N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED IN THE INTEREST OF MAKING AVAILABLE AS MUCH INFORMATION AS POSSIBLE

DOE/NASA/0241-1
NASA CR- 165328

DEVELOP AND TEST FUEL CELL POWERED
ON-SITE INTEGRATED TOTAL ENERGY SYSTEMS:
PHASE III, FULL-SCALE POWER PLANT DEVELOPMENT

1ST QUARTERLY REPORT: FEBRUARY - APRIL, 1981

ENGELHARD INDUSTRIES DIVISION
ENGELHARD CORPORATION
EDISON, NJ 08818
A. Kaufman, Contract Manager
G. K. Johnson, Contract Technical Coordinator

REPORT DATE: June 24, 1981

DOE/NASA/0241-1
NASA CR- 165328

DEVELOP AND TEST FUEL CELL POWERED
ON-SITE INTEGRATED TOTAL ENERGY SYSTEMS:
PHASE III, FULL-SCALE POWER PLANT DEVELOPMENT

1ST QUARTERLY REPORT: FEBRUARY - APRIL, 1981

ENGELHARD INDUSTRIES DIVISION
ENGELHARD CORPORATION
EDISON, NJ 08818
A. Kaufman, Contract Manager
G. K. Johnson, Contract Technical Coordinator

REPORT DATE: June 24, 1981

SECTION I. INTRODUCTION

Engelhard's objective under the present contract is to contribute substantially to the national fuel conservation program by developing a commercially viable and cost-effective phosphoric acid fuel cell powered on-site integrated energy system (OS/IES). The fuel cell offers energy efficiencies in the range of 35-40% of the higher heating value of available fuels in the form of electrical energy. By utilizing the thermal energy generated for heating, ventilating and air-conditioning (HVAC), a fuel cell OS/IES could provide total energy efficiencies in the neighborhood of 80%. Also, the Engelhard fuel cell OS/IES which is the objective of the present program offers the important incentive of replacing imported oil with domestically produced methanol, including coal-derived methanol.

Engelhard has successfully completed the first two phases of a five-phase program. The next three phases entail an integration of the fuel cell system into a total energy system for multi-family residential and commercial buildings. The mandate of Phase III is to develop a full scale 50kW breadboard power plant module and to identify a suitable type of application site. Toward this end, an initial objective in Phase III is to complete the integration and testing of the 5kW system whose components were developed during Phase II. Following the test of this sub-scale system, expected in August 1981, scale-up activities will be implemented as a total effort. Throughout this design and engineering program continuing technology support activity will be maintained to assure that performance, reliability, and cost objectives are attained.

SECTION II. TECHNICAL PROGRESS SUMMARY

TASK I - 5kW POWER SYSTEM DEVELOPMENT (97046)

This task is of limited duration (approximately six months) and has as its objective the complete integration of 5kW components developed during Phase II. This integrated 5kW system will be automated under microprocessor control.

REFORMER

For general reference a schematic of the reformer is shown in Figure 1 and the locations of thermocouples in the unit are shown in Figure 2.

A process variable study was carried out as part of the evaluation of the 5kW reformer. The main purpose of this exercise was to gain information necessary to design microprocessor-controller software for the integrated system. Variable loads were controlled by means of adjustments to the reformer feed rate (methanol/water mix) and were selected at 70%, 50% and 25% of design load. At each change of load, the fuel to the burner was adjusted to sustain complete methanol conversion in accordance with steady-state relationships established earlier. The response monitored included fractional conversion of methanol, CO content, and catalyst bed temperature profiles. The results of this 58-hour test are plotted in Figures 3 and 4.

Decrease in reformer load (via changes in reformer feed rate; see Figure 3) resulted in essentially constant methanol conversion ($\sim$99.5%) as shown by specific gravity measurements. The reformer inlet temperature required for this conversion level decreased from 672 K (399°C) at 70% load to 611 K (338°C) at 25% load. However, it is apparent from Figures 3 and 4 that the lower temperatures

SECTION II. - CONTINUED

required at 25% load result in a small, temporar, loss of
methanol conversion efficiency upon a sudden load increase to 70%.
Practically speaking, this does not seriously reduce the availability
of hydrogen to the stack.

There was a minor effect at constant load due to changes in
burner air/fuel ratio, which was varied from 1.0 to 1.50. At about
52 hours into the run, the fuel cell reactant air to the preheat
coil (lower coil in Figure 2) was increased from a very low arbitrary
value (2.83 m^3/hr) to its nominal value at 70% load (17.8 m^3/hr).
This caused the rapid drop in temperature noted, requiring increased
fuel and air flow to the burner. (This preheat coil will be removed
from the reformer - see Figure 7 - and its function will be served
by a cathode air preheat exchanger.) For the purposes of this test,
the adjustments were made manually.

The response time for step changes in operating parameters
is seen in Figure 3. It took approximately three hours for initial
attainment of 99.5% methanol conversior. Sudden disturbances (major
changes in load and fuel cell reactant air flow) lead to similar
response times. In a complete operating system, control measures
would be taken to speed up response if necessary for better system
operation.

The carbon monoxide level was constant ($\sim$2.5%) during the run
except at very low load due to the low space velocity and consequent
establishment of equilibrium conditions. At 52 hours the CO content
was very low (0.5%) due to low temperature. The response time for
CO content essentially follows the temperature (see Figures 3 and 4).

The temperature profile along the catalyst tubes of the 5kW
reformer under full load operation is shown in Figure 5. Two runs

SECTION II. - CONTINUED

are shown: one at a lower burner fuel flow rate and one at a higher rate required due to air flow through the fuel cell cathode air preheat coil.

The upturn in temperature through the exit portions of the tubes (Figure 5) is due to heat transfer from the combustion chamber to adjacent regions of the catalyst. This raises the process gas temperature above its minimum in the unit and serves to increase the CO content in the exit gas by means of the reverse shift reaction. Better thermal isolation between the burner section and the reactor tubes will be accomplished by some minor modifications (see Figure 6 for the original configuration and Figure 7 for the intended modifications):

1) More insulation in the burner section.

2) A smaller diameter tube to be inserted in the bottom half of the central duct and insulation to be placed in the annulus of this section.

3) Catalyst to be removed from the exit gas manifold, which is adjacent to the combustion chamber.

4) Cathode air preheat coil to be removed.

Modifications of the above types were recently made on an Engelhard-sponsored 5kW reformer of a design similar to this unit and proved to be effective in reducing the reheating effect.

A modified Beckett home heating oil burner is being utilized in the base of the 5kW reformer. The burner combusts methanol during start-up as well as anode vent gas to supply heat to drive

SECTION II. - CONTINUED

the methanol/steam reforming reaction in the catalyst tubes during steady-state operation (see Figure 1). The burner is capable of burning both fuels simultaneously if necessary. Previously, separate start-up and steady-state burners were used for reformer test purposes; the dual-fuel Beckett burner represents the desired configuration. Burner operation was evaluated in a reformer run, and performance was entirely satisfactory with respect to design expectations.

In a further step of integration the microprocessor unit, which will eventually control the operation of the entire 5kW integrated system, was used to control temperature in the reformer during operation. This test was set up to debug any hardware or software problems with the microprocessor in a real environment. The duration of the test was three hours, during which the micro-processor controlled reformer catalyst temperature by on/off combustion of methanol in the Beckett burner. Thermocouple 2R (Figure 2) was used as the sensor for this control. At the same time, the microprocessor performed safety checks for confirmation of combustion and proper blower operation. Temperatures within the catalyst bed remained within the designed $\pm$ 5 K control band throughout the test. Eventually the temperature control points set by the microprocessor will be responsive to the varying flow rates of $MeOH/H_2O$ process gas sent to the reformer according to load conditions of the system.

A first approximation has been obtained to the concentration profiles through the catalyst bed of the 5kW reformer. The reformer was fitted with sampling probes at several points along the length of one of the catalyst tubes. The material sampled at the various locations was cooled in 3 mm copper tubing and then completely condensed in a sample tube immersed in an ice bath. The condensate

SECTION II. - CONTINUED

was collected and analyzed by gas chromatography for methanol and water. The gas was analyzed on-line for H_2, CO_2, CO and methanol vapor. The run conditions at the time of sampling are listed in Table I. The unit was operating at about 70% of the design full load rate. At the time of sampling the temperature at the top (inlet) of the catalyst column was 590 K, at the tube midpoint 516 K, and at the exit 561 K.

The results of the gas phase analysis are listed in Table II; each component is listed as the percentage area of its GC peak with respect to the total area of all four peaks. Only CO has been absolutely calibrated so far. As shown in Table II, the CO level rises rapidly near the exit as the temperature rises and methanol concentration drops.

Good calibration curves exist for the liquid samples, the results for which are listed in Table III. Assuming that all of the unreacted methanol and water ends up in the condensate, the extent of methanol conversion can be related to methanol concentration in the condensate. For the particular H_2O/CH_3OH ratio employed, the relationship is:

$$\text{Fraction converted} = (5863.3-99.85C)/(5863.3-91.57C)$$

where C is the weight percentage of methanol in the condensate. The conversion data in the right-hand column of Table III were generated from this relationship.

As expected, the gas phase analysis is insensitive to conversion. It is not possible to close a material balance at each location because of the low flow rates. The liquid samples that were collected,

SECTION II. - CONTINUED

however, do provide a measure of the conversion through the catalyst bed. Refinements of this type of analysis will be applied to the single-tube reactor studies under Task III.

FUEL CELL STACK

A production problem has been encountered in the fabrication of a new type of unitized ABA bipolar plate for the 5kW stack. It is anticipated that this difficulty will be resolved soon; however, a back-up method of fabrication using conventional, bonded B-elements is available if needed. All other components for this stack are in hand. Significant design features of this stack are as follows:

Electrodes: 10% Pt on carbon cathode catalyst of the stabilized-support/stabilized-Pt type. Teflon content 50%. 10% Pt on carbon anode catalyst of the baseline type. Teflon content 45%. Nominal loading 0.46 mg Pt/cm^2 each electrode.

Matrix: Silicon carbide filler, TFE-30 binder; applied by blade-coating. Novel acid-management configuration.

Bipolar plates: Grooved ABA type. New unitized construction based on needled-felt A-elements. Novel edge-sealing method.

Cooling plates: Aluminum, spiral-flow type with new corrosion-protection feature. Placed in the stack at four-cell intervals.

SECTION II. - CONTINUED

Coolant: Therminol 66, replacing previously used
Therminol 44. (Therminol 66 has better high temperature
stability and higher permissible film temperatures.)
Distribution via channeling in end-plates interconnected
to cooling-plate bosses with fiberglass-braided Teflon
tubing.

Reactant manifolds: Aluminum box-type construction with
angle-seal gasket at vertical edges of hydrogen manifolds.
Insides of manifolds coated with liquid Viton for corrosion
protection.

Acid management: New, semi-automated system will be
retrofitted after stack is constructed.

INTEGRATED SYSTEM

The combination of a 72-cell 5kW stack (constructed under
Engelhard sponsorship), a 5kW methanol reformer (constructed under
this contract) and a DC-to-AC inverter was tested successfully in
a brief laboratory demonstration. Power generated was used to
operate building lighting during the period of the demonstration.
The current-voltage curves and the current-power curves of the
fuel cell stack are given in Figure 8. Performances both on
hydrogen (upper curves) and on reformate (lower curves) are shown.
When the stack was run on reformate, approximately 70% hydrogen
utilization was employed at 161 mA/cm^2 (150 A/ft^2).

The average reformate composition (dry basis) from the reformer
was 74% H_2, 24% CO_2 and 2% CO. The composition on a wet basis
is given in Figure 8. Complete methanol conversion in the

SECTION II. - CONTINUED

reformer was achieved at 523-533 K (250-260°C) at a weight-
hourly-space-velocity (WHSV) of about 0.5 kg CH_3OH/hr-kg catalyst.
The reforming catalyst was T2107RS from United Catalysts, Inc.

A preliminary schematic of the 5kW integrated system is
given in Figure 9. All ancillary components for this system
have been selected and received with the exception of the cathode
air preheat exchanger and the cell module voltage scanner.
Control software development is scheduled to be complete at the
end of June. The reformer unit will be ready after minor
modifications as described above. The construction of the stack
awaits only the completion of ABA bipolar plates as also described
above. The assembly of this system is scheduled for early August
with completed testing by early September.

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS

Sub-contract arrangements for work on this task have been
completed with Arthur D. Little, Inc. The subcontractor's progress
will be reported in the present sequence of Monthly Narratives and
Quarterly Reports.

TASK III - ON-SITE SYSTEM DEVELOPMENT

25kW STACK DESIGN

The preliminary design has been completed for the 25kW
stack and is shown in Figure 10 (manifolds in place) and Figure 11
(manifolds removed). The significant features of this design are:

SECTION II. - CONTINUED

- Carbon steel construction of manifolds, hold-down bars, tie-rods and end-plates.

- Independently sealed hydrogen and air manifolds.

- Gusset-type reactant manifold hold-down.

- Coolant manifolding external to reactant gas manifolds (see Figure 12).

- Ready access to air inlet and exit sections for implementation and maintenance of acid-management system.

- Adaptable to modular grouping of stacks.

- Low-cost, lightweight stack compressive loading.

- Stack compression follow-up via hold-down bars.

50kW FUEL PROCESSOR DESIGN

Apparatus is being designed for single-tube methanol/steam reforming analytical studies. This test arrangement will be electrically heated and the diameter of the catalytic reactor tube will be variable. Provisions will be made for the evaluation of radial, as well as axial, temperature profiles. Experimental information will be coupled with a two-dimensional mathematical reformer model currently being developed. Design information obtained from the combination of the model and the single-tube experiments will be used to develop prototype-size, flue-gas heated single-tube reactors, the first of which is scheduled to be tested in February 1982. The overall objective of this sequence is to design a 50kW reactor with optimized tube diameter and length, number of tubes and total volume.

SECTION II. - CONTINUED

OVERALL SYSTEM ANALYSIS

The major objective of this sub-task is to maximize overall fuel utilization and to minimize installed cost for the on-site, integrated energy system. To accomplish part of this objective, a computer model is being developed under subcontract with Physical Sciences, Inc. that will permit various alternatives to be evaluated.

A key element in powerplant design is the consideration of operations at off-design conditions. The full load, steady state conditions will be used to establish the size of the various components: reformer, blowers, pumps, heat exchangers, and fuel cell area. At part load, or off-design conditions, the unmodified unit could be inoperable or highly inefficient. In particular, some by-pass may be required around heat exchangers to maintain operations. Off-design analysis is an extension of the steady-state model developed by PSI under the previous contract.

Current work involves three areas of the subcontract: system or computer related items, revisions and improvements to the original steady-state program, and development of the off-design analysis.

Because it is a high-level language, BASIC is preferred for program development. At PSI this is done on micro-computers such as the TRS-80. Engelhard has a DEC 11/34 which uses FORTRAN listings. A TRS-80 program was purchased to convert BASIC to FORTRAN with minor programming time. Also, a program was developed to transmit listings between computers. This will save time and reduce errors.

SECTION II. - CONTINUED

Another effort in improving the program is the
development of reliable convergence routines. In off-design
analysis, equations of higher order must be solved to determine
the component output. For example, once the fuel cell area is
fixed, the performance equations (voltage versus current per unit
area) must be solved for voltage. A routine called Box's algorithm
has been developed to serve as part of a multi-dimensional conver-
gence routine in conjunction with the SECANT module used previously.

Improvements and modifications have been made to
existing modules. The methanol/water system is non-ideal; i.e., it
does not follow Raoult's Law. Existing literature data, which are
limited to atmospheric pressure, have been fitted to an expression
called the Four-Suffix Margules equation. Considerable error in
vaporizer design could occur without this modification. The fuel
cell performance equations that reflect Engelhard's most recent
catalyst developments have been incorporated in the modules called
the Fuel Cell Library.

WASTE HEAT UTILIZATION (HVAC)

The conclusions have been reviewed from a study* by
Arthur D. Little, Inc. on heating/ventilating/air-conditioning
(HVAC) applications of a 700-1000 kW air-cooled fuel cell delivering
heat at 389 K (240°F). These conclusions are that the outlook for
utilization of waste heat for wintertime heating is optimistic; but
not so for air-conditioning by means of an absorption chiller during
the summer. A number of changes from the assumptions used, such as

---

* "Study of Component Technologies for Fuel Cell On-Site Integrated
   Energy Systems", Final Report, December, 1980, by W. D. Lee and
   S. Mathias, A. D. Little, Inc. for NASA Contract DEN3-121.

SECTION II. - CONTINUED

a higher waste heat delivery temperature (as would be available from
a liquid-cooled fuel cell) and a lower condenser temperature (as
derivable from day-night thermal storage), could make air-conditioning
more attractive for the fuel cell system. Thermal storage features
that could improve system utility are being investigated. A promising
alternative scheme for the utilization of waste heat for air-conditioning
is in the design phase.

TASK IV - STACK SUPPORT

ANODE CATALYST

A developmental bimetallic anode catalyst formulation directed
toward improved CO-tolerance was tested in a single-cell at 464 K (191°C).
Under standard load (161 mA/cm^2, 150 A/ft^2) the cell voltage was steady
at 608 mV over a 350-hour test period on simulated reformate gas con-
taining 2% CO. This result will be followed up with longer-term testing.

The advantages to be gained with this type of catalyst are
shown in Figure 13, which compares a previous preparation of the same
catalyst with a standard catalyst in the presence of 1% CO. The duration
of that test was >1000 hours.

CATHODE CATALYST

An advanced cathode catalyst has been formulated which is
of the stabilized-support/stabilized-Pt type. The retention of
precious metal surface area of this catalyst in hot phosphoric acid
has been evaluated (upper curve, Figure 14). This test was conducted
for 500 hours at 477 K (204°C) and at a constant polarization of
700 mV vs. the reversible hydrogen electrode (RHE). Periodically

SECTION II. - CONTINUED

samples were removed and the active surface areas were measured by
cyclic voltammetry using the areas under the hydrogen adsorption
peaks. Comparison with the other curves of Figure 14 shows the
retention of active area in this advanced catalyst is superior to
that of Engelhard's standard cathode catalyst.

The advanced catalyst was fabricated into an electrode
with an active area of 76 x 76 mm (3" square) and tested for over
500 hours in a single-cell. This test was started at 436 K (163°C);
after a few days the temperature was increased to 464 K (191°C).
The open-circuit voltage stability of this cell on H_2/air is shown
in Figure 15. The voltage at 161 mA/cm^2 (150 A/ft^2) is shown for
both H_2/O_2 and H_2/air in Figure 16. The measured voltage averaged
about 665 mV on air during the latter part of the run, which is a
relatively high performance. The equivalent IR-free voltage is
695 mV. In this case, therefore, retention of high precious metal
area is correlated with superior cell performance. The voltage/
current and power/current curves on h_2/air after 400 hours of
operation are shown in Figure 17. The power curve is substantially
linear to quite high current densities, indicating attractive
capabilities in terms of higher current-density operation.

ELECTRODE SCALE-UP

Single-cell tests have been completed on six 76 x 76 mm
(3" square) sections of a scaled-up anode and cathode of full size
(0.33 x 0.56 m, 13 x 22 inches) with matrix applied. (The electrodes
previously fabricated in this program were 0.28 x 0.36 m (11 x 14
inches). A diagram of the locations of the samples is shown in
Figure 18. The open-circuit voltages and the load voltages of

SECTION II. - CONTINUED

these cells after 24 hours of operation are given in Table IV. The
IR-free voltages at 436 K (163°C) and standard current-density
(161 mA/cm^2, 150 A/ft^2) range from 660 mV to 680 mV. These results
are average to good when compared with general testing of previous,
smaller electrodes. On this basis the scale-up is considered successful.

COOLANT TUBING

Convoluted Teflon tubing reinforced with an external
stainless steel spiral appears promising for stack coolant dis-
tribution. It is both more flexible and cheaper than the fiberglass
braid-reinforced tubing used to-date. The new tubing has been sealed
to fittings successfully with commercial crimped rings. It has
performed successfully in extended bench testing in a Therminol
loop at 455 K (182°C). This tubing will now be used on large
stacks constructed in this program. In these applications the
stainless steel reinforcing spiral will not be in contact with
phosphoric acid mist.

COOLING PLATES

A new corrosion protection feature was successfully
tested on the cooling plates of a 10-cell sub-stack built under
Phase II. These plates saw over 1000 hours of service, mostly
at 477 K (204°C). Upon disassembly of the stack the protected
cooling plate surfaces were in excellent condition.

SECTION II. - CONTINUED

ACID MANAGEMENT

A new system is under development for the semi-automatic replenishment of phosphoric acid in working stacks. Preliminary test results on two 3-cell stacks have been quite promising. The performance of the stack tested longest (2000 hours to date) is shown in Figures 19 and 20. The active area of each cell is 0.178 x 0.272 m (7.0 x 10.7 in) and the operating temperature on H_2/air is 464 K (191°C). The steady open-circuit behavior (Figure 19) indicates that acid management has been very successful. The voltage at standard load current (161 mA/cm^2, 150 A/ft^2, Figure 20) shows a decline beginning at about 800 hours which was coincident with a laboratory power shut-down. This caused a severe temperature loss and excessive accumulation of water within the cells including areas nominally wet-proofed. The decline has been partially reversed by lowering the moisture content of the fuel gas. Testing of this stack will proceed as long as useful information on acid management continues to be obtained. This kind of accident would not be possible in a commercial unit because a load would not be permitted if stack temperature declined below a certain value.

Designs for versions of the semi-automatic acid-replenishment system suitable for 12-cell and 5kW stacks are being developed. Objectives for the acid management system include the following:

- Replenishment of acid lost during normal fuel cell operation.

- No interference with normal electrode operation.

SECTION II. - CONTINUED

- No acid-bridging between cells (no shunt currents and no differential hydrostatic pressure).

- Replenishment rate determined by demand.

- Facilitated transport of acid to all regions of the matrix.

TASK V - FUEL PROCESSING SUPPORT

A qualifying test for the bulk lot of methanol/steam reforming catalyst T2107RS as 3 mm (1/8") tablets was begun in the sub-scale reformer test apparatus. It was found that the catalyst was being contaminated by grease from the rebuilt feed pump. The situation was corrected and the run was restarted. Results will be reported in the May Monthly.

TASK VI - IMPROVED ELECTROCATALYSTS

Developmental electrocatalyst formulations are being prepared under Engelhard sponsorship. These are provided to the main program, and results have been reported under Task IV.

SECTION III. CURRENT PROBLEMS

In the fabrication of ABA bipolar plates of the new, unitized construction a problem of warpage has been encountered when the plates are grooved. Several approaches are being pursued for the solution of this problem. A back-up method of production based upon previously proven technology will be implemented if necessary.

In the context of system mathematical modelling it was found that explicit solutions could not be obtained in the off-design analysis of heat exchanger equations. Therefore, the outlet conditions from heat exchangers must be solved by iteration using convergence routines.

Data on the vapor pressure of methanol/water mixtures at higher pressures are lacking. The limited data available are old. A computer search of the literature of recent years failed to reveal new data. It may be desirable to obtain these data experimentally using our gas chromatograph for compositional analysis.

Neither of these modelling problems is associated with a critical path activity.

ENGELHARD

SECTION IV. WORK PLANNED

TASK I

- Continue efforts to improve ABA plate fabrication. Arrange back-up production method.

- Complete modifications to 5kW reformer.

- Continue software documentation for 5kW system control by microprocessor.

- Complete acquisition of ancillaries for 5kW system.

TASK II

- Arthur D. Little, Inc. to begin application analysis under subcontract.

TASK III

- Design single-tube reformer test station and apparatus.

- Begin detailed component design for waste-heat air-conditioning system.

ENGELHARD

SECTION IV. - CONTINUED

TASK IV

- Continue long-term test of 3-cell stack with semi-automatic acid-replenishment system.

- Assemble and test 3-cell stack with improved Engelhard catalysts.

TASK V

- Restart sub-scale qualifying test on T2107RS methanol/steam reforming catalyst.

SECTION V. FINANCIAL MANAGEMENT ANALYSIS

TASK I - 5kW POWER SYSTEM DEVELOPMENT

Manpower expenditures for this task through April were
very close to the projected level. However, the control system
development expenditures (which pertain both to this task and to
the full-size system) were charged to Task III, Sub-Task 4 (see
below). The most intensive effort was related to bringing the
bipolar plates into readiness for the 5kW stack. Materials
expenditures are well above the pro-rate level because the majority
of costs associated with bipolar plate fabrication have already
been incurred. Also, incremental bipolar plate costs have been
borne in bringing the needled-felt material into readiness for
this stack in place of the reticulated vitreous carbon.

Preparations for the balance of the system are proceeding
according to plan. Barring unusual difficulties from this point on,
the overall schedule for this task is essentially intact.

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS

The Task II effort will be performed under a subcontract
to Arthur D. Little, Inc. The Engelhard role will consist almost
entirely of guidance and supervision. The subcontract has not yet
been issued, and work under this task has therefore not been
initiated.

The subcontract is planned to be a 12-month effort, and
it will provide important perspective in terms of system configuration
and optimization under Task III. Every effort will be made to extract
information relating to selection of an application type as early as
possible.

TASK III - ON-SITE SYSTEM DEVELOPMENT

1. Large Stack Development

Effort on this sub-task has consisted of continuation of the 25kW stack design effort. Manpower expenditures through April were about 50% of the anticipated level. This was primarily due to concentration of specific manpower on Task I. Nevertheless, the preliminary 25kW stack design is in-place, and the schedule for detailed design specification is expected to be met.

2. Large Fuel Processor Development

Work on this sub-task has been delayed due to the intensity of effort on the 5kW fuel processing sub-system. Planned activity includes the design and setting up of single-tube reactors. Materials expenditures are in excess of the pro-rated budget because of the purchase of large batches of two candidate catalysts.

3. System Analysis

Minor in-house expenditures were planned for this sub-task through April. The main effort is being pursued through the PSI subcontract, in which the progress and expenditures are proceeding according to plan.

4. System Integration

Effort on this sub-task is proceeding at a rate well above the budgeted rate for the first few months of the contract. This activity is being concentrated in the HVAC sub-system area in order to lay the groundwork for anticipated subcontract effort, as well as on micro-processor development work for the control system. Establishment of design specifications and cost criteria for the 50kW power conditioner is scheduled to begin in July.

TASK IV - STACK SUPPORT

During April the stack support effort continued to focus on acid-management schemes and evaluation of developmental cathode catalysts. Two three-cell stacks devoted to acid-management studies were operated throughout the month.

Manpower expenditures through April were about one-third below the planned level, primarily due to concentrated effort on Task I. The Pfizer subcontract for bipolar plate scale-up and cost-reduction development has not yet been issued. Materials expenditures are somewhat low thus far, reflecting for the most part a lag in invoicing.

TASK V - FUEL PROCESSING SUPPORT

Sub-scale fuel processing support testing is proceeding. The initial activity in this area concerns qualification of large batches of catalyst that have been received for use during the Phase III program. Manpower expenditures are below planned levels due to emphasis on Task I.

TASK VI - IMPROVED ELECTROCATALYSTS

The development of advanced anode and cathode catalysts is proceeding under Engelhard sponsorship. Evaluation of these catalysts is accomplished under Task IV.

TASK VII - MANAGEMENT AND DOCUMENTATION

Expenditures in the management and documentation area are proceeding substantially according to plan.

TABLE I

5kW REFORMER RUN CONDITIONS

Feedstock	1.3 H_2O/MeOH (Sp. Gr. = 0.893/294 K)
Feed Rate	0.00385 m^3/hr (70% of Full Load)
Fuel to Beckett Burner	2.83 m^3/hr of Simulated Anode Vent Gas: 39% H_2, 5% CO, 56% CO_2
Air to Beckett Burner	~3.5 m^3/hr
Product Gas	5.75 m^3/hr
Exit Condensate Density	0.994 @ 281 K

TABLE II

GAS PHASE ANALYSIS - 5kW REFORMER RUN

SAMPLE LOCATION	GC RESULTS, AREA %			
	H_2	CO_2	CO	CH_3OH
Inlet of Tube, near	6.00	86.02	2.18[a]	5.80
Thermocouple KS-1	5.99	85.71	2.18	6.12
Middle of Tube, near	5.78	86.36	2.80[b]	5.06
Thermocouple KS-3	5.82	86.54	2.67	4.98
	5.80	86.52	2.67	5.00
Reactor Exit, near	5.84	85.23	8.55[c]	0.39
Thermocouple 13R	5.86	85.65	8.20	0.28
	5.85	85.14	8.78	0.23

a = 0.29% CO by volume
b = 0.49% " " "
c = 2.25% " " "

(For thermocouple locations refer to Figure 2.)

TABLE III

CONDENSATE ANALYSIS - 5kW REFORMER

SAMPLE LOCATION	SPECIFIC GRAVITY	CH_3OH Wt. %	CH_3OH Conversion, %
Feed	0.893	58.71	0
Inlet of Tube, near Thermocouple KS-1	-	56.98	27
Middle of Tube, near Thermocouple KS-3	-	50.91	65
Reactor Exit, near Thermocouple 13R	0.994	2.01	99.7

(For thermocouple locations refer to Figure 2.)

ENGELHARD

TABLE IV

FUEL CELL TEST RESULTS OF SCALED-UP ELECTRODES,
0.33 x 0.56 m.   DATA TAKEN AFTER 24 HOURS.

Sample No.	Run No.	V* (IR-Free) At 161 mA/cm^2	Open Circuit Voltage
1	827	0.680 V	0.901 V
2	829	0.660 V	0.886 V
3	830	0.666 V	0.860 V
4	831	0.674 V	0.898 V
5	828	0.661 V	0.894 V
6	832	0.663 V	0.925 V

* Cell-Voltage at 436 K (163°C) on H_2/Air reactants.
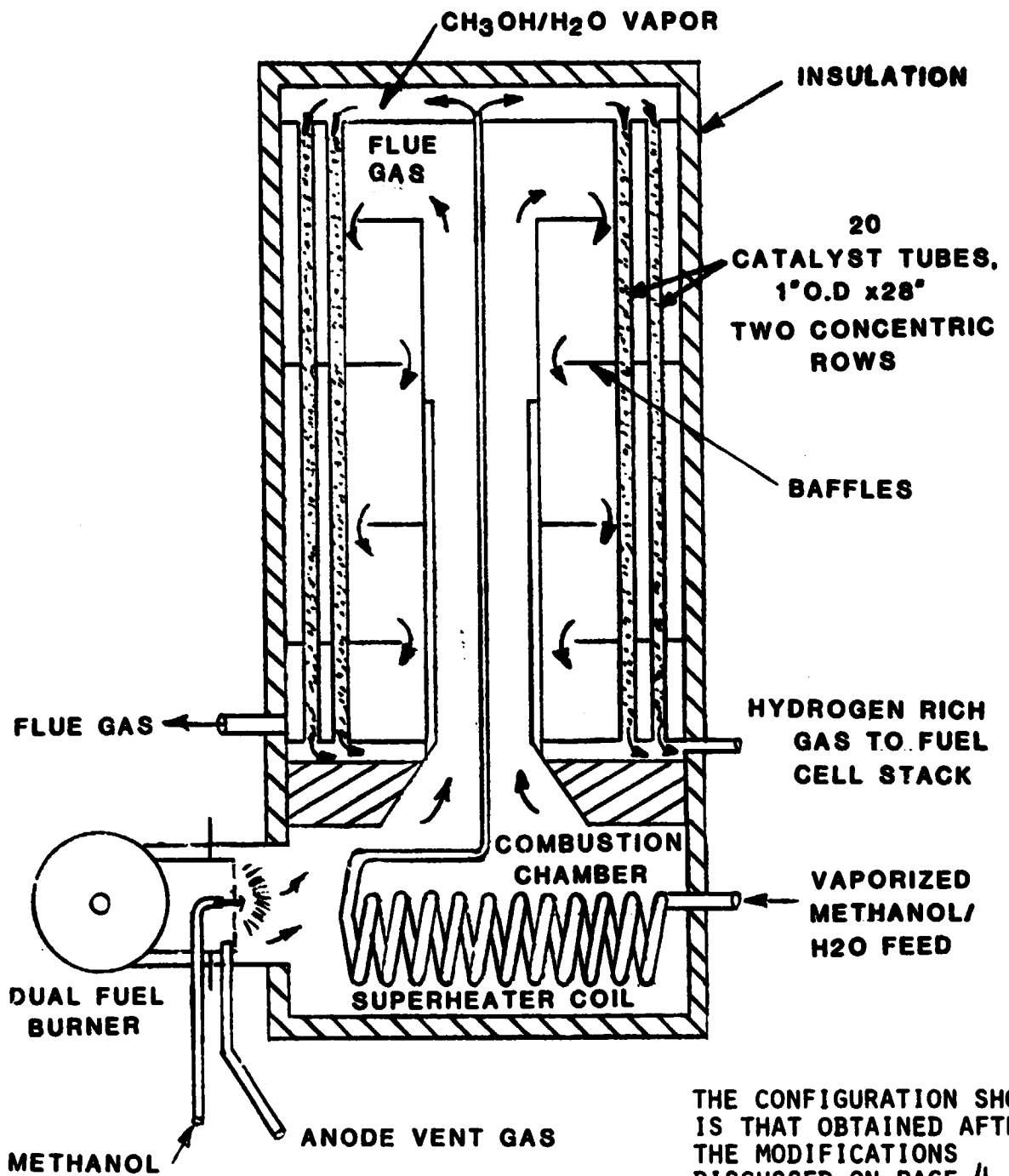
FIGURE 1   NASA 5KW METHANOL STEAM REFORMER

FLUE GAS

23R

FUEL CELL
· AIR

FUEL
BURNER

AIR

18SS
19SS
20SS
21SS
22SS

2R

4   2   1   3

6KS 1KS   3R   8R
7KS 2KS   4R   9R
8KS 3KS   5R   10R
9KS 4KS   6R   11R
10KS 5KS   7R   12R

16R

15R

TC 17R
18R
19R
20R
21R
22R

13R   PROCESS STREAM OUT
TC 16R

PROCESS STREAM IN
1R

TO FUEL CELL
24R

NOT TO SCALE

TUBE 1

TUBE 4

TUBE 3

TUBE 2
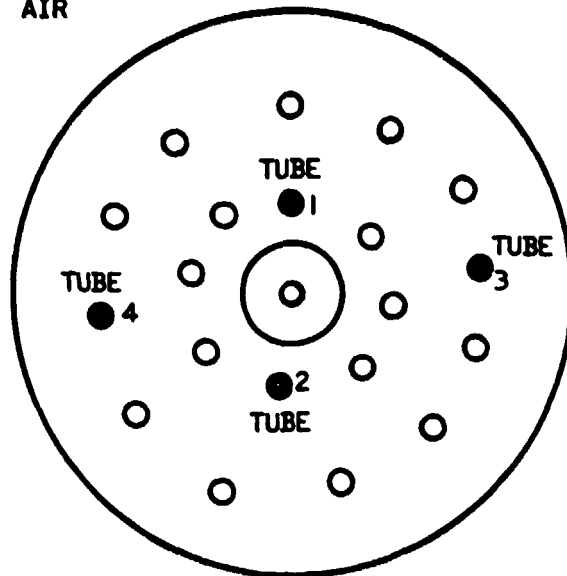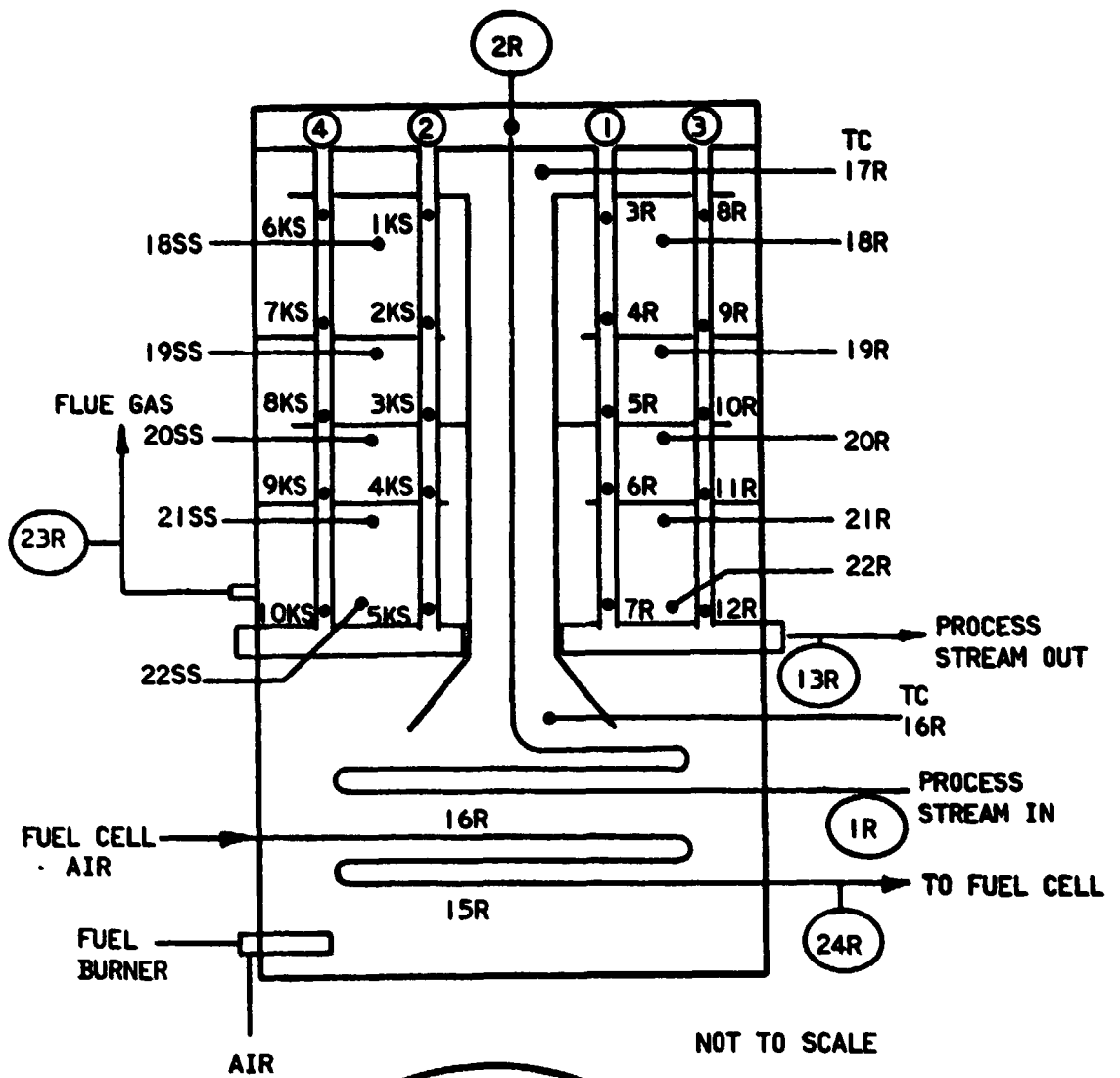
FIGURE 2   **THERMOCOUPLE LOCATION IN 5KW REFORMER**
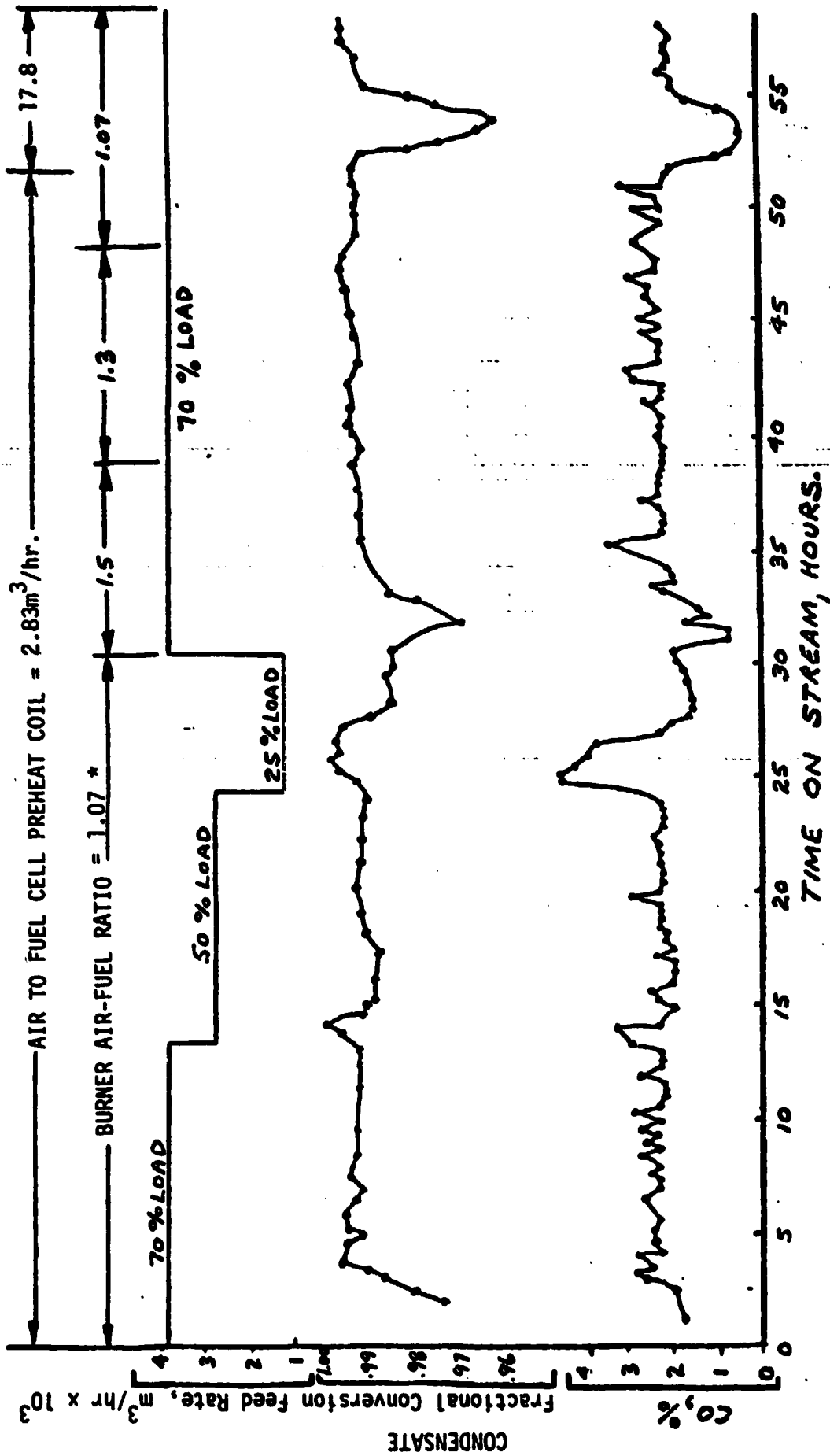
* Burner fuel was simulated anode vent gas: 40% H_2, 5% CO, 55% CO_2. Fuel flow at 100% load is 3.82 standard m^3/hr. Flows at lower loads were reduced proportionately. All conditions correspond to 75% H_2 utilization in the stack.

FIGURE 3.   PROCESS VARIABLE STUDY, 5 kW REFORMER

TIME ON STREAM, HOURS.

AIR TO FUEL CELL PREHEAT COIL = 2.83m^3/hr.

BURNER AIR-FUEL RATIO = 1.07 *

FIGURE 4. PROCESS VARIABLE STUDY, 5kw REFORMER

FIGURE 5. TEMPERATURE PROFILE IN 5KW REFORMER
(FULL LOAD, 99% CONVERSION)

INNER TUBES

0.25 m DIA.

OUTER TUBES

BAFFLES

CENTRAL DUCT

COMBUSTION CHAMBER

0.91 m

FIGURE 6.   5-KW METHANOL REFORMER

20 CATALYST TUBES IN TWO CONCENTRIC RINGS

INNER DUCT ADDED WITH INSULATION

SINGLE FLUE GAS EXHAUST

INERT ALPHA ALUMINA IN EXIT PLENUM

PROCESS GAS TO FUEL CELL STACK

PREHEAT COIL ENLARGED (AIR PREHEATER REMOVED)

MORE INSULATION

FIGURE 7.   **REVISION TO NASA 5KW REFORMER**

FIGURE 8. PERFORMANCE OF 72-CELL STACK (5 kW)

STACK NO.: 11,414
CELL AREA: 0.9 ft²
TIME: 100 HOURS
TEMP.: 355°F
REACTANTS: H₂-AIR, REFORMATE-AIR

REFORMATE COMPOSITION:
9.4%H₂O, 67.0%H₂, 21.8%CO₂, 1.8%CO

ORIGINAL PAGE IS
OF POOR QUALITY

FIGURE 9. NASA INTEGRATED SYSTEM

0.33 m (13")

0.56 m (22")

1.22 m (48")

FIGURE 10.

25 KW FUEL CELL STACK

0.33 m (13")

0.56 m (22")

1.22 m (48")

<u>FIGURE 11.</u>

<u>25 KW FUEL CELL STACK (MANIFOLDS REMOVED)</u>

FIGURE 12.   25 kW STACK CORNER DETAIL

Reformate/Air

65 H_2
24 CO_2
10 H_2O
1 CO

● 464K (191°C)
● 161 mA/cm^2 (150 A/FT^2)
● 75% Hydrogen Utilization

Bimetallic Catalyst

Standard Catalyst

Cell Voltage

Time (Days)

FIGURE 13.   CO TOLERANCE OF BIMETALLIC ANODE CATALYST.

FIGURE 14.   EFFECT OF AGING ON CARBON SUPPORTED Pt SURFACE AREA

FIGURE 15. OPEN-CIRCUIT VOLTAGE STABILITY OF SINGLE-CELL USING DEVELOPMENTAL CATALYST OF THE STABILIZED SUPPORT/STABILIZED PLATINUM TYPE
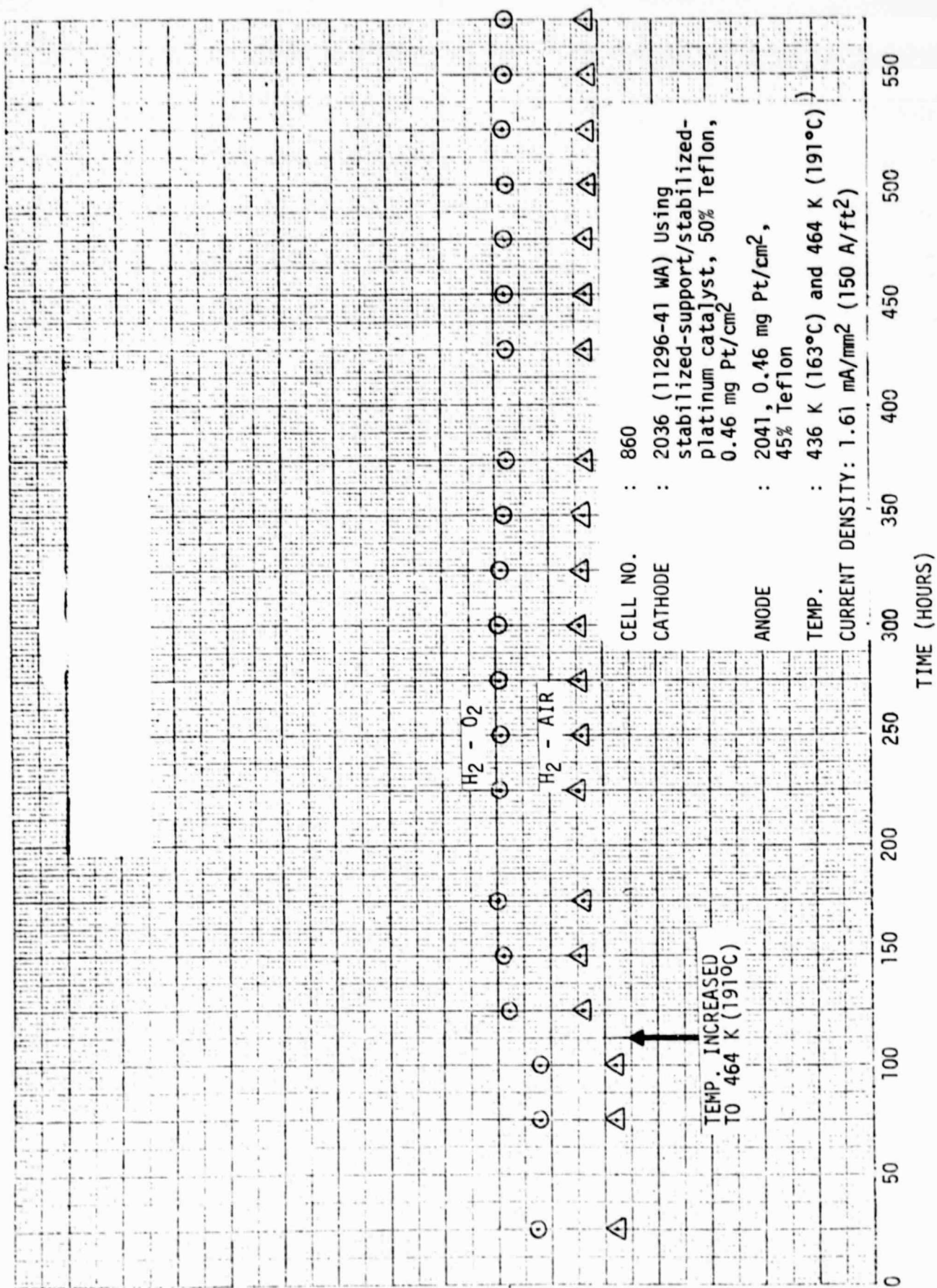
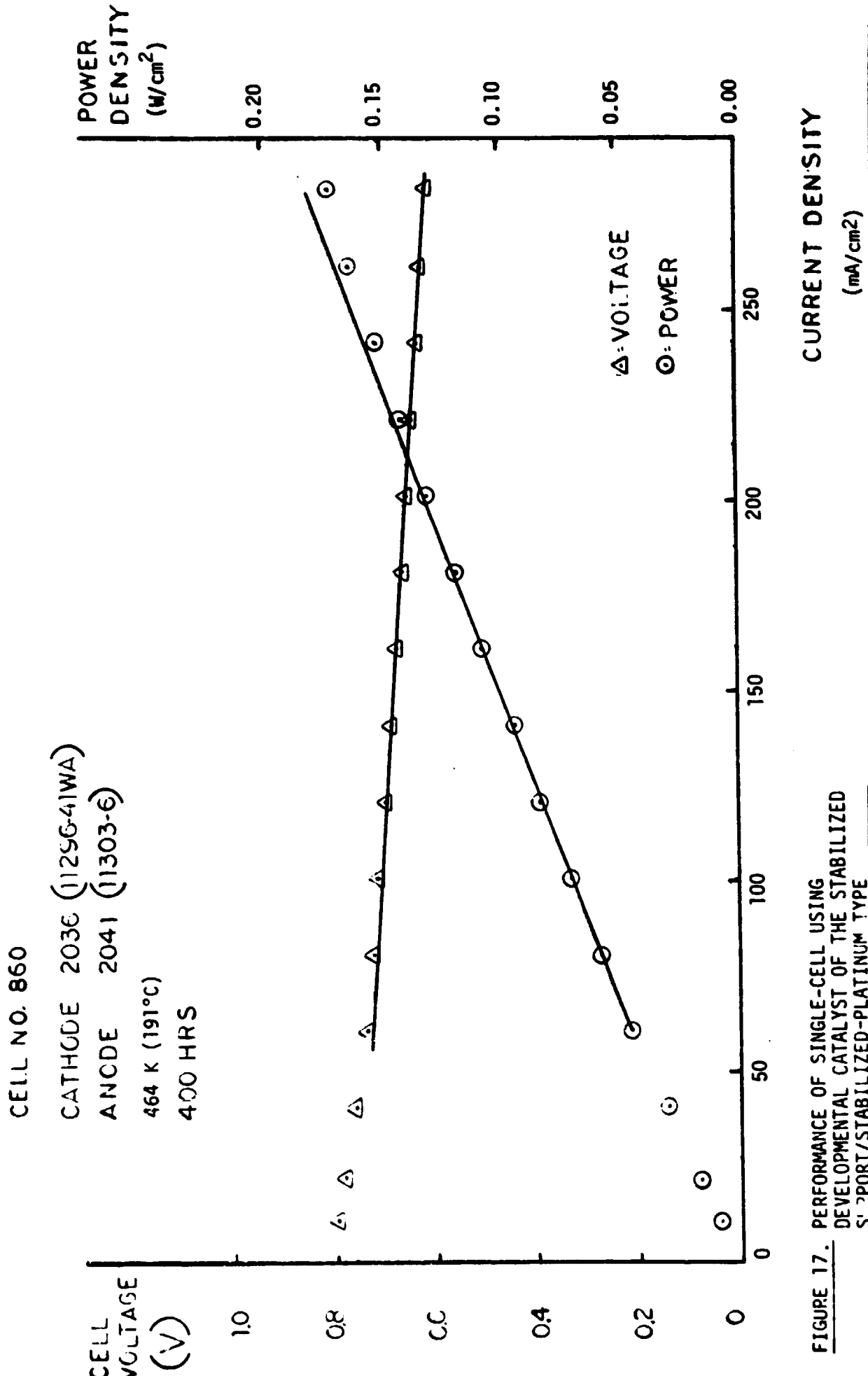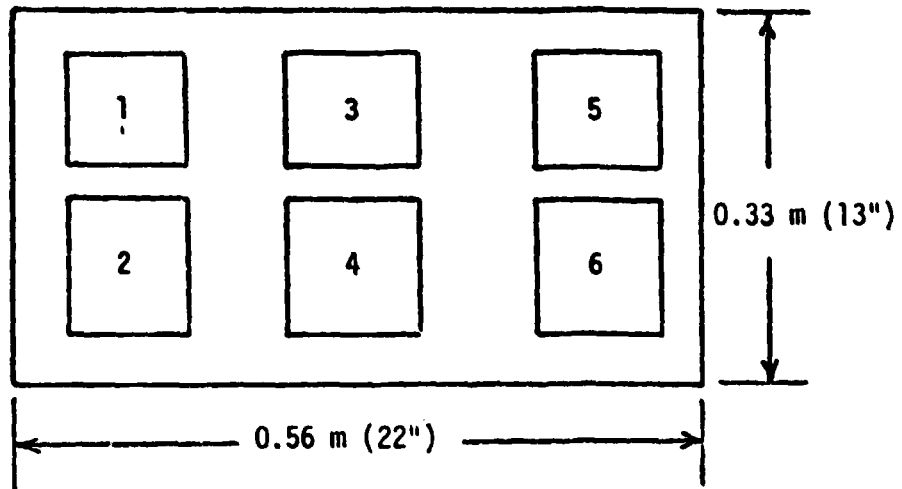FIGURE 16. VOLTAGE STABILITY OF SINGLE-CELL USING DEVELOPMENTAL CATALYST OF THE STABILIZED SUPPORT/STABILIZED PLATINUM TYPE

FIGURE 17. PERFORMANCE OF SINGLE-CELL USING DEVELOPMENTAL CATALYST OF THE STABILIZED SUPPORT/STABILIZED-PLATINUM TYPE

The test results are summarized in Table IV.

FIGURE 19.   Evaluation of Scaled-Up Electrodes

Six samples of scaled-up anodes and cathodes
were evaluated by single-cell testing.
Samples of 76 x 76 mm (3" square) active
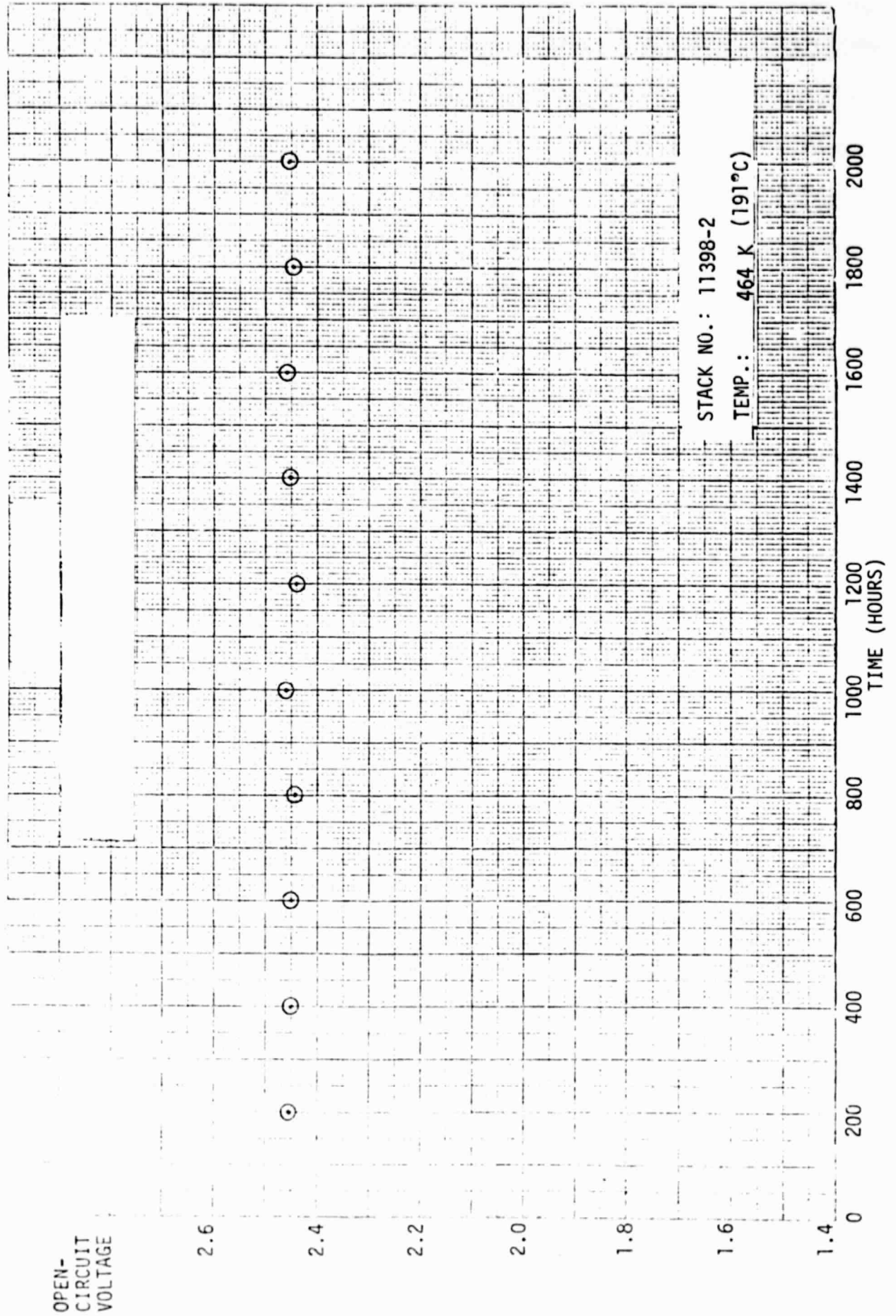area were cut from the full-size electrodes
as described above.

FIGURE 19. OPEN-CIRCUIT VOLTAGE STABILITY OF 3-CELL STACK WITH IMPROVED ELECTROLYTE MANAGEMENT SYSTEM
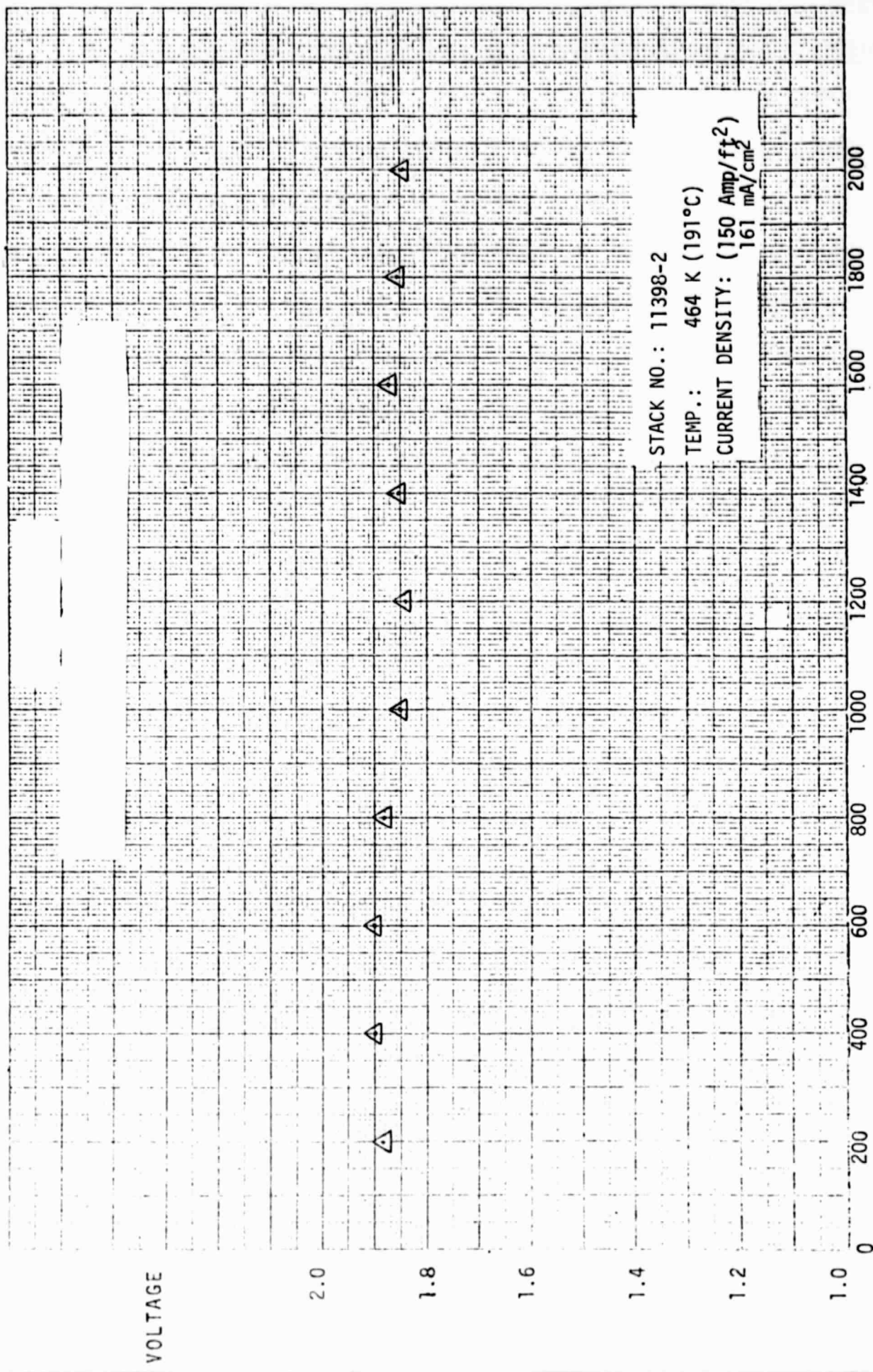
FIGURE 20. VOLTAGE STABILITY OF 3-CELL STACK WITH IMPROVED ELECTROLYTE MANAGEMENT SYSTEM