inspection	5,000	10,000	30,000
	493,400	755,700	1,497,100
Plant Support (10%)	-	-	149,700
Contingency (10%)	-	-	164,700
			1,811,500
Building w/Improvements (32,000 Ft^2)	-	-	480,000
Land - 5 Acres	-	-	25,000
Grand Total	493,400	755,700	2,316,500

5.1 Plant and Equipment (Continued)

Eagle-Picher recommends investment in the pilot plant at a production rate of 1000 batteries per year. Where duplicate pieces of equipment are required to meet this rate, it is also recommended that only one be assembled to demonstrate the rate capability.

Utilizing this approach, the capital investment in equipment for a pilot plant producing 1000 batteries with sintered positive electrodes per year would be $287,600. The investment for the sintered positive process is reduced considerably because much of the required equipment is currently being used for production and is available.

5.2 Battery Materials Usage

Table VI was assembled to indicate the scope of material usage. Parts and materials in their respective units of measure are listed in daily requirement quantities for the 1000 batteries per year production rate. The materials are broken down by process. Figure 25 shows the amount of nickel and zinc metal required for the 100,000 batteries per year production rate as a percentage of 1975 USA consumption.

5.3 Environmental Considerations

One of the major problems with electrochemical impregnation is the disposal of process expended chemicals. Eagle-Picher's process is such that this disposal will not be necessary. Nickel nitrate solution

TABLE VI
BATTERY PARTS/MATERIALS
MINIMUM DAILY REQUIREMENTS PER 1000 BATTERIES PER YEAR

Positive Electrode - Sintered

Nickel Powder - Lbs.	450
Nickel Wire Mesh - sq. ft.	877
Nickel Strip - sq. ft.	36
Nickel Nitrate - Lbs.	2071
Cobalt Nitrate - Lbs,	186

Negative Electrode

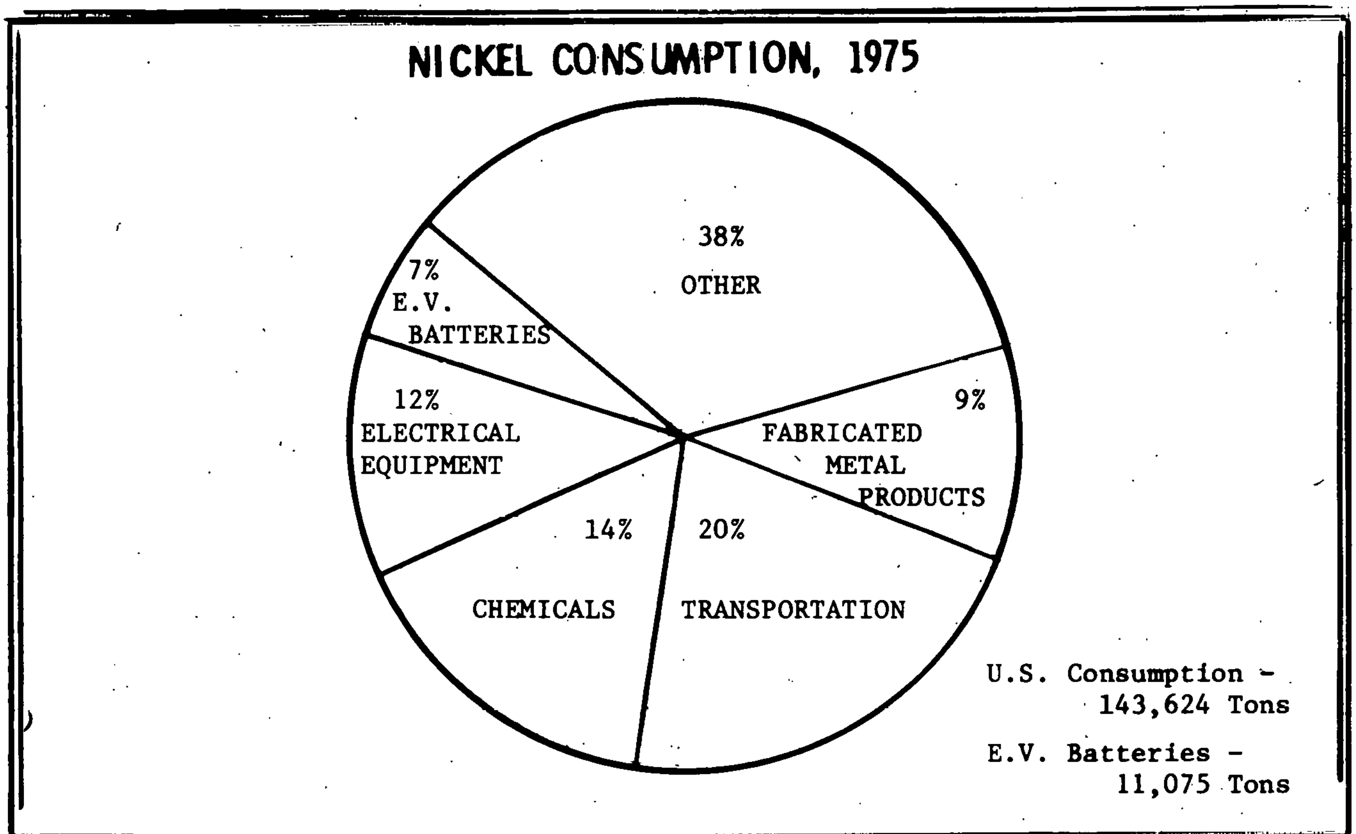
Zinc Oxide - Lbs.	690
Grid - Lbs.	75
Tab - Lbs.	37
Binder - Lbs.	18
Separator - Sq. Ft.	900

Cell Assembly

Cell Case - Ea.	65
Cell Cover - Ea.	260
Negative Terminal - Ea.	260
Positive Terminal - Ea.	260
Adhesive - Lbs.	25

Submodule/Module Assembly

Connector (ICC) - Ea.	194
Potting - Lbs.	60
Vent Assembly - Ea.	260
Connector (IMC) - Ea.	50
Cover - Ea.	65
Potassium Hydroxide - Lb.	500


NICKEL CONSUMPTION, 1975
38%
OTHER
7%
E.V.
BATTERIES
12%
ELECTRICAL
EQUIPMENT
9%
FABRICATED
METAL
PRODUCTS
14%
CHEMICALS
20%
TRANSPORTATION
U.S. Consumption -
143,624 Tons
E.V. Batteries -
11,075 Tons

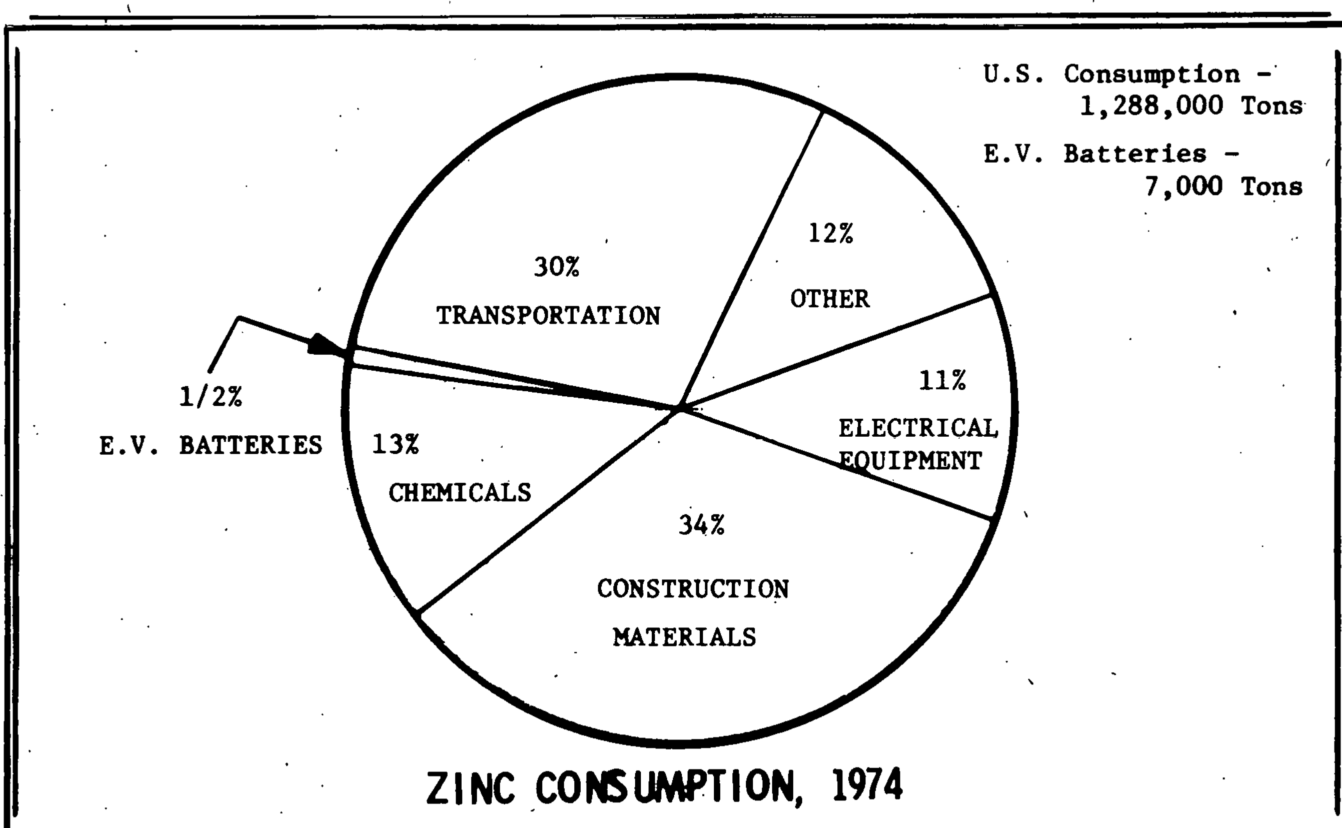
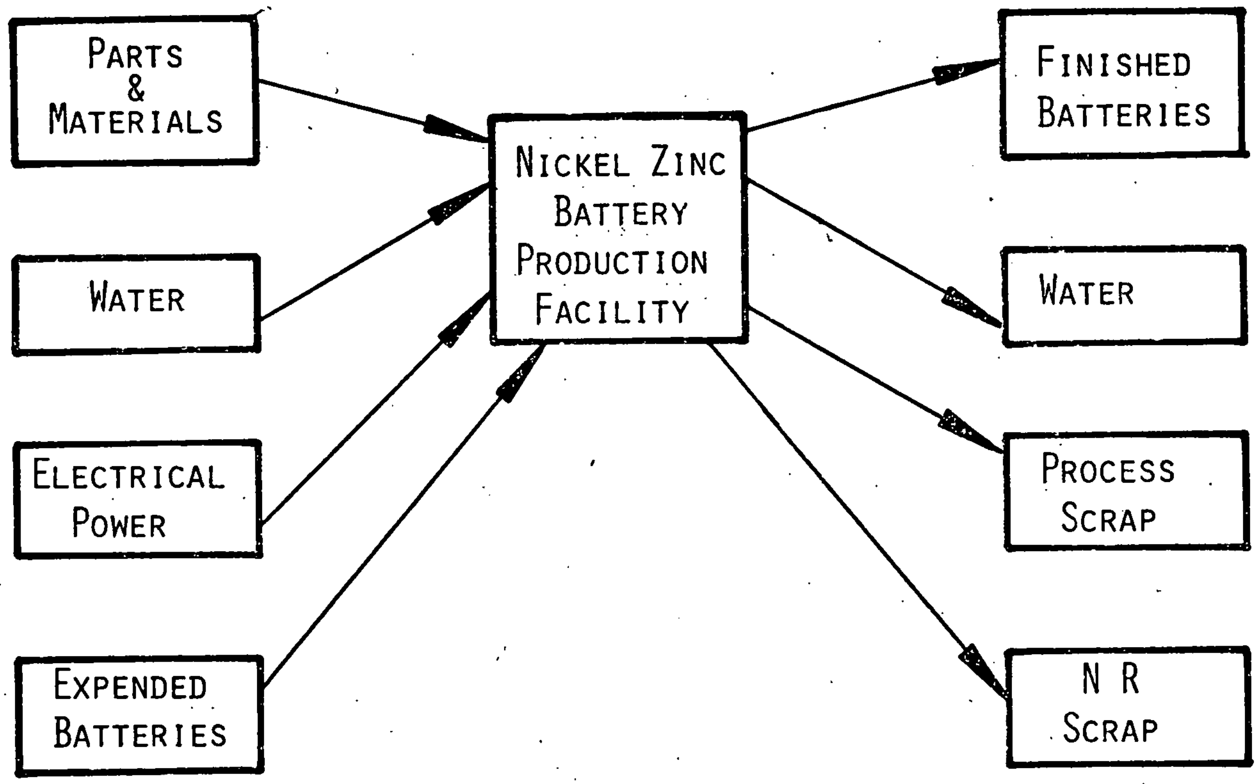

U.S. Consumption -
1,288,000 Tons
E.V. Batteries -
7,000 Tons
30%
TRANSPORTATION
12%
OTHER
1/2%
E.V. BATTERIES
13%
CHEMICALS
11%
ELECTRICAL
EQUIPMENT
34%
CONSTRUCTION
MATERIALS
ZINC CONSUMPTION, 1974

FIGURE 25

will be recirculated to a make-up bath tank where ingredients are added as necessary to support the process. The impregnation solution will be used continually in the process so that no process disposal will be required. Metal process scrap from the nickel electrode processing can be used as nickel nitrate solution make-up by treating with nitric acid. This would also apply to reject electrodes or electrode material. In this way, all metal scrap from the process can be returned to the process without loss. The only item remaining to be handled in positive processing is the rinse water. This can be subjected to normal treatment of waste water and discharged based upon local requirements.

Process scrap from the negative electrode processing would be a minimal amount of edge trim of grid and zinc oxide blend. Reject electrodes would also be added to this scrap. It is not considered to be economically advantageous to separate the metal grid from the blend material. Possibly, a source for zinc oxide use in other processes might develop, otherwise the material would be disposed of as scrap. Water disposal from the slurry process would be necessary, but would be simplified by the absence of normally used mercury compounds. Zinc would be the only substrate or magnitude in the wastewater.

A block diagram of the manufacturing facility with its inputs and outputs is shown in Figure 26. Environmental impact is estimated to be minimal, with the only significant problem being the treatment of waste water.



ENVIRONMENTAL CONSIDERATIONS

FIGURE 26

6.0 INSTALLED COSTS

Tables VII, VIII, and IX present a summary of material, labor and total installed costs per KWH at the pilot and production plant stages. Values are listed for both the non-sintered and sintered positive electrodes for comparison purposes to support the selection of the sintered electrode design over the non-sintered electrode design. The following comments will provide some background information concerning the calculation of these values.

1. Manhours have been estimated for each major process using the degree of automation included in the equipment cost estimate. An efficiency factor was used on each time estimate to arrive at a more realistic figure. The hourly rate for manufacturing/quality personnel is $10.76, which included overhead, consumable tooling, G&A and profit. The overhead includes supervisory labor.

2. Estimates for performing the quality assurance functions are based upon a factor of 10% of the manufacturing hours for the pilot facility and 5% for production. In moving into a production mode, it is felt that the quality assurance effort will be shifted to test and inspection equipment designed to perform specific functions, reducing the personnel required.

3. Material costs are compiled for the 64 cell, 25 KWH Baseline Design presented in Paragraph 2.1. Information as to pricing was obtained from latest records or purchase for the materials specified and parts/components of similar design. These costs are to be considered best estimates in 1976 dollars. No attempt was made to estimate price breaks based upon production quantity purchases. An allowance for scrap and reject parts has been included in all material quantities. Material costs include G&A and profit.

4. A scrap allowance has been included for the sintered electrode design, but not for the non-sintered electrode design. This discrepancy results from the difference in potential nickel to be recovered (sintered has nickel substrate, while non-sintered does not), and from the increased difficulty in processing the non-sintered electrode (binder and graphite must be separated). The scrap allowance is calculated considering an 80% yield, purchase of process chemicals (nitric acid), and processing labor. The nickel would be recovered as a nickel nitrate solution to be used in the impregnation process.

5. Distribution and installation costs have been calculated based on 2 hours per battery for installation and shipping charges of $11.00 per 100 pounds. Distribution and installation facilities must be included in the capital equipment category.

TABLE VII
MATERIAL COSTS

SINTERED POSITIVE ITEM	QUANTITY/KWH	UNIT COST	COST*
Nickel Powder	4.50 lbs.	$2.40/lb.	$12.06/KWH
Nickel Nitrate	20.71 lbs.	$ .80/lb	$18.48
Grid	8.77 ft^2	$ .35/ft^2	$ 3.42
Cobalt Nitrate	1.86 lb.	$1.00/lb	$ 2.08
Tab	.36 ft^2	$ .50/ft^2	.20
			$36.24/KWH

NON-SINTERED POSITIVE			
Nickel Nitrate	20.71 lbs.	$ .80/lb	$18.48
Cobalt Nitrate	1.86 lb.	$1.00/lb	$ 2.08
Grid	8.77 ft^2	$ .35/ft^2	$ 3.42
Graphite	1.18 lb	$ .55/lb	$ .72
Tab	.36/ft^2	$ .50/ft^2	$ .20
Binder	.088 lb	$4.50/lb	$ .44
Potassium Hydroxide	92 lb	$ .075/lb	$ 7.70
			$33.04/KWH

NEGATIVE			
Zinc Oxide	6.95 lb	$ .45/lb	$ 3.49
Grid	8.34 ft^2	$ .50/ft^2	$ 4.65
Tab	.36 ft^2	$ .50/ft^2	$ .20
Binder	.16 lb	$4.50/lb	$ .81
Separator	9.1 ft^2	$ .22/ft^2	$ 2.25
			$11.40/KWH

CELL ASSEMBLY			
Cell Case and Cover	.65 ea	$8.00/ea	$ 5.80
Terminals	5.11 ea	$ .35/ea	$ 2.00
Adhesive	.25 lb	$4.00/lb	$ 1.11
			$ 8.91/KWH

* Cost includes G & A and profit

TABLE VII
MATERIAL COSTS (cont.)

SUBMODULE/MODULE ASSEMBLY	QUANTITY/KWH	UNIT PRICE	COST
Intercell Connector	1.94 ea	$ .55/ea	$1.20
Potting	.60 lb	$2.16/lb	$1.44
Vent	2.55 ea	$ .40/ea	$1.16
Submodule Cover	.65 ea	$ .30/ea	$ .22
Submoduel Connector	.50 ea	$ .79/ea	$ .44
Potassium Hydroxide	4.91 lb	$ .075/lb	$ .41
			$4.87/KWH

TABLE VIII
INSTALLED COSTS - PILOT PLANT

	Non-Sintered Positive		Sintered Positive	
	$/KWH	Percent	$/KWH	Percent
Positive-Material	33.04	42.5	36.24	41.5
Labor	5.90	7.6	11.66	13.4
Negative-Material	11.40	14.6	11.40	13.0
Labor	2.93	3.8	2.93	3.4
Cell Assembly-Material	8.91	11.4	8.91	10.2
Labor	6.28	8.1	6.28	7.2
Submodule/Module				
Material	4.87	6.3	4.87	5.6
Labor	.60	.8	.60	.7
Handling/Support (Labor)	2.07	2.6	2.07	2.4
Quality Assurance (Labor)	1.78	2.3	2.37	2.7
Total Labor	19.56	25.2	25.91	29.7
Total Material	58.22	74.8	61.42	70.3
Grand Total	77.78		87.33	
Scrap Allowance	0		5.00	
Distribution and Installation	3.94		3.94	
Net Total	81.72		86.27	

TABLE IX
INSTALLED COSTS - PRODUCTION PLANT

	Non-Sintered Positive $/KWH	Non-Sintered Positive Percent	Sintered Positive $/KWH	Sintered Positive Percent
Positive-Material	33.04	46.0	36.24	45.9
Labor	4.69	6.5	8.52	10.8
Negative-Material	11.40	15.9	11.40	14.4
Labor	1.16	1.6	1.16	1.5
Cell Assembly-Material	8.91	12.4	8.91	11.3
Labor	4.69	6.5	4.69	5.9
Submodule/Module				
Material	4.87	6.8	4.87	6.2
Labor	.43	.6	.43	.5
Handling/Support	1.98	2.8	1.98	2.5
Quality Assurance	.65	.9	.82	1.0
Total Labor	13.60	18.9	17.60	22.3
Total Material	58.22	81.1	61.42	77.7
Grand Total	71.82		79.02	
Scrap Allowance	0		5.00	
Distribution and Installation	3.94		3.94	
Net Total	$75.76		$77.96	

7.0 LIFE CYCLE COST ANALYSIS

Using a value of \$78/KWH (Table IX) as the installed initial cost for a 25 KWH battery, several analyses can be made concerning the amortized life cycle costs. Figure 27 is a plot of initial costs per cycle as a function of achieved cycle life. For example, if the battery is capable of 400 cycles, then the cost per cycle is:

$$\frac{(25\ \text{KWH})(\$78/\text{KWH})}{400\ \text{Cycles}} = \$4.87/\text{Cycle}$$

If the battery is capable of 1000 cycle, then the cost per cycle is:

$$\frac{(25\ \text{KWH})(\$78/\text{KWH})}{1000\ \text{Cycles}} = \$1.95/\text{Cycle}$$

Figure 28 is a plot of initial costs per vehicle mile as a function of achieved cycle life. This plot is based on the following assumption:

1. Depth of discharge of 80%, or 20 KWH per cycle.
2. Battery initial costs of \$1949 (78 x 25)
3. Vehicle energy requirements of 180 to 220 WH/mile.

A sample calculation is shown below for an achieved cycle life of 400 cycles and a vehicle energy requirement of 180 WH/mile:

$$\frac{(\$1949)(180\ \text{WH/mile})}{(400\ \text{cycles})(20000\ \text{WH/cycle}} = \$.0439/\text{mile}$$

FIGURE 27
LIFE CYCLE COSTS
DOLLARS/CYCLE VS. CYCLE LIFE

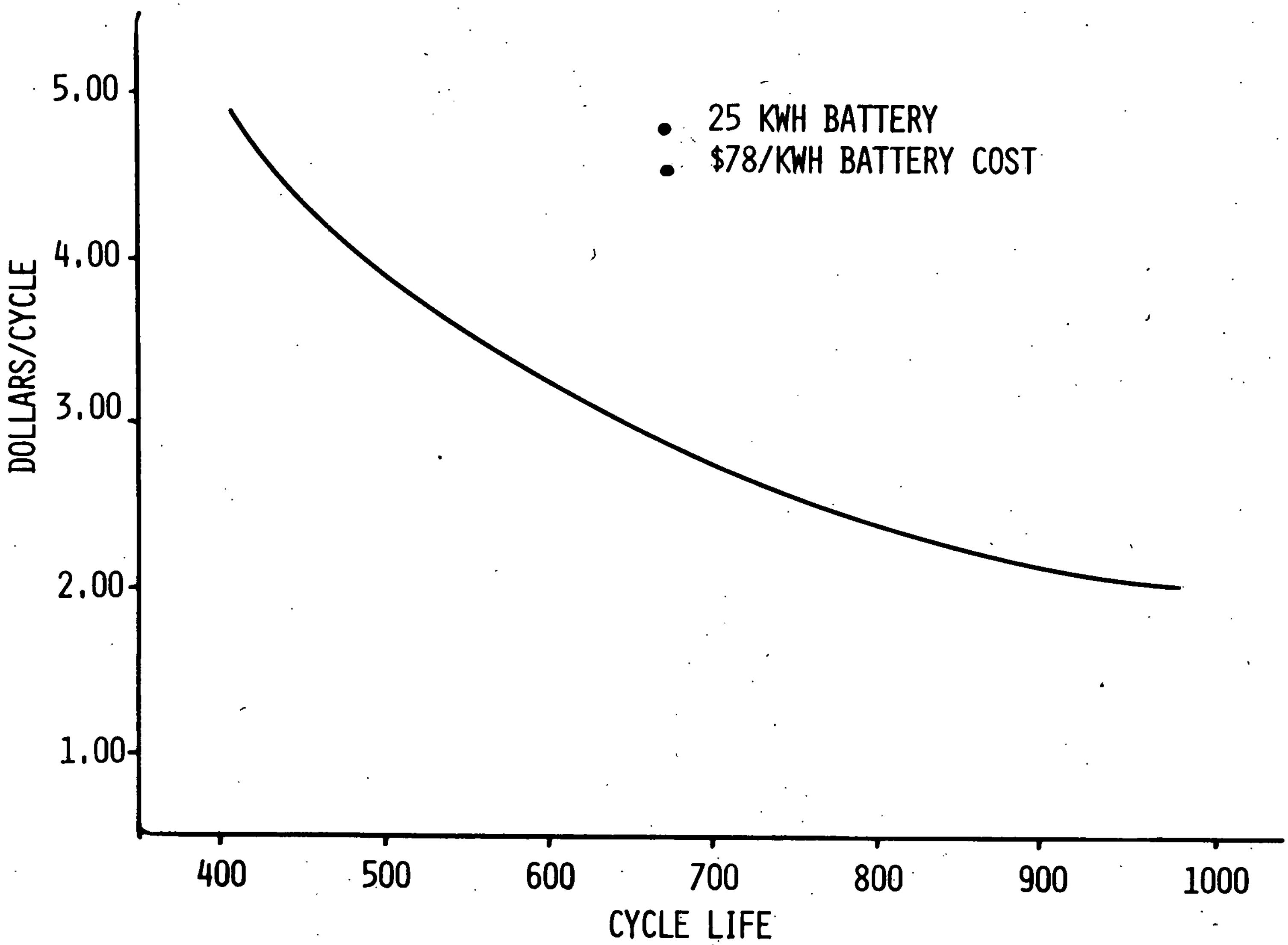


FIGURE 28
LIFE CYCLE COSTS
CENTS/MILE VS. CYCLE LIFE

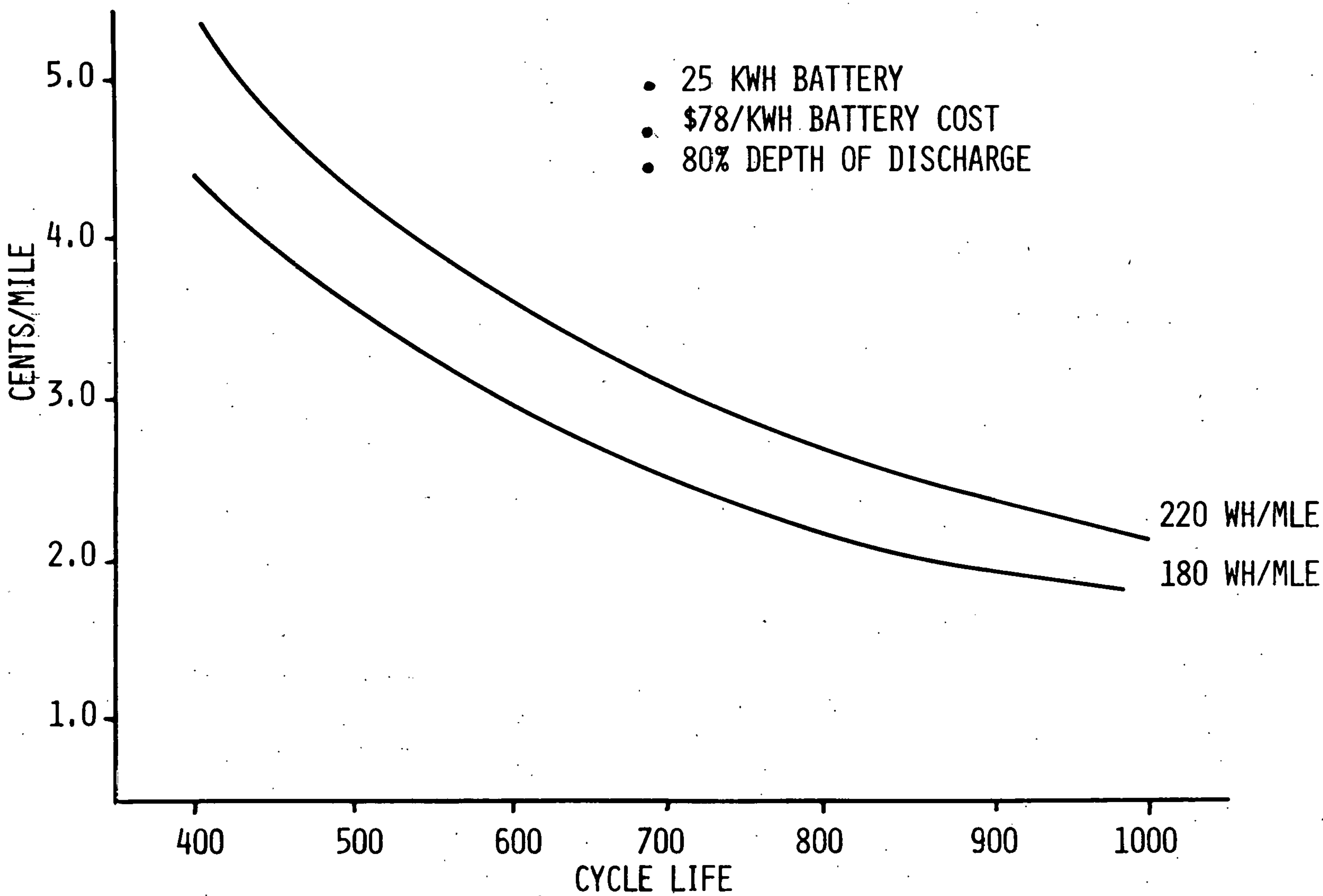
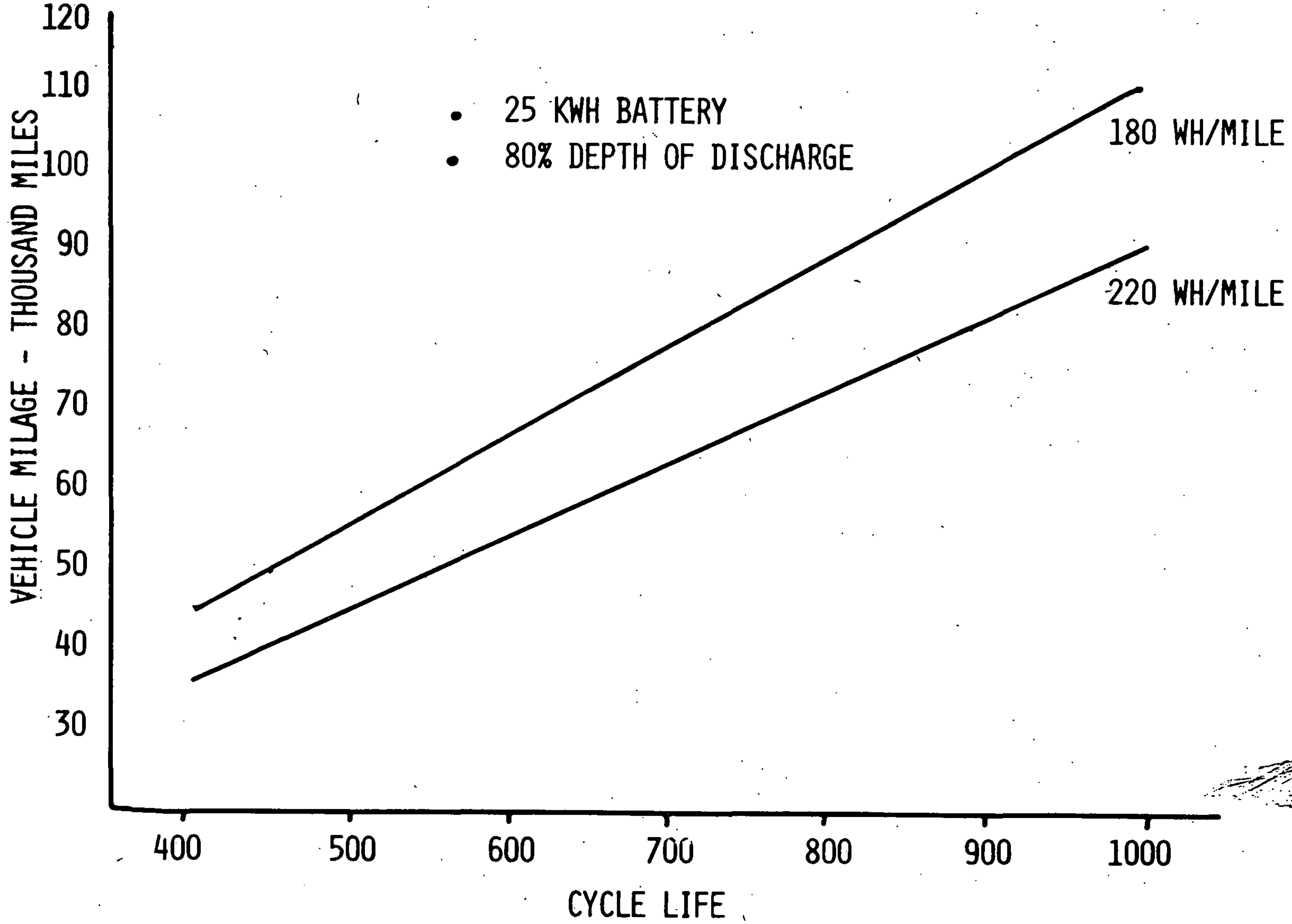


Figure 29 is a plot of vehicle milage as a function of achieved cycle life. A sample calculation is shown below:

(20,000 WH/cycle)(mile/180 WH)(400 cycles) = 44,400 miles

This plot points out the fact that present ANL battery requirements can be translated into a vehicle capability of 90,000 to 100,000 miles.

FIGURE 29
VEHICLE MILAGE VS. CYCLE LIFE



8.0 TEST PROCEDURES/TEST STANDARDS

The following tests have been designed in order to demonstrate the battery cycle life, power, charge retention and rate/temperature performance as required specifically for electric vehicle application. These tests are appropriate for any battery voltage, capacity or energy level. They are intended to be evaluation or acceptance type tests and would be based on other tests performed during the development effort.

8.1 Cycle Life Test

Batteries to be cycle life tested shall be discharged at the 2 or 4 hour rate for a period of time equivalent to 75% of their actual capacity. Charging shall be a constant potential input for 6 hours with the current initially limited to the c/3 rate. Tests shall be conducted at the following temperatures: -20°F, 0°F, 30°F, 75°F, 100°F and 120°F. Charging voltage shall be adjusted according to the manufactures' recommendations to compensate for the test temperature. A one hour stand period shall be allowed before and after each charge cycle. The manufacture shall specify a discharge cut-off voltage that shall be used to indicate 75% of the battery's actual capacity. The test shall be continued until the battery fails to deliver 50% of its rated capacity.

8.2 Peak Power Test

The test battery shall receive a 5 second discharge at stages of charge of 100%, 50% and 25%. The initial discharge rate shall be the

3c rate and increased on following discharges until the net power output from the battery decreases. The test shall be performed with the battery stabilized at each state of charge at temperatures of -20°F, 0°F, 30°F, 75°F, 100°F and 120°F. This test will define the battery's power delivery capabilities as a function of state of charge and temperature.

8.3 Charge Retention Test

A fully charged battery shall be allowed to stand open circuit at temperatures of -20°F, 0°F, 30°F, 75°F, 100°F and 120°F for periods of 30 and 60 days. The battery shall then be discharged at the c/4 rate at 75°F to 1.35 volts per cell. This test will measure the battery's retention of charge as a function of storage time and temperature.

8.4 Rate/Temperature Test

A fully charged battery shall be discharged to 1.35 volts per cell at temperatures of -20°F, 0°F, 30°F, 75°F, 100°F and 120°F. Discharge rates shall be c/2 and c/4. This test will demonstrate the battery's capacity as a function of discharge temperature and rate.

9.0 RESERACH AND DEVELOPMENT PLAN

The Research and Development Plan is being submitted as a separate document, Appendix 1 to Design and Cost Study.