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ADVANCED ALKALINE WATER ELECTROLYSIS TASK 2 SUMMARY REPORT

MODEL FOR ALKALINE WATER ELECTROLYSIS SYSTEMS

TELEDYNE ENERGY SYSTEMS
110 West Timonium Road
Timonium, Maryland 21093

April 1980

Work supported by the
DIVISION OF THERMAL AND MECHANICAL STORAGE
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DEPARTMENT OF ENERGY AND ENVIRONMENT
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

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TASK 2 SUMMARY REPORT

MODEL FOR ALKALINE WATER ELECTROLYSIS SYSTEMS

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Prepared for the
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1.0 SUMMARY

Task 2 of the Teledyne Energy Systems (TES) contract with the Brookhaven National Laboratory (BNL), BNL-480421-S involved the establishment of an engineering and economic model for the evaluation of various options in water electrolysis. The model, verification of the specific coding and four case studies are described in this summary report.

In brief terms, this new Fortran IV coded model has been prepared and has the following features.

(1) Based on operator controlled input or default values, starting with the required D.C. to the electrolysis module, a module is "designed" and the support plant is subsequently "designed."

(2) The manufacturing costs of both items are then calculated and subsequently recalculated into initial plant costs to the customer.

(3) The operating power costs as well as the associated operating costs for the plant are calculated.

(4) The costs are then evaluated with respect to a capitalization approach, suggested originally by EPRI (Ref. 6), and with respect to distinct inflation values for power and other operating costs to yield a levelized hydrogen cost, or alternatively defined, a time averaged weighted hydrogen cost.

The model, described in general terms in Section 3.1 of this report and detailed as Appendix C, was tested by evaluation of a nearly commercial technology, i.e., an 80 KW alkaline electrolyte system, operating at 60°C, which delivers approximately 255 SLM, hydrogen for applications such as electrical generator cooling or semiconductor manufacturing. The general output from these calculations are described in Section 3.2

and are presented in detail in Appendix A and Appendix B.

The calculated cost of hydrogen from this installed nonoptimized case system with an initial cost to the customer of $87,000 was $6.99/Kg H_2 ($1.67/100 SCF) on a 20-year levelized basis using 2.5¢/KWH power costs. This compares favorably to a levelized, average merchant hydrogen cost value of $9.11/Kg H_2 ($2.17/100 SCF) calculated using the same program.

The flexibility of the program was tested by evaluation of four "cases."

The first case (Section 4.1) showed the expected lowering of the cost of hydrogen as the plant size is increased from 80 KW case to 1000 KW, the largest size requested for this study by BNL. With a preestablished 6000 A/M^2 (600 ma/cm^2 = 557 amp/ft^2), levelized hydrogen costs of $5.30/Kg H_2 were calculated for the conventional Ni-200 wire screen technology at 125°C and $4.60/Kg H_2 was shown for the advanced cathode (C-AN) technology for the 1000 KW plant size.

The general effects of temperature for only the 80 KW plant size were studied for both electrode technologies and this case is described in Section 4.2. Approximately a 9% cost savings was calculated by increasing the operating temperature of the Ni screen from 55°C to 125°C and an additional 9% cost savings realized by utilization of the C-AN cathode technology.

Using the model to optimize the module design parameters of cell area, operating current density and operating temperature for again the 80 KW case (Study 3, Section 4.3), the minimum costs were found to be $5.92/Kg H_2 and $5.34/Kg H_2 for the Ni-200 screen and C-AN cathode technology, respectively. Both electrode technologies optimized with an 125°C operating temperature and an approximately 0.25 M^2 cell area, the baseline technology minimizing at 5000 ± 500 A/M^2 whereas the C-AN technology minimized at 6000 ± 500 A/M^2 operating current density. These values correspond closely to 4500 ± 500 A/M^2 value found in an earlier study and used in most of ARIES testing to date.

As BNL had originally requested plant duty or utilization factor be considered, Study 4 (Section 4.4) was concerned with the effects of both duty factor and electricity costs. The general finding was that a rather broad based insensitivity existed with respect to duty factor for the range of 60 to 100%. This finding was distinct from previous studies and was caused in general by two factors--the predominance of the electricity cost on the cost of gas relative to the other factors, and the "fact" that inflation affects the electrical and operating costs but does not significantly affect the cost of an installed plant.

Finally, with the usefulness of the program demonstrated, a comparison of "existing technology" cases for both advanced alkaline cells and the SPE (solid polymer electrolyte) was attempted. The results (Section 5.4) show the advanced alkaline technology to be superior to the SPE technology when attempting to base the comparison on a similarly sized, optimized and costed basis. Evaluation of the stated goals of both technologies was also attempted and the general findings were nearly identical costs of hydrogen from the two approaches. The reader must therefore decide on which technology is the more credible.

Several features of the model could be further refined and several additional subroutines which would increase the usefulness of the model are suggested. The specific values contained in the report were, of course, the particular results of the preselected estimates of the author after considerable consultation at TES. However, a critical review by an independent party which would lead to more accurate hydrogen costs is the next order of priority. The case studies discussed in this report have shown the next proposed experimental studies to lower the internal resistance of the electrode separator and improve the anode is the proper near term approach. Establishing the relationship of module operating temperature and module life would, as discussed, then be the next order of priority.

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2.0 INTRODUCTION

2.1 CONTRACT BACKGROUND

For the past four years, Teledyne Energy Systems (TES) has been working on a series of tasks for the development of advanced alkaline water electrolysis systems funded by the Department of Energy (DOE) under the direction of the Chemical/Hydrogen Energy Storage Systems Division and monitored by the Electrochemical Group at Brookhaven National Laboratory (BNL). Summarizing tersely, the main thrust of past efforts has been to identify approaches to achieve high efficiency electrolyzers. There are several feasible improvements in cell hardware technology, namely using improved (lower polarization) anodes and cathodes and less resistive separators. Also, since there are no easily accessible parasitic reaction pathways, elevation of operating temperature results in lower cell polarization and cell resistive losses with little loss in current efficiency. This further increases the operating efficiency of hydrogen production.

The original contract task was a materials study designed to identify and characterize stable thermoplastics that could be used for cell frame structural materials at temperatures up to 150°C (Ref. 8). Next, a high temperature applied research sized electrolyzer was built as a test bed for new technology. This system, called ARIES, was used in the following tasks to characterize the performance of baseline technology at temperatures up to 125°C. The baseline technology consisted of nickel-200 wire screen electrodes and bipolars, chrysotile asbestos interelectrode separators, polysulfone cell frames, and 316 stainless steel plumbing. The following two tasks again used the ARIES system in a series of six advanced electrode screening tests, and an extended test of a five-cell electrolysis module containing Teledyne proprietary cathodes (C-110) and Teflon-bonded nickel-200 powder anodes. Also tested for a short time were cells containing shear spun polybenzimidazole (PBI) fibrid, cast felt interelectrode separators. Although no significantly improved anode had been found, the best cathode identified, the properietary C-AN cathode, showed on the order of 300 mV lower polarization at ~5000 A/M^2 compared to the baseline technology cathode (Ref. 7).

2.2 PURPOSE OF TASK 2, CONTRACT 480421-S

This short history brings us to the present task, the development of a computerized model for alkaline water electrolysis systems (MAWES) which can allow one to optimize the critical system component parameters and predict the cost of hydrogen produced from an arbitrary technology electrolysis system.

This type of design and economic model is necessary for many reasons. First, in order to judge the effect of technical improvements, one cannot look solely at the energy conversion efficiency of the improved system but must also consider the cost of improvements as they affect the cost of the product, hydrogen. This means a complete cost/price analysis must be done for every change in design. The price sensitivity is affected by an improvement in voltage efficiency, for example, by decreasing the input power but, the electrode usually causes a capital equipment cost increase. Also, the sizes required for heat exhangers and pumps may change since less waste heat is generated. The net change in hydrogen price may increase for a small, capital intensive system bought at high interest rates. On the other hand, for a large, power intensive system purchased in an era when power costs are inflating, the price of gas may decrease. Obviously, the sensitivity is dependent on many interrelated economic and design factors.

The second general use of this model lies in its ability to predict areas in which improvement should be concentrated. From previous output, one may be able to detect which components or subsystems deserve further attention for purposes of price reduction and which ones have relatively minor cost effect. In addition, there may be parametric optimizations performed that allow the designer to do design trade-off studies, for example, one trade-off may be the module temperature rise versus heat exchanger size. Normally, the model is used to detect the optimum cell current density, number of cells and cell area. Many other such trade-offs can be envisioned and the model is designed to investigate these using, again, the cost of product gas as the ultimate judge of improvement.

In order to do a complete analysis, the model should be able to predict required sizes for the major system components and predict prices corresponding to those sizes. Of course, there is no way to do an ab *initio* calculation: several design curves must be input. Also, there are some points where the design seems to be a matter of historical preference (i.e., educated guesses) and no parametric design data is available. In these areas absolute values must be part of the input.

A major goal of this task is to use the developed model as an optimization tool. Therefore, the program must have optimization techniques built in as part of its operation. These techniques and the techniques for calculation of design and cost values are described in the following section.

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3.0 DESCRIPTION OF MODEL

3.1 MODEL DEVELOPMENT

3.1.1 Optimization Method

A design study of the type described in the task definition is, in essence, a classical nonlinear, constrained, optimization problem. In this case, the value to be optimized (minimized) is the price of product hydrogen. This price is not constant in an inflationary era, however, and careful attention must be paid to selecting the proper time-average price called the "Levelized Gas Price," P_L. Once the definition is made one still must relate this value to a rather large set of independent design and economic parameters. For this study the parameter list is some 262 variables long and is given in Appendix A. In an unconstrained problem the objective is to find a minimum price, P_L in a 262 dimension space, obviously a problem to be avoided.

There are two types of constraints encountered, range constraints and parametric constraints. The first type fall into the category of linear constraints and, as suggested, simply limit the allowable range of a given variable. For example, instead of an operating temperature (T) range of -273 to ∞ °C, one may only want to consider: $50°C \leq T \leq 150°C$, or one may want to set a variable constant, e.g., $100°C \leq T \leq 100°C$ (or T = 100°C). The second type of constraint, the parametric constraint is more difficult to handle. In this case there is some additional function of one or more variables which must be less than a specified value. For example, the cell voltage is not given in the parameter list and must be calculated from electrode characteristic curves, temperature and current density. As a parametric constraint though we have defined that the cell voltage (V) must not be endothermic ($V > 1.48$ volt). The program must then test for these and similar cases and set P_L arbitrarily high so that this out-of-bounds case does not appear as a minimum. The range constraints are more easily handled by never allowing any variable out of range at the outset.

The nonlinear constrained optimization program can be stated mathematically as:

$$\text{Minimize } P_L = f(X_1, X_2, \ldots, X_{262})$$

subject to range constraints,

$$L_i \leq X_i \leq U_i \qquad \text{for } i = 1 \text{ to } 262$$

and parametric constraints

$$C_j \leq f_j\,(X_1, \ldots, X_{262}) \qquad \text{for a set of j's.}$$

The size of this problem is still unmanageable and is even further complicated by the presence of the constraints in all but the case of total constraint described above, i.e., X_i = constant. This constraint reduces the dimension of the problem space by one, each time it is employed. In this program only 15 or fewer variables are allowed to vary, the others being fixed at the program initialization. The operator is allowed the flexibility of choosing which set of 15 (out of 262) he wishes to investigate. He may choose fewer or allow none at all to vary and the problem degenerates to a simple function evaluation. Several techniques exist for optimizing constrained functions, notably the SUMT" algorithm (Ref. 1) or the "Complex" algorithm (Ref. 2). Most require large numbers of function evaluations and are suitable for relatively simple functions. In this case, however, the function is anything but simple and requires on the order of 900 Fortran IV statements to evaluate.

This brings one face to face with the implicit problem in all optimizations: one must optimize the optimization. That is to say, one must gain as much information about the minimum at the least expense in computer time. Also one would like to know which variables are the truly sensitive ones and which can be eliminated from further consideration in addition to the optimum conditions. Another problem to contend with is the local versus global minimum problem. As illustrated in Figure 3-1, depending on the starting point, the minimum found may not be the true global minimum but only a local minimum for a small region of the variable space. No mathematical solution to this pitfall is known to this author.

To handle these problems for purposes of this contract, a simple grid search technique has been adopted where the specified variables are further constrained to discrete values within their allowed range. For example, one may see a statement in the output that looks like:

6.CCD = 4000 to 8000 in 5 steps

Roughly translated this means variable #6 (cell current density) has an allowed range of 4000 A/M^2 to 8000 A/M^2 and the program will test it five equally spaced values (4000, 5000, 6000, 7000, and 8000 A/M^2).* If there is another variable set up with two steps (e.g., 5.CAR = .05 to .10 Step 2) and a third with three steps (e.g., 3.PTMOD = 75 to 125 in 3 steps), the program will set up a 5 x 2 x 3 grid or array of values and then proceed to evaluate the objective function of each of the 30 points. The best result is saved and all information about it is printed. In addition, the program will find various suboptima, i.e., given a fixed value of the third variable the optimum of the 5 x 2 sub-

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* Variable mnemonics are translated in Appendix A. All units are S.I. unless otherwise defined.

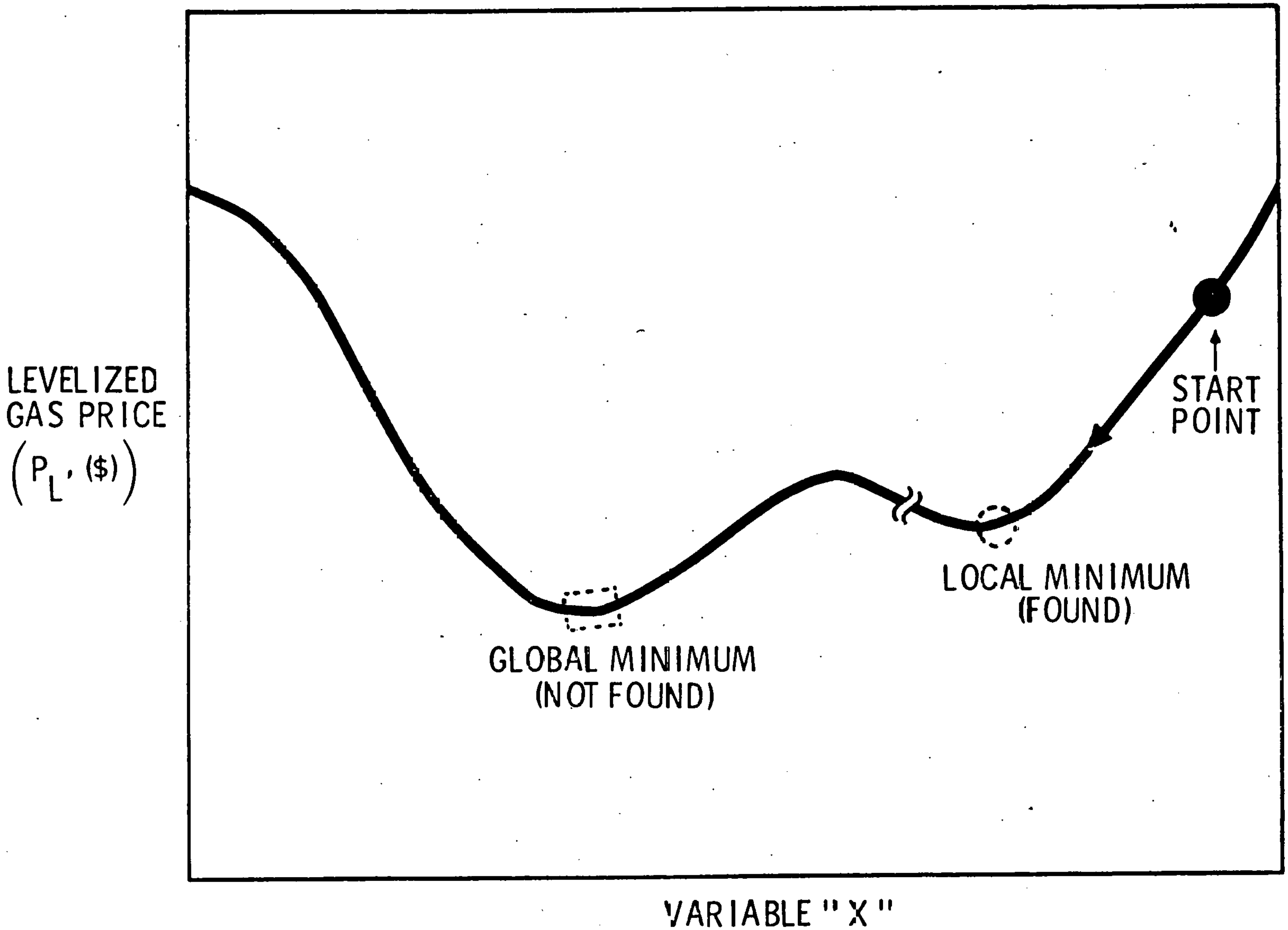


FIGURE 3-1. THE POTENTIAL PROBLEM OF OPTIMIZATION STUDIES

array can be detected. The variable ranges, number of steps, and the order of execution can all be controlled by the program operator as well as the choice of which 15 parameters are allowed to be variables. All of these assignments are carried out by the main program, "MAWES." The name "MAWES" is an acronym for "Model for Alkaline Water Electrolysis Systems."

Besides sequencing the variables through the various grid points and remembering optimum results, the main program has two other important tasks. The first is the initialization of all the other fully constrained parameters. It does this by two methods, internal initialization and data statement or external initialization. The program internally sets all parameters to a baseline or default value using a block data subroutine. If the operator wishes to modify any value, a data reading algorithm allows the change. The new information is supplied using data cards and is not an internal part of the program. The last task of the main program is calling the output subroutines and most importantly calling the subroutine which actually calculates the objective function, the price of hydrogen, based upon the 262 parameters. This subroutine is named, "ESTIM," and the calculation is described in Section 3.1.2.

3.1.2 Objective Function

The price of hydrogen required to offset the fixed and operating costs of a water electrolysis system is a very complicated function of several design and economic parameters. The starting point for any trade-off study is obviously the plant size, which can be described by its input power or by the amount of gas output. One must compare similar sized plants and the optimum design for one size will not necessarily be optimum for another. To complicate the issue, the two size parameters are not self-consistent, e.g., a 90% efficient 100 KW(in) plant produces more hydrogen than a 60% efficient 120 KW(in) plant. The chosen starting point is the plant D.C. busbar power.

In a computerized model such as this, one can not do a completely detailed design study especially if the goal is to optimize among the engineering and economic trade-offs. Chilton's Chemical Engineer's Handbook (Ref. 3) describes studies like this as "order of magnitude" estimates since generalized size versus cost curves are used in finding component costs rather than using firm price quotations. Obviously a full set of quotes and engineering drawings cannot be made for each computer iteration in the 262 dimensioned space. Chilton's estimates that this type of estimate will yield at best a ±40% final figure, but for doing design optimization studies this is more than adequate as long as the cases compared are not extremely different. Therefore, one should be cautious in comparing numbers generated here with firm numbers from other studies.

The model itself is structured in three segments, first a block of design routines size the individual components and calculate efficiencies, then a block of costing routines take those sizes along with manufacturing costs and rates for consumables to generate capital and operating costs. Finally, the last routine uses the above in a levelized revenue requirement calculation to yield the objective function, the levelized price of hydrogen. This levelized price is a time average weighted value to account for various rates of inflation in operating expenses. It is not the first year gas price but is more truly representative of the type of cost one should use in business decisions.

Figures 3-2 and 3-3 are block diagrams of the objective calculation. Subroutine calls are handled by the main subroutine, "ESTIM." "ESTIM" also makes a few early design calculations. These are discussed in the following section. "ESTIM" also handles the parametric constraints discussed in Section 3.1.1.

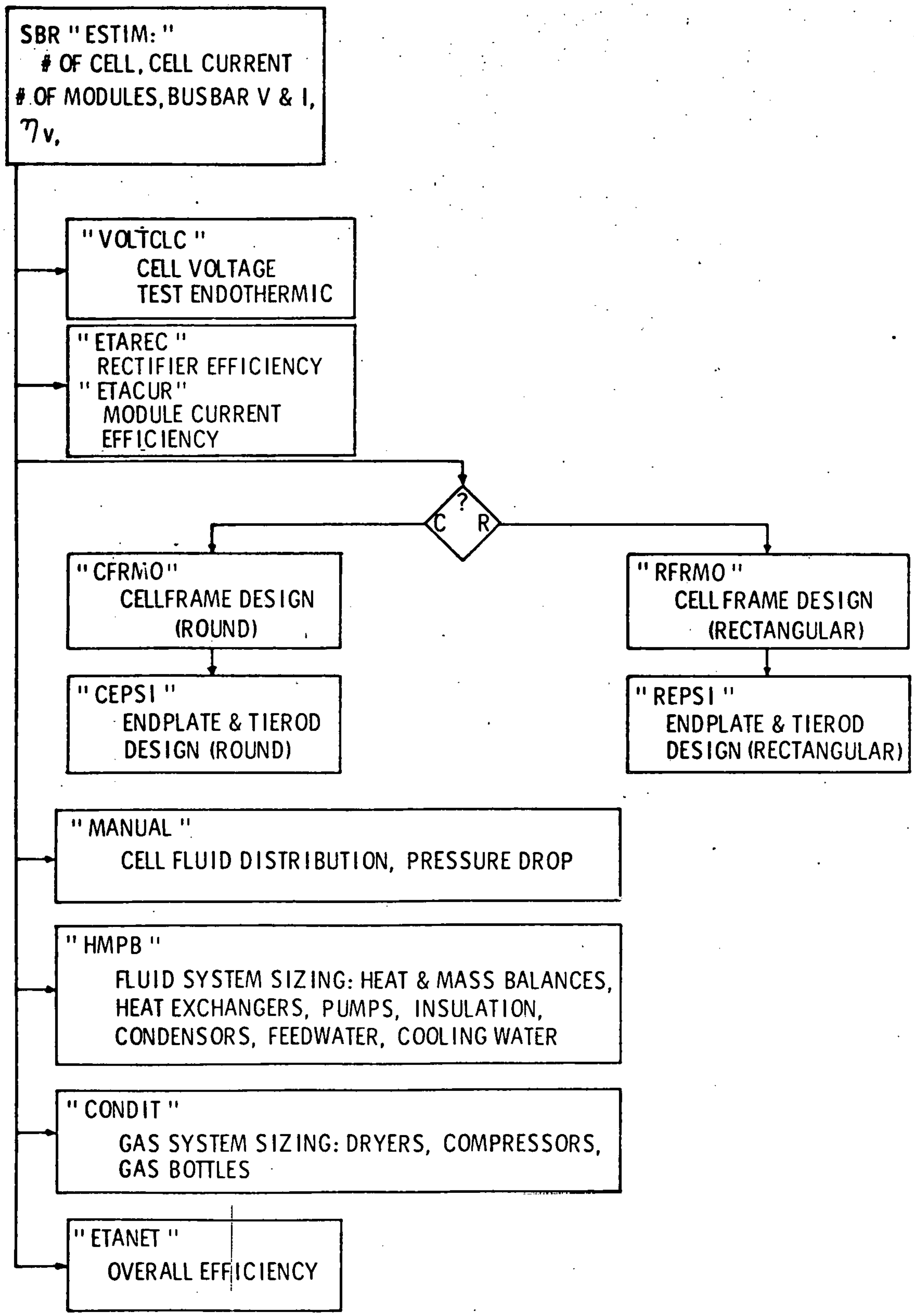


FIGURE 3-2. OBJECTIVE FUNCTION CALCULATION DESIGN SECTION

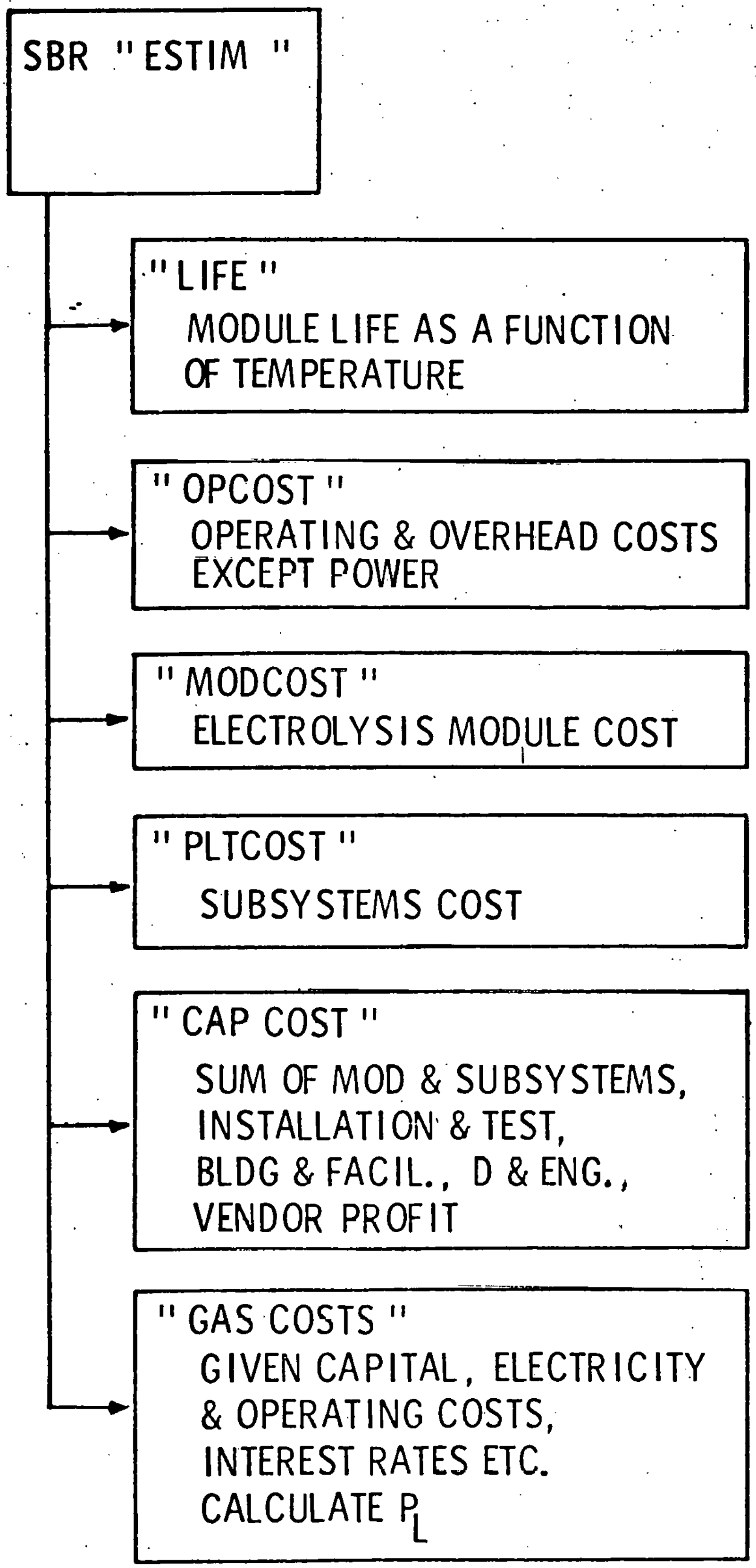


FIGURE 3-3. OBJECTIVE FUNCTION CALCULATION
COST & REVENUE REQUIREMENT SECTION

NOTE: In the next three sections (3.1.2.1, 3.1.2.2 and 3.1.2.3) whenever an input parameter is mentioned, the number in parentheses following refers to its position in the input list in Appendix A.

3.1.2.1 Design Routines

The cell voltage is calculated using subroutine "VOLTCLC" from interpolating the parametric coefficients (E, S and R) at three input temperatures (#8-#19). Given the cell voltage, area (#5), current density (#6) and D.C. input power (#1), the number of cells are calculated. This is rounded to the nearest integer and the D.C. power is adjusted accordingly. If the number of cells is larger than some arbitrary maximum (#33), the stack is divided into multiple modules. Busbar currents and voltages are calculated assuming cells electrically in series and modules in parallel. The voltage efficiency is calculated defining the isothermal cell voltage at operating temperature and standard state concentrations as 100% voltage efficiency. At this point, "ETAREC" and "ETACUR" are called. "ETACUR" calculates the net effect of shunt currents on current efficiency (η_i). In this type of system the current efficiency is near unity because of the absence of any side reactions and because of the low gas solubility in concentrated caustic. For 25 w/o KOH, solubility is on the order of 10^{-4} molar for both gases (Ref. 4). There are shunt current paths in the electrolysis module, however, which bypass one or more cells, reducing the current efficiency as shown conceptually in Figure 3-4. "ETACUR" treats this effect using a linearized Kirchhoff's law technique to solve self-consistently for the loop currents. If these currents are small and do not change the cell impedance significantly, this technique is valid. For larger shunt currents, a nonlinear technique must be used. The current efficiency is ultimately a function of electrolyte conductivity (in turn a function of temperature and concentration), number of cells, cell voltage and cell impedance. "ETAREC" is the rectifier efficiency and is considered a constant 95% value.

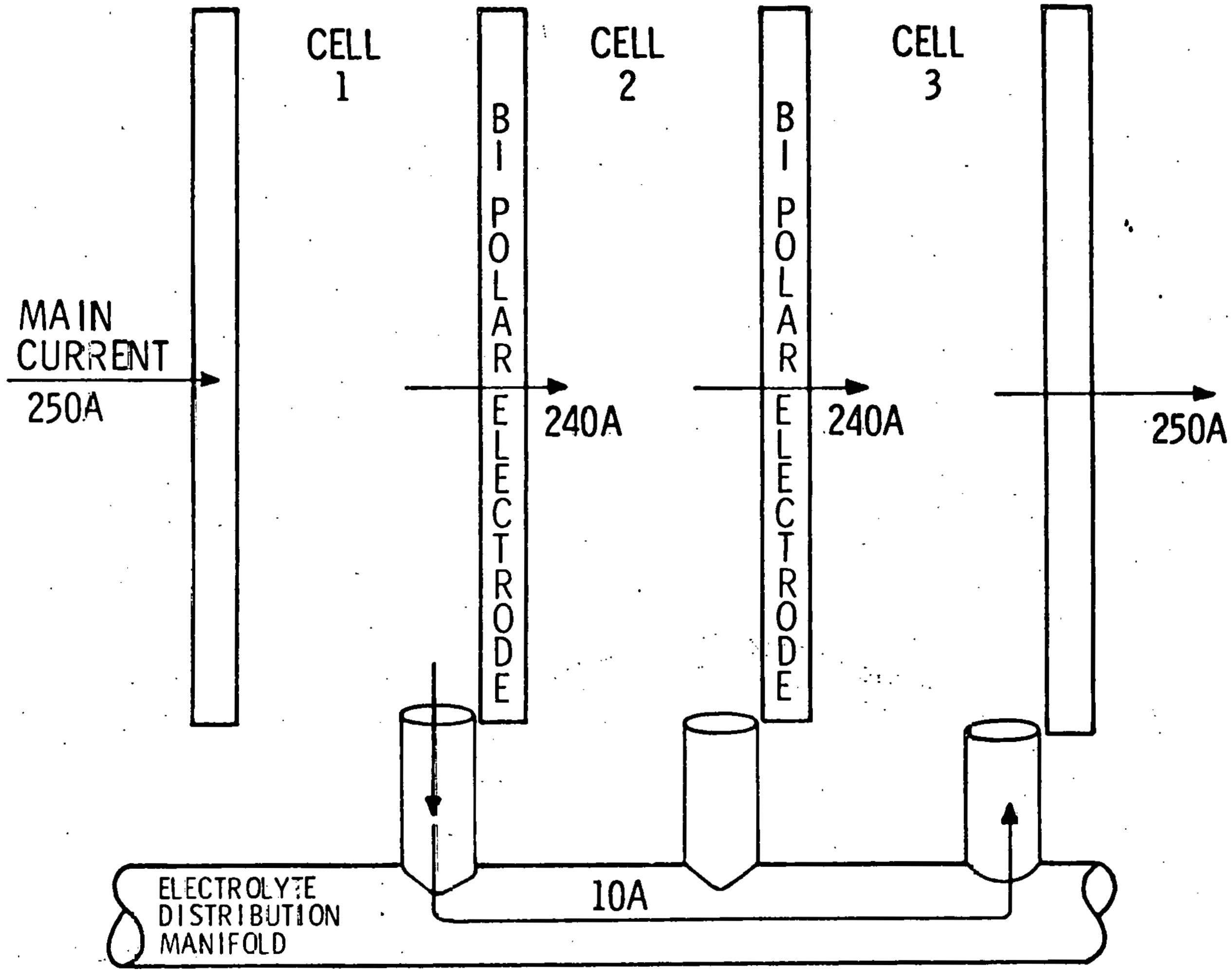
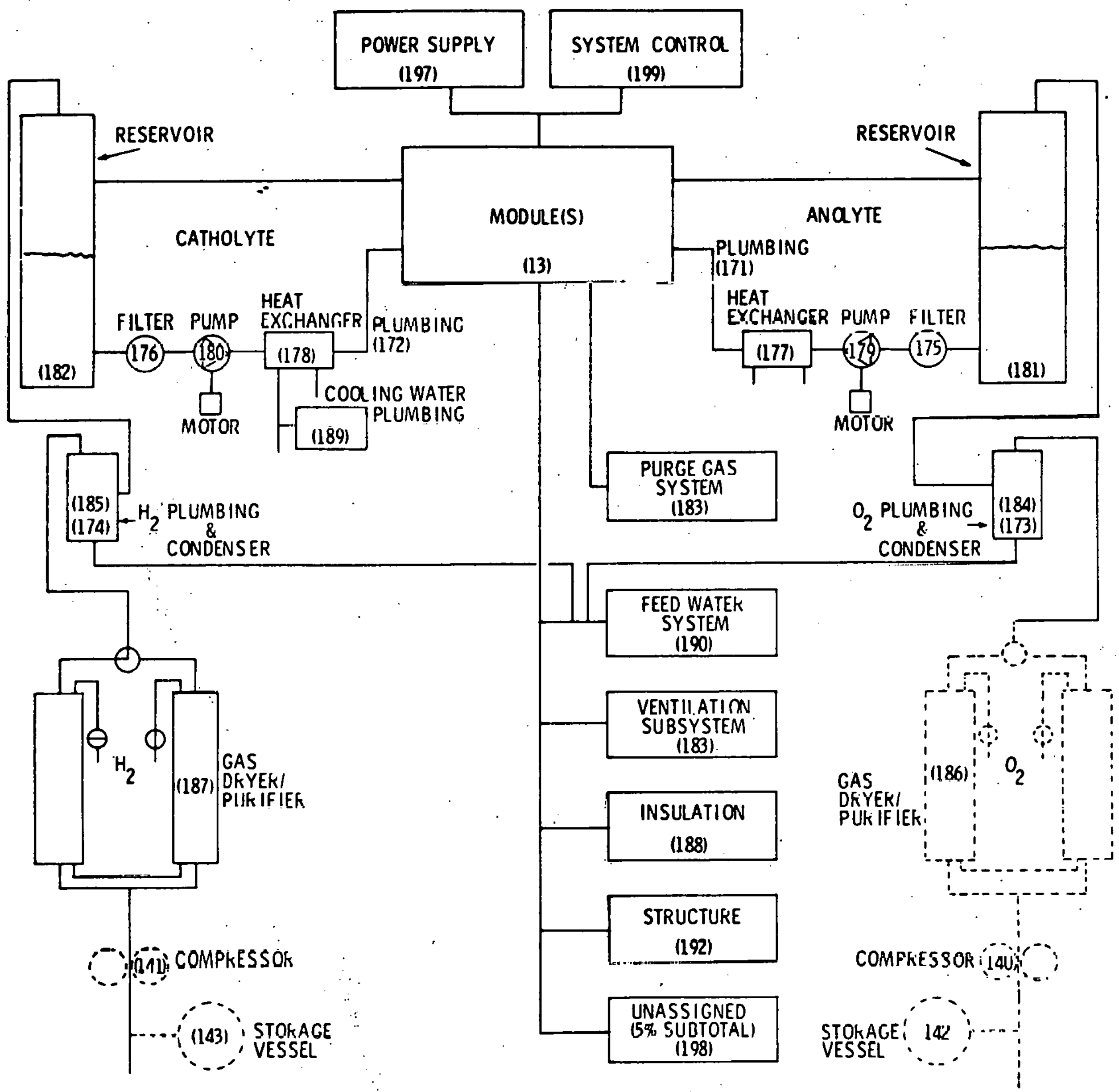


FIGURE 3-4. CONCEPTUAL SHUNT CURRENT BYPASSING CENTER CELL

After η_i is calculated, "ESTIM" calls either a round or rectangular module design routine depending on operator controlled input parameter "AMSTY" (#31). These routines calculate the cell frame annular thickness given internal pressure, temperature and a derated modulus of elasticity. The circular frame calculations are based on hoop stress and required seal length arguments. The rectangular case uses a beam loading calculation on the longest dimension to give the maximum plastic tensile stress. In addition, the amount of plastic and seal areas are found. Each of these routines calls an end plate and tie rod design routine. End plate thicknesses are calculated based on maximum deflection (#35) under load arguments. Tie rods are sized according to sealing loads, separator compression, and operating pressure. Tie rod safety factors (#55) are included, along with temperature effects (#51). Ultimately, these routines return design parameters such as end plate thicknesses and masses, tie rod lengths and diameters and associated costs.

The next routine called, 'MANANAL," calculates the required fluid mass flow through the electrolysis module based on a cursory heat balance routine given the electrolyte temperature difference across the module (#25). Individual cell flow is calculated using a momentum balance technique described in Ref. 5. Maximum cell flow is detected for purposes of checking parametric constraints in flow.

After "MANANAL" is executed, "HMPB" is called. This routine calculates sizes for the major components in the electrolyte loops using an energy and mass balance technique. A block diagram showing the major components is shown as Figure 3-5. The net energy input consists of the D.C. input power plus the electrolyte pump power. The net energy output consists of the product enthalpy and heat losses by convection, condensation, and heat exchangers. The routine starts by finding the required anolyte and catholyte flow rates based on the input temperature difference across the electrolysis



NOTES (1) NUMBERS REFER TO PROGRAM (COSTS) OUTPUT LOCATIONS.
(2) OXYGEN PURIFICATION, COMPRESSION AND STORAGE SUBSYSTEMS SET AT 0 FOR ALL STUDIES.
(3) HYDROGEN COMPRESSOR & STORAGE VESSEL SET AT 0 FOR ALL STUDIES.

FIGURE 3-5. SYSTEMS COMPONENT BLOCK DIAGRAM module and the calculated module heat load. Given the piping pressure drop per unit length (#100), the minimum pipe size is calculated. A required piping length is estimated from the plant size and a total pressure drop is found. An additional percentage is added to account for heat exchangers and flow meters. This is then added to the module pressure drop calculated above to give the total loop pressure drop. From here it is easy to find the required pump power and size using various efficiency factors (#106, #113). At this point the routine switches to consideration of energy balances starting with sizing the gas condensers. Feed water requirements are calculated by balancing the masses of gas and uncondensed water leaving the condenser. Convective heat losses are then estimated for the electrolysis module, fluid reservoirs, and piping. Insulation thicknesses and K values are inputs (#125-131). The heat exchangers are then sized for the net remaining heat load given cooling water temperatures and overall heat transfer coefficients (#97, 132, 133). Finally, the on-board electrolyte requirements are calculated. The next routine, "CONDIT" sizes the gas handling systems including dryers, compressors, and storage tanks. Dryer calculations are based on the required gas purity (#139 and 140) and the condenser outlet temperature. Dryer power requirements are a direct function of overall size. If high pressure outlet gas is required, the routine calculates the size and number of stages of compressors. If gas storage is required as specified by a storage mass, the routine returns the displacement volume of storage.

The final design routine calculates an overall production efficiency taking into account the dryer gas losses, auxiliary power losses, module current and voltage efficiencies and power conditioning efficiencies.

3.1.2.2 Costing Routines

The costing section of the objective calculation is comprised of five subroutines, "OPCOST," "PLTCOST," "MODCOST," "LIFE," and "CAPCOST."

The first routine, "OPCOST," assigns and sums all the yearly direct and indirect costs associated with plant operation except for capital costs, taxes, and electricity. Items addressed include cooling water, feed water, electrolyte, consumable parts, and labor. Overhead costs are assigned as a simple percentage of labor while general and administrative costs are a percentage of labor, overhead and "materials."

"PLTCOST" assigns original costs to all plant subsystems except for the electrolysis module. Most components are costed using an order of magnitude approximation of the form:

$$\frac{C_x}{C_1} = \left(\frac{S_x}{S_1}\right)^N$$

where C_1 and S_1 refer to a standard size (S_1) component and its cost (C_1), while S_x refers to an arbitrary size component, C_x to its cost. The exponential factor is generally less than one reflecting the economics of scale up. All major components are essentially treated this way excluding control systems, cooling water piping, feedwater subsystem and purge gas subsystems which are treated as constants. The exact values of the coefficients and exponents are input parameters. For fluid and gas exposed systems the costs are multiplied by material correction factors so that the additional expense of higher cost materials can be modeled.

The module costing is handled in much greater detail in subroutine "MODCOST." This routine breaks down the cost of the module into individual components. Structural parts include end plates, tie rods and associated hardware, cell frames, and seals.

Internal components include bipolar plates, anolyte and catholyte flow distribution members, anodes, cathodes, and interelectrode separators. With each of the internal members there is associated a material stock cost per unit size, a stock utilization factor to allow for scrap and waste, and a processing cost. In addition, there is a catalyst cost input for each electrode. Cell frames are costed according to the amount of plastic required, the price of the frame mold and its expected parts yield, and a processing cost per piece. End plates are costed according to their mass and material prices per unit mass and a machining cost. The bolts are costed in proportion to their mass also, with an additional factor for hardware. Assembly costs follow the equation:

Mod. Assy. Cost = K1 x area x # of cells + K2 x area,

where K1 and K2 are input constants (#261, 262). These factors are all summed to arrive at a module cost, MODCOST.

At this point in execution, the module life is calculated as a function of operating temperature. Two specified lifetimes are input (#224, 226), one at low temperature, one at high. The subroutine "LIFE" interpolates between these using an Arrhenius-type curve, i.e.:

$$\mathrm{LOG}_e\ (\mathrm{LIFE}) \alpha \left(\frac{1}{T_{abs}}\right)$$

where T_{abs} is in °Kelvin.

The total original capital cost of the system is calculated in subroutine "CAPCOST." For ease of calculation, all modules required during the life of the plant are considered to be bought at year zero. This does not introduce a large error if the discount rate and inflation rates are not widely divergent. In addition, refund values for all returned modules are estimated and credited to the original capital cost, thereby "avoiding" the capital gains taxes. The original capital cost is then made up of the sum of plant and module costs. A spare parts inventory is tacked on as a percentage of plant cost. Design and engineering costs are also estimated but only a fraction is assigned to the plant cost assuming more than one plant of a given design will be built. Then, a gross profit margin for components is added on to the sum of the above. This completes the components price or cost to the customer but there are two other capital costs addressed in this routine, the installation and checkout costs and the building and facilities costs. Both of these scale with the plant size using some exponent less than unity as above. Different profit margins can be associated with each of the three divisions, components, facilities, and installation.

3.1.2.3 Revenue Requirement Routine

The last subroutine, GASCOST, uses the previously generated total capital cost, yearly operating costs, and power consumption to do a revenue requirement calculation for the levelized and first year gas prices. Levelized prices are an important concept used throughout the subroutine. In essence, this concept allows one to take an irregular cash flow distributed over time and compute a present worth. This then is distributed as an even payment cash flow which has the same economic force as the original cash flow. These evened out payments (or credits) are called the "levelized" payments. In the prediction of prices in inflationary times, this concept generates a much more useful number for comparison purposes. It should not be compared to costs or prices at a single point in time, however. The details of the calculation were taken from and are discussed in a study guide prepared by the Electric Power Research Institute (Ref. 6). In this calculation the effects of different rates of inflation on operating and power costs can be addressed. In addition, this routine calculates tax rates, accelerated depreciation allowances, and investment tax credits. The initial investment can be broken into debt and equity financing and different interest rates can be assigned to each. Finally, there is a provision for a "retirement dispersion allowance" to add a safety factor for random differences in actual plant life.

This routine ends the objective function calculation and control is returned to the main program which tests for a lower levelized gas price than calculated in previous cases. Also returned are on the order of 200 other values such as design parameters, efficiencies, component sizes, and cost breakdowns. A list of these is given in Appendix B. Program execution notes are listed in Appendix C and a complete Fortran listing is contained in Appendix D. Figure 4-10 shows a sample final output optimum case. This run tested the sensitivity of three parameters, cell area (#5), current density (#6), and module temperature (#3) using a 4 x 8 x 4 grid or 128 function evaluations. Execution time was 0.9 C.P.U. seconds and the cost was $2.00 for daytime priority execution. This run was executed on a C.D.C. Cyber 76 computer operated by Itel, Inc. at their Dallas, Texas facility.

3.2 TEST OR BENCHMARK CASE STUDIES

3.2.1 Input

To evaluate the model's predictive power and to debug the program, a particularly interesting test case was tried, this being an 80 KW D.C., dual irriguous (i.e., anolyte and catholyte) system sized for electric power generator cooling. Appendix A lists the specific input parameters used for this case, while Appendix B lists the total output results. The following is a generalized discussion of the input.

The first major input parameter is, of course, the input module D.C. power. For this example, the required maximum hydrogen gas output is ~250 SLM which translates to ~50 KW or 11,000 Kg H_2/yr. Using a 62.5% D.C. to gas efficiency, this means a D.C. input requirement of 80 KW. Having selected a particular D.C. input, if a higher efficiency value for the module is subsequently calculated, then the output gas flow would be greater than required. It is possible to design the computer code to use a constant, specified gas output as the size parameter but this would require an expensive reiterative procedure to converge simultaneously on current efficiency, voltage efficiency, number of cells, and input power.

The other parameters can be grouped loosely into three divisions, (1) technical, (2) manufacturer, and (3) operator. Technical parameters include diverse items such as cell polarization characteristics, operating temperature and pressure, electrolyte concentration, module design and tie rod design parameters, flow curves, fluid systems and thermal systems design parameters, gas conditioning and storage systems design parameters, etc. The second grouping includes specific components cost vs. size curves, manufacturing and materials costs, catalyst costs, design and engineering costs, installation, test and facilities costs, etc. Also included in this set are profit margins on three general areas, components, installation and facilities. The third grouping includes both cost and technical items. Technical input from the system operator includes cooling water temperature and maximum flow rate, plant ambient temperature, gas storage requirements and outlet pressure. Economic input is comprised of items like power cost, duty factor, capitalization methods and interest rates, tax credits, accounting method, inflation rates, manpower costs, cooling water costs, etc.

For the baseline case, the cell polarization curves were taken from previous test results in this and preceding contracts. Baseline electrodes were nickel-200 wire screens and asbestos was used as a separator. Costs for this cell technology are fairly well established since commercial systems produced by TES utilize the same materials in a similar design. Module design parameters (fluidics and mechanics) were also taken in large part from commercial system data although there is the major difference that the commercial system operates in the "single irriguous" mode (single flowing electrolyte) whereas this baseline system uses two electrolyte streams. Cold rolled 18-8 stainless steel characteristics define the tie bolt parameters and 316 stainless steel was used in the end plate design (Ref. 9). Fluid manifolds were chosen from previous studies done for EPRI. Cell frame parameters were taken from UDEL® polysulfone design literature (Ref. 10).

System temperatures chosen are representative of those encountered in practice. An operating temperature of 60°C and an ambient of 25°C was selected. A module temperature rise of 8.33°C defines the electrolyte flow rate when coupled with the module heat load. The heat exchanger and condenser heat transfer coefficients as well as the various efficiencies are taken from the commercial design. Many of the numbers are arbitrary such as heat exchanger outlet temperatures, reservoir and filter sizes, etc. Educated guesses are the "rule of thumb" here. Gas conditioning system design parameters are based on molecular sieve dryer design (Ref. 11) and standard compressor design curves.

Cost curves were generated from commercial systems design and wherever available, standard cost vs. size exponents were used. The numbers represent mid-1979 prices and are the latest available to the author. Other economic factors such as capitalization methods and interest rates also are somewhat arbitrary and will vary widely from case to case. A power cost of $0.025/KWH was selected along with an inflation rate of 10%.

3.2.2 Results of Test/Benchmark Case

NOTE: In this section, the numbers in parentheses are referenced to the position in the output list in Appendix B.

The detail output results from the benchmark case are tabulated in Appendix B. The predicted levelized gas price (#1) is \$6.99/Kg H_2 and the first year (#16) price \$4.03/Kg H_2 or \$0.96/100 SCF. These prices reflect the revenue required to cover capital, power and operating expenses, with return on internal investment and taxes included in capital charges. The gas output mass (#10) is 9,554 Kg/yr at an 85% duty factor or translated to peak flow, 0.0214 Kg/min (9.01 SCF/min). Levelized total costs per year (#21) are \$66,835 which are factored into levelized capital cost per year (#24) of \$16,152, levelized power cost per year (#22) of \$35,879, and levelized operating costs per year (#23) of \$14,803. These three costs will be further subdivided and discussed in the following paragraphs.

The total capital price (#7) for the system is \$87,013 and includes the original selling price for the components (system and all electrolysis modules used over the 20-year book life), the cost of installation and startup, and building and facilities costs. Original design and engineering charges are also accounted for separately. For this case, module plus components costs (#28) amounted to \$34,186 which includes credits for returned electrolysis modules. This cost was then incremented by 75% to allow for vendor gross margin. Installation and startup costs (#27) were \$3,417, again to be incremented by 75% for profit margins. Finally, the building and facilities (#26) were estimated to cost \$17,108 with no profit assumed. Design and engineering costs (#200) were \$410,000, of which 1% was charged to this plant (i.e., amortize D & E over 100 plants). This sums finally to the total capital price (#7) of \$87,013.

For a 20-year book life system capitalized at a 11.4% discount rate (#17), capital costs must be recovered (#20) at 12.89% per year, i.e., 12.89% of the original capital cost must be paid back each of the 20 years to cover the original debt plus interest. An additional 5.4% is required for income taxes (#153) on equity return and 2% was required for property tax and insurance (input #172). An accelerated depreciation allowance (#152) of 2.5% can be taken, however. Another 0.75% for retirement dispersion (#155) must be allowed. The sum of all these costs yields a 18.56% yearly fixed charge rate (#25) on the original capital or $16,152/yr (#24). This is a levelized number but it should not change dramatically over time.

The components costs (#28) of $34,186 can be broken into $17,913 for non-electrolysis module components (#11) plus 1% ($180) for original spare parts inventory (input #187), and $16,094 for two electrolysis modules (#13) to last an estimated (#12) 10 years each. The cost for non-module components is further broken down in Table 3-1.

The estimated module cost (#66) of $10,258 can be attributed to costs for cell components, end plates, tie rods, and assembly. The baseline module requires 90 cells (#15) of 670 cm^2 area (0.72 ft^2) (input #5) which operate at a current density of 6000 A/M^2 (557 ASF). More will be said about the predicted module design later in this section. Module costs are broken down in Table 3-2. As mentioned before, these costs relate to nickel screen electrodes, asbestos separators, polysulfone cell frames, and stainless steel end plates. Material utilization factors for die cut parts are taken into account, in this case a 1.4 M^2 stock (square) size is required for a 1 M^2 (round) part.

A replacement module for this system costs $5,836 (#118). This smaller cost comes from the assumption that the end plates and tie rods are reusable but only an

Table 3-1. Components Cost - Baseline Case: 255 SLM H_2 Out

Fluid Systems Costs (Including Subassembly, Labor, and Burden)

	Catholyte		Anolyte	
Plumbing	$ 464.00	(#172)	$ 464.00	(#171)
Filter	77.64	(#176)	82.67	(#175)
Pump	769.60	(#180)	769.60	(#179)
Heat Exchanger	665.50	(#178)	659.90	(#177)
Reservoir/Phase Separator	904.90	(#182)	904.90	(#181)
	$2881.84		$2881.07	

Gas Systems Costs (Including Subassembly, Labor, and Burden)

	Hydrogen		Oxygen	
Plumbing	$ 219.90	(#174)	$219.90	(#173)
Condenser	228.70	(#185)	314.60	(#184)
Dryer	1736.00	(#187)	--	(#186)
Compressor	--	(#194)	--	(#193)
Bottle	--	(#196)	--	(#195)
	$2184.60		$534.50	

Other Costs (Including Subassembly, Labor, and Burden)

Purge Gas Plumbing	$ 130.00	(#183)
Insulation	--	(#188)
Cooling Water Plumbing	220.00	(#189)
Feed Water Plumbing	200.00	(#190)
Ventilation	210.80	(#191)
Structures	1732.00	(#192)
Control and Instrumentation	3400.00	(#199)
Power Supply	2685.00	(#197)
Unassigned (5% of subtotal)	853.00	(#198)
	$9430.80	

TOTAL $17,913 (#11)

Table 3-2. Module Cost Breakdown

	Cost Per Cell				
Cell Internal					
Bipolar Plate	$ 8.550	(#64)			
Flow Members (2)	5.783	(#65)			
Anode	6.778	(#162)			
Cathode	6.778	(#163)			
Separator	1.169	(#63)			
Cell Structural					
Cell Frames (2)	17.66	(#168)			
Cell Seals (2)	7.231	(#169)			
	$53.95		x 90 cells (#33)	=	$4855.50
Tie Rods	$188.80	(#166)	x 8 (input #49)	=	$1510.40
End Plates (pair)					$2984.00 (#165)
Assembly (L + B)					$ 907.50 (#170)
TOTAL MODULE COST (#66)					$10,257.40

effective small fraction of the cell internal and structural members are reusable. An additional 50% disassembly charge is tacked onto the returned module as a reassembly cost.

The yearly operating cost for the system, excluding power cost is broken into four categories: material, labor, overhead, and general and administrative. The yearly materials allotments are for cooling water, feed water, consumable parts, electrolyte, and purge gas, for a total of \$1493/year. Labor cost is estimated at \$2524/year (#159)(0.18 man year @ \$14,000/yr). The input overhead rate of 100% is applied to this labor cost to yield \$2524 (#161), while no G & A is charged (#160). The cooling and feed water requirements reflect the 85% duty cycle input, while the other material factors and labor requirements do not. The total is \$6,541 (#9) for the first year while the levelized figure (#23) is \$14,803 reflecting a 10% inflation rate (input #166) and 11.4% (#17) discount rate.

The yearly power cost is simply calculated from the A.C. power requirements (85.2 KW), duty factor (input #169) (85%) and power cost (input #167) (2.5¢/KWH). This cost turns out to be \$15,855/yr (#8) for the first year or \$35,879 (#22) for the levelized cost. The A.C. power of 85.2 KW (#2) is the sum of 877.6 watts for auxiliary systems (#137) and 84.3 KW for the electrolysis circuit. The overall system efficiency is 59.28% (#3) for A.C. in to gas out based on the heat of formation of water:

$$H_2(g) + 1/2\ O_2\ (g) \rightarrow H_2O(\ell) \qquad \Delta H = -2.86 \times 10^5 \text{ Joule}$$

Module efficiency is 63.9% (current efficiency = 95.49% (#34), voltage efficiency = 66.92% (#35)). Gas purification efficiency is 98.66% (#37) and rectifier efficiency was input at 95%.

Not only are the costs described above returned by the program, but also several design requirements for the electrolysis module, fluid loops, and gas conditioning systems. For the baseline case, the model predicted a 90-cell electrolysis module is required. The end plate dimensions are 57.7 cm (diam) x 9.8 cm (thickness (#51). The cell frame annular width is 11 cm (#46) and tie rod diameter is 2.2 cm (#49). Using heat exchangers with an overall heat transfer coefficient (U) of 568 W/M^2C and 35°C cooling water, the program predicts heat exchanger areas of 1.183 and 1.196 M^2 for anolyte and catholyte, respectively (#100, #101). Heat loads here are on the order of 14 KW each (#41, #102, #103). Condenser areas are 0.061 and 0.098 M^2 for oxygen and hydrogen (#86, #87). The total water mass flow rate is predicted to be 0.835 Kg/sec (#88) (12.9 gpm). The gas output mass flow rate for this case is 9554 Kg/year (#10) or using the 85% duty cycle, a peak output of 3.5609×10^{-4} Kg/sec (#123) (255.1 SLM or 540.5 SCFH).

Although many of the inputs were arbitrary and more than a few were educated guesses, the values returned for this case do reflect believable quantities based on past experience. It is important to remember though that this type of study yields price estimates with only limited (±40%) accuracy and should not be treated as project control estimates, much less final values. It is extremely useful for comparison of alternatives when the same values of economic variables are utilized, and even more useful as a tool for gauging the true sensitivity of design alternatives.

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4.0 SENSITIVITY STUDIES

The initial computer runs conducted as part of this task were arranged into four studies. Study One tests the sensitivity of the gas price to overall system size measured in terms of module input power. Two electrode technologies were evaluated, the first utilizing baseline nickel-200 screen electrodes, the second utilizing the C-AN advanced cathode and nickel-200 screen anode. As suggested by BNL at the start of the task, four sizes were employed, 80 KW, 250 KW, 500 KW, and 1000 KW (1 MW). Study Two tests the effect of operating temperature on the prices of the two electrode technologies. Study Three is a deeper effort based on Study Two and tests the effects of current density, temperature and module size on both technologies. The last study requested by BNL, Study Four, shows the effect of system duty factor and the electricity rates upon the gas price, again for both electrode technologies.

4.1 STUDY ONE. EFFECT OF PLANT SIZE

To ascertain the magnitude of the economies of scale on alkaline water electrolysis systems, the program was run for four sizes ranging from 80 to 1000 KW D.C. input power. For each size the computer picked an optimum cell area but the current density was set at 6000 amp/M^2 and the operating temperature at 60°C. Most of the inputs were the same as the baseline case, although a few estimates were required to be input for the bigger systems in the few areas where the model will not solve for the required size. Figure 4-1 shows a plot of gas price vs. size for the baseline technology. The model predicts a reasonably linear behavior for the price when plotted versus the logarithm of power, a slope of about -\$1.30/Kg H_2 per decade power. The price shown here is the 20-year levelized value. Figure 4-2 gives a similar plot for first year prices. The cost of electricity for all sizes was 2.5¢/KWH as in the baseline case. Also shown on

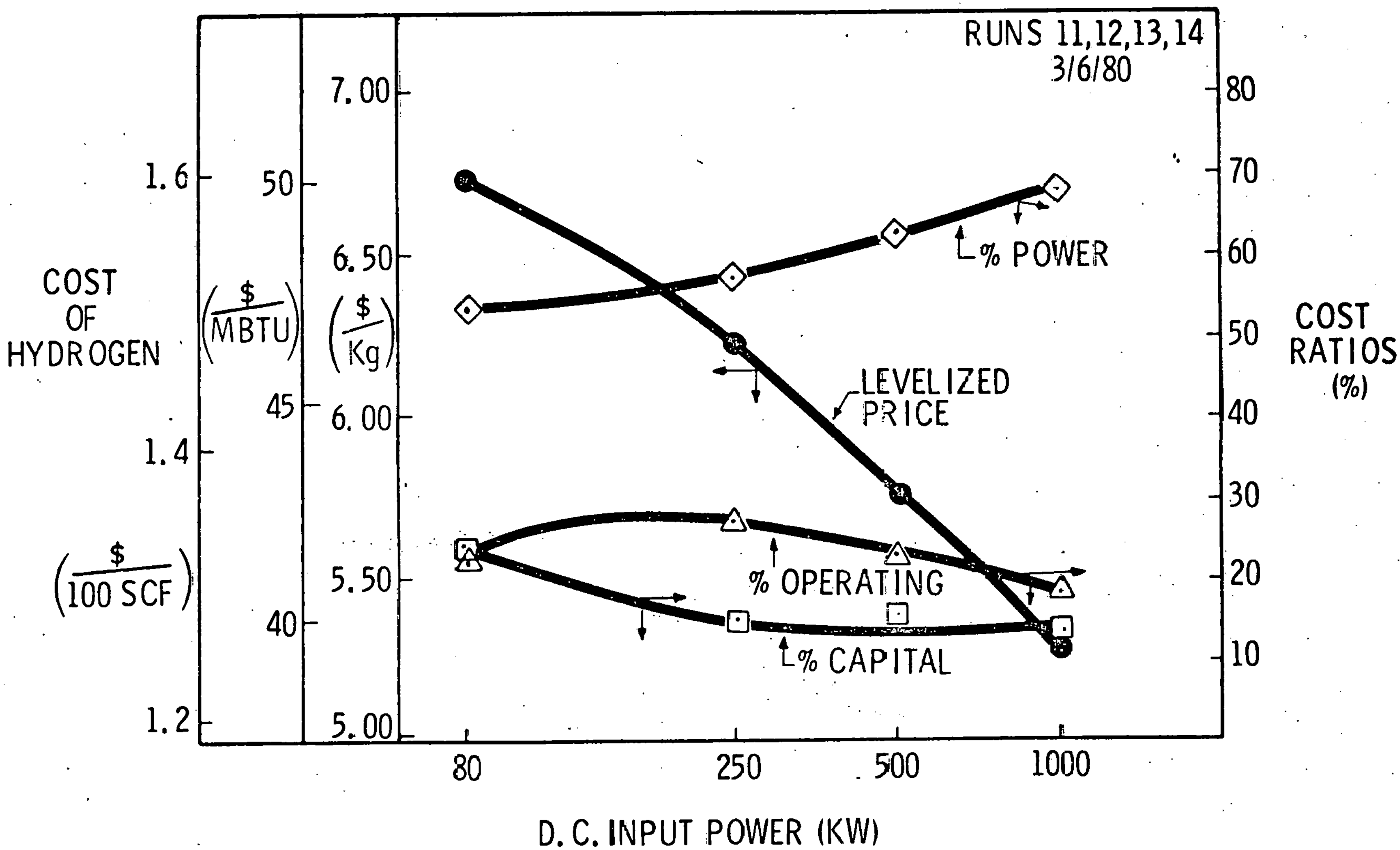

FIGURE 4-1. LEVELIZED GAS PRICE VS. SIZE: BASELINE TECHNOLOGY

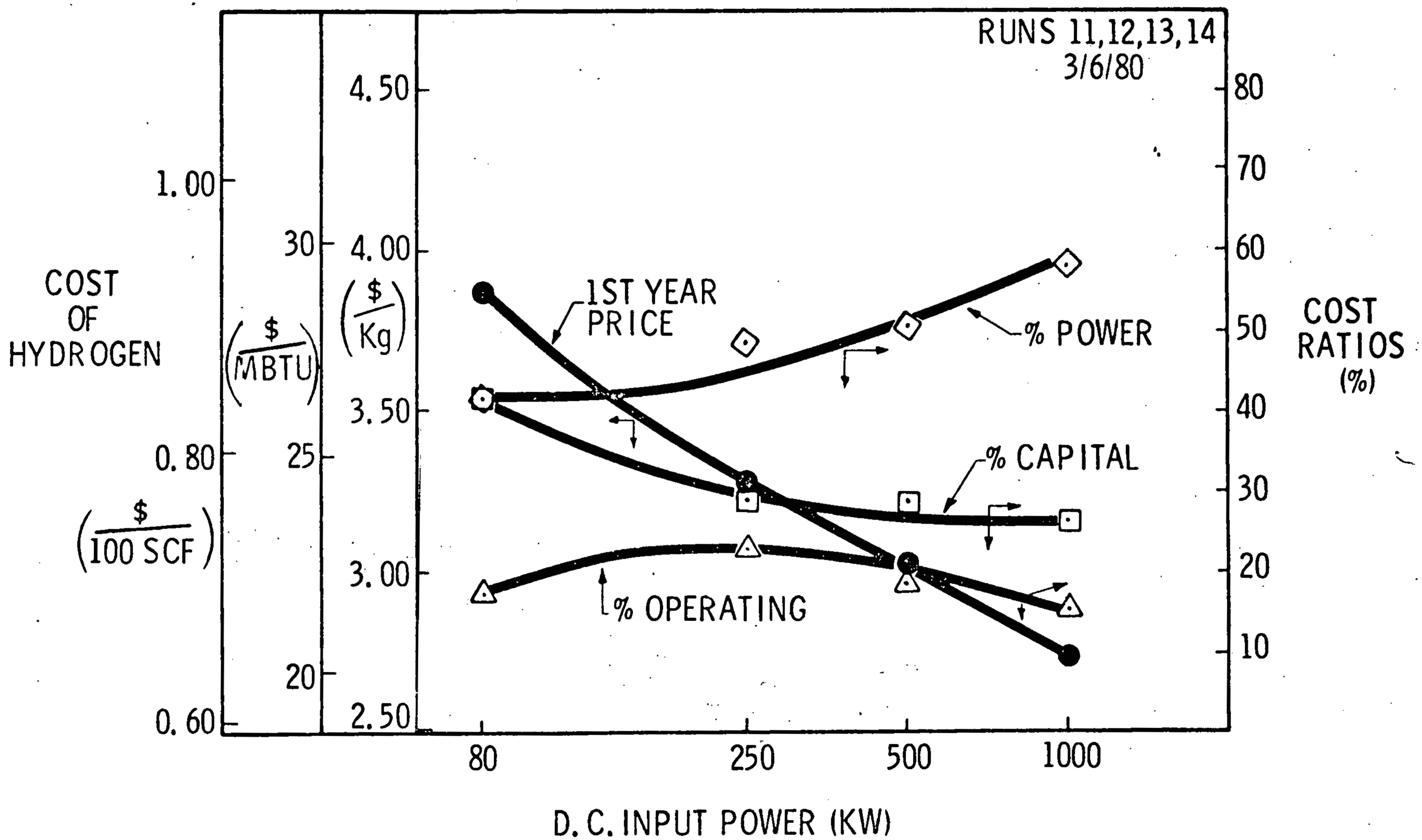

FIGURE 4-2. FIRST YEAR GAS PRICE VS. SIZE: BASELINE TECHNOLOGY

these plots are the proportion of yearly costs going to fixed capital costs, power costs, and to other operating costs. It is interesting to note that in the 80 KW system the capital and power costs share equal magnitude only when considering first year costs. Since capital is a (relatively) fixed value whereas power is inflationary, the levelized numbers reflect a much greater sensitivity to power costs. For larger plants, this dominance is increased since in the absence of size-dependent electricity rates, power costs show no economies of scale.

Figure 4-3 is a log-log plot of the major costs calculated for the baseline technology in this study. The first year power cost curve has a 45° slope in reference to the axes, again because of no economies of scale for power. The top curve is the total capital price of the system including installation and facilities. For the 80 KW system, the price is ~\$88K and increases to \$480K for the 1 MW (input) system. As indicated in the figure, the slope is much less than 45°. Whether the trend continues or not can not be predicted by this study since, as mentioned above, the cost curves utilized are accurate only in low power regimes. The indication is, though, that the price of hydrogen decreases dramatically with increasing system size and further study, including obtaining more accurate cost data, is warranted.

Similar runs were made using cost and current-voltage data for the C-AN advanced cathode technology. These are presented in Figures 4-4, 4-5, and 4-6. Comparing Figure 4-1 (baseline technology) and 4-4 (C-AN cathode technology), the levelized price curves, one notes that the cost ratio curves are almost superimposable. This may seem strange until the reader remembers that the model is comparing plants of similar input power and the C-AN containing plant would then use the same power to produce more gas. As indicated, the advanced technology results in a lower cost

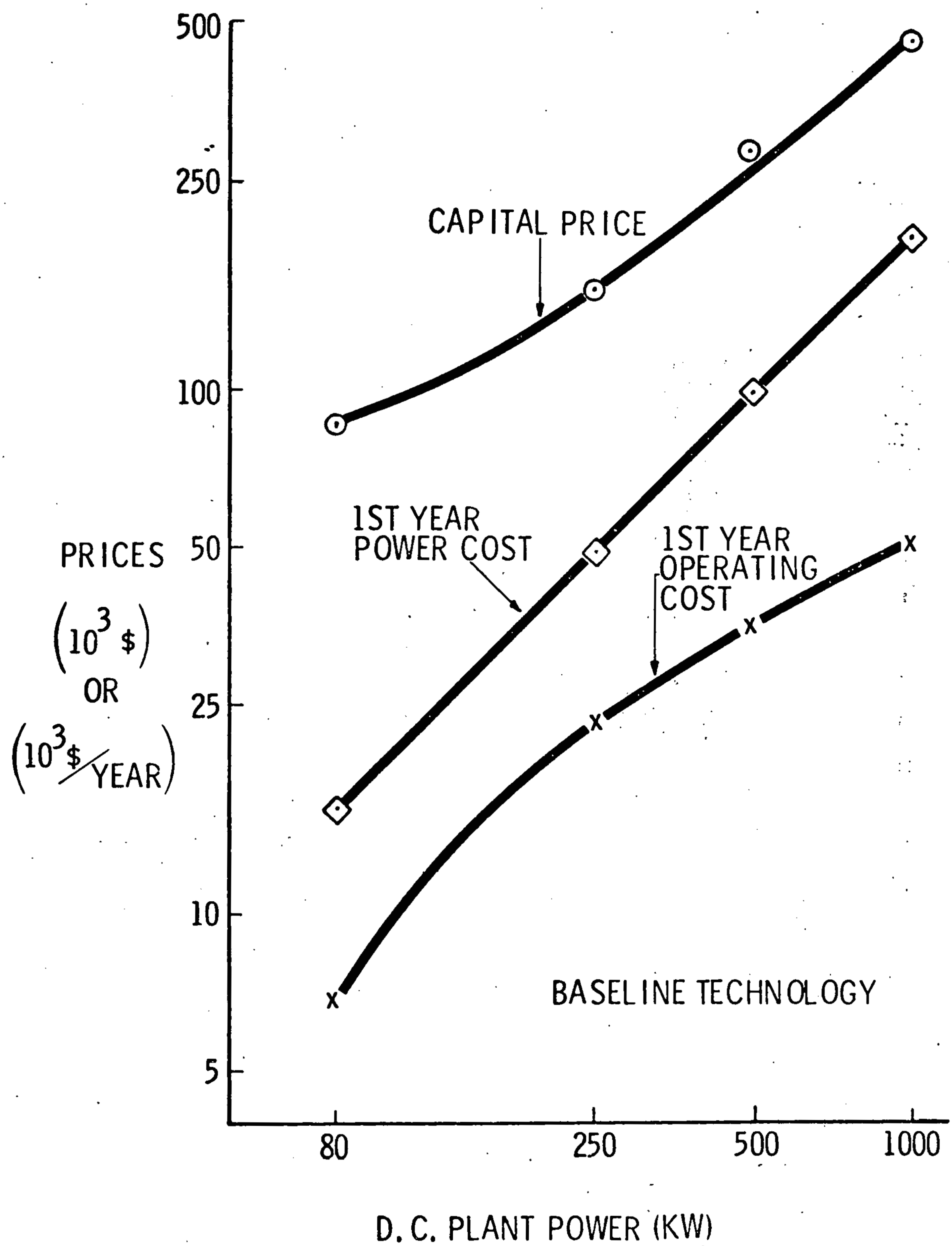

FIGURE 4-3. PRICE VS. SIZE FOR BASELINE TECHNOLOGY, 2.5¢/KWH

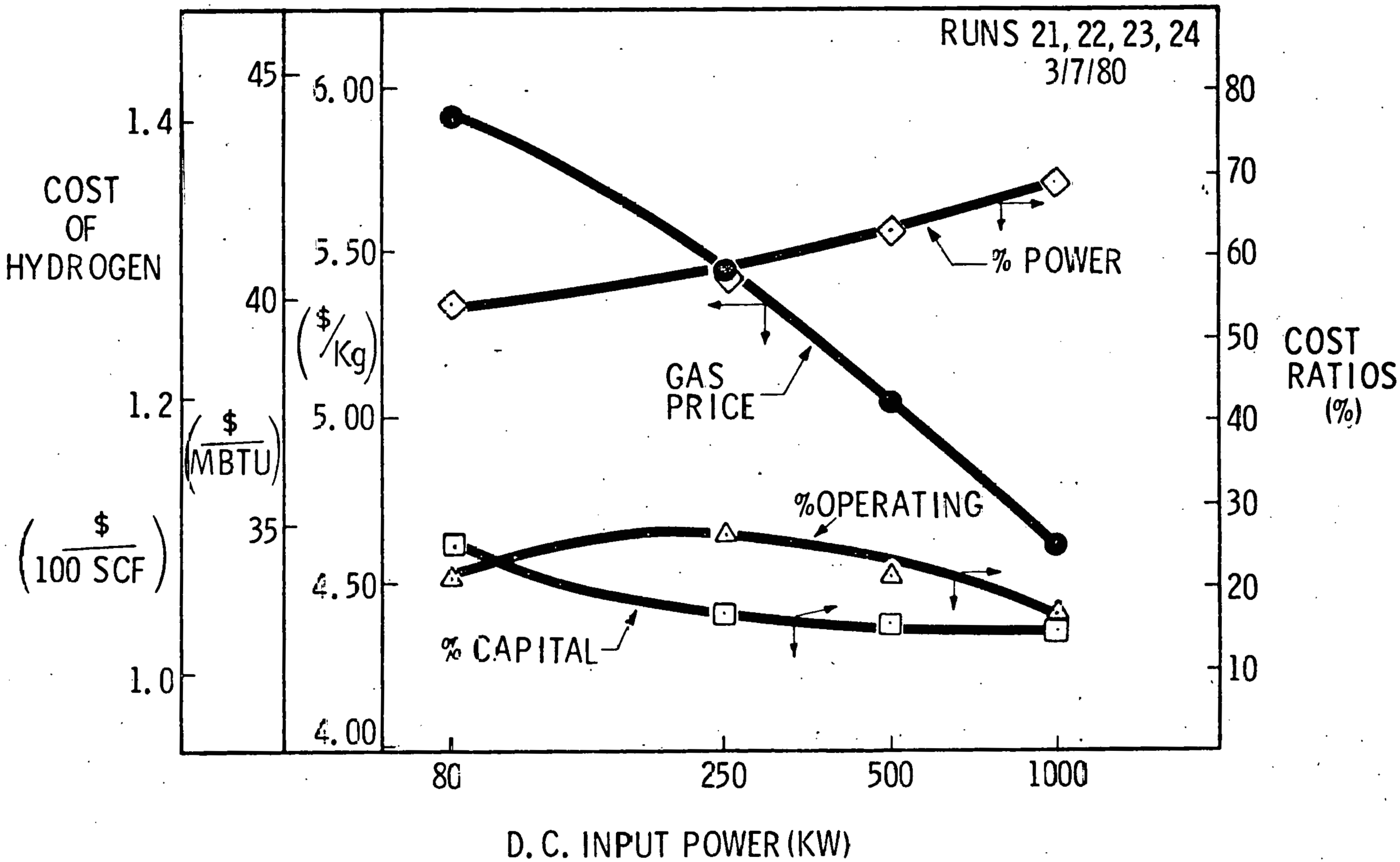

FIGURE 4-4. LEVELIZED GAS PRICE VS SIZE: C-AN CATHODE TECHNOLOGY

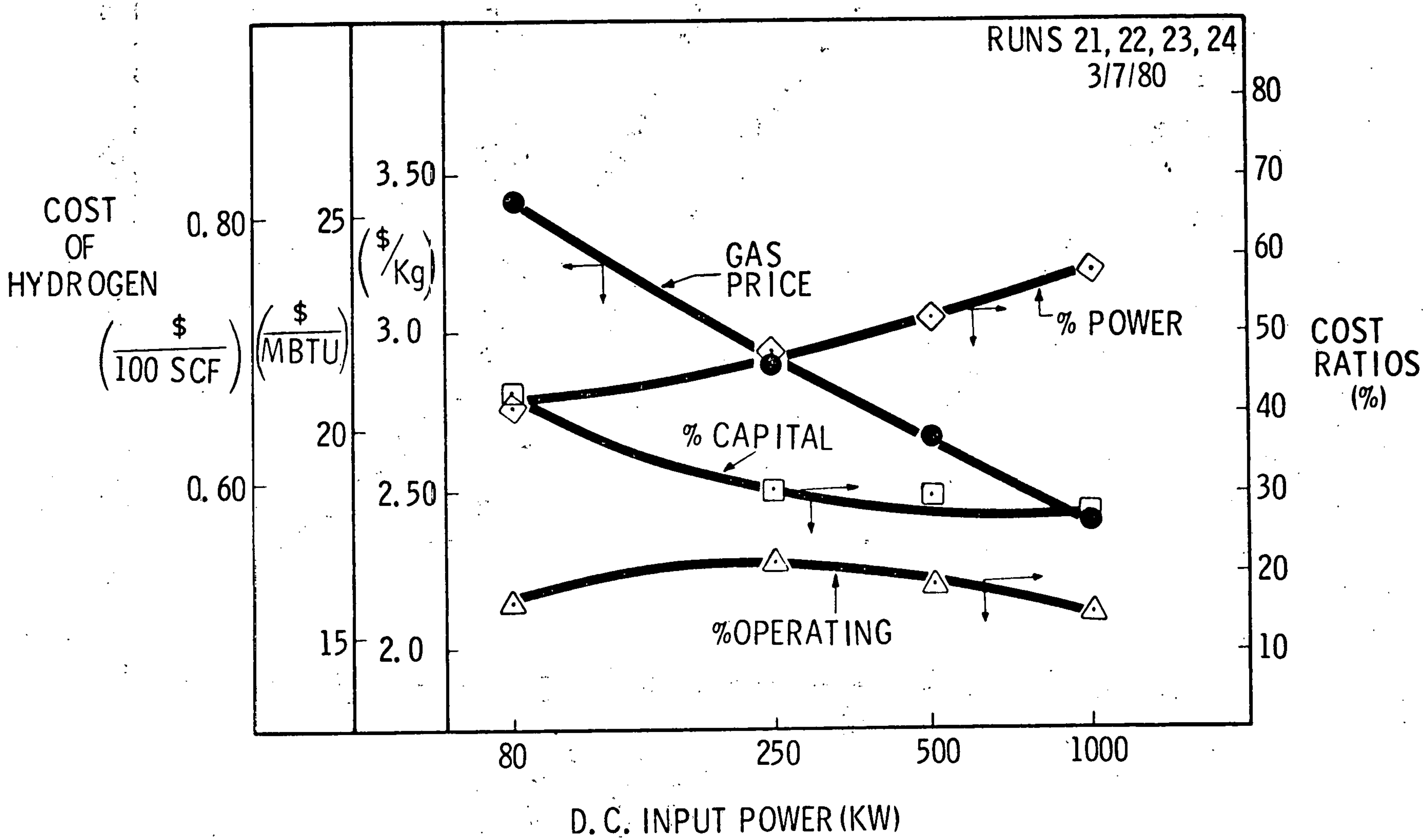

FIGURE 4-5. FIRST YEAR GAS PRICE VS. SIZE: ADVANCED CATHODE TECHNOLOGY

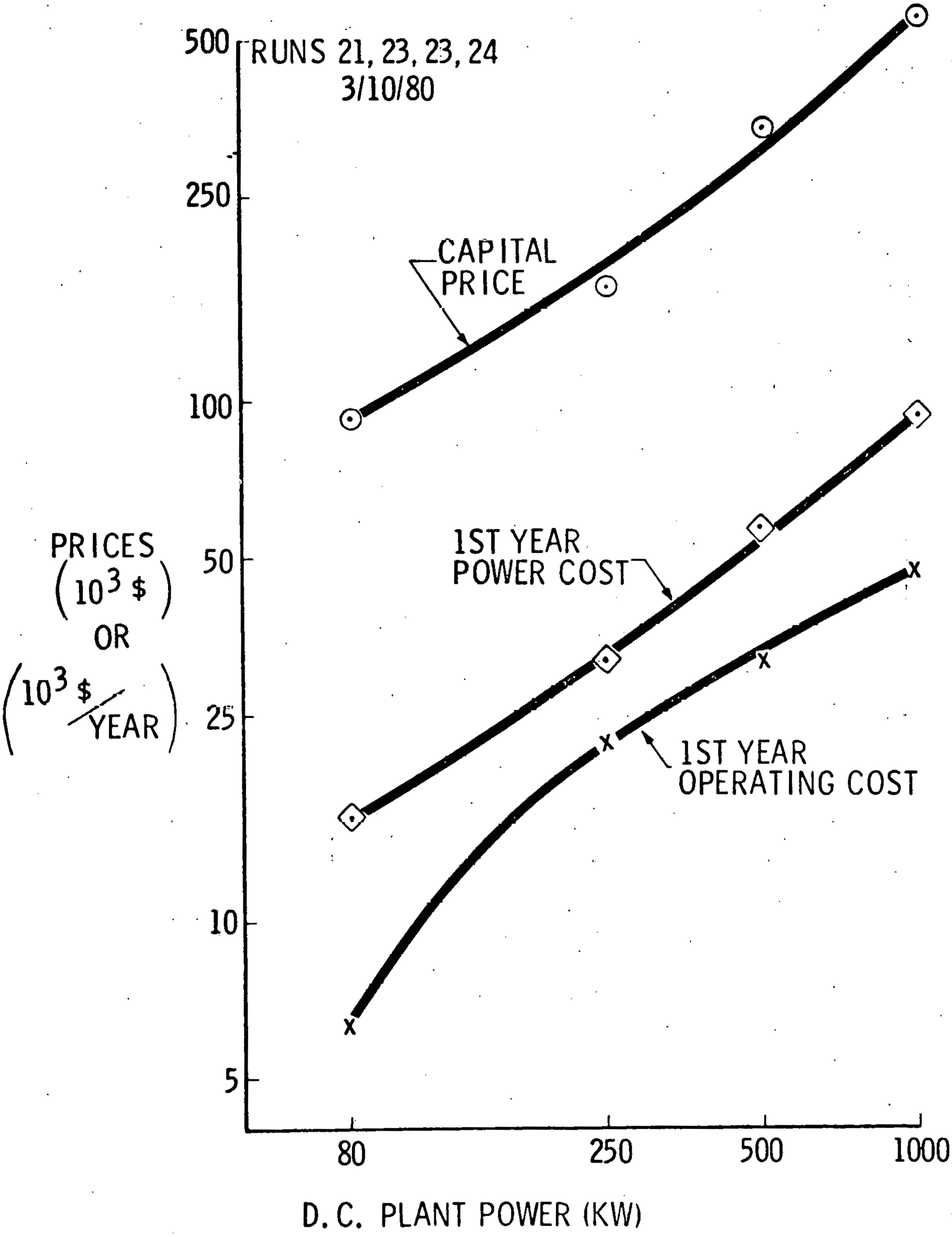

FIGURE 4-6. PRICE VS. SIZE: ADVANCED CATHODE TECHNOLOGY, 2.5¢/KWH

of hydrogen. Table 4-1 makes a comparison of the two technologies for the 80 and 1000 KW cases.

There is a small difference between the baseline case described in Section 3.2 and the 80 KW system here. This is because in this set of runs, the computer selected the optimum cell size of 0.15 M^2, over twice the area of the baseline cell. Figure 4-7 shows the effect of nickel-200 technology cell area on gas price for the four plant sizes. In the larger plants the effect is remarkably flat except in the low area region. For the 80 KW system, the effect is more pronounced, due mainly to the greater proportional price of end plates in the smaller modules. The minimums for all these curves will vary when other parameters are allowed to vary, particularly the cell current density as will be seen in the third study.

4.2 STUDY TWO. EFFECTS OF TEMPERATURE: 80 KW UNIT

This study consisted of two computer runs, the first for baseline nickel screen cell technology, the second for C-AN cathode technology. Temperature was varied from 55 to 125°C and while the other input parameters were kept at the baseline case values, the principal units being 85% utilization, 80 KW size and 2.5¢/KWH. Figure 4-8 summarizes the results from this study. The levelized price of hydrogen does, indeed, decrease with increasing temperature. Each of the curves here is made up of segments from a family of curves describing systems requiring 2, 3, or 4 electrolysis modules over the 20-year book life of the plant. Recalling that part of the input information is the module life at two temperatures, in this case, module life was estimated to be 10 years at 50°C and 5 years at 125°C. The program interpolated between these two lifetimes using an Arrhenius type behavior and calculated the number of modules required over the plant life, rounding to an integral number. A more detailed calculation may not

Table 4-1. Study One: C-AN vs Ni Screen Technologies, 80 and 1000 KW Plants @ 60°C, 6000 A/M^2

		Nickel Screen Cathode		C-AN Cathode	
Size		80 KW	1000 KW	80 KW	1000 KW
Levelized gas price	(\$/Kg)	6.73	5.29	5.91	4.623
First year gas price	(\$/Kg)	3.879	2.936	3.44	2.41
Gas output	(Kg/yr)	10,100	124,500	11,300	141,500
Efficiency	(%)	61.6	61.7	69.8	70.2
Cell voltage	(V)	2.213	2.213	1.948	1.948
Cell area	(M^2)	0.15	0.75	0.15	0.75
Cell cost	(\$)	91	370	95	387
Number of cells		41	101	46	115
Module cost	(\$K)	12	97	13	105
Capital price	(\$)	87,848	479,890	90,257	505,900

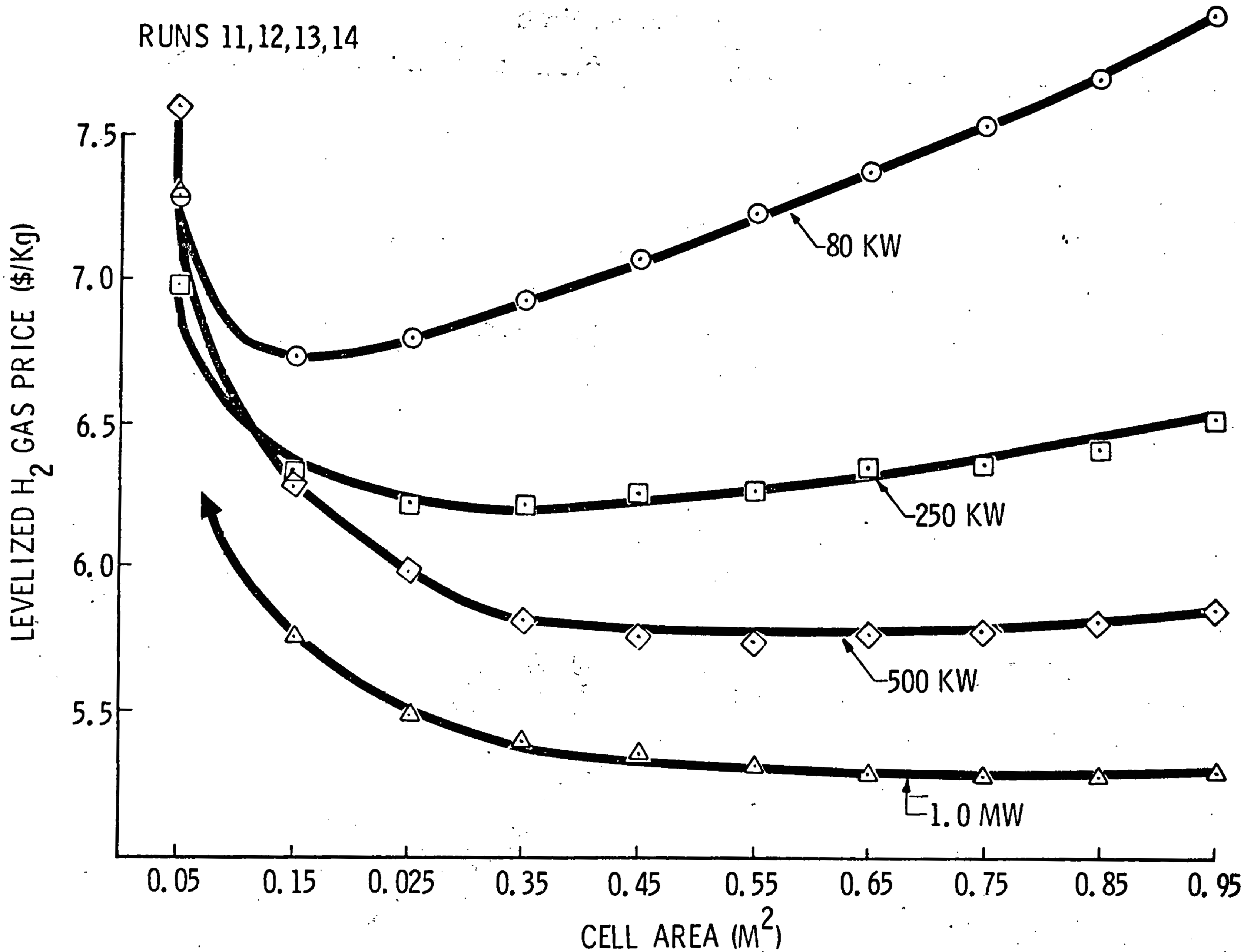

FIGURE 4-7. GAS PRICE VS. CELL AREA: BASELINE TECHNOLOGY

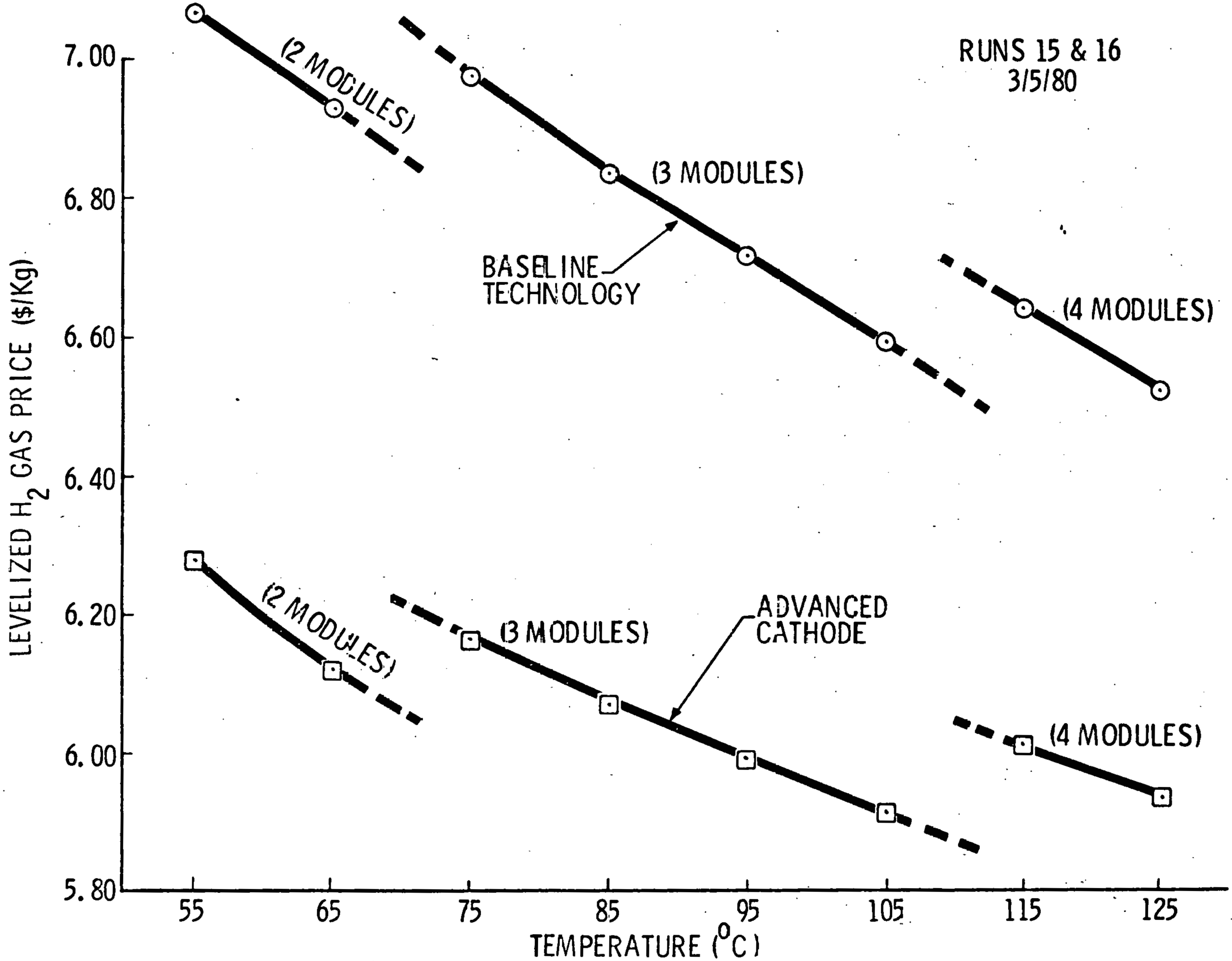

FIGURE 4-8. LEVELIZED H_2 FRICE FROM 80KW SYSTEM VS. MODULE TEMPERATURE 85% UTILIZATION, 2.5 /KWH

round this way but instead calculate the remaining life in the last module and take a resale credit for it, thus smoothing out the curve. It is interesting to note that because of this effect the minimum for the C-AN technology is at 105°C although the value at 125°C is very close. One additional reason for this can be seen by considering the values presented in Figure 4-9, a plot of current and voltage efficiency versus temperature. The voltage efficiencies of both technologies are increasing with temperature at close to the same rate. The current efficiencies are almost identical. (Not plotted are the gas purification efficiencies, 98.7% in all cases, and the rectifier efficiencies, 95% in all cases.) Therefore, from 55°C to 125°C the overall efficiency in the baseline system changes from 58.8% to 66.7%, an absolute increase of 7.96% and a relative increase of 13.55%. For the advanced technology, the absolute increase is 7.72% but the relative increase is only 11.65% since the low temperature efficiency is a higher value to begin with. This means that one does not gain as much going to higher temperatures in the advanced system case which explains part of the lower curve in Figure 4-8. Again, the significant conclusion is both curves indicate that operation at higher temperatures is economically advantageous if the module life (and system life) is not substantially diminished at higher temperatures.

4.3 STUDY THREE. OPTIMIZATION OF CELL SIZES AND CURRENT DENSITIES: 80 KW UNIT

This study was basically an expansion of Study Two in which temperature, current density, and cell area were allowed to vary, temperature from 50°C to 125°C in 25°C steps, current density from 3000 to 10,000 A/M^2 in 1000 A/M^2 steps, and cell area from 0.05 M^2 to 0.55 M^2 in 0.1 M^2 steps. This optimization was run for both technologies. Figure 4-10 is a plot of the levelized price of hydrogen versus cell current

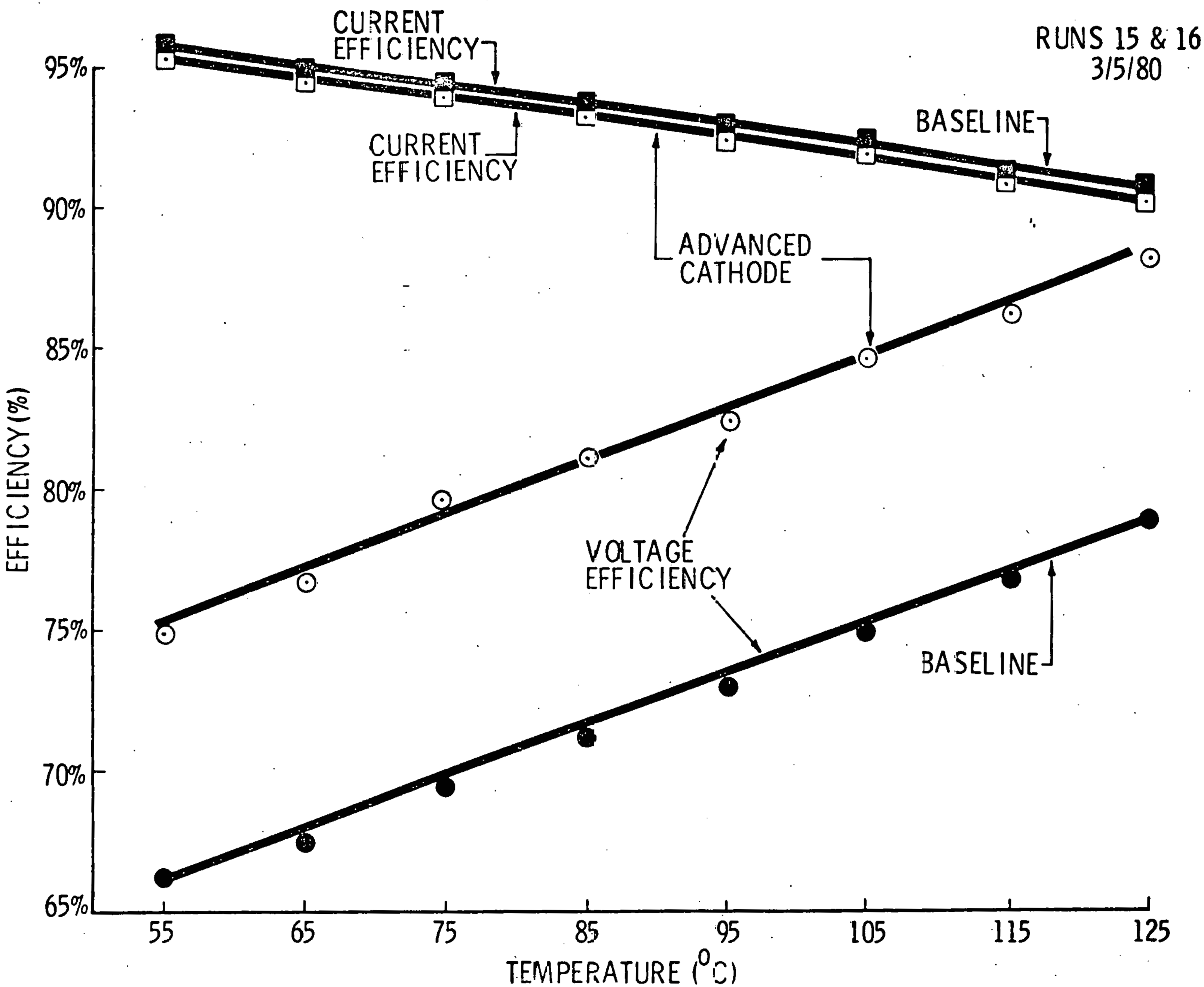

FIGURE 4-9. MODULE EFFICIENCY VALUES VS. OPERATING TEMPERATURE
80 KW UNIT

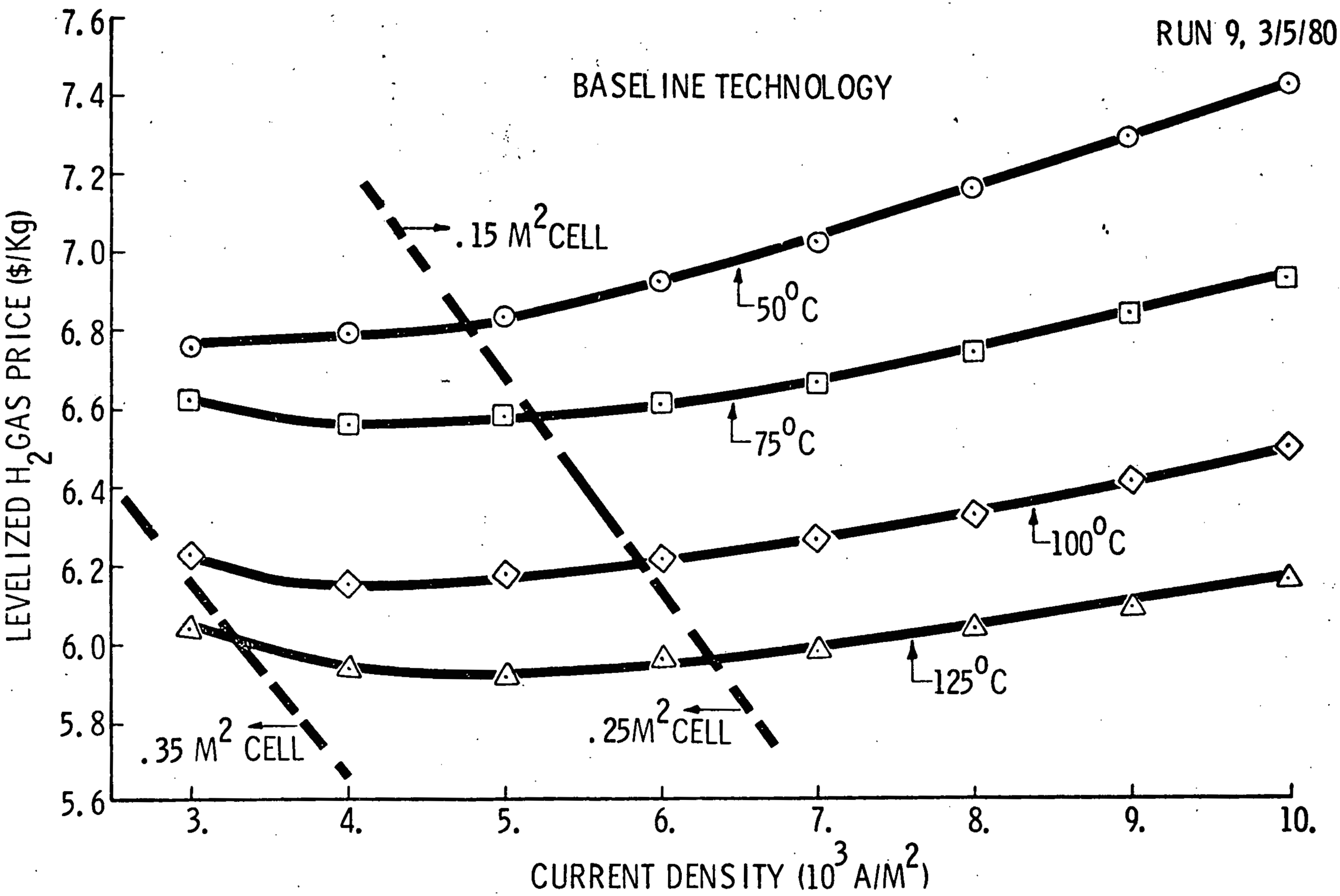

FIGURE 4-10. LEVELIZED GAS PRICE VS. TEMPERATURE & CURRENT DENSITY FOR BASELINE (Ni-200) CATHODE/ASBESTOS TECHNOLOGY. OPTIMUM CELL AREA IS 0.25 M^2, 80KW,2.5¢/KWH

density at the four temperatures for baseline technology electrodes. There is a rather broad minimum in all cases ranging from 3000 A/M^2 at 50°C to 5000 A/M^2 at 125°C. The program predicts a small area module (0.15 M^2) for higher current densities. The optimum cell area increases as current density decreases and the dashed lines on Figure 4-10 show which cell area is optimum. Figure 4-11 gives the same information for the C-AN cathode technology module and as before, significant savings are predicted independent of the operating conditions. The optimum current density is generally higher than in the baseline case. It is interesting to note that in the advanced technology case there were three combinations of parameters disallowed by the model due to thermal instability. They all were at 125°C, and 3000 A/M^2 and large module size. This is the reason that the lower curve in Figure 4-11 rises at the left side and actually crosses the 100°C curve. It is possible that insulation could be added to maintain 125°C operation, but since the optimum is at ~6000 A/M^2 anyway, this option was not pursued. The overall conversion for both technologies is shown as a function of temperature in Figure 4-12.

For this 80 KW case the minimum levelized gas price for baseline technology was \$5.92/Kg (\$1.40/100 SCF) and the first year price was \$3.60/Kg (\$0.85/100 SCF) occurring at a current density of 5000 A/M^2, cell area of 0.25 M^2 and at 125°C. For the advanced technology, the optimum levelized price was \$5.35/Kg (\$1.27/100 SCF) and the first year price was \$3.25/Kg (\$0.77/100 SCF) occurring at the same temperature and cell area but at 6000 A/M^2.

4.4 STUDY FOUR. EFFECT OF ELECTRICITY COSTS AND UNIT UTILIZATION (DUTY FACTOR): 80 KW UNIT

This study was conducted to test the sensitivity of the two technologies to the cost of electricity and the system duty factor. All other inputs were the same as the

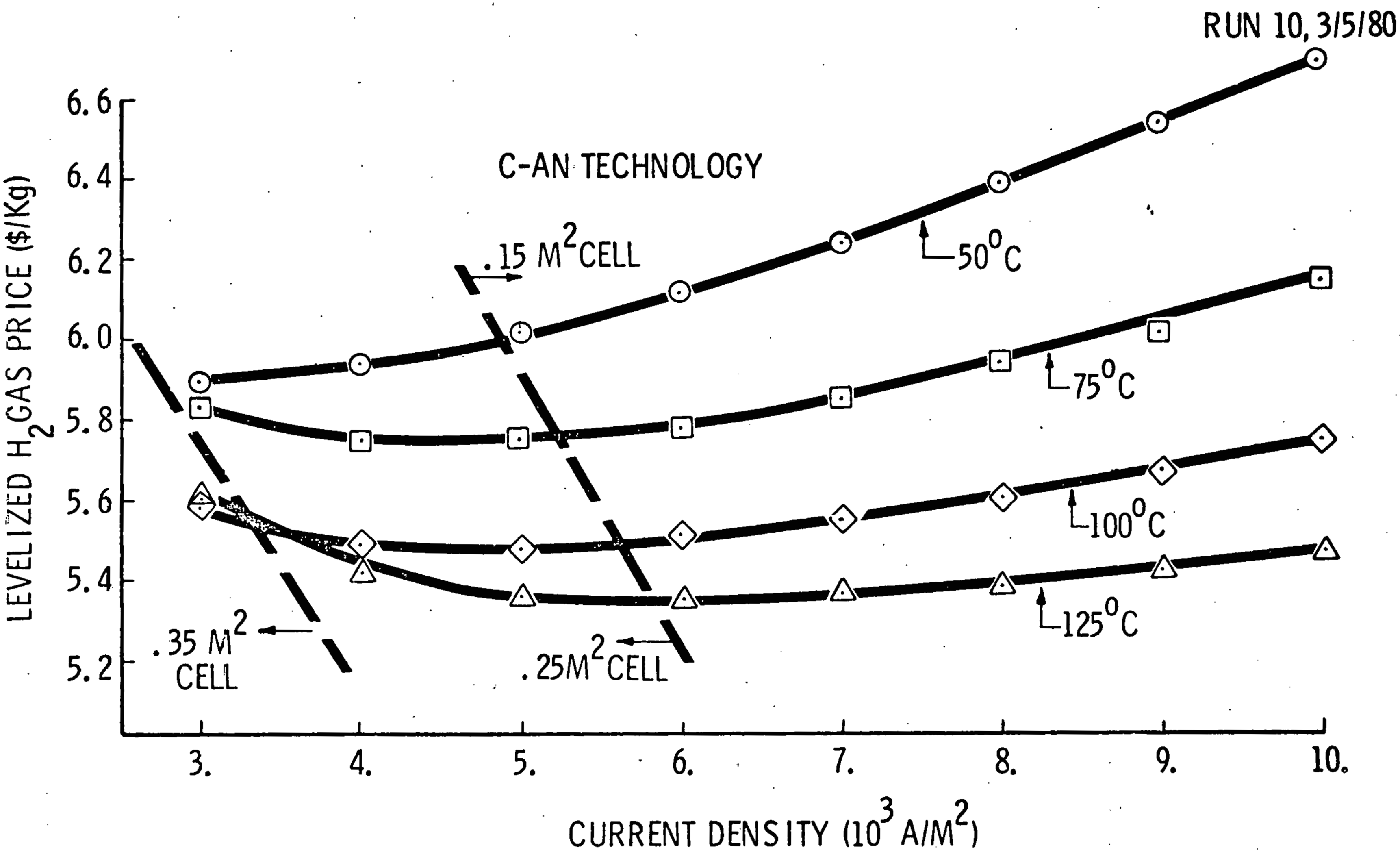

FIGURE 4-11. LEVELIZED GAS PRICE VS. TEMPERATURE & CURRENT DENSITY FOR ADVANCED CATHODE (C-AN)/ASBESTOS TECHNOLOGY. CPTIMUM CELL AREA IS ~ $0.25M^2$,80KW, 2.5 /KWH

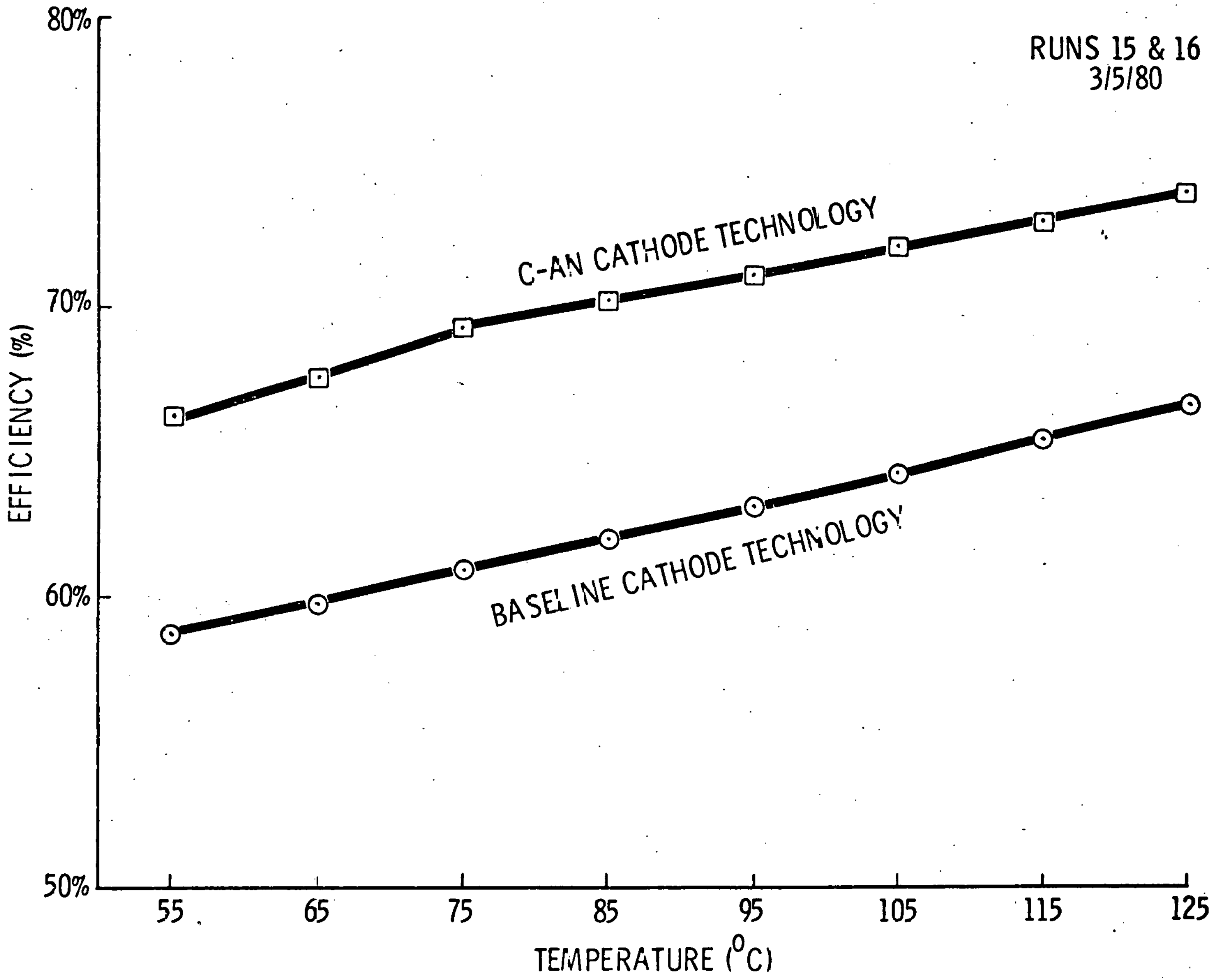

FIGURE 4-12. OVERALL EFFICIENCY VS. TEMPERATURE, 80KW UNIT

baseline case so these do not represent optimized modules at any given point, but serve to illustrate the cost trends. Figure 4-13 is a carpet plot of the results from the baseline technology run. As one would expect, the lowest gas costs occur for a 100% duty factor and lowest electricity cost. There is not a direct increase in gas cost as the duty factor decreases however. At 3¢/KWH the cost of hydrogen goes from $7.30/Kg to $8.90/Kg when the duty factor is decreased from 100% to 60%. Figure 4-14 is a similar plot for the advanced technology case. In order to facilitate direct comparison, Figure 4-15 presents the same two plots on one page.

Previous studies have emphasized the plant utilization or duty factor would have a significant influence on the cost of hydrogen. What is indicated in this study is that with use of 10% inflation as applied to the major cost factors in hydrogen economies, namely the power to the module and the other operating costs, duty factor, which only controls the capitalization expense, is not as significant an influence. What the proper value for inflation should be, remains for future studies. The selection of 10% may even be considered incredibly low at this report time.

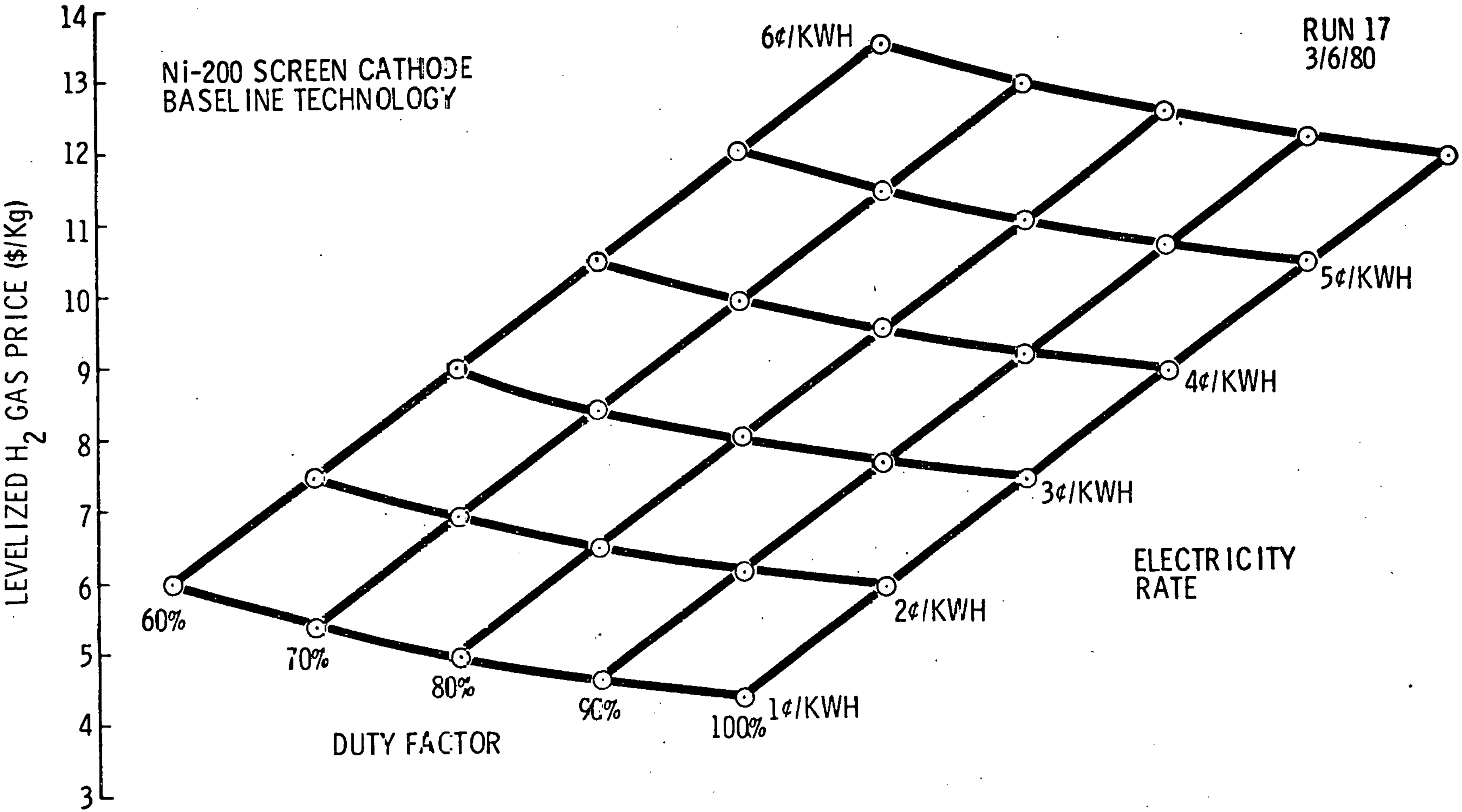

FIGURE 4-13. LEVELIZED GAS PRICE VS. ELECTRICITY COSTS & DUTY FACTOR, BASELINE TECHNOLOGY

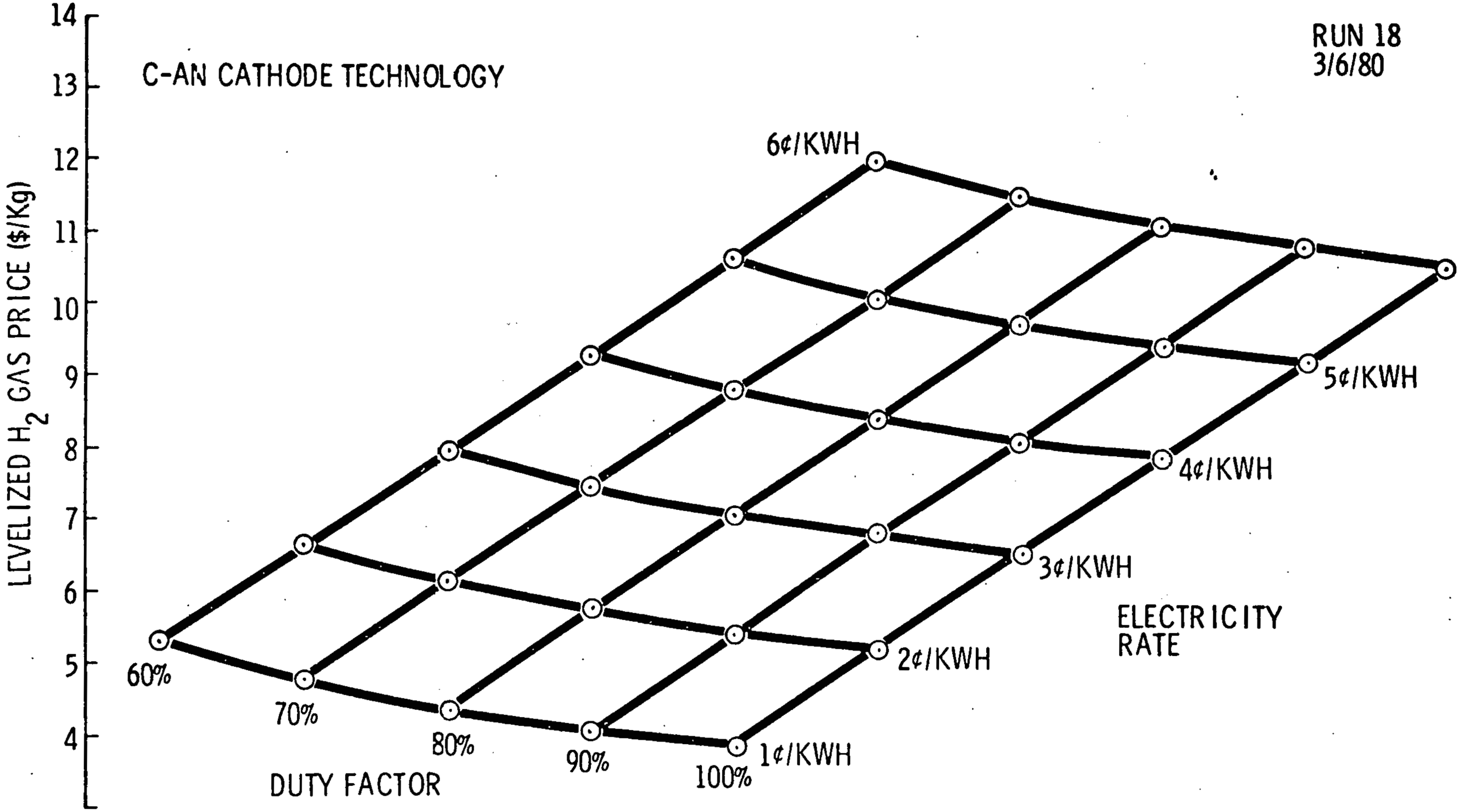

FIGURE 4-14. LEVELIZED GAS PRICE VS. ELECTRICITY COST & DUTY FACTOR, ADVANCED CATHODE TECHNOLOGY

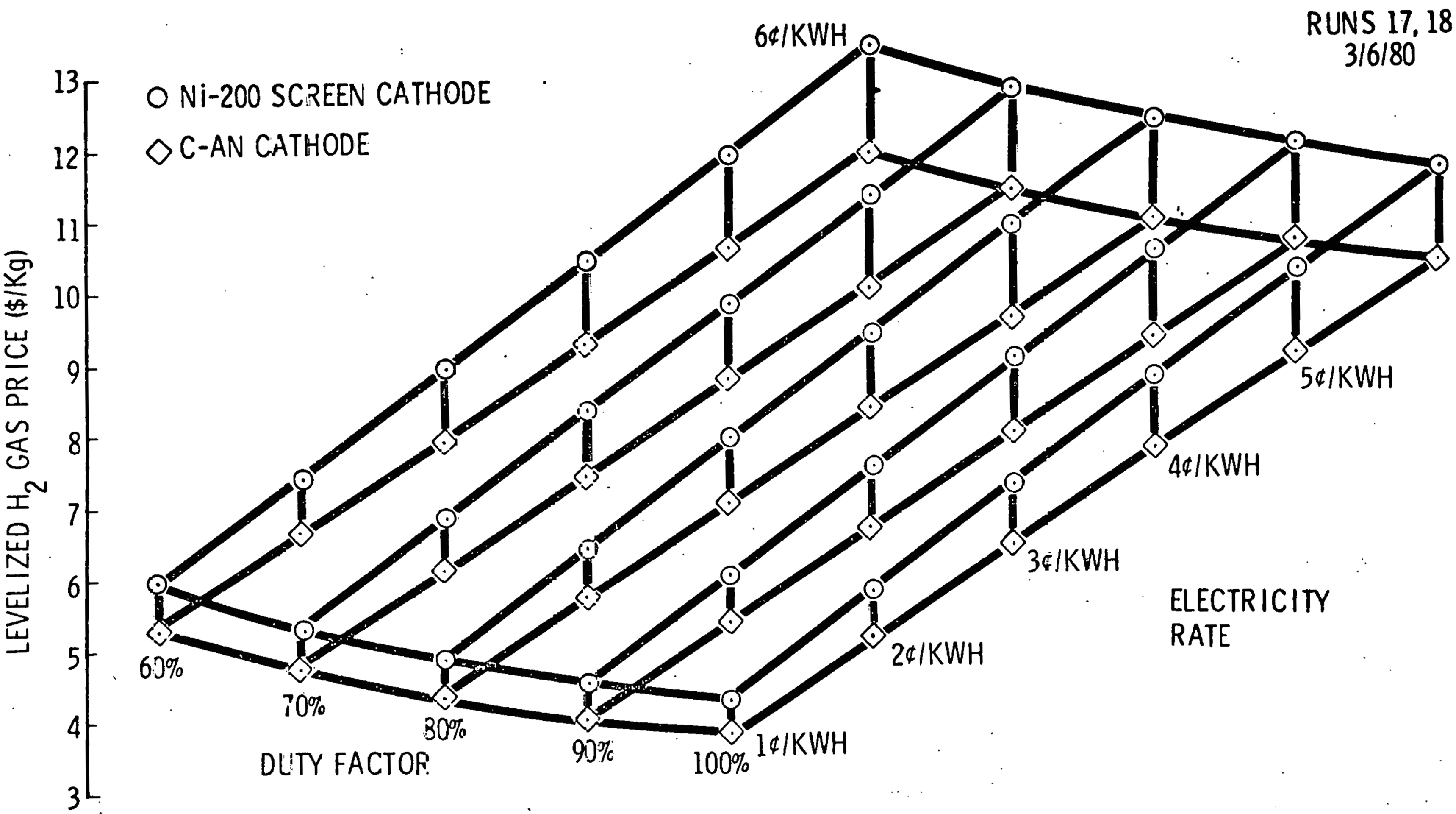

FIGURE 4-15. LEVELIZED GAS PRICE VS. ELECTRICITY COST & DUTY FACTOR, TWO TECHNOLOGIES

5.0 DISCUSSION

5.1 MODEL FOR ALKALINE WATER ELECTROLYSIS SYSTEMS: "MAWES"

5.1.1 General

By far the major amount of effort during this task went into the development of the "MAWES" computer program. It was not until near the end of the task period that the program was considered to be effectively "debugged." As shown in the previous section, several cases have been run using it and some of the program's strong points and drawbacks have become apparent.

On the positive side, the computer program is relatively flexible and easy to operate. Although it is structured for the alkaline electrolysis systems, it is flexible enough to allow many variations within normal configurations by only changing a few data cards. The main program also has no limitations with respect to plant size and operating temperature save the previously mentioned limitations in accuracy based on cost estimation and lifetime data.* The other major point is that while generating fairly detailed design and cost information, the program is rather rapid and therefore cheap to operate. If used in a compiled form, each case requires on the order of one cent to execute, and detailed output for a case only doubles that price. Finally, based on historical values, the model generates numbers that are in credible ranges and so the program becomes very useful for sensitivity studies and preliminary cost estimates.

There are some drawbacks, however, that deserve mention. As discussed in Section 3.1.1, the optimization technique used is limited to points on a user supplied grid. Considering the speed of execution using a more sophisticated "simplex" technique is certainly viable. It would also be advisable to develop another subroutine which would

* Added in proof: At present several of the subroutines do have constraints. Modifications to these subroutines would be fairly easy to make to allow calculations of larger plant economics.

allow the user to manipulate groups of variables in concert rather than independently. While this has not been necessary to date, there are several cases where one might wish to recalculate an input value based on other inputs, for example, the price curve for a heat exchanger based on its overall heat transfer coefficient. Another helpful addition would be an output subroutine which reports the results in a more convenient format such as in Tables 3-1 and 3-2, for example. As it stands now, the program possibly reports "too much," i.e., one can be deluged with data that, while interesting, is probably not necessary for every user.

5.1.2 The Objective Calculation

As mentioned above, the present objective calculation can be considered very powerful and certainly accurate within the constraints of available data. This is not to say that it should be considered in its final form. As design techniques improve these should continually be incorporated into the calculation. There are several places where the calculation could be improved and even speeded-up, and there are several points where more detailed analysis is warranted. In addition, since so much of the accuracy is dependent on accurate cost versus size curves, it is imperative that these curves be updated on at least an annual basis, especially in light of today's inflation. The module lifetime/temperature curves should be updated reflecting the results from ARIES testing. Areas where improved algorithms are advisable are (1) heat exchanger overall heat transfer coefficient calculation, (2) electrolyte reservoir design, (3) electrolyte filter sizing, (4) gas dryer design, (5) manifold electrolysis loss estimation, and (6) power conversion efficiency estimation. It may be advisable to eliminate the module internal fluid distribution calculation or replace it with a more flexible module pressure drop calculation. In the costing routines, one area that could be made more flexible is the calculation of the total capital price, especially with respect to vendor profit. As it presently stands, a simple gross profit margin is used but it may be advisable to estimate this number instead based on plant size, return on capital, projected sales and company profit goals. One final suggestion which deserves consideration is the choice of D.C. module power as an input and gas production rate as an output. In many cases one would rather have gas output fixed and calculate the required input power instead. This means, though, a time consuming reiterative technique would have to be used since the efficiency calculations flow most directly from the input power, current density and module parameters. It would also be advantageous to structure the program so the user can select either mode of calculation.

There are two additional "final" subroutines which could make the program more flexible and more realistic but should be considered only for single case, i.e., optimized plant, calculations since they are quite detailed. The first would be the development of a detailed year-by-year revenue requirement calculation. The levelized technique is very fast but it makes several argumentative assumptions such as constant rates of inflation, lumped (year zero) capitalization, fixed tax rates, etc. By using a year-by-year formal accounting procedure, one might more accurately predict product costs and time effects. The second development would be to employ a variable power and power cost factor. With this type of input, one could more accurately estimate the economics of operating an electrolyzer coupled to a variable power source, for example a solar array or off-peak power.

It must be reiterated that as it stands, the computer model is a powerful and effective tool for prediction and estimation. The above suggested improvements would serve to make it more so.

5.2 THE STUDY: A DISCUSSION OF FINDINGS

5.2.1 Baseline Findings

The most important result issuing from the baseline study was that the first year cost of hydrogen for a 80 KW, 60°C, proven technology electrolyzer is~$4/Kg or $0.96/ 100 SCF. Remembering that this case used 2.5¢/KWH power and 11.4% cost of money (discount rate), the price is competitive with merchant gas rates in many parts of the country. When considering levelized values, the hydrogen from an on-site generator becomes a better bargain. For example, if merchant gas is $0.96/100 SCF at the end of year zero, and 10%/yr inflation is forecast over 20 years with the discount rate at 11.4% then the levelized cost of merchant gas is $2.17/100 SCF compared to the levelized cost of electrolytic gas of $1.66/100 SCF. These costs reflect only one set of economic conditions, a certain amount of prognostication and a non-optimized system but the trend is certainly encouraging for small scale, on-site electrolytic hydrogen.

A second result of the baseline case study was the conclusion that the gas price tends to be energy intensive even for these small systems. It is important to remember that as a different set of economic assumptions can easily change the sensitivities, although increases in efficiency are justified, capital costs cannot be neglected. The first year price tends to emphasize capital cost over that of power but levelized prices indicate power and operating costs become more important. Most modern companies would tend to choose among economic alternatives based on the levelized price.

5.2.2 Sensitivity Study Findings

Several results of the four sensitivity studies tend to substantiate the baseline results.

First, the C-AN cathode technology does offer a real savings over nickel screen technology. Of course, this is a rather inexpensive technology, adding only $21/M^2 for catalysts and yielding a significant (~300 mV @ 5000 A/M^2) voltage reduction, so the benefits appear intuitively obvious. For a 80 KW system (Study Four, 80% duty factor) the levelized savings range from 55¢/Kg at 1¢/KWH electricity to $1.24/Kg at 5¢/KWH electricity or for all electricity rates, about 11% savings in gas cost.

Second, in all the trials, operation at as high a temperature as possible yielded the lowest gas price except for the previously discussed case shown in Figure 4-8. It is important to realize that these results are very sensitive to temperature/life data. If a module has more drastic limitations in life at high temperature than used in these studies, the optimum operating temperature could decrease significantly. The same holds true for component life effects and maintenance rate versus temperature effects. However, the results obtained thus far indicate that higher temperature operation is definitely worth pursuing.

Third, the current density chosen for ARIES testing was 4500 A/M^2. The current density sensitivities yielded in most cases a rather broad minimum centered in the 4000-6000 A/M^2 region for small plants. For larger plants, higher temperatures or more expensive cells, this value tends to become higher. However, there was no lifetime versus current density information built into the model. If such correlations exist then that information should be included and will affect the optimum current density accordingly. Perhaps more surprising was the tendency to optimize at larger cell areas. There are several assumptions implicit in the model which may have significantly influenced this result, e.g., the assembly and electrode costs proportional to cell area. This is another area where further study is warranted.

5.3 ADVANCED ALKALINE WATER ELECTROLYSIS PROGRAM DIRECTION, SOME SUGGESTIONS

Thus far, the MAWES computer model has served to reinforce the previous statements made by TES personnel relative to the advanced alkaline water electrolysis program. There are two possible explanations for this. First, we are excellent prognosticators, or second, our technical biases have been built into the computer code and input data. In view of the absence of hard data in so many areas, the second explanation is more likely. Since cell component life data probably has the largest bias, we recommend as a top priority the continued evaluation of materials and cell components in the ARIES system and other test fixtures in order to establish meaningful lifetime and performance data at elevated temperatures. It is also necessary to continue the development of the "Model for Alkaline Electrolysis Systems" in order to increase its flexibility and reliability. There are two aspects to this development, that of the model itself and that of its data base. Several improvements to the model have been discussed in Section 5.1.1 but these are not inclusive. The model should never be treated as a final version but should be continually improved. The same holds true for the data base. As mentioned previously, the order of magnitude cost estimation method yields at best 40% accuracy. This is obtainable only if the data is current and not too far removed in size from the systems under investigation.

Given these caveats, one can suggest a direction for the technology in general. First, since the studies to date indicate the levelized gas cost is energy intensive, efforts should be directed to finding higher efficiency cell components, concentrating on lowering the cell internal resistance and possibly the anode polarization without incurring overwhelming cell component cost increases. Second, high temperature operation should be pursued for the same reasons, keeping in mind that current efficiency effects cannot be neglected. Third, in order to keep capital costs from escalating, the module life and, in general, component reliability as functions of temperature should not be neglected. Fourth, novel approaches to cell and system design which could be less expensive should be encouraged. Since the predicted price of hydrogen for smaller systems indicates an edge over merchant gas, the market for such systems should make such efforts worthwhile to the developer.

For larger systems, there are possibly some overlooked uses that should be studied. First, it is not too early to investigate the economics of coupling solar photovoltaic power generation to electrolytic hydrogen production. Rapid strides are being made in the former while the problem of efficiently utilizing such a variable power source remains to be adequately addressed. Second, one should reinvestigate the economics of electrolytic hydrogen as a peak power shaving technology, this time for large coal-fired baseload plants. It may be advisable to build high efficiency baseload systems to cover peak demand while using the excess off-peak energy to produce hydrogen.

5.4 A PRELIMINARY COMPARISON OF ADVANCED ALKALINE (AAWE) AND SOLID POLYMER (SPE) ELECTROLYSIS: 1 MW SYSTEM

It is possible at this time to do a preliminary comparison of these two leading water electrolysis technologies. The MAWES program was used to predict the prices for advanced alkaline technology as it has been demonstrated to date and for a future goal technology. Data for the SPE case is taken from the latest General Electric Reports (Ref. 12 and 13). There, too, there are two cases, these being demonstrated and goal technologies. The same economic conditions should apply to each system and these are listed in Table 5-1.

Table 5-1. Economic Input Variables for SPE/AAWE Comparison*

Plant size	1 MW (thermal equivalent output)
Power cost	3.0 ¢/KW
Rate of inflation	0%
Cost of capital	10%
Percent debt financed	100%
Book life	6 years
Module life	6 years
Oxygen credit	None
Duty factor	90%
Investment tax credit	None
Capital recovery factor (calc.)	23%
Fixed charge rate (calc.)	23-3/4%

* SPE - Solid Polymer Electrolysis

AAWE - Advanced Alkaline Water Electrolysis

The demonstrated technology for alkaline water electrolysis consists of the best technology demonstrated to date using the ARIES test system. This is the C-AN cathode coupled with nickel screen anodes and asbestos separators. The SPE technology consists of the best reported performance of the 2-1/2 ft^2 G.E. technology. Table 5-2 is a comparison of the economic output values. The advanced alkaline data was obtained from the model for alkaline water electrolysis systems (MAWES), the SPE data from the G.E. reports. Zero inflation, although impossible, was used to equate the G.E. values of 1975 or 1980 constant dollars. In several places the reported SPE numbers are subject to variable interpretation but based on our understanding of the reports and limited conversations with BNL personnel, the comparison is valid. It is very interesting to note the closeness of the total system capital price. This is somewhat surprising in view of the report fact that the SPE design calls for titanium plumbing whereas the alkaline system is stainless steel. It is also intriguing to see a lower module cost predicted for the SPE technology than for the existing technology. This probably indicates either underestimation on the part of the SPE designers or overestimation on ours, or both. No further breakdown of the capital price is known for the SPE system but it would be enlightening to see how these separate items contribute to the overall price. One last factor that is extremely different is the yearly operating cost of the two systems. Although the use of the lower operating cost would be more advantageous, the higher value would appear to be more realistic considering that it involves burdened labor, cooling water, feed water and maintenance spares.

Examination of goals of both parties was made and the data are presented in Table 5-3. The goal technology for advanced alkaline water electrolysis incorporates the following features: (1) C-AN cathode, (2) a high temperature separator with half the

Table 5-2. Existing Technology - 1 MW Electrolyzer

(As Demonstrated in Applied Research Testing)

		SPE	AAWE
Gas output	(Kg/yr)	2.00×10^5	2.02×10^5
Peak output	(watts)	1.00×10^6	1.01×10^6
Current density	(A/M^2)	10,760	6,000
Operating temperature	(°C)	88	125
Cell area	(M^2)	0.23	0.90
Number of cells		~300	130
Cell voltage		1.85	1.68
Overall efficiency	(%)	72 (?)	81
Module cost	($)	100,000	140,000
Cell cost	($\$/M^2$)	588	489
Total capital price	($)	460,000*	468,000
Total yearly cost	($/yr)	466,000	454,500
Yearly power cost	($/yr)	328,600	293,700
Yearly operating cost	($/yr)	28,000	49,800
Yearly capital cost	($/yr)	109,200	111,000
Non-module plant cost	($)	?	101,000
Components cost	($)	?	240,900
Gross profit on components	($)	?	180,700
Building and facilities cost	($)	?	33,500
Gross profit on B & F	($)	?	0
Installation and standard cost	($)	?	6,700
Gross profit on I & S	($)	?	5,000
Design and engineering cost	($)	?	801,200
D & E per system	($)	0 (?)	801
Levelized cost of hydrogen	($/Kg)	2.33	2.25
	($/MBTU)	17.35	16.75
	($/GJ)	16.46	15.90

* "Installed cost" @ $460/KW (Ref. 13).

Table 5-3. Goal Technology - 1 MW Electrolyzer

		SPE	AAWE
Gas output	(Kg/yr)	2.00×10^5	2.09×10^5
Peak output	(MW)	1.00	1.04
Current density	(A/M^2)	10,760	10,000
Operating temperature	(°C)	150 (?)	125
Cell area	(M^2)	0.23	0.5
Number of cells		271	146
Cell voltage	(V)	1.60	1.55
Overall efficiency	(%)	87.5	87.4
Module cost	($)	65,000	66,700
Cell cost	$(\$/M^2)$	194	459
Total capital price	($)	400,000*	329,400
Total yearly cost	($)	388,700	406,650
Yearly power cost	($)	270,308	282,300
Yearly operating cost	($)	23,379	46,200
Yearly capital cost	($)	95,000	78,200
Non-module plant cost	($)	?	94,600
Total component cost	($)	?	162,200
Gross profit on components	($)	?	121,700
Building and facilities cost	($)	?	33,150
Gross profit on B & F	($)	?	0
Installation and startup cost	($)	?	6,611
Gross profit on I & S	($)	?	4,958
Design and engineering cost	($)	?	793,300
D & E per system	($)	?	793
Levelized cost of hydrogen	($/Kg)	1.944	1.947
	($/MBTU)	14.51	14.53
	($/GS)	13.76	13.78

* "Installed cost" @ $400/KW (Ref. 13).

resistance of the present chrysotile asbestos, (3) a lower overpotential anode, (4) single seal, single frame cell construction, and (5) a less costly end plate design. These advances are quite possible based on results reported by others working with this technology. The G.E., SPE announced goal technology remains as the 1975 data (Ref. 12, 13). The similarity in final prices was completely unexpected and many of the points raised concerning Table 5-2 above are visible here again.

All things considered, there is one inescapable conclusion. That is that advanced alkaline water electrolysis is a viable alternative to solid polymer electrolysis. Those who are familiar with both technologies and more importantly who are able to estimate the probability of success in achieving the goals in each cannot but help but conclude that alkaline water electrolysis should be an equal contender for the future market in water electrolysis technology.

6.0 ACKNOWLEDGMENTS

I would like to acknowledge and am grateful for the continuing support of this effort by the Department of Energy and the staff at BNL, specifically S. Srinivasan, A. Mezzina, G. Kissel and F. Salzano. At Teledyne Energy Systems, several people contributed to the MAWES program. Michael Miller wrote the original version of the fluid distribution, heat and mass balance codes. Marc Saltzman wrote the original module design and manifold losses routines. Saul Zuckman helped in our understanding of the levelized revenue requirement concept. Special thanks to E. Tilmes, M. Braczynski and D. Barrett who operate the company computer center, and to M. Gembarosky, F. Fahdt, and L. Mickle who prepare the text and artwork.

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APPENDIX A

INPUT PARAMETERS: Run No. 4, 3 March 1980

APPENDIX A
COMMON BLK1
INPUT PARAMETERS: Run No. 4, 3 Mar '80

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
1	DCPWR	Nominal D.C. Bus Power	W	80000.0
2	PTAMB	Plant Ambient Temperature	°C	25.0
3	PTMOD	Plant Working Temperature (Module)	°C	60.0
4	PLIFE	Plant Book Life	Yr.	20.0
5	CAR	Cell Active Gross Area	M^2	0.067
6	CCD	Cell Gross Current Density	A/M^2	6000.0
7	CTHK	Cell Thickness	M	8.62 E-3
8	ELOW	Polarization Parameters at TLOW	V	1.287
9	SLOW	Polarization Parameters at TLOW	V/Decade	0.191
10	RLOW	Polarization Parameters at TLOW	Ω	4.26E-5
11	TLOW	Expt. Temperature for #8, #9, & #10	°C	50.4
12	EMED	Polarization Parameters at TMED	V	1.068
13	SMED	Polarization Parameters at TMED	V/Decade	0.233
14	RMED	Polarization Parameters at TMED	Ω	3.00E-5
15	TMED	Expt. Temperature for #12, #13, & #14	°C	76.0
16	EHIGH	Polarization Parameters at THIGH	V	1.039
17	SHIGH	Polarization Parameters at THIGH	V/Decade	0.179
18	RHIGH	Polarization Parameters at THIGH	Ω	3.00E-5
19	THIGH	Expt. Temperature for #16, #17 & #18	°C	121.0
20	CCOMP	Cell Compression	Pa	2.413E6
21	ELCON	Electrolyte Average Conc. (Mass Fraction)	—	0.25
22	ELDELC	Conc. Catholyte − Conc. Anolyte	—	0.08
23	AMPRES	Module Pressure	Pa (gauge)	8.619E5
24	AMDELP	Press. H_2 − Press. O_2	Pa	0.0
25	AMDELT	Temp. Module Outlet − Temp. Module Inlet	°C	8.33

Appendix A
COMMON BLK1
Input Parameters

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
26	PCNTRL	CONTROL SYSTEMS POWER	W	500.0
27	—	—	—	—
28	—	—	—	—
29	—	—	—	—
30	—	—	—	—
31	AMSTY	MODULE STYLE FLAG	—	1.0
32	EPSTY	ENDPLATE STYLE FLAG	—	1.0
33	AMXCEL	MAXIMUM CELLS PER MODULE	—	150.0
34	AMASP	ASPECT RATIO (HORIZONTAL/VERTICAL)	—	1.0
35	EPDEF	ALLOWABLE END PLATE DEFLECTION	M	7.62E-5
36	EPMOD	END PLATE ELASTIC MODULUS @ 25 C	Pa	200.E9
37	EPMODT	TEMPERATURE COEFFICIENT FOR # 36	Pa/C	0.0
38	EPRHO	END PLATE DENSITY	Kg/M³	7950
39	EPNU	END PLATE POISSON'S RATIO	—	0.3
40	—	—	—	—
41	—	—	—	—
42	SLTHK	SEAL THICKNESS (PERCELL)	M	5.E-4
43	SLLD	SEALING LOAD @ 25°C	Pa	10.34E6
44	SLLDT	TEMPERATURE COEFFICIENT FOR # 43	Pa/C	0.0
45	SLMDIS	MINIMUM SEAL DISTANCE BETWEEN MANIFOLDS	M	0.05
46	—	—	—	—
47	—	—	—	—
48	—	—	—	—
49	TRNO	NUMBER OF TIE RODS	—	8.0
50	TRMOD	TIE ROD MODULUS OF ELASTICITY @ 25°C	Pa	200.E9

APPENDIX A
COMMON BLK1
INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
51	TRMODT	TEMPERATURE COEFFICIENT FOR #50	Pa/C	0.0
52	TRCTE	TIEROD COEFFICIENT OF THERMAL EXPASION	C^{-1}	1.85 E-5
53	TRYLD	TIEROD YIELD TENSILE STRENGTH @25°C	Pa	1.138E9
54	TRYLDT	TEMPERATURE COEFFICIENT FOR #53	Pa/C	0.0
55	TRSF	TIE ROD SAFETY FACTOR	—	0.33
56	TRRHO	TIEROD DENSITY	Kg/M^3	7950.0
57	TRNU	TIEROD POISSON'S RATIO	—	0.3
58	—	—	—	—
59	CFRHO	CELL FRAME PLASTIC DENSITY	Kg/M^3	1.24E3
60	CFMTS	CELL FRAME MAXIMUM TENSILE STR.@25°C	Pa	16.8E6
61	CFMTST	TEMPERATURE COEFFICIENT FOR #61	Pa/C	-1.02E5
62	CFMAN	MININMUM ANNULAR WIDTH	M	0.03
63	—	—	—	—
64	AINMAN	NUMBER OF INLET MANIFOLDS	—	1.0
65	OUTMAN	NUMBER OF OUTLET MANIFOLDS	—	1.0
66	AINDIAM	INLET MANIFOLD DIAMETER	M	0.04
67	OUTDIAM	OUTLET MANIFOLD DIAMETER	M	0.04
68	AINPL	INLET PORT LENGTH	M	0.04
69	OUTPL	OUTLET PORT LENGTH	M	0.04
70	AINPDR	INLET PORT DIAMETER TO CELL THICKNESS RATIO	—	0.233
71	OUTPDR	OUTLET PORT DIAMETER TO CELL THICKNESS RATIO	—	0.233
72	AINEL	INLET ENTRANCE LENGTH	M	0.2
73	OUTEL	OUTLET ENTRANCE LENGTH	M	0.2
74	—	—	—	—
75	—	—	—	—

APPENDIX A
COMMON BLK1
INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
76	—	—	—	—
77	—	—	—	—
78	—	—	—	—
79	—	—	—	—
80	SCFMNR	SINGLE CELL FLOW MINIMUM to AVERAGE RATIO	—	0.6
81	SCFMXR	SINGLE CELL FLOW MAXIMUM TO AVERAGE RATIO	—	1.4
82	SCFX	SINGLE CELL FLOW CURVE EXPONENT	—	1.536
83	SCFC	SINGLE CELL FLOW CURVE COEFFICIENT	—	6.72E-8
84	THTA1	MOMENTUM COEFFICIENT #1	—	1.05
85	THTA2	MOMENTUM COEFFICIENT #2	—	1.6
86	EPIX	END PLATE INLET FLOW CURVE EXPONENT	—	1.832
87	EPIC	END PLATE INLET FLOW CURVE COEFFICIENT	—	14.35E-6
88	EPOX	END PLATE OUTLET FLOW CURVE EXPONENT	—	1.832
89	EPOC	END PLATE OUTLET FLOW CURVE COEFFICIENT	—	14.35E-6
90	AFF	ANOLYTE FLOW TO TOTAL FLOW RATIO	—	0.5
91	ETD	END PLATE EFFECIVE TUBE DIAMETER	M	0.4
92	—	—	—	—
93	—	—	—	—
94	—	—		—
95	—	—	—	—
96	—	—	—	—
97	CWT	COOLING WATER TEMPERATURE	°C	35.0
98	CWMF	COOLING WATER MAXIMUM FLOW LIMIT	kg/s	1.89
99	FWT	FEED WATER TEMPERATURE	°C	25.0
100	DPDL	PRESSURE DROP PER UNIT LENGTH	Pa/M	2.26E3

Appendix A
COMMON BLK1
Input Parameters

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
101	PLMIN	MINIMUM LENGTH OF ELETROLYTE TUBING	M	2.0
102	PLK	TUBE LENGTH TO PLANT SIZE COEFFICIENT	$M/W^{1/3}$	0.18
103	FPDPPD	FILTER TO TUBING PRESSURE DROP RATIO	—	1.6
104	FSRC	FLOW SWITCH RESISTANCE COEFFICIENT	—	20.0
105	HXPDPPD	HEAT EXCHANGER TO TUBING PRESSURE DROP RATIO	—	0.4
106	ETAPMOT	ELECTROLYTE PUMP MOTOR EFFICIENCY	—	0.8
107	PKTH	TUBING THERMAL CONDUCTIVITY	W/MC	15.0
108	ELFH	ELECTROLYTE FILTER HEIGHT	M	0.4
109	ELFD	ELECTROLYTE FILTER DIAMETER	M	0.165
110	RESH	ELECTROLYTE RESERVOIR HEIGHT	M	1.22
111	RESD	ELECTROLYTE RESERVOIR DIAMETER	M	0.19
112	ELPWT	ELECTROLYTE TUBE WALL THICKNESS	M	1.016E-3
113	ETAPVM	ELECTROLYTE PUMP VOLUMETRIC & MECHANICAL η	—	0.8
114	TCOO	OXYGEN CONDENSER GAS OUTLET TEMPERATURE	C	50.0
115	TCOH	HYDROGEN CONDENSER GAS OUTLET TEMPERATURE	C	41.0
116	DTOO	OXYGEN CONDENSER WATER TEMP. RISE	C	8.5
117	DTOH	HYDROGEN CONDENSER WATER TEMP. RISE	C	8.5
118	—	—	—	—
119	OCHEF	OXYGEN CONDENSER EFFECTIVE H	W/M^2C	57.0
120	HCHEF	HYDROGEN CONDENSER EFFECTIVE H	W/M^2C	114.0
121	EIHWP	WATER PUMP SHAFT & FLUID EFFICIENCY	—	0.6
122	ETAWPM	WATER PUMP MOTOR EFFICIENCY	—	0.8
123	—	—	—	—
124	—	—	—	—
125	EPKTH	END PLATE THERMAL CONDUCTIVITY	W/MC	15.0

APPENDIX A
COMMON BLK1
INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
126	AMINST	MODULE INSULATION THICKNESS	M	0.0
127	AMINSK	MODULE INSULATION THERMAL CONDUCTIVITY	W/MC	0.01
128	CFKTH	CELL FRAME THERMAL CONDUCTIVITY	W/MC	0.26
129	RESHEF	RESERVOIR EFFECTIVE H	W/M²C	4000.0
130	RESINST	RESERVOIR INSULATION THICKNESS	M	0.0
131	RESINSK	RESERVOIR INSULATION THERMAL COND.	W/MC	0.01
132	UHXA	ANOLYTE HEAT EXCHAGER U.	W/M²C	568.0
133	UHXC	CATHOLYTE HEAT EXCHANGER U.	W/M²C	568.0
134	VOIDFR	CELL VOID FRACTION	—	0.5
135	—	—	—	—
136	—	—	—	—
137	HIOMR	O_2 IN H_2 MASS RATIO	—	0.002
138	OTMANCL	EFFECTIVE MANIFOLD CELLS	—	2.0
139	OPUR	REQ'D OXYGEN PURITY	—	0.98
140	HPUR	REQ'D HYDROGEN PURITY	—	0.9995
141	DONO	NUMBER OF OXYGEN DRYERS	—	2.0
142	DHNO	NUMBER OF HYDROGEN DRYERS	—	2.0
143	DOCYC	OXYGEN DRYER CYCLE TIME	sec	14400.0
144	DHCYC	HYDROGEN DRYER CYCLE TIME	sec	14400.0
145	DSMWR	WATER TO DRYER SEIVE MASS RATIO	—	0.15
146	DSVOID	DRYER SEIVE VOID VOLUME	—	0.15
147	DSCP	DRYER SEIVE HEAT CAPACITY	JOULE/KgC	1046.0
148	DTCHG	RECHARGE TEMPERATURE	C	300.0
149	DSDEN	DRYER SEIVE DENSITY	Kg/M³	714.0
150	DLDR	DRYER LENGTH TO DIAMETER RATIO	—	5.0

APPENDIX A
COMMON BLK1
INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
151	DWTHK	DRYER WALL THICKNESS	M	3.4E-3
152	DWDENS	DRYER WALL DENSITY	Kg/M^3	7950.0
153	DWCP	DRYER WALL HEAT CAPACITY	J/KgC	500.0
154	PHS	HYDROGEN STORAGE PRESSURE	Pa	0.0
155	POS	OXYGEN STORAGE PRESSURE	Pa	0.0
156	ETACOMP	COMPRESSOR EFFICIENCY	—	0.5
157	RATCOMP	MAXIMUM COMPRESSION RATIO	—	7.0
158	OMASR	REQ'D OXYGEN MASS STORAGE	Kg	0.0
159	HMASR	REQ'D HYDROGEN MASS STORAGE	Kg	0.0
160	DRPURG	DRYER PURGE FACTOR	—	0.2
161	CSR	COMMON STOCK EQUITY RATIO	—	0.30
162	RCR	RESERVE CAPITAL EQUITY RATIO	—	0.40
163	CSCOS	COMMON STOCK COST	—	0.08
164	RCCOS	RESERVE CAPITAL COST	—	0.15
165	DCOS	DEBT COST	—	0.10
166	AINF	INFLATION RATE	—	0.10
167	PCOS	POWER COST	$/KWH	0.025
168	PCER	POWER COST ESCALATION RATE	—	0.00
169	DUFACT	DUTY FACTOR	—	0.85
170	TXR	INCOME TAX RATE	—	0.46
171	TLR	TAX LIFE RATIO	—	0.667
172	TXCR	INVESTMENT TAX CREDIT RATE	—	0.00
173	PTXIR	PROPERTY TAX AND INSURANCE RATE	—	0.02
174	ACCTFLG	ACCOUNTING FLAG	—	1.0
175	CRVRZ	CELL RETURN VALUE RATIO (I/O)	—	0.75

APPENDIX A
COMMON BLK1
INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
176	ZRVY	ZERO RETURN VALUE YEAR	YR	10
177	PSV	PLANT SCRAP VALUE	$	0.0
178	CWSPCOS	COOLING WATER SPECIFIC COST	$/Kg	0.582E-4
179	FWSPCOS	FEEDWATER SPECIFIC COST	$/Kg	1.321E-3
180	AMNTRT	MAINTENANCE RATE	YR^{-1}	2.0
181	PGSVCOS	PURGE GAS COST	$/$M^3$	0.53
182	ALBRRT	LABOR RATE	$/yr	14000
183	OHRATE	OVERHEAD RATE	—	1.00
184	GARATE	GENERAL & ADMINISTRATIVE RATE	—	0.00
185	CASPCOS	CAUSTIC POTASH (45w/o) SPECIFIC COST	$/Kg	0.48
186	OPERTAU	OPERATING PERIOD	DAYS	14.0
187	AINVEN	INVENTORY FACTOR	—	0.01
188	DNEK	DESIGN & ENGINEERING COST	$/$W^{1/4}$	2.4 E4
189	DNEFACT	D & E AMORTIZATION (# of SYSTEMS)	—	100.0
190	GMARGC	GROSS MARGIN ON COMPONENTS	—	0.75
191	AINSTK	INSTALLATION & STARTUP CONSTANT	$/$W^{1/4}$	200.0
192	GMARGI	GROSS MARGIN ON INSTAL. & STARTUP	—	0.75
193	BLDGK	BUILDING CONSTANT	$/$M^2$	25.0
194	FACILK	FACILITIES CONSTANT	$/$W^{1/4}$	1000.0
195	GMARGBF	GROSS MARGIN ON BLDG. & FACILITIES	—	0.0
196	PLASCST	CELL FRAME PLASTIC COST	$/Kg	8.422
197	CELPMLD	CELL FRAME YIELD PER MOLD SET	—	2.0E5
198	AMOPCOS	MOLD OPERATING COST PER OPERATION	$	3.0
199	FRPCEL	FRAMES PER CELL	—	2.0
200	SLPCEL	SEALS PER CELL	—	2.0

APPENDIX A

COMMON BLK1

INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
201	SLMCOS	SEAL MATERIAL COST	$/M²	11.50
202	SLPCOS	SEAL PROCESSING COST	$	0.60
203	ANSCOS	ANODE STOCK COST	$/M²	69.60
204	ANCCOS	ANODE CATALYST COST	$/M²	0.00
205	ANPRCOS	ANODE PROCESSING COST	$	0.25
206	CASCOS	CATHODE STOCK COST	$/M²	69.60
207	CACCOS	CATHODE CATALYST COST	$/M²	0.00
208	CAPRCOS	CATHODE PROCESSING COST	$	0.25
209	SEPSCOS	SEPARATOR STOCK COST	$/M²	5.00
210	SEPPCOS	SEPARATOR PROCESSING COST	$	0.70
211	BPTHK	BIPOLAR THICKNESS	M	4.572 E-4
212	BPDENS	BIPOLAR DENSITY	Kg/M³	8900.0
213	BPMSCOS	BIPOLAR MATERIAL SPECIFIC COST	$/Kg	13.23
214	BPPCOS	BIPOLAR PROCESSING COST	$	3.50
215	FMTHK	FLOW MEMBER THICKNESS	M	1.60E-3
216	FMSPCOS	FLOW MEMBER MATERIAL SPECIFIC COST	$/M³	1.66 E+4
217	FMPCOS	FLOW MEMBER PROCESSING COST	$	0.40
218	EPMSCOS	ENDPLATE MATERIAL SPECIFIC COST	$/Kg	6.93
219	EPMFGCS	ENDPLATE MANUFACTORING COST	$/SET	650.0
220	TRMCOS	TIEROD MATERIAL COST	$/Kg	6.24
221	TRPCOS	TIEROD PROCESSING COST	$	1.10
222	TRHCOS	TIEROD HARDWARE COST (DIAMETER)	$/M	900.0
223	—	—	—	—
224	AMLFL	MODULE LIFE AT TMLLOW	Yr	10.
225	TMLLOW	TEMPERATURE FOR #224	C	50.

APPENDIX A
COMMON BLK1
INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
226	AMLFH	MODULE LIFE AT THIGH	Yr	5.
227	TMLHIGH	TEMPERATURE FOR # 226	C	125.
228	AMCF	ANOLYTE MATERIAL COST FACTOR	—	1.
229	CMCF	CATHOLYE MATERIAL COST FACTOR	—	1.
230	OMCF	OXYGEN MATERIAL COST FACTOR	—	1.
231	HMCF	HYDROGEN MATERIAL COST FACTOR	—	1.
232	ELPBK1	FLUID PLUMBING PRICE COEFFICIENT	$/M³	4.764E5
233	ELPBK2	FLUID PLUMBING EXPONENT	—	0.5
234	GSPBK1	GAS PLUMBING PRICE COEFFICIENT	$/W	5.3
235	GSPBK2	GAS PLUMBING EXPONENT	—	0.33
236	FILK1	FILTER PRICE COEFFICIENT	$/(M³/SEC)	1.739E5
237	FILK2	FILTER EXPONENT	—	1.0
238	HXK1	HEAT EXCHANGER PRICE COEFFICIENT	$/M²	5.767E2
239	HXK2	HEAT EXCHANGER EXPONENT	—	0.8
240	PUMPK1	PUMP PRICE COEFFICIENT	$/LOG(PWR)	384.8
241	PUMPK2	PUMP EXPONENT	—	1.0
242	RESK1	RESERVOIR PRICE COEFFICIENT	$/M³	4312.
243	RESK2	RESERVOIR EXPONENT	—	0.5
244	RESK3	RESERVOIR MINIMUM PRICE	$	250.0
245	CONK1	CONDENSER AREA PRICE COEFFICIENT	$/M²	5956.0
246	CONK2	CONDENSER MASS FLOW PRICE COEFFICIENT	$/(KG/SEC)	3.63E5
247	CONK3	CONDENSER EXPONENT	—	0.8
248	AINSK1	INSULATION PRICE COEFFICIENT	$/M³	93.0
249	CWPBK1	COOLING WATER PLUMBING COST	$	220.0
250	FWPBK1	FEED WATER PLUMBING COST	$	200.0

APPENDIX A
COMMON BLK1
INPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE DATA
251	CNINK1	CONTROL & INSTRUMENTATION COST	$	3400.0
252	PURGK1	PURGE GAS SYSTEM COST	$	130.0
253	DRYK1	DRYER COST COEFFICIENT	$/(KG/SEC)	3.01E+6
254	DRYK2	DRYER EXPONENT	—	0.7
255	VENK1	VENTILATION COST COEFFICIENT	$/M²	212.0
256	STRK1	STRUCTURE COST COEFFICIENT	$/M²	1742.0
257	COMK1	COMPRESSOR COST COEFFICIENT	$/STAGE·KG/SEC	5.0E7
258	BOTK1	GAS BOTTLE COST COEFFICIENT	$/M³	7000.0
259	PSK1	POWER SUPPLY COST COEFFICIENT	$/W	3.356E-2
260	UNASK1	UNASSIGNED COST COEFFICIENT	—	0.05
261	ASSYK1	MODULE ASSEMBLY CELL COEFFICIENT	$/CELL M²	28.9
262	ASSYK2	MODULE ASSEMBLY ENDPLATE COEFFICIENT	$/M²	867.0

APPENDIX B

OUTPUT PARAMETERS: Run No. 4, 3 March 1980

APPENDIX B

COMMON BLK2

OUTPUT PARAMETERS: RUN NO. 4, 3 MAR '80

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
1	ALVGPRX	LEVELIZED GAS PRICE	$/Kg	6.995
2	ACPWR	A.C. BUS POWER	W	8.517 E+4
3	ETATOT	OVERALL EFFICIENCY	—	0.5928
4	CVOLT	CELL VOLTAGE	V	2.213
5	BBV	BUS BAR VOLTAGE	V	199.2
6	BBI	BUS BAR CURRENT	A	402.0
7	CAPPRIX	CAPITAL PRICE	$	8.701E+4
8	APCOS	ANNUAL POWER COST	$	1.586 E4
9	AOCOS	ANNUAL OPERATING COST	$	6541.0
10	GASOUT	ANNUAL GAS OUTPUT	Kg	9554.0
11	PLTCOS	COMPONENTS COST (NO MODULE)	$	1.791 E4
12	AMLF	MODULE LIFE	Yr	8.954
13	TMODCOS	MODULE COSTS (TOTAL OVER LIFE)	$	1.609E4
14	SYSAREA	SYSTEM FLOOR AREA	M^2	.9945
15	TOTCEL	NO. OF CELLS PER SYSTEM	—	90.0
16	SPGPRX	1ST YEAR GAS PRICE	$/Kg	4.03
17	RDISC	DISCOUNT RATE	—	0.1140
18	DEBTRAT	PORTION OF CAPITAL FINANCED BY DEBT	—	0.30
19	WCC	WORKING CAPITAL COST	—	0.1140
20	CRFB	CAPITAL RECOVERY FACTOR (BOOK)	—	0.1789
21	ALATC	LEVELIZED ANNUAL TOTAL COST	$	6.684E+4
22	ALAPC	LEVELIZED ANNUAL POWER COST	$	3.588 E+4
23	ALAOC	LEVELIZED ANNUAL OPERATING COST	$	1.480 E+4
24	ALACC	LEVELIZED ANNUAL CAPITAL & TAX COST	$	1.615E+4
25	ALAFCR	LEVELIZED ANNUAL FIXED CHARGE RATE	—	.1856

APPENDIX B

COMMON BLK2

OUTPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
26	BLDGFCL	BUILDING & FACILITIES COST	$	1.711 E+4
27	AINSTL	INSTALATION & STARTUP COST	$	3417.0
28	COMPCOS	COMPONENTS COST	$	3.419E+4
29	WOUT	GAS OUTPUT, HIGHER HEATING VALUE	W	5.05 E+4
30	EFFI	EFFECTIVE AMP-CELLS	A	3.455 E+4
31	CELCUR	CELL CURRENT	A	402.0
32	PMOD	MODULES PER PLANT	—	1.0
33	AMCEL	CELLS PER MODULE	—	90.0
34	ETAV	VOLTAGE EFFICIENCY	—	0.669
35	ETAI	CURRENT EFFICIENCY	—	0.9549
36	ETAR	RECTIFIER EFFICIENCY	—	0.9530
37	ETAP	PURIFICATION EFFICIENCY	—	0.9866
38	PPWR	ACTUAL D.C. POWER	W	8.0086 E+4
39	ETAM	MODULE EFFICIENCY	—	0.6391
40	VTH	ISOTHERMAL CELL VOLTAGE	V	1.481
41	AMODQ	MODULE HEAT LOAD	W	2.890 E+4
42	AMLEN	MODULE LENGTH	M	0.971
43	CFMAS	CELL FRAME MASS	Kg	1.345
44	CFVOD	CELL FRAME VERTICAL O.D.	M	0.512
45	CFHOD	CELL FRAME HORIZONTAL O.D.	M	0.512
46	CFAW	CELL FRAME ANNULAR WIDTH	M	0.110
47	CFSAR	CELL FRAME SEAL AREA	M^2	0.1336
48	TRLEN	TIE ROD LENGTH	M	1.145
49	TRDIAM	TIE ROD DIAMETER	M	2.17 E-2
50	TRMAS	TIE ROD MASS (PER ROD)	Kg	26.96

APPENDIX B
COMMON BLK2
OUTPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
51	EPTHK	END PLATE THICKNESS	M	9.261E-2
52	EPAR	END PLATE AREA	M^2	0.2617
53	EPVOL	END PLATE VOLUME	M^3	2.554E-2
54	EPMAS	END PLATE MASS	Kg	203.1
55	AMMFL	MODULE MASS FLOW RATE	Kg/SEC	1.119
56	AMVFL	MODULE VOLUMETRIC FLOW RATE	M^3/SEC	9.240E-4
57	VELIN	INLET MANIFOLD VELOCITY	M/SEC	0.3676
58	VELOUT	OUTLET MANIFOLD VELOCITY	M/SEC	0.3676
59	PDSTK	STACK PRESSURE DROP	Pa	703.0
60	PDMOD	MODULE PRESSURE DROP	Pa	1860.0
61	CFMAX	MAXIMUM SINGLE CELL FLOW	M^3/SEC	5.133E-6
62	CFMIN	MINIMUM SINGLE CELL FLOW	M^3/SEC	4.796E-6
63	SEPCOS	SEPARATOR COST PER CELL	$/CELL	1.169
64	BPCOS	BIPOLAR COST PER CELL	$/CELL	8.550
65	FMCOS	FLOW MEMBER(S) COST PER CELL	$/CELL	5.783
66	OMODCOS	ORIGINAL SINGLE MODULE COST	$	1.026E+4
67	PIDA	ANOLYTE TUBING I.D.	M	2.0E-2
68	PIDC	CATHOLYTE TUBING I.D.	M	2.0E-2
69	PODA	ANOLYTE TUBING O.D.	M	2.10E-2
70	PODC	CATHOLYTE TUBING O.D.	M	2.10E-2
71	PHDA	ANOLYTE PUMP HEAD	Pa	4.025E+4
72	PHDC	CATHOLYTE PUMP HEAD	Pa	4.853E+4
73	PIPA	ANOLYTE PUMP INPUT POWER	W	100.0
74	PIPC	CATHOLYTE PUMP INPUT POWER	W	100.0
75	QOCON	OXYGEN CONDENSER HEAT LOAD	W	64.89

APPENDIX B
COMMON BLK2
OUTPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
76	QHCON	HYDROGEN CONDENSER HEATLOAD	W	172.5
77	OMFL	OXYGEN MASS FLOW RATE TO DRYER	Kg/sec	2.864 E-3
78	HMFL	HYDROGEN MASS FLOW RATE TO DRYER	Kg/sec	3.609 E-4
79	WMFLO3	WATER MASS FLOW TO O_2 DRYER	Kg/sec	1.922 E-5
80	WMFLH3	WATER MASS FLOW TO H_2 DRYER	Kg/sec	2.389 E-5
81	FWMFL	FEED WATER MASS FLOW RATE	Kg/sec	3.268 E-3
82	PSPA	ANOLYTE PUMP SHAFT POWER	W	44.62
83	PSPC	CATHOLYTE PUMP SHAFT POWER	W	50.53
84	CWFLOC	OXYGEN CONDENSER COOLING WATER FLOW	Kg/sec	1.823 E-3
85	CWFLHC	HYDROGEN CONDENSER COOLING WATER FLOW	Kg/sec	4.847 E-3
86	OCAR	OXYGEN CONDENSER AREA	M^2	6.438 E-2
87	HCAR	HYDROGEN CONDENSER AREA	M^2	12.76 E-2
88	CWMFL	TOTAL COOLING WATER MASS FLOW	Kg/sec	0.8354
89	FWPP	FEED WATER PUMP POWER	W	100.0
90	QMODCV	MODULE CONVECTIVE HEAT LOSS	W	74.20
91	PLENA	LENGTH OF ANOLYTE TUBING	M	4.863
92	PLENC	LENGTH OF CATHOLYTE TUBING	M	4.863
93	WMFLO2	WATER MASS FLOW, O_2 CONDENSER RETURN	Kg/sec	1.111 E-5
94	WMFLH2	WATER MASS FLOW, H_2 CONDENSER RETURN	Kg/sec	2.095 E-5
95	WMFLO1	WATER MASS FLOW INTO O_2 CONDENSER	Kg/sec	3.0328 E-5
96	WMFLH1	WATER MASS FLOW INTO H_2 CONDENSER	Kg/sec	4.484 E-5
97	STKLEN	MODULE STACK LENGTH	M	0.7753
98	QRESCV	RESERVOIR CONVECTIVE HEAT LOSS	W	219.4
99	QPIPECV	PIPING CONVECTIVE HEAT LOSS	W	189.5
100	AHXAR	ANOLYTE HEAT EXCHANGER AREA	M^2	1.183

APPENDIX B

COMMON BLK2

OUTPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
101	CHXAR	CATHOLYTE HEAT EXCHANGER AREA	M^2	1.196
102	CWFLAHX	COOLING WATER FLOW, ANOLYTE H.X.	Kg/sec	0.426
103	CWFLCHX	COOLING WATER FLOW, CATHOLYTE H.X.	Kg/sec	0.403
104	QAHX	ANOLYTE H.X. HEAT LOAD	W	1.414E4
105	QCHX	CATHOLYTE H.X. HEAT LOAD	W	1.414E4
106	DTCAHX	COOLING WATER ΔT, ANOLYTE H.X.	°C	7.932
107	DTCCHX	COOLING WATER ΔT, CATHOLYTE H.X.	°C	8.380
108	AVOL	ONBOARD ANOLYTE VOLUME	M^3	4.0371E-2
109	CVOL	ONBOARD CATHOLYTE VOLUME	M^3	4.0371E-2
110	PWAT	ONBOARD WATER MASS (100% H_2O)	Kg	73.21
111	PKOH	ONBOARD KOH MASS (100% KOH)	Kg	24.57
112	PMFL	PLANT ELECTROLYTE MASS FLOW	Kg/sec	1.115
113	PAMFL	ANOLYTE MASS FLOW	Kg/sec	0.5576
114	PCMFL	CATHOLYTE MASS FLOW	Kg/sec	0.5576
115	PAVFL	ANOLYTE VOLUME FLOW	M^3/sec	4.754E-4
116	PCVFL	CATHOLYTE VOLUME FLOW	M^3/sec	4.465E-4
117	GVOL	GAS VOLUME	M^3	3.885E-2
118	RMODCOS	REPLACEMENT MODULE COST	$	5836.0
119	—	—	—	—
120	OMFLH	OXYGEN MASS FLOW IN H_2	Kg/sec	7.219E-7
121	HMFLO	HYDROGEN MASS FLOW IN O_2	Kg/sec	3.408E-5
122	OMFOUT	OXYGEN MASS FLOW TO COMPRESSOR	Kg/sec	2.594E-3
123	HMFOUT	HYDROGEN MASS FLOW TO COMPRESSOR	Kg/sec	3.561E-4
124	WMFLO5	WATER MASS FLOW TO O_2 COMPRESSOR	Kg/sec	5.188E-5
125	WMFLH5	WATER MASS FLOW TO H_2 COMPRESSOR	Kg/sec	1.804E-7

APPENDIX B
COMMON BLK2
OUTPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
126	WMFLO4	WATER MASS FLOW, O_2 DRYER VENT	Kg/sec	0.0
127	WMFLH4	WATER MASS FLOW, H_2 DRYER VENT	Kg/sec	2.371 E-5
128	DSMO	OXYGEN DRYER SEIVE MASS	Kg	0.0
129	DSMH	HYDROGEN DRYER SEIVE MASS	Kg	1.138
130	DDO	OXYGEN DRYER DIAMETER	M	0.0
131	DDH	HYDROGEN DRYER DIAMETER	M	5.0 E-2
132	DLO	OXYGEN DRYER LENGTH	M	0.0
133	DLH	HYDROGEN DRYER LENGTH	M	.4059
134	DPO	OXYGN DRYER POWER	W	0.0
135	DPH	HYDROGEN DRYER POWER	W	38.82
136	DPN	NET DRYER POWER	W	77.64
137	AUXPWR	TOTAL AUXILIARY SYSTEMS POWER	W	877.6
138	OCPWR	OXYGEN COMPRESSOR POWER	W	0.0
139	HCPWR	HYDROGEN COMPRESSOR POWER	W	0.0
140	OCOMPS	OXYGEN COMPRESSOR STAGES	—	0.0
141	HCOMPS	HYDROGEN COMPRESSOR STAGES	—	0.0
142	OSTOR	OXYGEN STORAGE VOLUME	M^3	0.0
143	HSTOR	HYDROGEN STORAGE VOLUME	M^3	0.0
144	EMPTY	—	—	—
145	EMPTY	—	—	—
146	PCLF	POWER COST LEVELIZING FACTOR	—	2.263
147	GINLF	INFLATION LEVELIZING FACTOR	—	2.263
148	SLDEPR	STRAIGHT LINE DEPRECIATION	—	5.0 E-2
149	ATDEPR	ACCELERATED TAX DEPRECIATION	—	7.93 E-2
150	PLFT	PLANT LIFE FOR TAX PURPOSES	Yr	13.0

APPENDIX B

COMMON BLK2

OUTPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
151	CRFT	CAPITAL RECOVERY FACTOR (TAX)	—	0.1511
152	ALARDA	LEVELIZED ACCEL. DEPR. TAX ALLOWANCE	—	2.496 E-2
153	ALAIT	LEVELIZED INCOME TAX	—	5.422E-2
154	ALAITCA	LEVELIZED INVESTMENT TAX CREDIT	—	0.0
155	RDA	RETIREMENT DISPERSION ALLOWANCE	—	7.5 E-3
156	ACWCOST	ANNUAL COOLING WATER COST	$	1304.0
157	AFWCOST	ANNUAL FEEDWATER COST	$	115.8
158	AMATCOS	ANNUAL MATERIALS COST	$	1553.0
159	ALBRCOS	ANNUAL LABOR COST	$	2524.0
160	AGACOST	ANNUAL G&A COST	$	0.0
161	AOHCOST	ANNUAL OVERHEAD COST	$	2524.0
162	ANCOST	ANODE COST	$	6.778
163	CACOST	CATHODE COST	$	6.778
164	CELCOST	TOTAL CELL COST	$	53.95
165	EPCOST	ENDPLATE COST (PAIR)	$/MODULE	2984
166	TRCOST	TIE ROD COST - TOTAL ASSY	$/TIEROD	118.8
167	MOLDCOS	MOLD COST	$	6.625 E+4
168	CFCOST	CELL FRAME COST	$/CELL	17.66
169	SLCOST	SEAL COST	$/CELL	7.23
170	ASSYCOS	MODULE ASS'Y COST	$/MODULE	902.5
171	ANPBCOS	ANOLYTE PLUMBING COST	$	464.0
172	CAPBCOS	CATHOLYTE PLUMBING COST	$	464.0
173	OXPBCOS	OXYGEN PLUMBING COST	$	219.9
174	HYPBCOS	HYDROGEN PLUMBING COST	$	219.9
175	ANFLCOS	ANOLYTE FILTER COST	$	82.67

APPENDIX B

COMMON BLK2

OUTPUT PARAMETERS

#	MNEMONIC	ITEM	UNITS	BASELINE RESULTS
176	CAFLCOS	CATHOLYTE FILTER COST	$	77.64
177	ANHXCOS	ANOLYTE H.X. COST	$	659.9
178	CAHXCOS	CATHOLYTE H.X. COST	$	665.5
179	ANPMCOS	ANOLYTE PUMP COST	$	269.6
180	CAPMCOS	CATHOLYTE PUMP COST	$	269.6
181	ANRSCOS	ANOLYTE RESERVOIR COST	$	904.9
182	CARSCOS	CATHOLYTE RESERVOIR COST	$	904.9
183	PURGCOS	PURGE SYSTEM COST	$	130.0
184	OXCNCOS	OXYGEN CONDENSER COST	$	314.6
185	HYCNCOS	HYDROGEN CONDENSER COST	$	228.7
186	OXDRCOS	OXYGEN DRYER COST	$	0.0
187	HYDRCOS	HYDROGEN DRYER COST	$	1736.0
188	AINSCOS	INSULATION COST	$	0.0
189	CWPBCOS	COOLING WATER PLUMBING COST	$	220.0
190	FWPBCOS	FEED WATER PLUMBING COST	$	200.0
191	VENTCOS	VENT SYSTEM COST	$	210.8
192	STRTCOS	STRUCTURAL COST	$	1732.0
193	OXCMCOS	OXYGEN COMPRESSOR COST	$	0.0
194	HYCMCOS	HYDROGEN COMPRESSOR COST	$	0.0
195	OXBOTCOS	OXYGEN BOTTLE COST	$	0.0
196	HYBOTCOS	HYDROGEN BOTTLE COST	$	0.0
197	PSCOS	POWER SUPPLY COST	$	2685.0
198	UNASCOS	UNASSIGNED COSTS	$	853.0
199	CNINCOS	CONTROL & INSTRUMENTATION COST	$	3400.0
200	DNECOS	PLANT DESIGN & ENGINEERING COST (TOTAL)	$	4.10 E+5

B-10

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APPENDIX C

DATA DECK STRUCTURE

TELEDYNE ENERGY SYSTEMS

FORTRAN PROGRAMMING FORM

TITLE: MAWES INPUT DECK FORMAT

ANALYST: M. Yaffe

JOB NO.:

DATE: 3/19/80

SHEET 1 OF 1

ITEM	Card content (columns 1–80)
1	RUN # DDDDD
2	I/Φ FLAG DDDDD
3	←— Title, Line One ——→
4	# OF PARAMETERS DDDDD
5	PARAM # DDDDD. XXXXXXX = ±D.DDDDDE±DDD
6	.
7	.
8	.
9	←— Title, Line Two ——→
10	# ΦF ACTIVE LΦΦPS DDDDD
11	PARAM # DDDDD. XXXXXXX = ±D.DDDDDE±DDD , TΦ ±D.DDDDDE±DDD
12	IN DDDDD STEPS WITH DDDDD ΦUTPUT
13	.
14	.
15	.
16	.
17	END

SAMPLE DECK

NOTES

1. X = Alphanumeric
   D = Digit

2. I.0 flag (card 2) allows for extended output
   If last digit = 1 then extended output for all cases
   If last digit = 0 then extended output for optimum case
   If 4th digit = 0 then compact output format
   If 4th digit = 1 then open output format

3. # of parameters (card 4) should correspond to number of parameter cards (cards 5-8)

4. # of active loops (card 10) should correspond to number of loop cards ÷ 2 (cards 11-16)

5. In parameter cards (card 5), 1st digit field is parameter #, alpha field is parameter name, 2nd digit field is value

6. In 1st loop card (card 11), 1st digit field is parameter #, alpha field is parameter name, 2nd digit field is minimum value, 3rd digit field is maximum value

7. In 2nd loop card (card 12), 1st digit field is number of values to be tried, min and max included, 2nd digit field is loop output flag. If "0", then skip I.0 at this level, if "1", then print optimum result at this level

INPUT DECK

```
RUN #                                    00025
I/O FLAG                                 00010
1MW OUTPUT,GOAL TECH.,6YR.LIFE,10% COST OF MONEY
# OF INPUT PARAMETERS                    00040
PARAM #   00001    DCPWR    = +1.13000E+006
PARAM #   00004    PLIFE    = +6.0
PARAM #   00008    ELOW     = +1.292
PARAM #   00009    SLOW     = +0.073
PARAM #   00010    RLOW     = +2.67900E-005
PARAM #   00011    TLOW     = +50.4
PARAM #   00012    EMED     = +1.261
PARAM #   00013    SMED     = +0.065
PARAM #   00014    RMED     = +1.97400E-005
PARAM #   00015    TMED     = +76.0
PARAM #   00016    EHIGH    = +1.207
PARAM #   00017    SHIGH    = +0.056
PARAM #   00018    RHIGH    = +1.33400E-005
PARAM #   00019    THIGH    = +121.0
PARAM #   00203    ANSCOS   = 85.00
PARAM #   00204    ANCCOS   = 20.00
PARAM #   00207    CACCOS   = +21.5
PARAM #   00208    CAPRCOS  = +1.00
PARAM #   00218    EPMSCOS  = 3.46
PARAM #   00219    EPMFGCOS= 100.0
PARAM #   00199    FRFCEL   = +1.0
PARAM #   00200    SLPCEL   = +1.0
PARAM #   00216    FMSPCOS  = +0.00
PARAM #   00217    FMPRCOS  = +0.00
PARAM #   00261    ASSKI    = +17.34
PARAM #   00066    AINDIAM  = +0.08
PARAM #   00067    OUTDIAM  = +0.08
PARAM #   00058    CWMF     = +30.0
PARAM #   00111    RESD     = +0.38
PARAM #   00189    DNEFACT  = +1000.0
PARAM #   00049    TRNO     = +16.0
PARAM #   00167    PCOS     = +0.03
PARAM #   00166    AIMF     = +0.0
PARAM #   00161    CSR      = +0.0
PARAM #   00162    RSR      = +0.0
PARAM #   00165    DCCS     = +0.10
PARAM #   00169    DLFACT   = +0.90
PARAM #   00176    ZRVY     = +6.0
PARAM #   00224    AMLFL    = +6.0
PARAM #   00226    AMLFH    = +6.0
OPTIMIZE W.R.T. CAR,DELT,CCD,&PTMOD
# OF ACTIVE LOOPS                        00004
PARAM #   00025     AMDELT  = 5.0                 TO          10.0
   IN     00003 STEPS         00000 OUTPUT
PARAM #   00005     CAR     = 0.5                 TO          1.0
   IN     00006 STEPS         00000 OUTPUT
PARAM #   00006     CCD     = 5000.0              TO          10000
   IN     00011 STEPS         00001 OUTPUT
PARAM #   00003     FTMOD   = 75.0                TO          125.0
   IN     00006 STEPS         00001 OUTPUT
       END
```

APPENDIX D

"MAWES" LISTING

```
      PROGRAM MAWES (INPUT,OUTPUT,DEBUG=OUTPUT)
C MODEL FOR THE DESIGN AND ECONOMIC ANALYSIS OF ALKALINE WATER ELECTROLYSIS
C  SYSTEMS, WRITTEN 12/19/79 BY M.R.YAFFE, CODED IN FORTRAN EXTENDED VERSION
C  VERSION 4, CDC-CYBER 76, NOS/BE 1 OP.SYS.
C COMMENT CARDS HAVE "C" IN COLUMN 1, DEBUG CARDS HAVE "C$" IN COLUMNS 1&2
      COMMON/BLK1/PARAM(300)/BLK2/ESTOUT(200)
      COMMON/BLK3/PNAME(300),ENAME(200),TITLE1(8),TITLE2(8)
      COMMON/BLK4/PMEM(15,31)/BLK5/IFLAG(32)/BLK6/ESTMEM(500)
      COMMON/BLK7/NLOOP,DLOOP(15,2),MLOOP(15,3)
100   FORMAT(30X,I5,1X)
101   FORMAT(10X,I5,15X,E13.5,1X)
102   FORMAT(10X,I5,15X,E13.5,12X,E13.5,1X)
103   FORMAT(10X,I5,15X,I5,1X)
104   FORMAT(8(A10))
105   FORMAT(80X)
C BEGIN MAIN PROGRAM: READ RUN NUMBER,READ EXTENDED I/O FLAG
      READ 100 ,NRUN
      READ 100,IOFLAG
      READ 104,(TITLE1(I),I=1,8)
      READ 100,NPAR
C READ NUMBER OF INPUT PARAMETERS, THEN READ PARAMETERS
      IF (NPAR.EQ.0)  GO TO 2
      DO 1 I=1,NPAR
1     READ 101,I2,PARAM(I2)
      READ 104,(TITLE2(I),I=1,8)
      CALL HEADING(NRUN)
C READ NUMBER OF LOOPS USED
      READ 100,NLOOP
      IF (NLOOP.EQ.0) 5,2
2     DO 3 I=1,NLOOP
C READ VARIABLE NUMBER,MINIMUM VALUE,MAXIMUM VALUE,# OF STEPS,OUTPUT FLAG
      READ 102,MLOOP(I,1),DLOOP(I,1),DLOOP(I,2)
3     READ 103,MLOOP(I,2),MLOOP(I,3)
      READ 105
4     GO TO 215
C IF NO OPTIMIZATION LOOPS,THEN CALL "ESTIM" AND GO TO OUTPUT
5     CALL ESTIM
      READ 104
      GO TO 16
C BEGIN OPTIMIZATION LOOPS HERE
```

```
  215 PMEM(15,1)=1.0E10
      DO 2015 I=2,30
 2015 PMEM(15,I)=0.0
      M15=MLOOP(15,2)
      DO 2215 N15=1,M15
      IF (MLOOP(15,2).EQ.1) 2315,2415
 2315 PARAM(MLOOP(15,1))=DLOOP(15,1)
      GO TO 214
 2415 PARAM(MLOOP(15,1))=DLOOP(15,1)+(N15-1)*
     2(DLOOP(15,2)-DLOOP(15,1))/(MLOOP(15,2)-1)
  214 PMEM(14,1)=1.0E10
      DO 2014 I=2,30
 2014 PMEM(14,I)=0.0
      M14=MLOOP(14,2)
      DO 2214 N14=1,M14
      IF (MLOOP(14,2).EQ.1) 2314,2414
 2314 PARAM(MLOOP(14,1))=DLOOP(14,1)
      GO TO 213
 2414 PARAM(MLOOP(14,1))=DLOOP(14,1)+(N14-1)*
     2(DLOOP(14,2)-DLOOP(14,1))/(MLOOP(14,2)-1)
  213 PMEM(13,1)=1.0E10
      DO 2013 I=2,30
 2013 PMEM(13,I)=0.0
      M13=MLOOP(13,2)
      DO 2213 N13=1,M13
      IF (MLOOP(13,2).EQ.1) 2313,2413
 2313 PARAM(MLOOP(13,1))=DLOOP(13,1)
      GO TO 212
 2413 PARAM(MLOOP(13,1))=DLOOP(13,1)+(N13-1)*
     2(DLOOP(13,2)-DLOOP(13,1))/(MLOOP(13,2)-1)
  212 PMEM(12,1)=1.0E10
      DO 2012 I=2,30
 2012 PMEM(12,I)=0.0
      M12=MLOOP(12,2)
      DO 2212 N12=1,M12
      IF (MLOOP(12,2).EQ.1) 2312,2412
 2312 PARAM(MLOOP(12,1))=DLOOP(12,1)
      GO TO 211
 2412 PARAM(MLOOP(12,1))=DLOOP(12,1)+(N12-1)*
     2(DLOOP(12,2)-DLOOP(12,1))/(MLOOP(12,2)-1)
```

```
211   PMEM(11,1)=1.0E10
      DO 2011 I=2,30
2011  PMEM(11,I)=0.0
      M11=MLOOP(11,2)
      DO 2211 N11=1,M11
      IF (MLOOP(11,2).EQ.1) 2311,2411
2311  PARAM(MLOOP(11,1))=DLOOP(11,1)
      GO TO 210
2411  PARAM(MLOOP(11,1))=DLOOP(11,1)+(N11-1)*
     2(DLOOP(11,2)-DLOOP(11,1))/(MLOOP(11,2)-1)
210   PMEM(10,1)=1.0E10
      DO 2010 I=2,30
2010  PMEM(10,I)=0.0
      M10=MLOOP(10,2)
      DO 2210 N10=1,M10
      IF (MLOOP(10,2).EQ.1) 2310,2410
2310  PARAM(MLOOP(10,1))=DLOOP(10,1)
      GO TO 209
2410  PARAM(MLOOP(10,1))=DLOOP(10,1)+(N10-1)*
     2(DLOOP(10,2)-DLOOP(10,1))/(MLOOP(10,2)-1)
209   PMEM(09,1)=1.0E10
      DO 2009 I=2,30
2009  PMEM(09,I)=0.0
      M09=MLOOP(09,2)
      DO 2209 N09=1,M09
      IF (MLOOP(09,2).EQ.1) 2309,2409
2309  PARAM(MLOOP(09,1))=DLOOP(09,1)
      GO TO 208
2409  PARAM(MLOOP(09,1))=DLOOP(09,1)+(N09-1)*
     2(DLOOP(09,2)-DLOOP(09,1))/(MLOOP(09,2)-1)
208   PMEM(08,1)=1.0E10
      DO 2008 I=2,30
2008  PMEM(08,I)=0.0
      M08=MLOOP(08,2)
      DO 2208 N08=1,M08
      IF (MLOOP(08,2).EQ.1) 2308,2408
2308  PARAM(MLOOP(08,1))=DLOOP(08,1)
      GO TO 207
2408  PARAM(MLOOP(08,1))=DLOOP(08,1)+(N08-1)*
     2(DLOOP(08,2)-DLOOP(08,1))/(MLOOP(08,2)-1)
```

```
  207   PMEM(07,1)=1.0E10
        DO 2007 I=2,30
 2007   PMEM(07,I)=0.0
        M07=MLOOP(07,2)
        DO 2207 N07=1,M07
        IF (MLOOP(07,2).EQ.1) 2307,2407
 2307   PARAM(MLOOP(07,1))=DLOOP(07,1)
        GO TO 206
 2407   PARAM(MLOOP(07,1))=DLOOP(07,1)+(N07-1)*
       2(DLOOP(07,2)-DLOOP(07,1))/(MLOOP(07,2)-1)
  206   PMEM(06,1)=1.0E10
        DO 2006 I=2,30
 2006   PMEM(06,I)=0.0
        M06=MLOOP(06,2)
        DO 2206 N06=1,M06
        IF (MLOOP(06,2).EQ.1) 2306,2406
 2306   PARAM(MLOOP(06,1))=DLOOP(06,1)
        GO TO 205
 2406   PARAM(MLOOP(06,1))=DLOOP(06,1)+(N06-1)*
       2(DLOOP(06,2)-DLOOP(06,1))/(MLOOP(06,2)-1)
  205   PMEM(05,1)=1.0E10
        DO 2005 I=2,30
 2005   PMEM(05,I)=0.0
        M05=MLOOP(05,2)
        DO 2205 N05=1,M05
        IF (MLOOP(05,2).EQ.1) 2305,2405
 2305   PARAM(MLOOP(05,1))=DLOOP(05,1)
        GO TO 204
 2405   PARAM(MLOOP(05,1))=DLOOP(05,1)+(N05-1)*
       2(DLOOP(05,2)-DLOOP(05,1))/(MLOOP(05,2)-1)
  204   PMEM(04,1)=1.0E10
        DO 2004 I=2,30
 2004   PMEM(04,I)=0.0
        M04=MLOOP(04,2)
        DO 2204 N04=1,M04
        IF (MLOOP(04,2).EQ.1) 2304,2404
 2304   PARAM(MLOOP(04,1))=DLOOP(04,1)
        GO TO 203
 2404   PARAM(MLOOP(04,1))=DLOOP(04,1)+(N04-1)*
       2(DLOOP(04,2)-DLOOP(04,1))/(MLOOP(04,2)-1)
```

```
203   PMEM(03,1)=1.0E10
      DO 2003 I=2,30
2003  PMEM(03,I)=0.0
      M03=MLOOP(03,2)
      DO 2203 N03=1,M03
      IF (MLOOP(03,2).EQ.1) 2303,2403
2303  PARAM(MLOOP(03,1))=DLOOP(03,1)
      GO TO 202
2403  PARAM(MLOOP(03,1))=DLOOP(03,1) +(N03-1)*
     2(DLOOP(03,2)-DLOOP(03,1))/(MLOOP(03,2)-1)
202   PMEM(02,1)=1.0E10
      DO 2002 I=2,30
2002  PMEM(02,I)=0.0
      M02=MLOOP(02,2)
      DO 2202 N02=1,M02
      IF (MLOOP(02,2).EQ.1) 2302,2402
2302  PARAM(MLOOP(02,1))=DLOOP(02,1)
      GO TO 201
2402  PARAM(MLOOP(02,1))=DLOOP(02,1)+(N02-1)*
     2(DLOOP(02,2)-DLOOP(02,1))/(MLOOP(02,2)-1)
201   PMEM(01,1)=1.0E10
      DO 2001 I=2,30
2001  PMEM(01,I)=0.0
      M01=MLOOP(01,2)
      DO 2201 N01=1,M01
      IF (MLOOP(01,2).EQ.1) 2301,2401
2301  PARAM(MLOOP(01,1))=DLOOP(01,1)
      GO TO 200
2401  PARAM(MLOOP(01,1))=DLOOP(01,1)+(N01-1)*
     2(DLOOP(01,2)-DLOOP(01,1))/(MLOOP(01,2)-1)
C CALL MAIN CALCULATION SBR. "ESTIM" TO GENERATE DESIGN DATA, SYSTEM COSTS,
C  AND RESULTING GAS PRICES.
200   CALL ESTIM
C SAVE RESULTS IF BETTER THAN PREVIOUS RESULTS AT EACH LEVEL
      DO 8  I=1,NLOOP
      IF (ESTOUT(1).GE.PMEM(I,1)) GO TO 8
      DO 10 I1=1,16
10    PMEM(I,I1) = ESTOUT(I1)
      DO 9 I1=1,NLOOP
9     PMEM(I,16+I1)=PARAM(MLOOP(I1,1))
```

```
      8   CONTINUE
          IF (ESTOUT(1).GE.ESTMEM(1))GO TO 13
          DO 11 I=1,200
     11   ESTMEM(I)= ESTOUT(I)
          DO 12 I=1,300
     12   ESTMEM(I-200)= PARAM(I)
     13   IF((IOFLAG.EQ.0).OR.(IOFLAG.EQ.10)) GO TO 14
          CALL LIMOUT1
     14   ESTOUT(1)=1.0E10
          DO 15 I=2,200
     15   ESTOUT(I)=0.0
          IF (MLOOP(1,3).EQ.0)2201,2501
   2501   K=1
          CALL LIMOUT2(K)
   2201   PMEM(1,1)=1.0E10
          IF (MLOOP(2,3).EQ.0)2202,2502
   2502   K=2
          CALL LIMOUT2(K)
   2202   PMEM(2,1)=1.0E10
          IF (MLOOP(3,3).EQ.0)2203,2503
   2503   K=3
          CALL LIMOUT2(K)
   2203   PMEM(3,1)=1.0E10
          IF (MLOOP(4,3).EQ.0)2204,2504
   2504   K=4
          CALL LIMOUT2(K)
   2204   PMEM(4,1)=1.0E10
          IF (MLOOP(5,3).EQ.0)2205,2505
   2505   K=5
          CALL LIMOUT2(K)
   2205   PMEM(5,1)=1.0E10
          IF (MLOOP(6,3).EQ.0)2206,2506
   2506   K=6
          CALL LIMOUT2(K)
   2206   PMEM(6,1)=1.0E10
          IF (MLOOP(7,3).EQ.0)2207,2507
   2507   K=7
          CALL LIMOUT2(K)
   2207   PMEM(7,1)=1.0E10
          IF(MLOOP(8,3).EQ.0)2208,2508
```

```
 2508  K=8
       CALL LIMOUT2(K)
 2208  PMEM(8,1)=1.0E10
       IF (MLOOP(9,3).EQ.0)2209,2509
 2509  K=9
       CALL LIMOUT2(K)
 2209  PMEM(9,1)=1.0E10
       IF (MLOOP(10,3).EQ.0)2210,2510
 2510  K=10
       CALL LIMOUT2(K)
 2210  PMEM(10,1)=1.0E10
       IF (MLOOP(11,3).EQ.0)2211,2511
 2511  K=11
       CALL LIMOUT2(K)
 2211  PMEM(11,1)=1.0E10
       IF (MLOOP(12,3).EQ.0)2212,2512
 2512  K=12
       CALL LIMOUT2(K)
 2212  PMEM(12,1)=1.0E10
       IF (MLOOP(13,3).EQ.0)2213,2513
 2513  K=13
       CALL LIMOUT2(K)
 2213  PMEM(13,1)=1.0E10
       IF (MLOOP(14,3).EQ.0)2214,2514
 2514  K=14
       CALL LIMOUT2(K)
 2214  PMEM(14,1)=1.0E10
       IF (MLOOP(15,3).EQ.0)2215,2515
 2515  K=15
       CALL LIMOUT2(K)
 2215  PMEM(15,1)=1.0E10
 17    DO 18 I=1,200
 18    ESTOUT(I)=ESTMEM(I)
       DO 19 I=1,300
 19    PARAM(I)=ESTMEM(I+200)
 16    CALL EXCUT1 (IOFLAG,NRUN)
       STOP
       END
```

```
      BLOCK DATA
C THE BASELINE CASE IN "BLOCK DATA" REPRESENTS 80.0 KW(DC) DUAL IRRIG. SYSTEM
      COMMON/BLK1/PARAM(300)
      COMMON/BLK2/ESTOUT(200)
      COMMON/BLK3/PNAME(300),ENAME(200)
      COMMON/BLK4/PMEM(15,31)
      COMMON/BLK5/IFLAG(32)
      COMMON/BLK6/ESTMEM(500)
      COMMON/BLK7/NLOOP,DLOOP(15,2),MLOOP(15,3)
      DATA (ESTOUT(I),I=1,200)/1.0E10,199*0.0/
      DATA ((PMEM(I,I1),I=1,15),I1=1,31)/15*1.0E10,450*0.0/
      DATA (IFLAG(I),I=1,32)/32*0/
      DATA (ESTMEM(I),I=1,500)/1.0E10,499*0.0/
      DATA NLOOP/0/
      DATA ((DLOOP(I,I1),I=1,15),I1=1,2)/30*0.0/
      DATA ((MLOOP(I,I1),I=1,15),I1=1,3)/15*300,15*1,15*0/
      DATA (PNAME(I),I=  1,100)/
     &7HDCPWR  ,7HPTAMB  ,7HPTMOD  ,7HPLIFE  ,7HCAR    ,7HCCD    ,        1-  6
     &7HCTHK   ,7HELOW   ,7HSLOW   ,7HRLOW   ,7HTLOW   ,7HEMED   ,        7- 12
     &7HSMED   ,7HRMED   ,7HTMED   ,7HEHIGH  ,7HSHIGH  ,7HRHIGH  ,       13- 18
     &7HTHIGH  ,7HCCOMP  ,7HELCON  ,7HELDELC ,7HAMPRES ,7HAMDELP ,       19- 24
     &7HAMDELT ,7HPCNTRL ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,       25- 30
     &7HAMSTY  ,7HEPSTY  ,7HAMXCEL ,7HAMASP  ,7HEPDEF  ,7HEPMOD  ,       31- 36
     &7HEPMODT ,7HEPRHO  ,7HEPNU   ,7HEMPTY  ,7HEMPTY  ,7HSLTHK  ,       37- 42
     &7HSLLD   ,7HSLLDT  ,7HSLMDIS ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,       43- 48
     &7HTRNO   ,7HTRMOD  ,7HTRMODT ,7HTRCTE  ,7HTRYLD  ,7HTRYLDT ,       49- 54
     &7HTRSF   ,7HTRRHO  ,7HTRNU   ,7HEMPTY  ,7HCFRHO  ,7HCFMTS  ,       55- 60
     &7HCFMTST ,7HCFMAN  ,7HEMPTY  ,7HAINMAN ,7HOUTMAN ,7HAINDIAM,       61- 66
     &7HOUTDIAM,7HAINPL  ,7HOUTPL  ,7HAINPDR ,7HOUTPDR ,7HAINEL  ,       67- 72
     &7HOUTEL  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,       73- 78
     &7HEMPTY  ,7HSCFMNR ,7HSCFMXR ,7HSCFX   ,7HSCFC   ,7HTHTA1  ,       79- 84
     &7HTHTA2  ,7HEPIX   ,7HEPOX   ,7HEPIC   ,7HEPOC   ,7HAFF    ,       85- 90
     &7HETD    ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,       91- 96
     &7HCWT    ,7HCWMF   ,7HFWT    ,7HDPDL   /                           97-100
      DATA (PARAM(I),I=  1,100)/
     &80000.   ,25.     ,60.     ,20.     ,0.067   ,6000.   ,        1-  6
     &8.62E-3  ,1.2872  ,0.191   ,4.26E-5 ,50.4    ,1.068   ,        7- 12
     &0.233    ,3.00E-5 ,76.     ,1.039   ,0.179   ,3.00E-5 ,       13 -18
     &121.     ,2.413E6 ,0.25    ,0.08    ,8.619E5 ,0.      ,       19 -24
     &8.33     ,500.    ,0.0000000,0.0000000,0.0000000,0.0000000,   25- 30
```

```
     &1.       ,1.       ,150.     ,1.       ,7.62E-5  ,200.E9   ,        31- 36
     &0.       ,7950.    ,0.3      ,0.0000000,0.0000000,5.E-4    ,        37- 42
     &10.34E6  ,0.       ,0.05     ,0.0000000,0.0000000,0.0000000,        43- 48
     &8.       ,200.E9   ,0.       ,1.85E-5  ,1.138E9  ,0.0      ,        49- 54
     &0.33     ,7950.    ,0.3      ,0.0000000,1.24E3   ,16.8E6   ,        55- 60
     &-1.02E5  ,0.03     ,0.0000000,1.       ,1.       ,0.04     ,        61- 66
     &0.04     ,0.04     ,0.04     ,0.233    ,0.233    ,0.2      ,        67- 72
     &0.2      ,0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,        73- 78
     &0.0000000,0.6      ,1.4      ,1.536    ,6.72E-8  ,1.05     ,        79- 84
     &1.6      ,1.832    ,14.35E-6 ,1.832    ,14.35E-6 ,0.5      ,        85- 90
     &0.4      ,0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,        91- 96
     &35.      ,1.89     ,25.      ,2.26E3   /                            97-100
      DATA (PNAME(I),I=101,200)/
     &7HPLMIN  ,7HPLK    ,7HFPDPPC ,7HFSRC   ,7HHXPDPPD,7HETAPMOT,       101-106
     &7HPKTH   ,7HELFH   ,7HELFD   ,7HRESH   ,7HRESD   ,7HELPWT  ,       107-112
     &7HETAPVM ,7HTCOO   ,7HTCOH   ,7HDTOO   ,7HDTOH   ,7HEMPTY  ,       113-118
     &7HOCHEF  ,7HHCHEF  ,7HETAWP  ,7HETAWPM ,7HEMPTY  ,7HEMPTY  ,       119-124
     &7HEFKTH  ,7HAMINST ,7HAMINSH ,7HCFKTH  ,7HRESHEF ,7HRESINST,       125-130
     &7HRESINSK,7HUHXA   ,7HUHXC   ,7HVCIDFR ,7HEMPTY  ,7HEMPTY  ,       131-136
     &7HHIOMR  ,7HOIMANCL,7HOPUR   ,7HHPUR   ,7HDONO   ,7HCHNO   ,       137-142
     &7HDOCYC  ,7HOHCYC  ,7HDSMUR  ,7HDSVOID ,7HDSCP   ,7HDTCHG  ,       143-148
     &7HDSDEN  ,7HDLOR   ,7HDWTHK  ,7HDWDENS ,7HDWCP   ,7HPFS    ,       149-154
     &7HPOS    ,7HETACOMP,7HRATCOMP,7HOMASR  ,7HHMASR  ,7HORPURG ,       155-160
     &7HCSR    ,7HRCR    ,7HCSCOS  ,7HRCCOS  ,7HDCOS   ,7HAINF   ,       161-166
     &7HPCOS   ,7HPCER   ,7HDUFACT ,7HTXR    ,7HTLR    ,7HTXCP   ,       167-172
     &7HPTXIR  ,7HACCTFLG,7HCRVRZ  ,7HZRVY   ,7HPSV    ,7HCWSPCOS,       173-178
     &7HFWSPCOS,7HAMNTR  ,7HPGSVCCS,7HALBRRT ,7HOHRATE ,7HGARATE ,       179-184
     &7HCASPCOS,7HOPERTAU,7HAINVEN ,7HDNEK   ,7HONEFACT,7HGMARGC ,       185-190
     &7HAINSTK ,7HGMARGI ,7HBLK    ,7HFCLK   ,7HGMARGBF,7HPLASCST,       191-196
     &7HCFLPLMD,7HMOPCOST,7HFRPCEL ,7HSLPCEL /                           197-200
      DATA (PARAM(I),I=101,200)/
     &2.       ,0.18     ,1.6      ,20.      ,0.4      ,0.8      ,       101-106
     &15.      ,0.4      ,0.165    ,1.22     ,0.19     ,1.016E-3 ,       107-112
     &0.8      ,50.      ,41.      ,8.5      ,8.5      ,0.0000000,       113-118
     &57.      ,114.     ,0.6      ,0.8      ,0.0000000,0.0000000,       119-124
     &15.      ,0.       ,0.01     ,0.26     ,4000.    ,0.       ,       125-130
     &0.01     ,568.     ,568.     ,0.5      ,0.0000000,0.0000000,       131-136
     &0.002    ,2.       ,0.98     ,0.9995   ,2.       ,2.       ,       137-142
     &14400.   ,14400.   ,0.15     ,0.15     ,1046.    ,300.     ,       143-148
     &714.     ,5.       ,3.40E-3  ,7950.    ,500.     ,0.       ,       149-154
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     &0.       ,0.5      ,7.       ,0.       ,0.0      ,0.2       ,       155-160
     &0.30     ,0.40     ,0.08     ,0.15     ,0.10     ,0.10      ,       161-166
     &0.025    ,0.00     ,0.85     ,0.46     ,0.667    ,0.00      ,       167-172
     &0.02     ,1.0      ,0.75     ,10.0     ,0.0      ,0.582E-4  ,       173-178
     &1.321E-3 ,2.0      ,0.53     ,14000.   ,1.0      ,0.0       ,       179-184
     &0.48     ,14.      ,0.01     ,2.4E4    ,100.0    ,0.75      ,       185-190
     &200.     ,0.75     ,25.      ,1000.    ,0.0      ,8.422     ,       191-196
     &200000.  ,3.0      ,2.       ,2.       /                            197-200
      DATA (PNAME(I),I=201,300)/
     &7HSLMCOS ,7HSLPCOS ,7HANSCOS ,7HANCCOS ,7HANPRCOS,7HCASCOS ,        201-206
     &7HCACCOS ,7HCAPRCOS,7HSEPSCOS,7HSEPPCOS,7HBPTHK  ,7HBPDENS ,        207-212
     &7HBPMSCOS,7HBPPCOS ,7HFMTHK  ,7HFMSPCOS,7HFMPCOS ,7HEPMSCOS,        213-218
     &7HEPMFGCS,7HTRMCOS ,7HTRPCOS ,7HTRHCOS ,7HEMPTY  ,7HAMLFL  ,        219-224
     &7HTNLLOW ,7HAMLFH  ,7HTMLHIGH,7HAMCF   ,7HCMCF   ,7HCMCF   ,        225-230
     &7HHMCF   ,7HELPBK1 ,7HELPBK2 ,7HGSBPK1 ,7HGSPBK2 ,7HFILK1  ,        231-236
     &7HFILK2  ,7HHXK1   ,7HHXK2   ,7HPUMPK1 ,7HPUMPK2 ,7HRESK1  ,        237-242
     &7HRESK2  ,7HRESK3  ,7HCONK1  ,7HCONK2  ,7HCONK3  ,7HAINSK1 ,        243-248
     &7HCWPBK1 ,7HFWPBK1 ,7HCNIK1  ,7HPURGK1 ,7HDRYK1  ,7HDRYK2  ,        249-254
     &7HVENK1  ,7HSTRTK1 ,7HCOMK1  ,7HBOTK1  ,7HPSK1   ,7HUNASK1 ,        255-260
     &7HASSYK1 ,7HASSYK2 ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,        261-266
     &7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,        267-272
     &7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,        273-278
     &7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,        279-284
     &7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,        285-290
     &7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,        291-296
     &7HEMPTY  ,7HEMPTY  ,7HEMPTY  ,7HDUMMY  /                            297-300
      DATA (PARAM(I),I=201,300)/
     &11.50    ,0.60     ,69.6     ,0.0      ,0.25     ,69.6      ,       201-206
     &0.0      ,0.25     ,5.00     ,0.70     ,4.572E-4 ,8900.     ,       207-212
     &13.23    ,3.50     ,0.16E-2  ,1.66E4   ,0.40     ,6.93      ,       213-218
     &650.     ,6.24     ,1.10     ,900.     ,0.0000000,10.       ,       219-224
     &50.0     ,5.0      ,125.0    ,1.       ,1.       ,1.        ,       225-230
     &1.       ,4.764E5  ,0.5      ,5.3      ,0.33     ,1.739E5   ,       231-236
     &1.0      ,5.767E2  ,0.8      ,384.8    ,1.       ,4312.     ,       237-242
     &0.5      ,250.     ,5956.    ,3.63E5   ,0.8      ,93.0      ,       243-248
     &220.     ,200.     ,3400.    ,130.     ,3.00E6   ,0.7       ,       249-254
     &212.     ,1742.    ,5.0E7    ,7000.    ,3.356E-2 ,0.05      ,       255-260
     &28.9     ,867.0    ,0.0000000,0.0000000,0.0000000,0.0000000,        261-266
     &0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,        267-272
     &0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,        273-278
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&0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,     279-284
&0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,     285-290
&0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,0.0000000,     291-296
&0.0000000,0.0000000,0.0000000,0.0000000/                         297-300
 DATA (ENAME(I),I=1,100)/
&7HALVGPRX,7HACPWR  ,7HETATOT ,7HCVOLT  ,7HBBV    ,7HBPI    ,      1- 6
&7HCAPPRIX,7HAPCOS  ,7HAOCOS  ,7HGASOUT ,7HPLTCOS ,7HAMLIFE ,      7- 12
&7HTMODCOS,7HSYSAREA,7HTOTCEL ,7HSPGPRX ,7HDRISC  ,7HDEBTRAT,     13- 18
&7HWCC    ,7HCREB   ,7HALATC  ,7HALAPC  ,7HALAOC  ,7HALACC  ,     19- 24
&7HALAFCR ,7HBLDGFCL,7HAINSTL ,7HCOMPCOS,7HWOUT   ,7HEFFI   ,     25- 30
&7HCELCUR ,7HPMOD   ,7HAMCEL  ,7HETAV   ,7HETAI   ,7HETAR   ,     31- 36
&7HETAP   ,7HPPWR   ,7HETAM   ,7HVTH    ,7HAMODQ  ,7HAMLEN  ,     37- 42
&7HCFMAS  ,7HCFVOD  ,7HCFHOD  ,7HCFAN   ,7HCFSAR  ,7HTRLEN  ,     43- 48
&7HTRDIAM ,7HTRMAS  ,7HEPTHK  ,7HEPAR   ,7HEPVOL  ,7HEPMAS  ,     49- 54
&7HAMMFL  ,7HAMWFL  ,7HVELIN  ,7HVELOUT ,7HPDSTK  ,7HPDMOD  ,     55- 60
&7HCFMAX  ,7HCFMIN  ,7HSEFCOS ,7HBPCOS  ,7HFMCOS  ,7HOMODCOS,     61- 66
&7HPIDA   ,7HPIDC   ,7HPODA   ,7HPODC   ,7HPHDA   ,7HPHDC   ,     67- 72
&7HPIPA   ,7HPIPC   ,7HQCCON  ,7HQHCON  ,7HOMFL   ,7HHMFL   ,     73- 78
&7HWMFLO3 ,7HWMFLH3 ,7HFWMFL  ,7HPSPA   ,7HPSPC   ,7HCWFLOC ,     79- 84
&7HCWFLHC ,7HOCAP   ,7HHCAR   ,7HCWMFL  ,7HFWPP   ,7HGMODCV ,     85- 90
&7HPLENA  ,7HPLENC  ,7HWMFLO2 ,7HWMFLH2 ,7HWMFLO1 ,7HWMFLH1 ,     91- 96
&7HSTKLEN ,7HORESCV ,7HGPIPECV,7HAHXAR  /                         97-100
 DATA (ENAME(I),I=101,200)/
&7HCHXAR  ,7HCWFAHX ,7HCWFCHX ,7HQAHX   ,7HQCHX   ,7HDTAHX  ,    101-106
&7HDTCHX  ,7HAVOL   ,7HCVOL   ,7HPWAT   ,7HPKOH   ,7HPMFL   ,    107-112
&7HPAMFL  ,7HPCMFL  ,7HPAVFL  ,7HPCVFL  ,7HGVOL   ,7HRMODCOS,    113-118
&7HEMPTY  ,7HOMFLH  ,7HHMFLO  ,7HOMFLOUT,7HHMFLOUT,7HWMFLO5 ,    119-124
&7HWMFLH5 ,7HWMFLO4 ,7HWMFLH4 ,7HDSMO   ,7HDSMH   ,7HDDO    ,    125-130
&7HDDH    ,7HDLO    ,7HDLH    ,7HDPO    ,7HDPH    ,7HDPN    ,    131-136
&7HAUXPWR ,7HOCPWR  ,7HHCPWR  ,7HOCOMPS ,7HHCOMPS ,7HOSTOR  ,    137-142
&7HHSTOR  ,7HEMPTY  ,7HEMPTY  ,7HPCLF   ,7HGINLF  ,7HSLDEPR ,    143-148
&7HATDEPR ,7HPLFT   ,7HCPFT   ,7HALAADA ,7HALAIT  ,7HALAITCA,    149-154
&7HPDA    ,7HACWCOST,7HAFWCOST,7HAMATCOS,7HALBRCOS,7HACACOS ,    155-160
&7HAOHCOS ,7HANCOST ,7HCACOST ,7HCELCOST,7HEPCOST ,7HTRCOST ,    161-166
&7HMOLDCOS,7HCFCOST ,7HSLCOST ,7HASSYCOS,7HANPBCOS,7HCAPBCOS,    167-172
&7HOXPBCOS,7HHYPBCOS,7HANFLCOS,7HCAFLCOS,7HANHXCOS,7HCAHXCOS,    173-178
&7HANPMCOS,7HCAPMCOS,7HANRSCOS,7HCARSCOS,7HPURGCOS,7HOXCNCOS,    179-184
&7HHYCNCOS,7HOXDRCOS,7HHYDRCOS,7HAINSCOS,7HCWPBCOS,7HFWPBCOS,    185-190
&7HVENTCOS,7HSTRTCOS,7HOXCMCOS,7HHYCMCOS,7HOXBTCOS,7HHYBTCOS,    191-196
&7HPSCOS  ,7HUNASCOS,7HCNINCOS,7HDNECOS /                        197-200
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      SUBROUTINE HEADING(NRUN)
      COMMON/BLK1/PARAM(300)
      COMMON/BLK3/PNAME(300),ENAME(200),TITLE1(8),TITLE2(8)
      CALL DATE(TODAY)
      PRINT 100
  100 FORMAT(1H1/
     & 10X,48HX       X      XX      XX      XX   XXXXXXXX  XXXXXXXX/
     & 10X,48HXX      XX    XXXX     XX      XX   XX        XX       /
     & 10X,48HXXX    XXX   XX  XX    XX      XX   XX        XX       /
     & 10X,48HXXXXXXXXX   XX    XX   XX      XX   XX        XX       /
     & 10X,48HXX XX  XX   XX    XX   XX  XX  XX   XXXXX     XXXXXXXX/
     & 10X,48HXX      XX  XXXXXXXX   XXXXXXXX   XX              XX/
     & 10X,48HXX      XX  XX    XX   XXX  XXX   XX              XX/
     & 10X,48HXX      XX  XX    XX   XX    XX   XX              XX/
     & 10X,48HXX      XX  XX    XX   X      X   XXXXXXXX  XXXXXXXX)
      PRINT 106,NRUN,TODAY
  106 FORMAT(1H0,10X,10HRUN NUMBER,I3,14H. EXECUTED ON ,A10)
      PRINT 102,(TITLE1(I),I=1,8),(TITLE2(I),I=1,8)
  102 FORMAT(11X,8A10/8A10)
      PRINT 103,(I,PNAME(I),PARAM(I),I=1,262)
  103 FORMAT (60(2X,5(I3,1H.,A7,1H=,1PG11.4,2X)/))
      RETURN
      END
```

```
      SUBROUTINE ESTIM
C$    DEBUG
C$    CALLS
C$    FUNCS
C$    TRACE
C$    STORES(DCPWR,PPWR,AMCEL,CI,PMOD)
C SUBROUTINE "ESTIM" IS TRAFFIC CONTROL CENTER FOR DESIGN & COST ESTIMATION
C  SEE REFERENCE TABLE FOR MNEMONIC DEFINITIONS AND UNITS
      COMMON/BLK1/DCPWR,PT,PTMOD,X3,CAR,CCD,X6(24),AMSTY,EPSTY,AMXCEL,
     2X33(190),AMLFL,TLCW,AMLFH,THIGH
      COMMON/BLK2/ALGPRX,ACPWR,ETATOT,CV,BBV,BBI,CAPCOS,APCOS,AOCOS,AGO,
     2PLTCOSZ,AMLF,AMCOSZ,SAR,PCEL,Y15(15),CI,PMOD,AMCEL,ETAV,ETAI,ETAP,
     3ETAP,PPWR,ETAM,VTH,AMODG,AMLEN,Y42(2),CFHOD
      COMMON/BLK5/IFLAG(32)
      DIMENSION AMES(32,4)
      DATA ((AMES(I,J),J=1,4),I=1,9)/
     110H1-ENDOTHER,10HMIC AVERAG,10HE CELL VOL,10HTAGE      ,
     210H2-INLET MA,10HNIFOLDS OV,10HERSIZED   ,10H          ,
     310H3-OUTLET M,10HANIFOLDS O,10HVERSIZED  ,10H          ,
     410H4-SUBMINIM,10HUM FLOW IN,10H ONE OR MO,10HRE CELLS  ,
     510H5-OVERMAXI,10HMUM FLOW I,10HN ONE OR M,10HORE CELLS ,
     610H6-REQ'D CO,10HOLING WATE,10HR FLOW TOO,10H LARGE    ,
     710H7-HEAT LOS,10HS AT CONDE,10HNSER TOO L,10HARGE      ,
     810H8-HEAT LOS,10HS BY CONVE,10HCTION TOO ,10HLARGE     ,
     910H9-NET HEAT,10H LOSS TOO ,10HLARGE     ,10H          /
  100 FORMAT(29H0NEXT CASE IS OUT OF RANGE ON)
  101 FORMAT(1X,4A10)
      DO 200 I=1,32
  200 IFLAG(I)=0
      CALL VOLTCLC , RETURNS(1000)
      CI  =CAR*CCD
      PPWR=DCPWR
      PCEL=PPWR/(CV*CI)
      PMOD=PCEL/AMXCEL
      PMOD=AINT(PMOD)+1.0
      AMCEL=AINT(PCEL/PMOD) +1.0
      PCEL = AMCEL*PMOD
      PPWR = PCEL* CI  *CV
      BBV = AMCEL*CV
      BBI = CI  *PMOD
```

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      VTH=1.4813+1.638E-4*(PT-25.)
      ETAV= VTH/CV
      CALL ETAREC
      I=IFIX(AMSTY)
      IF(I.EQ.2) GO TO 202
      CALL CFRMO,RETURNS(1000)
      GO TO  205
202   CALL RFRMO,RETURNS(1000)
205   CALL ETACUR
      ETAM= ETAI   *ETAV
      AMODQ=(1.0-ETAM)*CI*BBV
      CALL MANANAL,RETURNS(1000)
      CALL HMPB   ,RETURNS(1000)
      SAR= 2.*PMOD*AMLEN*CFHOD
      CALL CONDIT
      CALL ETANET
      CALL PLTCOST
      CALL LIFE(TLOW,AMLFL,THIGH,AMLFH,PTMOD,AMLF)
      CALL MODCOST
      CALL CAPCOST
      CALL OPCOST
      CALL GASCOST
      RETURN
1000  PRINT 100
      DO 206 N=1,32
      IF (IFLAG(N).EQ.0) GO TO 206
      PRINT 101,AMES(N,1),AMES(N,2),AMES(N,3),AMES(N,4)
206   CONTINUE
      ALGPRX =1.0E10
      RETURN
      END
```

```
      SUBROUTINE EXOUT1(IOFLAG,NRUN)
      COMMON/BLK1/PARAM(300)
      COMMON/BLK2/ESTOUT(200)
      COMMON/BLK3/PNAME(300),ENAME(200),TITLE1(8),TITLE2(8)
      COMMON/BLK7/NLOOP,DLOOP(15,2),MLOOP(15,3)
  100 FORMAT (2X,8A10/8A10)
  101 FORMAT (18H1 OPTIMUM FOR RUN ,I4,6H WITH ,I2,16H LOOP PARAMETERS)
  102 FORMAT (20H0  INPUT PARAMETERS )
  103 FORMAT (60(2X,5(I3,1H.,A7,1H=,1PG11.4,2X)/))
  104 FORMAT (20H0 OUTPUT PARAMETERS )
  105 FORMAT (15(3X,I3,1H.,A7,1H=,1PG11.4,4H TO ,1PG11.4,4H IN ,I5,
     &             19H STEPS, OPTIMUM AT ,1PG11.4/))
  106 FORMAT (150(1H0,2(I3,1H.,A7,1H=,1PG11.4,42X)/))
      PRINT 101,NRUN,NLOOP
      PRINT 100,(TITLE1(I),I=1,8),(TITLE2(I),I=1,8)
      PRINT 105,(MLOOP(I,1),PNAME(MLOOP(I,1)),DLOOP(I,1),DLOOP(I,2),
     &             MLOOP(I,2),PARAM(MLOOP(I,1)),I=1,NLOOP)
      IF ((IOFLAG.EQ.10).OR.(IOFLAG.EQ.11)) GO TO 1
      PRINT 102
      PRINT 103,(I,PNAME(I),PARAM(I),I=1,262)
      PRINT 104
      PRINT 103,(I,ENAME(I),ESTOUT(I),I=1,200)
      GO TO 2
    1 PRINT 102
      PRINT 106,(I,PNAME(I),PARAM(I),I=1,262)
      PRINT 104
      PRINT 106,(I,ENAME(I),ESTOUT(I),I=1,200)
    2 RETURN
      END
```

```
      SUBROUTINE  ETACUR
C$    DEBUG
      COMMON/BLK1/X0(2),PTMOD,X3,CAR,X5,CTHK,X7(13),ELCON,ELDELC,AMPRES,
     2AMDELP,AMDELT,X25(38),AMN(2,5)
      COMMON/BLK2/Y0(3),CV,Y4(26),CI,PMOD,AMCEL,ETAV,ETAI
      DIMENSION          R1(2,2),R2(2,2),R4(2,2),ALOS(2,2)
C     L=IN,OUT, K=H,C
      RHO(T,C)=1./(12.02-.4358*T+10.05*T*C+195.9*C-14.08*T*C*C
     $-414.5*C*C)
      Z=CV/CI
      DO 1 K=1,2
      DO 1 L=1,2
      TMAN=PTMOD+(FLOAT(L)-1.5)*AMDELT
      CMAN=ELCON +(1.5-FLOAT(K))*ELDELC
      R=RHO(TMAN,CMAN)*(1.+1.25*(L-1)*(3-K))
      R1(L,K)=(R        *AMN(L,3))/(0.7854*(CTHK*AMN(L,4))**2)
      R2(L,K)=(R        *CTHK)/(.7854*AMN(L,2)**2)
      R4(L,K)=(R        *AMN(L,5))/(0.7854*AMN(L,2)**2)
1     CALL LOS(CI,AMCEL,Z,R1(L,K),R2(L,K),R4(L,K),ALOS(L,K))
      TOTLOS= AMN(1,1)*(ALOS(1,1)+ALOS(1,2))+AMN(2,1)*(ALOS(2,1)+ALOS(2,
     22))
      ETAI= 1.0-TOTLOS/(CI*AMCEL*CV)
      RETURN
      END
```

```
      SUBROUTINE LOS(I1,AN,Z,R1,R2,R4,ALOS)
C$    DEBUG
C$    AREA (*,50),(300,*)
C$    STORES (I1,AN,Z,R1,R2,R4,ALOS,I,F1,D1,E1,D,E)
      REAL I1
      DIMENSION A(200),B(200), I(202),P(201)
      DOUBLE PRECISION A,B,I,P,D,E,D1,E1,S1,S2
      N1=IFIX(AN)
      N2=N1+1
      D1=Z/(R2+2.0*R1+Z)
      E1=R1/(R2+2.0*R1+Z)
      A(1)=1.0
      A(2)=0.0
      B(1)=0.0
      B(2)=1.0
      D=-Z/R1
      E=(R1+R4+Z)/R1
      A(3)=D
      B(3)=E
      S1=0.0
      S2=1.0
      E=(Z+2.0*R1+R2)/R1
      DO 100  N= 3,N1
      A(N+1)=A(N)*E-A(N-1)+D
      B(N+1)=B(N)*E-B(N-1)
      S1=S1+A(N)
      S2=S2+B(N)
  100 CONTINUE
      S1=S1+A(N2)
      S2=S2+B(N2)
      F1=(D1+E1*A(N1)-A(N2))/(B(N2)-E1*B(N1))
      I(1)=AN*I1/(N1-S1-S2*F1)
      I(2)=F1*I(1)
 50   DO 200 J=3,N2
      I(J)=A(J)*I(1)+B(J)*I(2)
  200 CONTINUE
      P(1)=I(2)
      I(N1+2)=0.0
      DO 300 J=2,N2
      P(J)=I(J+1)-I(J)
```

```
300   CONTINUE
      ALOS=(I(1)-I1)*AN
      RETURN
      END
```

```
      SUBROUTINE VOLTCLC,RETURNS(N)
      COMMON/BLK1/X0,X1, T    ,X3,X4,CCD,X6,CVP(4,3)
      COMMON/BLK2/Y0(3),CV/BLK5/IFLAG(32)
      I=3
      IF (T.LE.CVP(4,2))I=1
      T1=(T-CVP(4,I))/(CVP(4,2)-CVP(4,I))
      R= (CVP(3,2)-CVP(3,I))*T1+CVP(3,I)
      S= (CVP(2,2)-CVP(2,I))*T1+CVP(2,I)
      E= (CVP(1,2)-CVP(1,I))*T1+CVP(1,I)
      CV= E+ S*(ALOG10(CCD))+ R*CCD
      IF (CV.GT.1.48) GO TO 1
      IFLAG(1)=1
      RETURN N
    1 RETURN
      END
```

```
      SUBROUTINE ETAREC
      COMMON/BLK2/Y1(35),ETAR
      ETAR=0.95
      RETURN
      END
```

```
      SUBROUTINE CFRMO, RETURNS(N)
C$    DEBUG
      COMMON/BLK1/X0,X1,PTMOD,X3,CAR,X5,CTHK,X7(12),CCOMP,X20(2),AMPRES,
     2X23(8),EPSTY,X32,AMASP,EPDEF,EPMOD,EPMODT,EPRHO,EPNU,X39(2),SLTHK,
     3SLLO,SLLDT,SLMDIS,SLDCDIS,X46(2),TRNO,TRMOD,TRMODT,TRCTE,TRUTS,
     4TRUTST,TRSF,TRRHO,TRNU,X57,CFRHO,CFMTS,CFMTST,CFMAN,X62,AMN(2,5)
      COMMON/BLK2/Y0(41),AMLEN,CFMAS,CFVOD,CFHOD,CFAN,CFSAR
      COMMON/BLK5/IFLAG(32)
      R=SQRT(CAR/3.14159)
      ARC=(R+AMN(1,3)+AMN(1,2)/2.0)*1.5708
      HOLE=AMN(1,1)*AMN(1,2)*2.0+(2.0*AMN(1,1)-1.0)*SLMDIS
      IF (HOLE.GT.ARC) IFLAG(2)=1
      ARC=(R+AMN(2,3)+AMN(2,2)/2.0)*1.5708
      HOLE=AMN(2,1)*AMN(2,2)*2.0+(2.0*AMN(1,1)-1.0)*SLMDIS
      IF (HOLE.GT.ARC) IFLAG(3)=1
      IF (IFLAG(2)+IFLAG(3).GT.0) RETURN N
      TS=(CFMTS-(PTMOD-25)*CFMTST)
      SAND= AMAX1((AMN(1,2)+AMN(1,3)),(AMN(2,2)+AMN(2,3)))
      AND =AMPRES*(R+SAND)/TS
      IF  (AND.LE.CFMAN) AND=CFMAN
      CFAN= SAND+AND
      CFHOD= 2*(CFAN+R)
      CFVOD=CFHOD
      CFSAR=.7834*(CFHOD**2-4.*R**2-2.*(AMN(1,1)*AMN(1,2)**2+AMN(2,1)
     8*AMN(2,2)**2))
      CFMAS=CFSAR*(CTHK-SLTHK)*CFRHO
      I=IFIX(EPSTY)
      IF (I.EQ.2) GO TO 102
101   CALL CEPSI
      RETURN
102   CALL CEPSI
      RETURN
      END
```

```
      SUBROUTINE CEPSI
C$    DEBUG
      COMMON/BLK1/X0,X1,PTMOD,X3,CAR,X5,CTHK,X7(12),CCOMP,X20(2),AMPRES,
     2X23(8),EPSTY,X32,AMASP,EPDEF,EPMOD,EPMODT,EPRHO,EPNU,X39(2),SLTHK,
     3SLLD,SLLDT,SLMDIS,SLDCDIS,X46(2),TRNO,TRMOD,TRMODT,TRCTE,TRUTS,
     4TRUTST,TRSF,TRRHO,TRNU,X57,CFRHO,CFMTS,CFMTST,CFMAN,X62,AMN(2,5)
      COMMON/BLK2/ Y0(32),AMCEL,Y33(8),AMLEN,CFMAS,CFVOD,CFHOD,CFAN,
     2CFSAR,TRLEN,TRDIAM,TRMAS,EPTHK,EPAR,EPVOL,EPMAS
      SLP=(SLLD+ (PTMOD-25.)*SLLDT)
      E   =(EPMOD+(PTMOD-25.)*EPMODT)
      P= AMPRES+CCOMP
      TRTS=TRSF* (TRUTS+(PTMOD-25.)*TRUTST)
      AM=1.0/EPNU
      RO= SQRT(CAR/3.14159)
      AO= CFHOD/2.
      F1= (12*AM+4.0)*AO*AO/(AM+1.0)
      F2=   +4.0*RO*RO*ALOG(RO/AO)
      F3= -(7.*AM+3.)*RO*RO/(AM+1.0)
      F=0.1875*AMPRES*(AM*AM-1.)*RO*RO*(F1+F2+F3)/(E*AM*AM)
      AL17=0.25*(1.-.25*(1.0-EPNU)*(1.-(RO/AO)**4)-(RO/AO)**2 *(1.0-
     &(1.0+EPNU)*ALOG(RO/AO)))
      AL11=0.015625*(1.0+4.0*((RO/AO)**2)-5.0*((RO/AO)**4)+ 4.0*((RO/AO)
     &**2)*(2.0+((RO/AO)**2))*ALOG(RO/AO))
      G=(SLP*(AO**4)/(2.0*E))*(AL17/(1.+EPNU)-2.*AL11)*12.*(1.0-EPNU**2)
      EPTHK=((F+G)/EPDEF)**.333
      AMLD= (0.7854*AO**2 -CFSAR)*P +CFSAR*SLP
      TRDIAM=SQRT(     AMLD/(TRNO*0.7854*TRTS))
      EPAR= 3.14159*((AO   )+1.5*TRDIAM)**2
      EPVOL= EPAR*EPTHK
      EPMAS= EPVOL*EPRHO
      AMLEN= AMCEL*CTHK+2.0*EPTHK
      TRLEN= AMLEN+8.0*TRDIAM
      TRNO=TRNO
      TRRHO=TRRHO
      TRMAS= TRLEN*TRNO*TRRHO*0.7854*TRDIAM**2
      RETURN
      END
```

```
      SUBROUTINE RFRMO,RETURNS(N)
      COMMON/BLK1/X0,X1,PTMOD,X3,CAR,X5,CTHK,X7(12),CCOMP,X20(2),AMPRES,
     2X23(8),EPSTY,X32,AMASP,FPDEF,EPMOD,EPMODT,EPRHO,EPNU,X39(2),SLTHK,
     3SLLD,SLLDT,SLMDIS,SLDCDIS,X46(2),TRNO,TRMOD,TRMODTTTRCTE,TRUTS,
     4TRUTST,TRSF,TRRHO,TRNU,X57,CFRHO,CFMTS,CFMTST,CFMAN,X62,AMN(2,5)
      COMMON/BLK2/Y0(41),AMLEN,CFMAS,CFVOD,CFHOD,CFAN,CFSAR
      COMMON/BLK5/IFLAG(32)
      VIL= SQRT(CAR/AMASP)
      HIL=CAR/VIL
      HOLE= AMN(1,1)*AMN(1,2)+(2.*AMN(1,1)+1.0)*SLMDIS
      IF(HOLE.GT.HIL) IFLAG(2)=1
      HOLE= AMN(2,1)*AMN(2,2)+(2.*AMN(2,1)+1.0)*SLMDIS
      IF(HOLE.GT.HIL) IFLAG(3)=1
      IF(IFLAG(2)+IFLAG(3).GT.0) RETURN N
      TS=   CFMTS-(PTMOD-25.)*CFMTST
      AND= SQRT((CAR*AMPRES)/(1.33*TS))
      IF(AND.LE.CFMAN) AND= CFMAN
      CFVOD= VIL+ 2.*AND+ AMN(1,2)+AMN(2,2)+AMN(1,3)+AMN(2,3)
      CFHOD = HIL+2.*AND
      CFRAN= (CFVOD-VIL)/2.0
      CFSAR=CFVOD*CFHOD-HIL*VIL -1.5708*(AMN(1,1)*AMN(1,2)**2+AMN(2,1)*
     &AMN(2,2)**2)
      CFMAS=CFSAR*(CTHK-SLTHK)*CFRHO
      I=IFIX(EPSTY)
      IF (I.EQ.2) GO TO 102
  101 CALL REFSI
      RETURN
  102 CALL REFSI
      RETURN
      END
```

```
      SUBROUTINE REPSI
      COMMON/BLK1/X0,X1,PTMOD,X3,CAR,X5,CTHK,X7(12),CCOMP,X20(2),AMPRES,
     2X23(8),EPSTY,X32,AMASP,EPDEF,EPMOD,EPMODT,EPRHO,EPNU,X39(2),SLTHK,
     3SLLD,SLLDT,SLMDIS,SLDCDIS,X46(2),TRNO,TRMOD,TRMODT,TRCTE,TRUTS,
     4TRUTST,TRSF,TRRHO,TRNU,X57,CFRHO,CFMTS,CFMTST,CFMAN,X62,AMN(2,5)
      COMMON/BLK2/ Y0(32),AMCEL,Y33(8),AMLEN,CFMAS,CFVOD,A0,CFAN,CFSAR,
     2TRLEN,TRDIAM,TRMAS,EPTHK,EPAR,EPVOL,EPMAS
      SLP=(SLLD+(PTMOD-25.)*SLLDT)
      E  = EPMOD +(PTMOD-25.)*EPMODT
      TRTS= TRSF*(TRUTS+(PTMOD-25.)*TRUTST)
      P= AMPRES+CCOMP
      Q= P-SLP
      A2= 0.5*SQRT(CAR)
      AMLD=CFSAR*SLP +CAR*P
      P1=Q*A2+SLP*CFVOD
      T= (Q*(A2**3/24.)*(4.0*CFVOD-A2)+(SLP*CFVOD**2/24.)*(3.*CFVOD**2)
     &    -P1*(CFVOD**3)/3.)
      EPTHK=ABS(12.*T/(E*EPDEF))**.333/1.52
      TRDIAM=SQRT(   AMLD/(TRNO*0.7854*TRTS))
      EPAR= 3.14159*((A0/2)+1.5*TRDIAM)**2
      EPVOL= EPAR*EPTHK
      EPMAS= EPVOL*EPRHO
      AMLEN= AMCEL*CTHK+2.0*EPTHK
      TRLEN= AMLEN+8.0*TRDIAM
      TRMAS= TRLEN*TRNO*TRRHO*0.7854*TRDIAM**2
      RETURN
      END
```

```
      SUBROUTINE MANANAL,RETURNS(NO)
C$    DEBUG
C$    AREA (*,8),(2,*)
C$    TRACE
C$    GOTOS
      EXTERNAL DEN ,VIS,CP
      COMMON/BLK1/X0(2),PTMOD,X3,CAR,CCD,CTHK,X7(12),CCOMP,ELCON,ELDELC,
     2AMPRES,AMDELP,AMDELT,X25(38),AMN(2,5),X73(6),SCFMNR,SCFMXR,SCFX,
     3SCFC,THTA1,THTA2,EPIX,EPIC,EPOX,EPOC,AFF,ETD
      COMMON/BLK2/Y0(32),AMCEL,Y33(7),AMODG,Y41(13),AMMFL,AMVFL,VI,VO,
     2POSTK,PDMOD,CFMAX,CFMIN,X62(34),ALEN
      COMMON/BLK5/IFLAG(32)
      DIMENSION G8(3),E(2),G(200),Z(200)
      J=1
      N=IFIX(AMCEL)
      RHOI=  DEN(PTMOD,ELCON)
      VISI= VIS(PTMOD,ELCON)/RHOI
      CPI=  CP(PTMOD,ELCON)
      AMMFL= AMODG/(AMDELT*CPI)
      AMVFL=AMMFL/RHOI
      AVFL=AMVFL*AFF
      ALEN=CTHK*AMCEL
      VI= AVFL/(AMN(1,1)*0.7854*AMN(1,2)**2)
      G1=AVFL
      G8(2)=AVFL/AMCEL
      ASUBR=AMCEL*(CTHK*AMN(1,4)/AMN(1,2))**2
      ARAT=(AMN(1,1)*AMN(1,2)**2)/(AMN(2,1)*AMN(2,2)**2)
1     G3=G8(2)
      V1=VI
      G9=0.0
      V3=G3/(AMN(1,1)*0.7854*(CTHK*AMN(1,4))**2)
      PC=(G3/SCFC)**SCFX
      RENO= V1      *AMN(1,2)/VISI
      FI=64./RENO
      IF (RENO.GT.2000.) FI=0.316/RENO**.25
      RENO=RENO*AMN(2,2)/AMN(1,2)
      FO=64./RENO
      IF(RENO.GT.2000.) FO=0.316/RENO**.25
8     DO 2  I=1,N
      P=(FI/(2.0*AMN(1,1)*AMN(1,2)) + FO*ARAT**2/(2.0*AMN(2,1)*AMN(2,2))
```

```
     2)*V1**2 -(THTA1-THTA2*ARAT**2)*V1*(ASURF/ALEN)*V3
      P=-(RHOI*P)*CTHK
      G9=G9+G3
      G(I)=G3
      P0=P0+P
      IF (P0.LT.0.0) GO TO 3
      G3= SCFC*(P0**(1.0/SCFX))
      V3= G3/(AMN(1,1)*0.7854*(CTHK*AMN(1,4))**2)
      V1= ((G1-G3)/G1)*V1
      G1= G1-G3
      RENO= V1      *AMN(1,2)/VISI
      FI=64./RENO
      IF (RENO.GT.2000.) FI=0.316/RENO**.25
      RENO=RENO*AMN(2,2)/AMN(1,2)
      F0=64./RENO
      IF(RENO.GT.2000.) F0=0.316/RENO**.25
 2    CONTINUE
 3    E(2)= G9-AVFL
      IF (ABS(E(2)).LT.0.1) GO TO 760
      IF (J.GT.1)GO TO 690
      G8(1)=G8(2)
      G8(2)=G8(2)-E(2)/AMCEL
      GO TO 720
 690  G8(3)=G8(2)-E(2)*(G8(2)-G8(1))/(E(2)-E(1))
      G8(1)=G8(2)
      G8(2)=G8(3)
 720  E(1)=E(2)
      Z(J)= G8(1)
      J=J+1
      GO TO 1
 760  PDSTK=P0
      PDMOD=PDSTK+(AVFL/EPIC)**EPIX+(AVFL/EPGC)**EPOX
C CHECK FOR OUT OF BOUNDS ON SINGLE CELL FLOW
      CFMAX=G(1)
      CFMIN=G(1)
 9    DO 4 I=2,N
      CFMAX= AMAX1(CFMAX,G(I))
 4    CFMIN= AMIN1(CFMIN,G(I))
      IF(CFMIN.GE.(AVFL*SCFMNR/AMCEL)) GO TO 5
      IFLAG(4)=1
```

```
      RETURN NO
    5 IF(CFMAX.LE.(AVFL*SCFMXR/AMCEL)) GO TO 6
      IFLAG(5)=1
      RETURN NO
    6 RETURN
      END
```

```
      SUBROUTINE HMPB, RETURNS(N)
C$    DEBUG
C$    TRACE
      EXTERNAL DEN ,VIS,CP
      REAL NUS,KAIR
      COMMON/BLK1/DCPWR,PTAMB,PTMOD,X3,CAR,X5(15),ELCON,ELDELC,
     1AMPRES,AMDELP,
     2AMDELT,Y25(5),AMSTY,X31(58),AFF,X90(6),CWT,CWMF,FWT,CPDL,PLMIN,
     3PLK,FPDPPD,FSRC,HYPDFPD,ETAPMOT,PK,ELFH,ELFD,RESH,RESD,ELPW,ETAPVM
     4,TCOO,TCOH,DTOO,DTOH,X18,OCHEF,HCHEF,ETAWP,ETAWPM,X122(2),EPKTH,
     5AMINST,AMINSK,CFKTH,RESHEF,RESINST,RESINSK,UHXA,UHXC,VOIDFR,X134
      COMMON/BLK2/Y0(29),EFFI,CI,PMOD,AMCEL,Y33,ETAI,Y35(5),AMODQ,AMLEN,
     2Y42,CFVOD,CFHOD,CFAN,Y46(4),EPTHK,EPAR,Y52(7),PDMOD,Y60(6),DA,DC,
     3ODA,ODC,PHDA,PHDC,P1FA,PIPC,GCONO,QCONH,OMFL,HMFL,WMFLO3,WMFLH3,
     4FWMFL,PPA,PPC,CWOC,CWHC,DCAR,HCAR,CUMFL,WPP,QMODL,RLENA,RLENC,
     5WMFLO2,WMFLH2,WMFLO1,WMFLH1,ALEN,CRFS,GPIPE,HXAAR,HXCAR,CWFHXA,
     6CWFHXC,GHXA,G-XC,DTA,DTC,AVOL,CVOL,PWAT,PKOH,PMFL,PAMFL,PCMFL,
     7PAVFL,PCVFL,GVOL
      COMMON/BLK5/IFLAG(32)
      VISAIR(T)=1.E-6*(-4.228+.04027*(T+273.15)+ 9.342E-5*(T+273.15)**2)
      HVAP(T)=1.E6*(2.460-9.19)E-4*T-9.609E-6*T**2)
      VP(T,C)=133.322*EXP(1.539+.9883*C-8.906*C**2+.06512*T-.006288*C*T
     &+.001653*T*C**2-1.406E-4*T**2+2.207E-5*C*T**2+3.819E-6*C**2*T**2)
      KAIR(T)=4.164E-3 +7.267E-7*(T+273)
      CPWV(T)=8137.0-37.343*(T+273)+.0748*(T+273)**2-4.956E-5*(T+273)**3
      CPH(T)=6441.3+63.105*(T+273)-.16838*(T+273)**2+1.521E-4*(T+273)**3
      CPO(T)=950.68-.4451*(T+273)+1.395E-3*(T+273)**2-8.46E-7*(T+273)**3
      ALFA(T)=(-.2999 + 1.714E-3*(T+273))*1E-4
      CPW=4186.7
C   CALC     MASS FLOWS
      CONC= ELCON+0.5*ELDELC
      CONA= ELCON-0.5*ELDELC
      CFF = 1.- AFF
      RHOA= DEN(PTMOD,CONA)
      RHOC= DEN(PTMOD,CONC)
      EFFI= CI*AMCEL*PMOD*ETAI
      PMFL=AMODQ*PMOD/(AMDELT*(AFF*CP(PTMOD,CONA)+CFF*CP(PTMOD,CONC)))
      PAMFL= AFF*PMFL
      PCMFL= CFF*PMFL
      PCVFL= PCMFL/RHOC
```

```
      PAVFL= PAMFL/RHOA
      HMFL= EFFI*1.04470E-8
      OMFL= EFFI*8.29096E-8
C     ELECTROLYTE PIPE SIZE SELECTION
      DA= VA=ODA=0
      DC= VC=ODC=0
      IF (AFF.EQ.1.) GO TO 2
    1 DC= 0.01 + DC
      RE=PCMFL/(0.7854*DC*VIS(PTMOD,CONC))
      VC=PCVFL/(0.7854*DC**2)
      F=64./RE
      IF(RE.GT.2000.) F=0.316/RE**.25
      DPDLC= F*RHOC*VC**2/(2.*DC)
      IF (DPDLC.GT.DPDL) GO TO 1
      ODC=DC+ELPW
    2 DA=DA+0.01
      RE=PAMFL/(0.7854*DA*VIS(PTMOD,CONA))
      VA=PAVFL/(0.7854*DA**2)
      F=64./RE
      IF(RE.GT.2000.) F=0.316/RE**.25
      DPDLA= F*RHOA*VA**2/(2.*DA)
      IF (DPDLA.GT.DPDL) GO TO 2
      ODA=DA+ELPW
C     PRESSURE DROP/PUMP SIZING
      PPC=PIPC=    RLENC=0
      IF (AFF.EQ.1.) GO TO 4
      RLENC=(PLMIN+ PLK*(DCPWR**.333))*(CFF)
      FSPDC=(RHOC*FSFC*VC**2)/2.
      PHDC  =(RLENC*DPDLC)*(1.0+FPDPPD+HXPDPPD)+FSPDC + PDMOD
      ETAHDC=(1-0.8/(PCMFL*15.85  )**.25)*ETAPVM
      PPC=PHDC*PCVFL/ETAHDC
      PIPC=PPC/ETAPMOT
      IF (PIPC .LT.100.) PIPC=100.
    4 RLENA=(PLMIN+PLK*(DCPWR**.333))*AFF
      FSPDA=(RHOA*FSFC*VA**2)/2.
      PHDA = (RLENA*DPDLA)*(1.0+FPDPPD+HXPDPPD)+FSPDA+ PDMOD
      ETAHDA=(1-0.8/(PAMFL*15.85) **.25)*ETAPVM
      PPA=PHDA*PAVFL/ETAHDA
      PIPA= PPA/ETAPMOT
      IF (PIPA.LT.100.) PIPA=100.
```

```
C   HYDROGEN CONDENSER HEAT AND MASS BALANCE
      T=TCOH
      TCIH=PTMOD+0.5*AMDELT
      IF (TCIH.LT.T) T=TCIH
      PH=AMPRES+0.5*AMDELP
      VPRW=VP(TCIH,CONC)
      WMFLH1=(18.0153*VPRW*HMFL)/(2.0159*(PH-VPRW+1.01325E5))
      VPRW=VP(T,0.0)
      WMFLH3=(18.0153*VPRW*HMFL)/(2.0159*(PH-VPRW+1.01325E5))
      WMFLH2=WMFLH1-WMFLH3
      IF (WMFLH2.LT.0.0)  WMFLH2=0.0
      QCONH=(HMFL*CPH((T+TCIH)/2.)+WMFLH1*CPWV((T+TCIH)/2.))*(TCIH-T)
     8           +WMFLH2*HVAP((T+TCIH)/2.)
      CWHC=QCONH/(DTOH*CPW)
      HCAR=QCONH/(HCHEF*((TCIH-T-DTOH)/ALOG((TCIH-CWT-DTOH)/(T-CWT))))
C OXYGEN CONDENSER HEAT AND MASS BALANCE
      T=TCOO
      TCIO=TCIH
      IF (TCIO.LT.T) T=TCIO
      PO=AMPRES-0.5*AMDELP
      VPRW=VP(TCIO,CONA)
      WMFLO1=(18.0153*VPRW*OMFL)/(31.9988*(PO-VPRW+1.01325E5))
      VPRW=VP(T,0.0)
      WMFLO3=(18.0153*VPRW*OMFL)/(31.9988*(PO-VPRW+1.01325E5))
      WMFLO2=WMFLO1-WMFLO3
      IF (WMFLO2.LT.0.0) WMFLO2=0.0
      TAV =(T+TCIO)/2.
      QCONO=(OMFL*CPO(TAV) +WMFLO1*CPWV(TAV) )*(TCIO-T)+WMFLO2*HVAP(TAV)
      CWOC=QCONO/(DTOO*CPW)
      OCAR=QCONO/(OCHEF*((TCIO-T-DTOO)/ALOG((TCIH-CWT-DTOH)/(T-CWT))))
C CALUCULATE NET REMAINING HEAT LOAD, SETFLAG 7 IF NEGATIVE
      QREM=AMODQ*PMOD+PPC+PPA-QCONO-QCONH
      IF(QREM.GT.0.) GO TO 5
      IFLAG(7)=1
      RETURN N
5     CWMFL=CWOC+CWHC
      IF(CWMFL.LT.CWMF)GO TO 6
      IFLAG(6)=1
      RETURN N
C FEEDWATER REQUIREMENTS
```

```
 6     FWMFL = HMFL+OMFL+WMFLO3+WMFLH3
       WPP=AMPRES*FWMFL/(997.*ETAWF*ETAWPM)
       IF (WPP.LT.100.) WPP=100.
C CONVECTIVE HEAT LOSS CALCULATIONS,RA=RALEIGH #,NU=NUSSELT #,TF=FILM T.
C   MODULE ENDPLATES
       TS=(PTAMB+PTMOD)/2.
       ALC= AMSTY*CFVOD/2.
 7     TF=(TS+PTAMB)/2.
       RA=  9.8*(ALC**3)*(TS-PTAMB)/((TF+273.15)*VISAIR(TF)*ALFA(TF))
       NUS= 0.59*(RA**.25)
       IF(RA.GT.10E9) NUS=0.1*(RA**.33)
       H= NUS*KAIR(TF)/ALC
       TSN=(PTMOD/((EPTHK/EPKTH)+(AMINST/AMINSK))+(PTAMB*H))
     &  /(  1. /((EPTHK/EPKTH)+(AMINST/AMINSK))+(  1. *H))
       IF (     ABS(TS-TSN).LT.5) GO TO 8
       TS= TSN
       GO TO 7
 8     QEP= 2.*EPAR*H*(TSN-PTAMB)
C   MODULE SIDES
       TS=(PTMOD+   PTAMB)/2.
       ALC=CFVOD
       IF(AMSTY.EQ.2.) ALC=ALEN *CFVOD/(ALEN+CFVOD)
 9     H= 1.32*(((TS-PTAMB)/ALC)**.25)
       TSN=(PTMOD*CFKTH/CFAN+PTAMB*H)/(CFKTH/CFAN+H)
       IF   ( ABS(TSN-TS).LT.5) GO TO 10
       TS= TSN
       GO TO 9
 10    QMODL=QEP+ 3.1416*ALEN *ALC*H*(TSN-PTAMB)
       QREM= QREM-PMOD*QMODL
       IF(QREM.GT.0) GO TO 11
       IFLAG(8)=1
       RETURN N
 11    CONTINUE
C   RESERVOIRS
       ANR= 1+ 2.*CFF
       ALC= RESH
       TS=(PTAMB*2+PTMOD)/ 3.
 12    TF=(TS+PTAMB)/2.
       RA=  9.8*(ALC**3)*(TS-PTAMB)/((TF+273.15)*VISAIR(TF)*ALFA(TF))
       H=1.42*(((TS-PTAMB)/ALC)**.25)
```

```
      IF(RA.GT.1E9) H= 1.32*((TS-PTAMB)**.333)
      TSN=(PTMOD/((1./RESHEF)+(RESINST/RESINSK))+(PTAMB*H))
     &   /(  1. /((1./RESHEF)+(RESINST/RESINSK))+(  1. *H))
      IF(  ABS(TSN-TS).LT.5) GO TO 13
      TS= TSN
      GO TO 12
   13 QRES= ANR*ALC*3.14*RESD*H*(TSN-PTAMB)
C   PIPING HEAT LOSSES
      TS=PTMOD
      TF=(PTAMB+PTMOD)/2.
      ALC= ODA*AFF+ODC*CFF
      RA=  9.8*(ALC**3)*(TS-PTAMB)/((TF+273.15)*VISAIR(TF)*ALFA(TF))
      H= 1.32*(((TS-PTAMB)/ALC)**.25)
      IF(RA.GT.1E9) H=1.25*((TS-PTAMB)**.333)
      AREA=(RLENA*ODA+RLENC*ODC)*3.1416
      QPIPE= H*AREA*(TS-PTAMB)
      QREM= QREM-QPIPE-QRES
      IF(QREM.GT.0.) GO TO 17
      IFLAG(9)=1
      RETURN N
C     HEAT EXCHANGER
   17 HXCAR=CWFHXC =0
      IF (CFF.EQ.0) GO TO 14
      QHXC=QREM*CFF
      DTC=QHXC/(PCMFL*CP(PTMOD,ELCON+ELDELC/2.))
      CWFHXC = QHXC/(DTC*CPW)
      HXCAR= QHXC/(UHXC* (PTMOD-DTC/2.-CWT))
   14 QHXA=QREM*AFF
      DTA=QHXA/(PAMFL*CP(PTMOD,ELCON-ELDELC/2.))
      CWFHXA =QHXA/(DTA*CPW)
      HXAAR= QHXA/(UHXA* (PTMOD-DTA/2.-CWT))
      CWMFL=CWMFL+CWFHXA+CWFHXC
      IF (CWMFL.LT.CWMF) GO TO 15
      IFLAG(6)=1
      RETURN N
   15 CONTINUE
C   ELECTROLYTE VOLUME &MASS
      CVOL=0
      AVOL=.5*ALEN*CAR*VOIDFR+.7854*(.5*RESD**2*RESH+ELFD**2*ELFH)
      IF(CFF.GT.0) CVOL=AVOL+.7854*RLENC*DC**2
```

```
      AVOL=AVOL+.7854*RLENA*DA**2
      GVOL=.432*RESD**2*RESH/AFF
      PKOH=(AVOL*RHOA*CONA)+(CVOL*RHOC*CONC)
      PWAT=(AVOL*RHOA*(1.-CONA))+(CVOL*RHOC*(1-CONC))
      RETURN
      END
```

```
      SUBROUTINE  CONDIT
C$    DEBUG
C$    TRACE
      COMMON/BLK1/X0,PTAMB,X2(20),AMPRES,AMDELP,X24(89),TCOO,TCOH,
     2X115(21),HIOMR,OIMANCL,
     3OPUR,HPUR,DONO,DHNO,DOCYC,DHCYC,DSMWR,DSVOID,DSCP,DTCHG,DSDEN,
     4DLDR,DWTHK,DWDEN,DWCP,PHS,POS,FTACOMP,RATCOMP,OMASR,HMASR,DRPURG
      COMMON/BLK2/Y0(29),EFFI,CI,PMOD,AMCEL,Y33(3),ETAP,Y37(39),OMFL,
     2HMFL,WMFLO3,WMFLH3,Y80(36),GVOL,Y117,Y118,OMFLH,HMFLO,
     3OMFLD,HMFLD,WMFLO5,WMFLH5,WMFLO4,WMFLH4,DSMO,DSMH,DDO,DDH,DLO,
     4DLH,DPO,DPH,DPN,Y136,OCPWR,HCPWR,OCOMPS,HCOMPS,OSTOR,HSTOR
      WMFLH3=WMFLH3
      WMFLO3=WMFLO3
      PINH=AMPRES+.5*AMDELP*1.01E5
      PINO=AMPRES-.5*AMDELP*1.01E5
      DENO=PINO/(260. *(273.15+TCOO))
      DENH=PINH/(4124.*(273.15+TCOH))
C  HYDROGEN DRYER CALCULATION-(PER DRYER)
      OMFLH=HIOMR*HMFL
      HMFLD=HMFL-0.1260*OMFLH
      WMFLH5=(1-HPUR)*HMFLD
      WMFLH4=WMFLH3-WMFLH5
      IF (WMFLH4.LT.0) WMFLH4=0
      DSMH= WMFLH4*DHCYC/(DSMWR*DHNO)
      VD= DSMH/DSDEN
      GVOL=GVOL+.25*VD*DHNO
      HMFLD= HMFLD - DSVOID*VD*DENH/DHCYC-WMFLH4*DRPURG
      ETAP=HMFLD/HMFL
      DDH=    (AINT(100*(2.*VD/(3.14159*DLDR))**.333))/100.
      IF (DDH.GT.0) GO TO 1
      DLH=0
      GO TO 2
1     DLH=2*VD/(3.14159*DDH**2)
2     DMM= 3.14159*DWDEN*DWTHK*(DLH*DDH+DDH**2)
      DPH=(DTCHG-TCOH)*(DWCP*DMN+DSCP*DSMH)/DHCYC
C  OXYGEN DRYER CALCULATION
      HMFLO= PMOD*(CI*AMCEL -EFFI)*OIMANCL*1.0447E-8
      OMFLD=OMFL-7.936*HMFLO
      WMFLO5=(1-OPUR)*OMFLD
      WMFLO4=WMFLO3-WMFLO5
```

```
      IF (WMFLO4.LT.0) WMFLO4=0
      DSMO= WMFLO4*DOCYC/(DSMWR*DONO)
      VD= DSMO/DSDEN
      GVOL=GVOL+.25*VD*DONO
      OMFLD =OMFLD- DSVOID*VD*DENO/DOCYC -WMFLO4*DRPURG
      DDO=    (AINT(100*(2.*VD/(3.14159*DLOR))**.333))/100.
      IF(DDO.GT.0) GO TO 3
      DLO=0
      GO TO 4
    3 DLO=2*VD/(3.14159*DDO**2)
    4 DMM= 3.14159*DWDEN*DWTHK*(DLO*DDO+DDO**2)
      DPO= (DTCHG-TCOO)*(DWCP*DMM+DSCP*DSMO)/DOCYC
C  NET POWER & MATERIAL REQUIREMENTS
      DPN= DPO*DONO+DPH*DHNO
C  COMPRESSOR CALCULATION -ASSUME ADIABATIC PROCESS,K=1.395
C  HYDROGEN
      POUT=PHS+1.015E5
      RAT=POUT/PINH
      HCPWR=0
      HCOMPS=4.
      IF(RAT.LE.RATCOMP**3.) HCOMPS=3.
      IF(RAT.LE.RATCOMP**2.) HCOMPS=2.
      IF(RAT.LE.RATCOMP    ) HCOMPS=1.
      IF(RAT.LE.1.         ) HCOMPS=0.
      IF(HCOMPS.EQ.0.) GO TO 5
      HCPWR=HCOMPS*HMFLD*4124.*(TCOH+273)*(RAT**(.283/HCOMPS)-1)/ETACOMP
C   OXYGEN
    5 POUT=POS+1.015E5
      RAT=POUT/PINO
      OCPWR=0.
      OCOMPS=4.
      IF (RAT.LE.RATCOMP**3.) OCOMPS=3.
      IF (RAT.LE.RATCOMP**2.) OCOMPS=2.
      IF (RAT.LE.RATCOMP    ) OCOMPS=1.
      IF (RAT.LE.1          ) OCOMPS=0.
      IF (OCOMPS.EQ.0 ) GO TO 6
      OCPWR=OCOMPS*OMFLD*260*(TCOO+273.)*(RAT**(.283/OCOMPS)-1.)/ETACOMP
C  STORAGE
    6 HSTOR = HMASR*4124*(PTAMB+273.)/(PHS+1.015E5)
      OSTOR=  OMASR*260 *(PTAMB+273.)/(POS+1.015E5)
```

```
      RETURN
      END
```

```
      SUBROUTINE ETANET
      COMMON/BLK1/X0(25),PCNTRL
      COMMON/BLK2/Y0,ACPWR,ETATOT,CV,BBV,BBC,Y6(22),WOUT,Y29(6),ETAR,
     2Y36(36),PIPA,PIPC,Y74(14),WPP,Y89(33),HMFLD,Y123(12),DPN,AUXPWR,
     3OCPWR,HCPWR,Y139(30)
      WOUT=HMFLD*1.418E8
      AUXPWR=PIPC+PIPA+WPP+DPN+OCPWR+HCPWR+PCNTRL
      ACPWR=BBC*BBV/ETAR +AUXPWR
      ETATOT=WOUT/ACPWR
      RETURN
      END
```

```
      FUNCTION DEN(T,C)
C     C= MASS FRACTION KOH, T= DEG. C ,DEN= DENSITY KOH,KG/M**3
      DEN=1004-.1179*T-3.221E-3*T**2+918.*C-1.944*C*T+.01430*C*T**2+
     2224.*C**2+.912*T*C**2-2.367E-2*C**2*T**2
      RETURN
      END
```

```
      FUNCTION CP(T,C)
C     T IN CELCIUS, C IN MASS FRACTION , CP IN JOULE/KG-C
      T1=T+273.15
      X=2.1397-9.68137E-3*T1+2.68536E-5*T1**2-2.42139E-8*T1**3
      Y= 2.921E-2+8.954E-1*C-1.62*ALOG10(C+0.25)
      CP=X*Y*4184
      RETURN
      END
```

```
      FUNCTION VIS(T,C)
C     T IN CELCIUS. C IN MASSFRACTION, VISCOSITY IN PASCAL-SEC.
      X=1./(T+273.15)
      VIS=-5.372+.6604*C+2.133*C**2+1256.*X-4.096E+5*X**2+7.185E7*X**3
      VIS=10.**VIS
      RETURN
      END
```

```
      SUBROUTINE LIFE(T1,AL1,T2,AL2,T,AL)
C CALCULATE A LIFETIME AT T(C) GIVEN LIFE AT T1 & T2- ARRHENHUS THEORY
      TA=1./(T1+273.15)
      TB=1./(T2+273.15)
      TC=1./(T +273.15)
      ALA= ALOG(AL1)
      ALB= ALOG(AL2)
      AL= ALA+(TC-TA)*(ALA-ALB)/(TA-TB)
      AL= EXP(AL)
      RETURN
      END
```

```
      SUPROUTINE OPCOST
C ESTIMATE 1ST YEAR OPERATING COST,INCL. MATERIALS, LABOR, OVERHEAD, G&A
C$    DEBUG
C$    STORES(CWCOS,FWCOS,AKOHCOS,APGCOS,AMATCOS,ALBRCOS,AOHCOS,
C$   &AGACOS,AOCOS,GARATE)
      COMMON/BLK1/X0(168),DF,X169(8),CWSPCOS,FWSPCOS,AMNTRT,PGSVCOS,
     2ALBRRT,OHRATE,GARATE,CPSPCOS,OPERTAU
      COMMON/BLK2/Y0,ACPWR,Y2(6),AOCOS,Y9,PLTCOSZ,Y11(69),FWMFL,Y81(6),
     2CWMFL,Y88(22),PKOH,Y111(5),GVOL,Y117(38),ACWCOS,AFWCOS,AMATCOS,
     3ALBRCOS,AGACOS,AOHCOS
C MATERIALS COST
      GARATE=GARATE
      ACWCOS=CWMFL*CWSPCOS*3.15576E7*DF
      AFWCOS=FWMFL*FWSPCOS*3.15576E7*DF
      AKOHCOS=PKOH*AMNTRT*CPSPCOS/0.45
      APGCOS= (365./OPERTAU)*5.*GVOL*PGSVCOS
      AMATCOS= 0.001*PLTCOSZ +APGCOS +AFWCOS +AKOHCOS +ACWCOS
C LABOR, OVERHEAD, G&A
      ALBRCOS=(0.25*ALOG10(ACPWR/1.E5))*ALBRRT
      AOHCOS= OHRATE*ALBRCOS
      AGACOS= GARATE*(AOHCOS+ALBRCOS+AMATCOS)
      AOCOS=AOHCOS+AGACOS+ALBRCOS+AMATCOS
      RETURN
      END
```

```
      SUBROUTINE MODCOST
C$    DEBUG
C CALCULATE THE ORIGINAL MODULE COST FOR ROUND OR RECTANGULAR MODULE
C  BASED ON OVERALL SIZES
      COMMON/BLK1/X(3),PLIFE,CAR,X5(25),AMSTY,EPSTY,X32(9),SLTHK,X42(6),
     2TRNO,X49(125),CRVRZ,ZRVY,X176(19),
     3PLASCST,CELPMLD,AMOPCST,FRPCEL,SLPCEL,SLMCOS,
     4SLPCOS,ANSCOS,ANCCOS,ANPRCOS,CASCOS,CACCOS,CAPRCOS,SEPSCOS,
     5SEPPCOS,BPTHK,BPDENS,BPMSCOS,BPPCOS,FMTHK,FMSPCOS,FMPCOS,EPMSCOS,
     6EPMFGCS,TRMCOS,TRPCOS,TRHCOS,X222(38),ASSYK1,ASSYK2
      COMMON/BLK2/Y0(11),AMLIFE,TMODCOS,Y13(18),PMOD,AMCEL,Y33(9),CFMAS,
     2CFVOD,CFHOD,Y45,CFSAR,TRLEN,TRDIAM,TRMAS,Y50,EPAR,Y52,EPMAS,Y5(8),
     3SEPCOST,BPCOST,FMCOST,OMODCOS,Y66(51),RMODCOS,Y119(43),
     4ANCOST,CACOST,CELCOST,EPCOST,TRCOST,AMLDCST,CFCOST,SLCOST,ASSYCOS
C CALCULATE CELL FRAME COSTS, (MCLDCST BASED ON HP&TO QUOTATIONS)
      AMLDCST=100000.*ALOG(4.19*CFSAR+1.38)
      CFCOST=CFMAS*PLASCST+AMLDCST/CELPMLD+AMOPCST*FRPCEL
C CALCULATE CELL SEAL COST
      SLCOST=SLPCEL*(SLMCOS*CFVOD*CFHOD+SLPCOS)
C CALCULATE CELL INTERNAL PARTS COST. UF=STOCK AREA/PART AREA
      UF=1.1
      IF (AMSTY.EQ.1.) UF=1.4
      ANCOST=ANSCOS*CAR*UF+ANCCOS*CAR+ANPRCOS
      CACOST=CASCOS*CAR*UF+CACCOS*CAR+CAPRCOS
      SEPCOST=SEPSCOS*CAR*UF+SEPPCOS
      BPCOST=BPTHK*CAR*UF*BPDENS*BPMSCOS+BPPCOS
      FMCOST=2.*FMTHK*CAR*UF*FMSPCOS+2.*FMPCOS
C SUM OF CELL PARTS COSTS
      CELCOST= CFCOST+SLCOST+ANCOST+CACOST+SEPCOST+BPCOST+FMCOST
C CALCULATE ENDPLATE COST
      EPCOST=2.*EPMAS    *EPMSCOS*EPMFGCS*EPAR
C CALCULATE TIEROD COST
      TRCOST=TRMAS*TRMCOS+TRPCOS+TRHCOS*TRDIAM
C ORIGINAL MODULE COST (PARTS PLUS ASSEMBLY)
      ASSYCOS=EPAR*(AMCEL*ASSYK1+ASSYK2)
      OMODCOS=CELCOST*AMCEL + TRCOST*TRNO + EPCOST + ASSYCOS
C REPLACEMENT MODULE COST CALCULATION
      R=AMLIFE/ZRVY
      IF (R.GE.1.) R=1.0
      RMODCOS = ASSYCOS*1.5 + AMCEL*CELCOST*(1.-CRVRZ*(1.-R))
```

```
C TOTAL LIFE MODULE COSTS
      ANORMOD= AINT(PLIFE/AMLIFE+0.5)-1.0
      TMODCOS = PMOD*(CMODCOS+ANORMOD*RMODCOS)
      RETURN
      END
```

```
      SUBROUTINE PLTCOST
C CALCULATE INDIVIDUAL SUBSYSTEM COSTS AND SUM FOR TOTAL
C$    DEBUG
C$    STORFS(PLTCOS)
      COMMON/BLK1/DCPWR,X1,PTMOD,X3(19),AMPRES,X23(2),PCNTRL,X26(63),
     2AFF,X90(6),CWT,X97,FWT,DPOL,X100(2),FPDPPD,X103,HXPDPFD,X105(4),
     3RESH,RESD,
     4ELPW,X112(6),OCHEF,HCHEF,X120(5),AMINST,AMINSK,X127,X128,RESINST,
     5RESINSK,UHXA,UHYC,X133(7),DONO,DHNO,X142(11),PHS,PCS,X155(72),
     6AMCF,CMCF,OMCF,HMCF,ELPBK1,ELPBK2,GSPBK1,GSPBK2,FILK1,FILK2,HXK1,
     7HXK2,PUMPK1,PUMPK2,RESK1,RESK2,RESK3,CONK1,CONK2,CONK3,AINSK1,
     8CWPBK1,FWPBK1,CNIK1,PURGK1,DRYK1,DRYK2,VENK1,STRTK1,COMK1,BOTK1,
     9PSK1,UNASK1
      COMMON/BLK2/Y0,ACPWR,Y2(8),PLTCOS,Y11(2),SAR,Y14(17),PMOD,
     1Y32(9) ,AMLEN,Y42,CFVOD,CFHCD,Y45(6),EPAR,Y52(14),DA,DC,ODA,ODC,
     2Y70(2),PIPA,PIPC,Y74(11),OCAR,HCAR,Y87(3),RLENA,RLENC,Y92(4),ALEN,
     3Y97(2),HXAAR,HXCAR,Y101(13),PAVFL,PCVFL,Y116(5),OMFLD,HMFLD,
     4Y123(2),WMFLO4,WMFLH4,
     5Y127(2),DOC,DOH,DLC,DLH,Y133(3),DSMN,Y137(2),OCOMPS,HCOMPS,OSTOR,
     6HSTOR,Y143(27),ANPBCOS,CAPBCOS,OYPBCOS,HYPBCOS,ANFLCOS,CAFLCOS,
     7ANHXCOS,CAHXCOS,ANPMCOS,CAPMCOS,ANRSCOS,CARSCOS,PURGCOS,OXCNCOS,
     8HYCNCOS,OXDRCOS,HYDRCOS,AINSCOS,CWPBCOS,FWPBCOS,VENTCOS,STRTCOS,
     9OXCMCOS,HYCMCOS,OXBTCOS,HYBTCOS,PSCOS,UNASCOS,CNINCOS
      ANPBCOS= ELPBK1*(ODA**2)*RLENA**ELPBK2*AMCF
      CAPBCOS= ELPBK1*(ODA**2)*RLENC**ELPBK2*CMCF
      OXPBCOS= GSPBK1*DCPWR**GSPBK2*CMCF
      HYPBCOS= GSPBK1*DCPWR**GSPBK2*HMCF
      ANFLCOS= FILK1*(PAVFL)**FILK2*AMCF
      CAFLCOS= FILK1*(PCVFL)**FILK2*CMCF
      ANHXCOS= HXK1*HXAAR**HXK2*AMCF
      CAHXCOS= HXK1*HXCAR**HXK2*CMCF
      ANPMCOS= PUMPK1*ALOG10(PIPA)*AMCF**.5
      CAPMCOS=0.
      IF(PIPC.EQ.0) GO TO 1
      CAPMCOS= PUMPK1*ALOG10(PIPC)*CMCF**.5
    1 ANRSCOS= RESK1*(RESH*RESD**2)**RESK2*AMCF**.5
      CARSCOS= RESK3
      IF(AFF.EQ.1) GO TO 2
      CARSCOS= RESK1*(RESH*RESD**2)**RESK2*CMCF**.5
    2 OXCNCOS= (CONK1*OCAR+CONK2*OMFLD)**CONK3*OMCF
```

```
      HYCNCOS= (CONK1*HCAR+CONK2*HMFLD)**CONK3*HMCF
      OXDRCOS= DRYK1*WMFLO4**DRYK2*OMCF
      HYDRCOS= DRYK1*WMFLH4**DRYK2*HMCF
      OXCMCOS= COMK1*OMFLD*OCOMPS*OMCF
      HYCMCOS= COMK1*HMFLD*HCOMPS*HMCF
      OXBTCOS= BOTK1*OSTOR*OMCF
      HYBTCOS= BOTK1*HSTOR*HMCF
      AINSCOS= AINSK1* (3.14*RESH*RESD+.5*3.14*RESD**2)*RESINST/AFF
     &        +AINSK1*PMOD*AMINST*(AMLEN*2.*(CFHOD+CFVOD)+2.*EPAR)
      CWPBCOS=CWPBK1
      FWPECOS= FWPEK1
      CNINCOS= CNIK1
      PURGCOS= PURGK1
      VENTCOS= VENK1*SAR
      STRTCOS=STRTK1*SAR
      PSCOS = PSK1*DCPWR
      PLTCOS= ANPBCOS+CAPBCOS+OXPBCOS+HYPBCOS+ANFLCOS+CAFLCOS+ANHXCOS
     &       +CAHXCOS+ANPMCOS+CAPMCOS+ANRSCOS+CARSCOS+OXCNCOS+HYCNCOS
     &       +AINSCOS+CWPBCOS+FWPECOS+CNIMCOS+PURGCOS+OXDRCOS+HYDRCOS
     &       +VENTCOS+STRTCOS+OXCMCOS+HYCMCOS+OXBTCOS+HYBTCOS+PSCOS
      UNASCOS=PLTCOS*UNASK1
      PLTCOS=PLTCOS+UNASCOS
      RETURN
      END
```

```
      SUBROUTINE CAPCOST
C ESTIMATE ORIGINAL COST TO BE CAPITALIZED
      COMMON/BLK1/X0(3),PLF,X4(170),CSVZ,ESVZ,X176(10),AINV,DNEK,
     2DNEFACT,GMARGC,AINSTK,GMARGI,BLK,FCLK,GMARGB
      COMMON/BLK2/Y0,ACPWR,Y2(4),CAPCOS,Y7(3),PLTCOSZ,AMLF,TMODCOS,SAR,
     2Y14(11),BLFCL,AINST,COMPCOS,Y28(3),PMOD,AMCEL,Y33(166),DNECOS
      SIZE=ACPWR**.25
      COMPCOS= PLTCOSZ*(1.+AINV)+TMODCOS
      DNECOS=DNEK*SIZE
      AINST=(AINSTK*SIZE)
      BLFCL=(BLK*SAR+FCLK*SIZE)
      CAPCOS= COMPCOS*(1.+GMARGC)+AINST*(1.+GMARGI)+BLFCL*(1.+GMARGB)
     &        +DNECOS/DNEFACT
      RETURN
      END
```

```
      SUBROUTINE GASCOST
C COST CALCULATIONS BASED ON EPRI  PS-866-SR
      REAL K1,K2
      COMMON/BLK1/X0(3),PLF,CAR,X5(155),CSR,PSR,CSCOS,PSCOS,DCOS,AINF,
     2PCOS,PCER,DF,TXR,TLR,TXCR,PTXIR,ACTTFLG,CSVZ,ESVZ,PSVZ
      COMMON/BLK2/ALGPRX,ACPWR,ETATOT,Y3(3),CAPCOS,APCOS,AOCOS,AGO,
     2Y10,AMLF,Y12(3),SPGPRX,RDISC,DP ,WCC,CRFB,ALATC,ALAPC,
     3ALAOC,ALACC,ALAFCR,Y25(6),PMOD,AMCEL,Y33(112),PCLF,
     4GINLF,SLDPR,ATDPR,PLFT,CRFT,ALAADA,ALAIT,ALAITCA,RDA
      DR=1.-CSR-PSR
      WCC=CSCOS*CSR+PSCOS*PSR+DCOS*DR
      RDISC=WCC
      CRFB=RDISC*(1.+RDISC)**PLF/((1.+RDISC)**PLF-1.)
      RDA=0.008775-1.05E-4*PLF
      IF(RDA.LT.0.0075) RDA=0.0075
C INCOME TAX CALCULATION
2     SLDPR=(1.-PSVZ/CAPCOS)/PLF
      ALAIT=(CRFB+RDA-SLDPR)*(1.-DR*DCOS/WCC)*TXR/(1.-TXR)
      PLFT=AINT(PLF*TLR+0.5)
      CRFT=RDISC*(1.+RDISC)**PLFT/((1.+RDISC)**PLFT-1.)
      ATDPR=2.*CRFB*(PLFT-1./CRFT)/(PLFT*(1.+PLFT)*WCC)
      AITCM=CAPCOS*TXCR
      AITC=25000.+(0.6*(AITCM-25000.))
      IF(AITCM.LT.25000.) AITC=AITCM
      IF (ACTTFLG.EQ.2.) GO TO 3
      ALAADA=(ATDPR-SLDPR)*TXR/(1.-TXR)
      ALAITCA=AITC*CRFB/((1.+RDISC)*CAPCOS)
      GO TO 4
3     ALAADA=(ATDPR-SLDPR)*TXR*(1.-TXR*DR*DCOS/WCC)/(1.-TXR)
      ALAITCA=(AITC*CRFB/((1.+RDISC)*CAPCOS))*(1.-DR*DCOS/WCC)
4     CONTINUE
C LEVELIZING FACTORS
      ALAFCR=CRFB+RDA+ALAIT-ALAITCA-ALAADA+PTXIR
      ALACC=ALAFCR*CAPCOS
      K1=(1.+AINF)/(1.+RDISC)
      GINLF=CRFB*K1*(1.-K1**PLF)/(1.-K1)
      ALAOC=AOCOS*GINLF
      K2=(1.+AINF)*(1.+PCER)/(1.+RDISC)
      PCLF= CRFB*K2*(1.-K2**PLF)/(1.-K2)
C GAS OUTPUT & PRICE  CALC
```

```
      APCOS=ACPWR*8.760*DF*PCOS
      ALAPC=APCOS*PCLF
      ALATC=ALACC+ALAPC+ALACC
      AGO=ACPWR*ETATOT*8760.*DF/39351.
      ALGPRX=ALATC/AGO
      SFGPRX=(ALACC+(ALAPC/PCLF)+(ALAOC/GINLF))/AGO
      RETURN
      END
```

```
      SUBROUTINE LPMOUT1
      COMMON/BLK1/PARAM(300)
      COMMON/BLK2/ESTOUT(200)
      COMMON/BLK3/PNAME(300),ENAME(200)
      COMMON/BLK7/MLOOP,DLOOP(15,2),MLOOP(15,3)
  101 FORMAT (18H1  LOOP PARAMETERS)
  102 FORMAT (60(3X,5(I3,1H., A7,1H=,1PG11.4,2X)/))
  103 FORMAT (20H0 OUTPUT PARAMETERS )
C MLOOP(X,1)=PARAM #
      PRINT 101
      DO 1 I=1,15
      IF(MLOOP(I,1).EQ.300) GO TO 1
      DO 1 I=1,15
      IF(MLOOP(I,1).EQ.300) GO TO 1
      PRINT 102, MLOOP(I,1),PNAME(MLOOP(I,1)),PARAM(MLOOP(I,1))
    1 CONTINUE
      PRINT 103
      PRINT 102,(I,ENAME(I),ESTOUT(I),I=1,200)
      RETURN
      END
```

```
      SUBROUTINE LIMOUT2(K)
      COMMON/BLK4/PMEM(15,31)
      COMMON/BLK3/PNAME(300),ENAME(200)
      COMMON/BLK7/NLOOP,DLOOP(15,2),MLOOP(15,3)
      J=16+K
      PRINT 100,K,MLOOP(K,1),PNAME(MLOOP(K,1)),PMEM(K,J)
100   FORMAT (19H0 OPTIMUM FOR LEVEL,I3,6H WITH ,I3,1H.,A7,1H=,1PG11.4)
      K1=K-1
      PRINT 101
101   FORMAT (26H    DOMAIN OF OPTIMIZATION:)
      IF (K1.EQ.0) GO TO 3
      DO 1 I=1,K1
      PRINT  102,MLOOP(I,1),PNAME(MLOOP(I,1)),DLOOP(I,1),DLOOP(I,2),
     &          MLOOP(I,2),PMEM(K,16+I)
102   FORMAT (3X,I3,1H.,A7,1H=,1PG11.4,4H TO ,1PG11.4,4H IN ,I5,
     &        19H STEPS, OPTIMUM AT ,1PG11.4)
1     CONTINUE
3     K1=K+1
      IF (K1.EQ.16) GO TO 4
      DO 2 I=K1,15
      J=16+I
      IF (MLOOP(I,1).EQ.300) GO TO 2
      PRINT 103,MLOOP(I,1),PNAME(MLOOP(I,1)),PMEM(K,J)
103   FORMAT (3X,I3,1H.,A7,1H=,1PG11.4)
2     CONTINUE
4     PRINT 104
104   FORMAT (18H    OPTIMUM RESULTS)
      PRINT 105,(I,ENAME(I),PMEM(K,I),I=1,16)
105   FORMAT (10(3X,5(I3,1H.,A7,1H= ,1PG11.4,2X)/))
      RETURN
      END
```