(NASA-CR-168020) DEVELOP AND TEST FUEL CELL POWERED ON-SITE INTEGRATED TOTAL ENERGY SYSTEM Quarterly Report (Engelhard Industries, Inc.) 47 p HC A03/MF A01 CSCL 10A G3/44

N83-15839

Unclas 02335

DOE/NASA/0241-5
NASA CR- 168020

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

5TH QUARTERLY REPORT: FEBRUARY - APRIL, 1982

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

REPORT DATE: November 3, 1982

PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT DEN3-241

for
U.S. DEPARTMENT OF ENERGY
ENERGY TECHNOLOGY
DIVISION OF FOSSIL FUEL UTILIZATION
UNDER INTERAGENCY AGREEMENT DE-AI-01-80ET17088

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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, 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 the 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 and has as its objective the complete integration of 5kW components developed during Phase II. This integrated 5kW system is automated under microprocessor control.

Seventy ABA bipolar plates and 50 A-elements were received from Pfizer for the rebuild of the 5kW stack. These were subjected to rigorous checks for uniformity of thickness. The Engelhard specification for thickness uniformity is 5 mils maximum difference between thickest and thinnest areas. After resanding of some of the ABA plates by Pfizer all of these are within specification. The A-elements, however, do not sand well in the sander at Pfizer because they are too flexible to be held down properly. An alternate procedure for sanding A-elements to specification (surface-grinding) has been developed at Engelhard, and these components were reworked in March using this method.

To provide a better check on the performance and quality of these components, a 12-cell stack using the new A and ABA plates was built and tested in March. This stack is a precursor to the 5kW rebuild; a specific purpose was to confirm that the reactant edge-seal problem encountered in the first 5kW build (due to faulty ABA bonding) has been solved with changes in ABA fabrication technique.

The results of testing this 12-cell sub-stack are shown in Figures 1 and 2. The sub-stack was tested for two days on H_2/air at 464 K (375 °F) and 80% H_2-utilization. Figure 1 shows the current-voltage performance of the entire sub-stack at the test conditions and Figure 2 gives the average cell performance. At rated current density (161 mA/cm^2) this average was 602 mV/cell. Although somewhat low in the typical performance band, this was considered satisfactory, and the sub-stack is being stored at 120 °C until the remaining sub-stacks are ready.

Each subsequent 12-cell sub-stack for the 5kW rebuild will be stored in a clamping fixture at 120 °C until the entire stack can be assembled.

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS (97047)

The purpose of this task is to develop an application model for on-site integrated energy systems, with some emphasis on a system of 50kW (electrical) modular capability. The model will consider fuel availability and costs, building types and sizes, power distribution requirements (electrical and thermal), waste heat utilization potential, types of ownership of the OS/IES, and grid connection vs. stand-alone operation. The work of this task is being carried out under subcontract by Arthur D. Little, Inc. (ADL).

ADL has previously identified the electric utility rate structure as a key factor in determining the overall economics of grid-connected OS/IES. They have completed rate structure analyses for four representative utilities including projections to the year 1990:

Georgia Power Company (high load growth; little oil)
Commonwealth Edison (low load growth; little oil)
Houston Lighting and Power Co. (high load growth; much gas)
Southern California Edison (low load growth; much oil)

SECTION II. - CONTINUED

The complex form of these structures requires that a simplification be developed by ADL for presentation at a later date. It is apparent, however, that the prevailing electric rate structure is the single most important variable (besides fuel choice) in determining the economic attractiveness of OS/IES. Engelhard will continue to review this conclusion as the ADL study progresses. At this point most of ADL's calculations are predicated upon the use of natural gas as primary fuel because it has already been shown that, at present prices, the economics of methanol-based OS/IES are far less attractive.

Four building types are included in the study:

Offices
Retail stores
Apartment complexes
Hospitals

The ADL objectives are to:

- Rank building types and system sizes and configurations by internal rate of return on investment.
- Develop the general relationship between electric rate structure and internal rate of return.
- Determine market potential by building type and region.
- Identify most desirable application site(s) for a 100 kW prototype power plant.

SECTION II. - CONTINUED

TASK III - ON-SITE SYSTEM DEVELOPMENT

This task forms the core of the Phase III Contract. Work under this task will result in the breadboard design of a system for an on-site application. The power plant will be designed for a rated output of 50kW (electrical) or some multiple thereof. The fuel processor and power conditioner will each be 50kW modules, while the 50kW fuel cell will comprise two 25kW stack modules, This task is accordingly broken down into four sub-tasks as follows:

3.1 Large Stack Development (97048)
3.2 Large Fuel Processor Development (97038)
3.3 Overall System Analysis (97051)
3.4 Overall System Design and Development (97064)

A large part of Sub-Task 3.3 is being carried out by Physical Sciences Inc. (PSI) under subcontract.

LARGE STACK DEVELOPMENT (97048)

A single-cell in full-sized configuration (0.33 m x 0.56 m, 13" x 22") was assembled and tested in the variable-stack test fixture (Aug.-Oct., 1981 Quarterly Report, Figure 6). This was the first test in this program of a full-sized cell. Part of the purpose of the test was to check the fixture itself and associated reactant distribution design, in addition to evaluating the cell components. For this test the fixture was heated externally with electrical heating pads and insulated across the top outside surfaces.

CVD-upgraded needled-felt A-elements were employed for reactant distribution. These were grooved and wet-proofed. Engelhard standard catalysts and electrode fabrication methods were used for the anode and cathode.

The cell was run on H_2/air at partial load (108 mA/cm^2) and low H_2-utilization for 19 days (450 hours). The cell temperature was maintained at 444 K (340 °F) and acid was replenished manually as necessary. The performance was constant throughout the run. At the 200-hour point voltage/current data were obtained using a high hydrogen flow rate (See below). This information is plotted in Figure 3. The voltage at rated current (161 mA/cm^2) is 553 mV, which is low compared with usual cell performance. Most of this deficiency was traceable to excessive IR-losses in this cell. The total IR-loss was 93 mV at 161 mA/cm^2, which can be compared to a normal value of 30-40 mV. If the "excess" IR-drop of about 60 mV is added back to the observed voltage, the result is about 610 mV at 161 mA/cm^2, which indicates acceptable performance of the electrodes.

Excessive IR-loss in this cell appeared to be due to non-uniform thickness of the needled-felt A-elements. Because of difficulties with precision sanding of flexible materials at the time the cell was built, the preferred specification of 5 mils maximum variation was relaxed. It has been learned from this test that the specification must be adhered to, and a much more precise surface grinding procedure has since been developed at Engelhard. The latter procedure will be used in the future, rather than sanding, for flexible elements.

The other problem observed in this stack test was uneven reactant gas distribution at normal flow rates. This was more pronounced on the hydrogen side than on the air side. In the original design of the fixture a single, centrally-located port was installed on each of the two inlet manifolds.

Part of the purpose of the test was to check the adequacy of this arrangement. The sensitivity of cell output to total flow rates, especially of hydrogen, indicated that there was insufficient "spreading" of the flow along the leading edges of the A-elements. At low flow rates the grooves at the ends of the rows became starved since the grooves toward the center represented the paths of least resistance. Several approaches are being considered for improving the distribution of flows in this fixture at design rates (see under Task IV below).

No difficulties were encountered in this cell test other than the two described above.

LARGE FUEL PROCESSOR DEVELOPMENT (97038)

The emphasis of the fuel processor development program has shifted toward the use of commercially available shell-and-tube heat exchangers as the basic structure of the design. Catalysts will be retained in the 1" tubes and flue gas will be fed through the shell side.

A 5kW-equivalent unit has been ordered as the first step in this development. The vendor is the Perry Co. of Hainesport, N.J. A 50kW-equivalent unit has also been ordered but will not be fabricated until the optimum baffle spacing has been established. Preliminary calculations of shell-side heat transfer coefficients and pressure drops as functions of baffle spacing are shown in Table I for both sizes. The 8 cm baffle spacing has been specified for the 5kW unit (maximum heat transfer coefficient with acceptable pressure drop). It appears that a longer baffle spacing will have to be selected for the 50kW unit, however, due to pressure drop considerations.

The test station is being assembled for test of the 5kW unit, which are expected to begin in May. The results of these tests will be used to establish the final configuration for the full-sized unit. T2107RS catalyst (Zn/Cu oxides) will be used in both 5kW and 50kW processors.

Full-Size Single-Tube Design and Evaluation

In the original Statement of Work selection of tube diameter was considered to be a key to scale-up from 5kW to the 50kW size. The program included design and evaluation of a full-diameter single-tube reformer. During the design phase, two complementary observations indicated that tube size was restricted to a narrow selection. The computer modelling indicated large radial temperature gradients with 5.1 cm (2") diameter tubes. These gradients were cut in half with a 2.5 cm (1") tube. Experiments with a 5.1 cm single tube supported the conclusions derived from the calculations. In discussions with vendors of heat exchangers it was apparent that 2.5 cm (1") and 1.9 cm(3/4") tubes are standard sizes for conventional heat exchangers. Even though fewer tubes would be required at 5.1 cm diameter, the cost of the reformer would actually be greater due to the expense of rolling these larger tubes into the tube sheet with non-standard jigs.

The 1.9 cm size tube was considered too small for 3.2 mm (1/8") diameter catalyst pellets, which are the smallest tablets that are commonly manufactured. The rule-of-thumb in reactor design is to have at least 8-pellet-diameter tubes; i.e., the 2.5 cm size.

Since it appears feasible to meet performance and cost objectives with reformers constructed by commercial shell-and-tube heat exchanger vendors, the program of Task 3.2 has been modified to reflect this change.

The discussion that follows documents the calculations and experiments that led to this decision.

Two-Dimensional Computer Modelling

Predictions obtained with the two-dimensional reformer computer model are illustrated in Figures 4 through 11. Figures 4 and 5 show the predicted conversion and average bed temperature profiles, respectively, for a 50kW reformer based on direct scale-up (by increasing the number of tubes) of the 5kW reformer, which has 20 one-inch diameter tubes. Figures 6, 7, 8 and 9 show corresponding results for a second 50kW reactor configuration better suited to the higher capacity; this configuration has half the number of tubes but their length is doubled (that is, the same catalyst volume in used). Figure 6 shows the flue gas and reactant gas temperatures to be almost equal at the end of the 1.27 m (4.18 ft) bed for 2.5 cm (1") diameter tubes. Figure 7 shows the radial ΔT versus distance down a reactor tube. The 5.1 cm (2") diameter tube shows a 28 K (50 °F) maximum raidal ΔT about 1/4 of the distance down the bed. Figures 8 and 9 show how conversion is affected by tube diameter for an assumed wall-heat-transfer coefficient of 20.4 $kJ/hr \cdot m^2 \cdot K$ (outermost radial position in reformer tube to flue gas). This value of H_W was derived from a fit of the two-dimensional model with experimental data from the 20 tube 5kW reformer. With this low heat transfer coefficient full conversion is not achieved in the 5.1 cm diameter tube at 1.27 m. Figures 10 and 11 show that about 2.4 m (WHSV = 0.23) would be required for the 5.1 cm diameter tube to provide 99.9% conversion (although less than 1.5 m is required for 99% conversion).

Single-Tube Studies

Radial profiles have been measured in a 5.1 cm (2") diameter tubular reactor heated by gas flowing in the annulus. The results are being compared with those predicted by the two-dimensional model described in the preceding section. Calculations have shown radial temperature gradients in excess of 28 K (50 °F) for tubes 5.1 cm (2") in diameter. A key parameter in these calculations is H_w, the heat transfer coefficient at the wall. Since the estimation of H_w is not straightforward, experimental data are required to select an appropriate value of H_w.

The experimental set-up is shown in Figure 12 where catalyst is contained in a 5.1 cm (2") diameter tube. The outer shell is a 7.6 cm (3") diameter tube and flue gas flows in the annulus. Prevaporized and superheated process gas ($MeOH/H_2O$) enters the reactor through a flared section which serves to distribute the gases uniformly across the bed.

Preliminary studies with inert packing has shown unusually large radial profiles at the 10.2 cm position. This was possibly due to entrance effects. The set of thermocouples at the 39.4 cm position gave a smooth profile of the expected magnitude. Therefore, catalyst was loaded into a zone centered about this middle set of thermocouples, with inert packing (alumina) above and below the catalyst zone.

Heating tape on the outside of the shell prevented heat-loss to the outside. Air was used to simulate flue gas and this was metered to give the same mass flow rate as flue gas in actual operation. This air was preheated before entering the reactor shell.

The results from two runs are presented to illustrate the type of data obtained with this equipment. In both runs 1100 ml/hr of methanol/water mix (1.3 H_2O/CH_3OH) was fed to the unit containing 259 g of T2107RS (Cu/Zn) catalyst. The WHSV* in both cases was 1.90 g methanol/hr/g catalyst. The condensate was collected and analyzed for CH_3OH and H_2O by gas chromatography. The gas was measured for volumetric flow rate using a dry-test meter and analyzed for H_2, CO, CO_2, H_2O, and CH_3OH.

Figure 13 shows the temperature profile obtained in Run 3ST. The flue-gas (FG) temperature was essentially constant across the zone of the catalyst at about 640 K. The process gas temperature dropped in the axial direction above the catalyst bed (due to axial heat conduction). The radial profile showed 66 K difference between the center-line and the wall. About 67% methanol conversion was observed with an average bed temperature of 493 K (428 °F).

In Run 4ST (Figure 14) the flue-gas temperature was lowered to 489 K by cutting back on the power to the heating tapes. The radial temperature difference was only 22 K. Methanol conversion was 28% at an average bed temperature of 467 K (381 °F).

Figure 15 summarizes the results of these two runs. The very steep radial profile of Run 3ST results from the high wall tmeperature and strong driving force between the flue gas and the tube wall. When this driving force is lowered, as in Run 4ST, the radial gradient is lower. Note that in the two cases the temperatures at the center-line are nearly equivalent.

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* Weight-hourly-space-velocity (g CH_3OH/g catalyst/hr)

A comparison of average bed temperature and conversion level is as follows:

Run No.	3ST	4ST
Average Bed Temp, K	493	467
Methanol Conv., %	67	28

The increase in conversion is what would be expected for a first-order reaction with an activation energy of 84 kJ/mole.

These two runs illustrate how radial temperature gradient changes with driving force (difference in temperature between flue gas and wall) and reaction rate (as shown by methanol conversion). Tests in progress at the same flue gas and inlet temperatures, but with ethanol added to the feed, will show the effect of changing catalyst activity on the radial temperature gradient. A test with C70-2RS, which is much less active than T2107RS, is also scheduled.

Evaluation of Ethanol Contaminant in Single-Tube Experiments

The experimental set-up illustrated in Figure 12 (previous section) was also used for the test runs of this section. Figure 12 shows the 5.1 cm (2") diameter tube and thermocouple locations. Catalyst was loaded into the zone centered about the set of thermocouples at the 39.4 cm position. Inert alumina was packed below and above the catalyst zone.

Two types of catalyst were compared in these runs. With T2107RS (Cu/Zn), 238 ml weighing 259 g was used. With C70-2RS (Cr/Zn), 238 ml weighed 293 g.

SECTION II. - CONTINUED

Part of the purpose of the tests was to determine the effect of reduced catalyst activity on the radial profile in the 5.1 cm (2") diameter reactor. It was known from previous work that small amounts of ethanol lowered the activity. This observation was used to moderate activity without changing catalyst. A second feed tank was installed which made it possible to switch from normal feedstock to feedstock containing ethanol without upsetting the temperature control.

In switching from the regular feedstock (1.3 H_2O/CH_3OH) to the same mix spiked with 1% by volume ethanol, the bed temperature increased even though the inlet temperature to the reactor remained constant. The activity declined even though the average bed temperature was higher. The results are summarized below.

RUN No.	6ST-1	6ST-2
Feed Rate, ml/hour	1100	1100
MeOH, Wt%	55.11	55.08
Feed Density, g/ml	0.893	0.893
H_2O/CH_3OH, Molar Ratio	1.45	1.45
Product Condensate Weight, g	225	443
Unreacted MeOH in Cond., wt. %	29.0	39.9
Product Gas Make, l/hr	1385	1035
MeOH Conversion, %	82.2	61.8
WHSV	2.09	2.09
Average Bed Temp, K	524	546

The average bed temperature is the average of the five radial thermocouples at the mid-zone location. In the two runs the inlet temperature above the catalyst bed was the same (about 588 K). Figure 16 shows the radial profiles with the two types of feed. The radial ΔT declined in the presence of ethanol, consistent with the decline in activity.

SECTION II. - CONTINUED

How much lower is the activity with 1% ethanol added? Assuming a first order reaction with an activation energy of 84 kJ/mole, the rate constants are calculated as follows:

Feedstock	Regular	Regular + 1% EtOH
Temperature, K	524	546
WHSV	2.09	2.09
Conversion, %	82.2	61.8
k @ 524 K	3.61	0.93

Therefore, 1% ethanol lowers activity by a factor of four.

Comparison Between Catalysts

Previous runs on the sub-scale test unit had shown Cr/Zn catalyst (C70-2RS) to be stable at high temperatures (673 K+) but less active than the Cu/Zn catalysts (e.g., T2107RS).

Comparison between the two types is shown in the following table:

Catalyst	T2107RS	C70-2RS
Type	Cu/Zn	Cr/Zn
Volume Charged, ml	238	238
Wt. Charged, g	259	293
Bed Density, g/ml	1.09	1.23
Run No.	6ST-1	7ST
WHSV	2.09	1.91
Feed Rate, ml/hr	1100	1100
MeOH in Feed, Wt %	55.08	57.0
Average Bed Temp, K	524	601
Methanol Conv., %	82.2	49.3
k @ 524 K	3.61	0.110
ΔT_{radial}, K	69	31

The Cu/Zn catalyst is about 33 times as active as the Cr/Zn catalyst as measured by this procedure, which is approximate due to radial and axial gradients. However, it provides a useful comparison.

SECTION II - CONTINUED

OVERALL SYSTEM ANALYSIS (97051)

Physical Sciences Inc. is proceeding with the development of modules for off-design analysis. This work is expected to be completed by about May. The purpose of these modules is to predict system behavior and stability at load conditions less than 100%.

OVERALL SYSTEM DESIGN AND DEVELOPMENT (97064)

A subcontract with the Trane Co. of LaCrosse, Wisconsin is in the final stages of negotiation. The work of the subcontract is focussed on HVAC design and equipment.

TASK IV - STACK SUPPORT (97049)

The purpose of this task, which will continue throughout the contract, is to investigate new materials and component concepts by experimentation and the use of small-stack trials. The criteria for choosing activities under this task will be the possibilities of improved performance or reduced cost, or both. Improvements in and performances of electrocatalysts, though generated under Engelhard-sponsored Task VI, will be reported under Task IV.

CORROSION CURRENTS ON GRAPHITE ADHESIVE

The graphite adhesive used at Pfizer for bonding ABA bipolar plates together is made by Union Carbide and in its green state consists of three components: a pitch, a resin and a solvent. After application the adhesive is cured at a mild condition to remove the solvent. It is then treated at 1370 K (1100 °C) to partially graphitize the remaining components. This heat-treated material has been tested for electrochemical corrosion.

The results of the corrosion test at 0.9V and 477 K in phosphoric acid are shown in the upper curve of Figure 17. The magnitude of the currents in the test is judged to warrant investigation of ways of making these bonding layers more corrosion-resistant.

Samples of the adhesive were further heat-treated at 1970 K and 2670 K, respectively, in addition to the usual treatment at 1370 K. The two lower curves in Figure 17 show the results of these tests. The sample heat-treated at 2670 K was expected to be completely graphitized and, correspondingly, shows very low corrosion rates. This treatment temperature could be expected to solve any potential problem but would add considerably to the expense of preparing the plates.

An alternate approach to reducing the corrodibility of the adhesive is to apply additional CVD (chemically vapor-deposited carbon) over the heat-treated adhesive. The effectiveness of this approach in reducing corrosion currents is shown in Figure 18 where the corrosion rates at 1.0 V are reduced by two orders of magnitude by the CVD layer.

The processing sequence for ABA elements and plates at Pfizer is being changed to take advantage of the observations above. The needled-felt A-elements are only partially CVD'ed initially. Final CVD is done after the plates are completely assembled and the adhesive has been heat-treated. The adhesive layers will thereby be protected from corrosion as they come into contact with phosphoric aicd.

Single-Cell Test Improvement with Acid Management

A small single-cell test station for 7.6 x 7.6 cm (3" x 3") electrodes has been fitted for semi-automatic acid replenishment (similar to that used in stack tests). Prior to this, the useful life of single-cell tests for evaluating catalyst and electrode performance was limited by the initial acid inventory in the test cell. Once attrition of acid began to cause overall performance to decline, the quality of the data was not sufficient to evaluate on-going component performance per se.

Figure 19 shows the results of the first long-term test with acid management in such a station. Temperature was raised to full operating level and acid management was begun at 700 hours. After a period of adjustment, the voltage stability of this cell was much better than is generally observed without acid replenishment.

Improved Flow Distribution in Full-Sized Test Fixture

As described above under Task 3.1, the flow distribution of reactants (particularly hydrogen) is not uniform in the full-sized test fixture. Two approaches are being used to correct this problem. One is to install a distribution tube, perforated with a line of small apertures, along the inside of each inlet manifold. Most of the pressure drop would be taken across these apertures, rather than across distribution plates in the stack. A second approach is to install an open-cell polymer curtain across each inlet face of the stack within the inlet manifolds. The most promising candidate for this application is Solimide, a polyimide foam that costs less than $\$1/ft^2$ in 1/8" thickness. Pressure drop tests will be conducted to establish what thickness will provide a pressure drop large enough to minimize the unbalancing effect of all the other pressure drops, but not so large as to place a high power burden on the air blower.

The approach that is judged best will be incorporated into the planned 3-cell test in this fixture.

SECTION II. - CONTINUED

TASK V - FUEL PROCESSING SUPPORT (97050)

The intent of this task is to provide background data and information to support the design and construction of an optimized 50kW fuel processor under Task III. Most of the effort of this task was devoted to screening and longevity testing of catalysts for methanol/steam reforming. This task is now complete.

The major work in this task has involved long-term comparative testing of two methanol steam-reforming catalysts: T2107RS (copper/zinc/chromium/aluminum oxides, reduced and stabilized) and C70-2RS (zinc/chromium oxides, reduced and stabilized). Some points of comparison between these two catalysts are:

	T2107RS	C70-2RS
Bulk Density, g/ml	1.09	1.55
Surface area, m^2/g	91	26
Cost, $/L (small lots)	56.50	100

Data from the runs on these two catalysts have been presented in previous reports. The conclusions and recommendations from this study are summarized below:

- Sub-scale test data indicate better stability for C70-2RS than for T2107RS. This includes both better thermal tolerance and better tolerance of ethanol impurity.

- Poisoning with 800 ppm ethanol in feedstock is reversible and can be temperature-compensated on C70-2RS; this is not true for T2107RS.

- C70-2RS is less active than T2107RS, but the lower activity can be compensated for by an increase in operating temperature.

- Commercial methanol from either DuPont or Celanese is quite pure and can be reformed by T2107RS.

- T2107RS has shown good performance so far in 5kW processing units.

- Use of T2107RS in the 50kW unit is recommended, with purchase of 60 L of C70-2RS as a back-up for contingencies.

SECTION II. - CONTINUED

TASK VI - IMPROVED ELECTROCATALYSTS (97039)

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

SECTION III. CURRENT PROBLEMS

The reactant flow distribution in the full-sized variable-stack test fixture is to be improved by one of the methods described under Task IV.

SECTION IV. WORK PLANNED

TASK I

- Continue assembly and testing of 12-cell sub-stacks for 5kW stack rebuild.

TASK II

- Arthur D. Little to complete computer runs on economic case studies.

TASK III

- Full-sized 3-cell stack to be assembled in test fixture.
- Testing to begin of 5kW shell-and-tube methanol reformer.
- The Trane Co. to begin building energy and economic survey work to establish basis for HVAC equipment design.

TASK IV

- Tests to be conducted of prototype of the non-metallic cooling plate.
- Improved flow distribution system for full-sized test fixture to be devised.

TASK V

- Completed.

SECTION V. FINANCIAL MANAGEMENT ANALYSIS

TASK I - 5kW POWER SYSTEM DEVELOPMENT

Preparation of new ABA bipolar plates for the 5kW stack was completed at Pfizer during April, and downstream processing has begun. Minor in-house expenses were incurred.

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS

Expenditures by Arthur D. Little, Inc. were well above the planned level in April, as anticipated. Overall spending remains below projections, however.

TASK III - ON-SITE SYSTEM DEVELOPMENT

1. Large Stack Development

Labor hours for this sub-task were essentially on-target for April as well as for cumulative effort to-date. Cumulative expenditures are above the planned level because of materials costs running ahead of schedule.

2. Large Fuel Processor Development

Cost and hours for April were slightly above the projected level. Expenditures overall are about 15% below plan to date. The 5kW-equivalent sub-scale shell-and-tube reformer evaluation program is now in progress.

3. System Analysis

Effort at Physical Sciences Inc. directected toward analysis of the system under off-design and transient conditions has been completed except for the final reporting. Full subcontract funding has now been expended.

SECTION V. - CONTINUED

4. System Integration

In-house effort on the HVAC sub-system was conducted to lay the groundwork for the subcontract that began 4/1/82 (The Trane Co.). Manpower expenditures remain above budget, but overall costs are well below the projected level because of the subcontract starting later than planned. Initial subcontract invoices will be reflected in the May report.

TASK IV - STACK SUPPORT

Manpower expenditures for this task were above the plan level for the second consecutive month, although total expenditures to date remain below projections.

TASK V - FUEL PROCESSING SUPPORT

Manpower requirements for methanol reforming catalyst evaluation have been reduced from anticipated levels. Total expenditures are well below those projected. April charges indicate a credit that pertained to Task III, Sub-Task 2.

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

EFFECT OF BAFFLE SPACING ON SHELL-SIDE HEAT TRANSFER COEFFICIENT AND PRESSURE DROP FOR HEAT-EXCHANGER TYPE PROCESSORS

I. 5kW HEAT EXCHANGER

Baffle Spacing, cm	Number of Baffles	ho $kJ/hr \cdot m^2 \cdot K$	ΔP, Pa
23	4	28	8
15	6	35	15
8	11	51	90

II. 50kW HEAT EXCHANGER

Baffle Spacing, cm	Number of Baffles	ho $kJ/hr \cdot m^2 \cdot K$	ΔP, Pa
23	4	61	175
15	6	76	500
8	11	112	3000

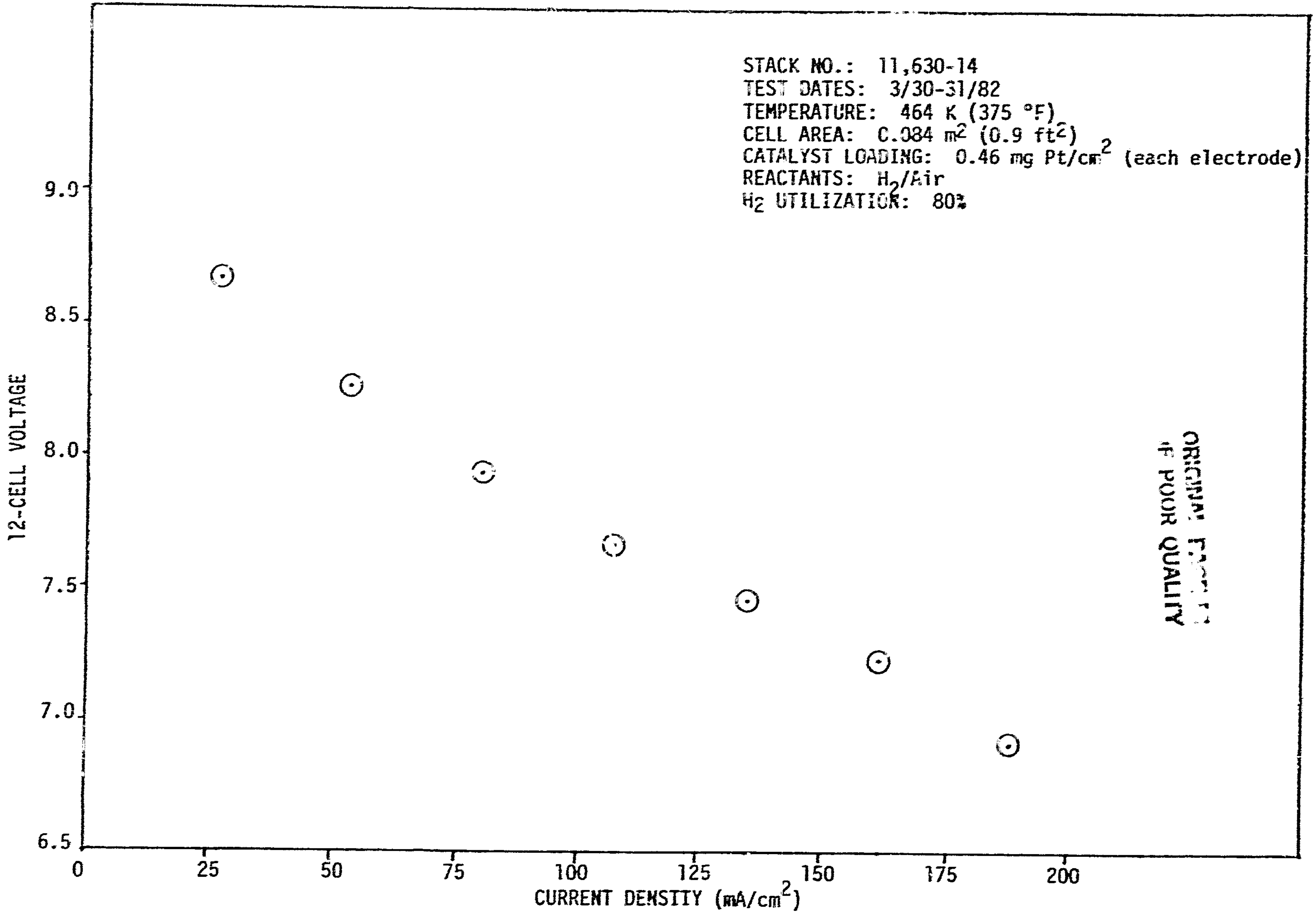


FIGURE 1 PERFORMANCE OF 12-CELL STACK UTILIZING NEEDLED-FELT ABA PLATES

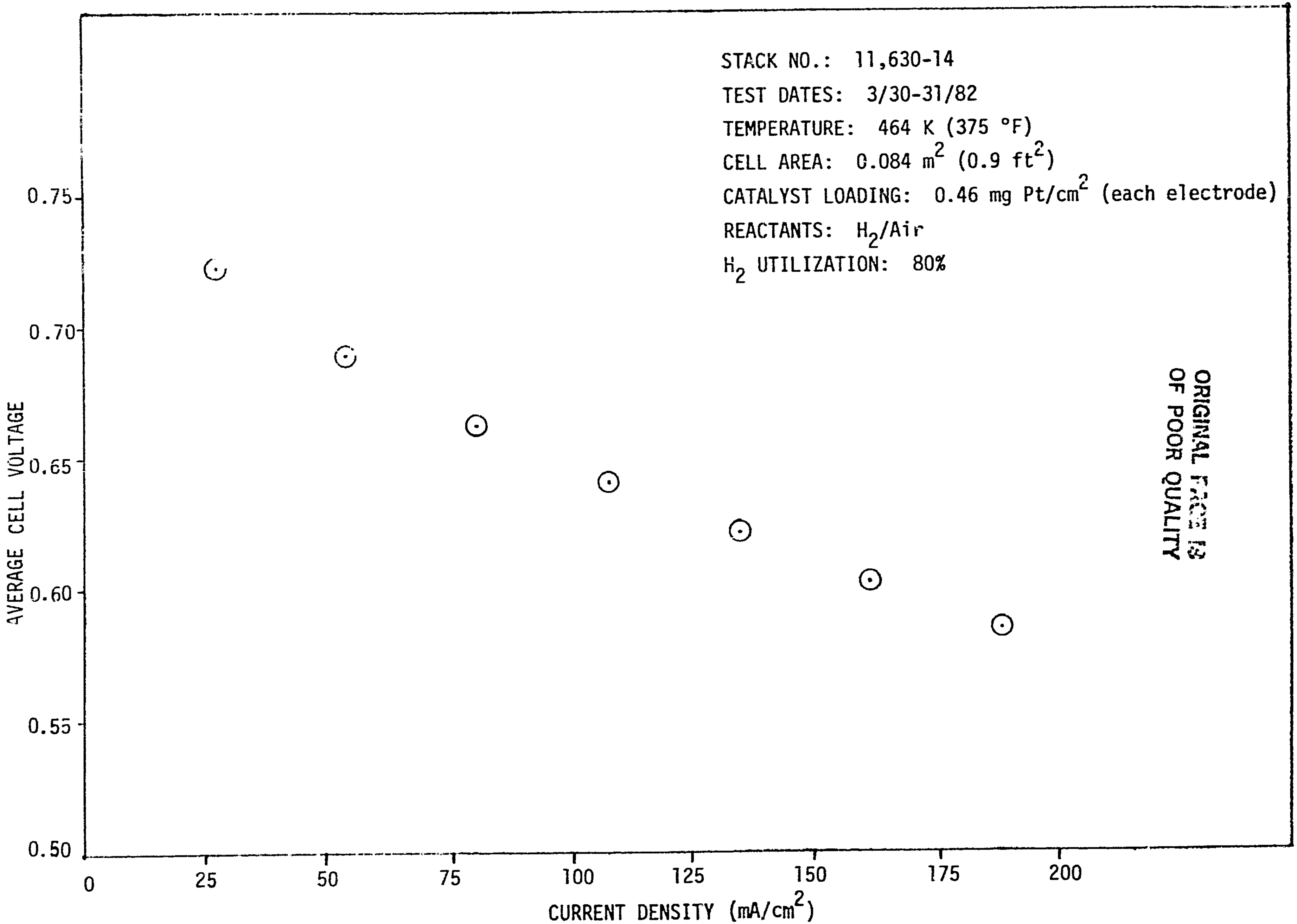


FIGURE 2 AVERAGE CELL PERFORMANCE OF 12-CELL STACK UTILIZING NEEDLED-FELT ABA PLATES

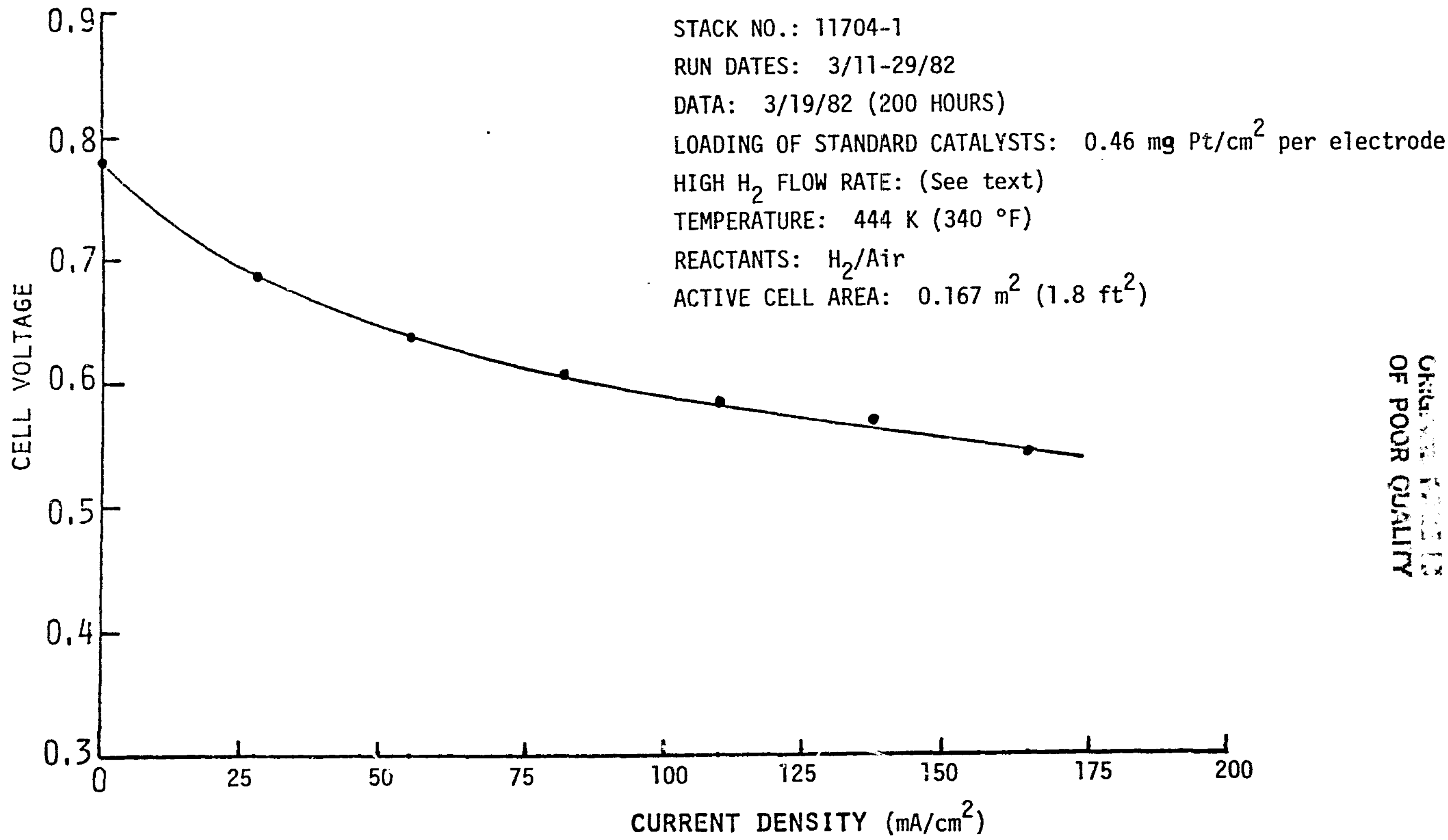
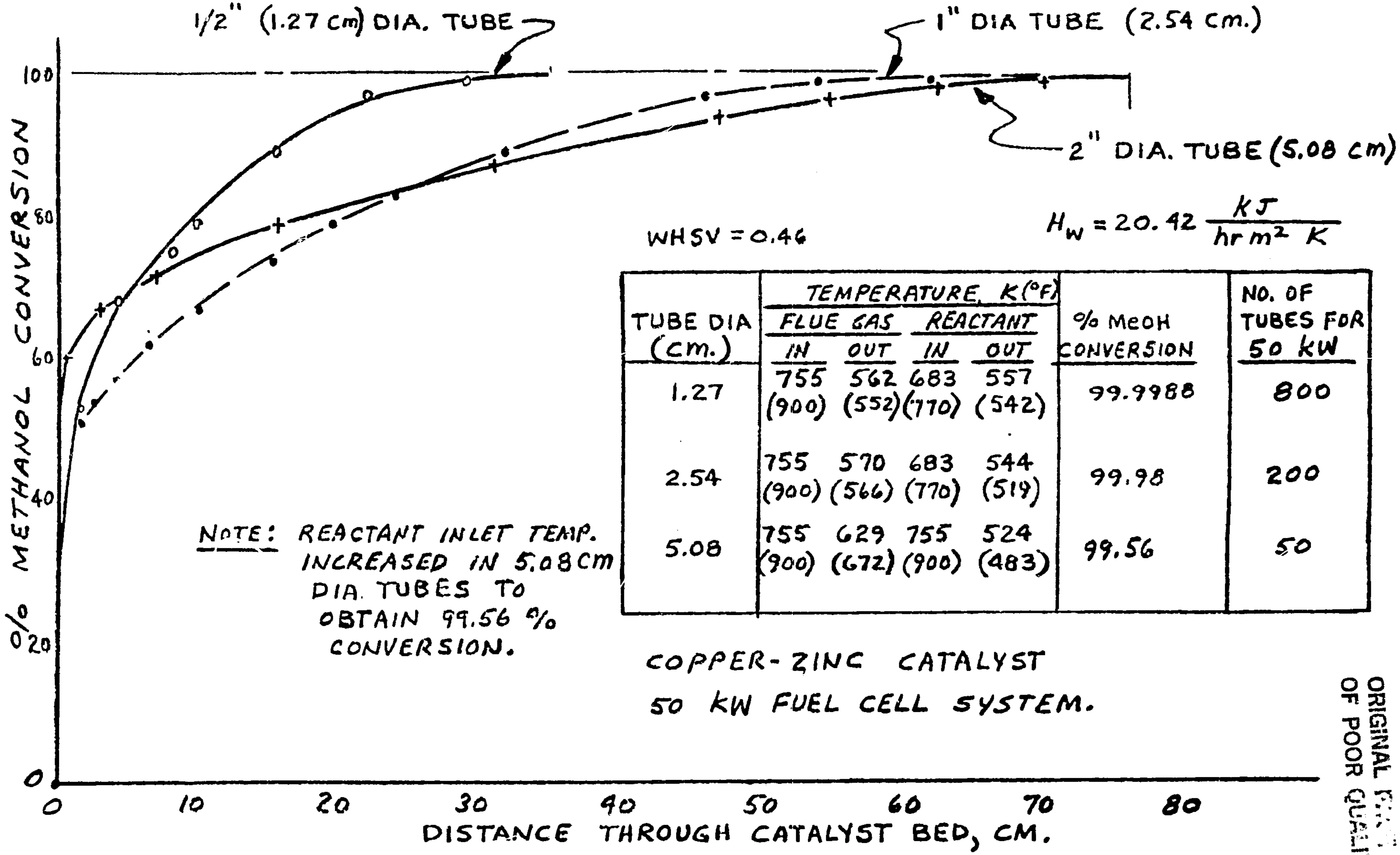


FIGURE 3 PERFORMANCE OF 13" x 22" SINGLE CELL



WHSV = 0.46

$H_W = 20.42 \frac{kJ}{hr\, m^2\, K}$

TUBE DIA (cm.)	TEMPERATURE, K (°F) FLUE GAS IN	FLUE GAS OUT	REACTANT IN	REACTANT OUT	% MeOH CONVERSION	NO. OF TUBES FOR 50 kW
1.27	755 (900)	562 (552)	683 (770)	557 (542)	99.9988	800
2.54	755 (900)	570 (566)	683 (770)	544 (519)	99.98	200
5.08	755 (900)	629 (672)	755 (900)	524 (483)	99.56	50

NOTE: REACTANT INLET TEMP. INCREASED IN 5.08 cm DIA. TUBES TO OBTAIN 99.56 % CONVERSION.

COPPER-ZINC CATALYST
50 kW FUEL CELL SYSTEM.

FIGURE 4 AXIAL CONCENTRATION PROFILES IN SINGLE-TUBE REFORMERS (2-D MODEL PREDICTION)

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10-14-81

TUBE DIA. (CM.)	TEMPERATURE K (°F) FLUE GAS IN	FLUE GAS OUT	REACTANT IN	REACTANT OUT	% MeOH CONVERSION	NO. OF TUBES FOR 50 kW
1.27	755 (900)	562 (552)	683 (770)	557 (542)	99.9988	800
2.54	755 (900)	570 (566)	683 (770)	544 (519)	99.98	200
5.08	755 (900)	629 (672)	755 (900)	524 (483)	99.56	50

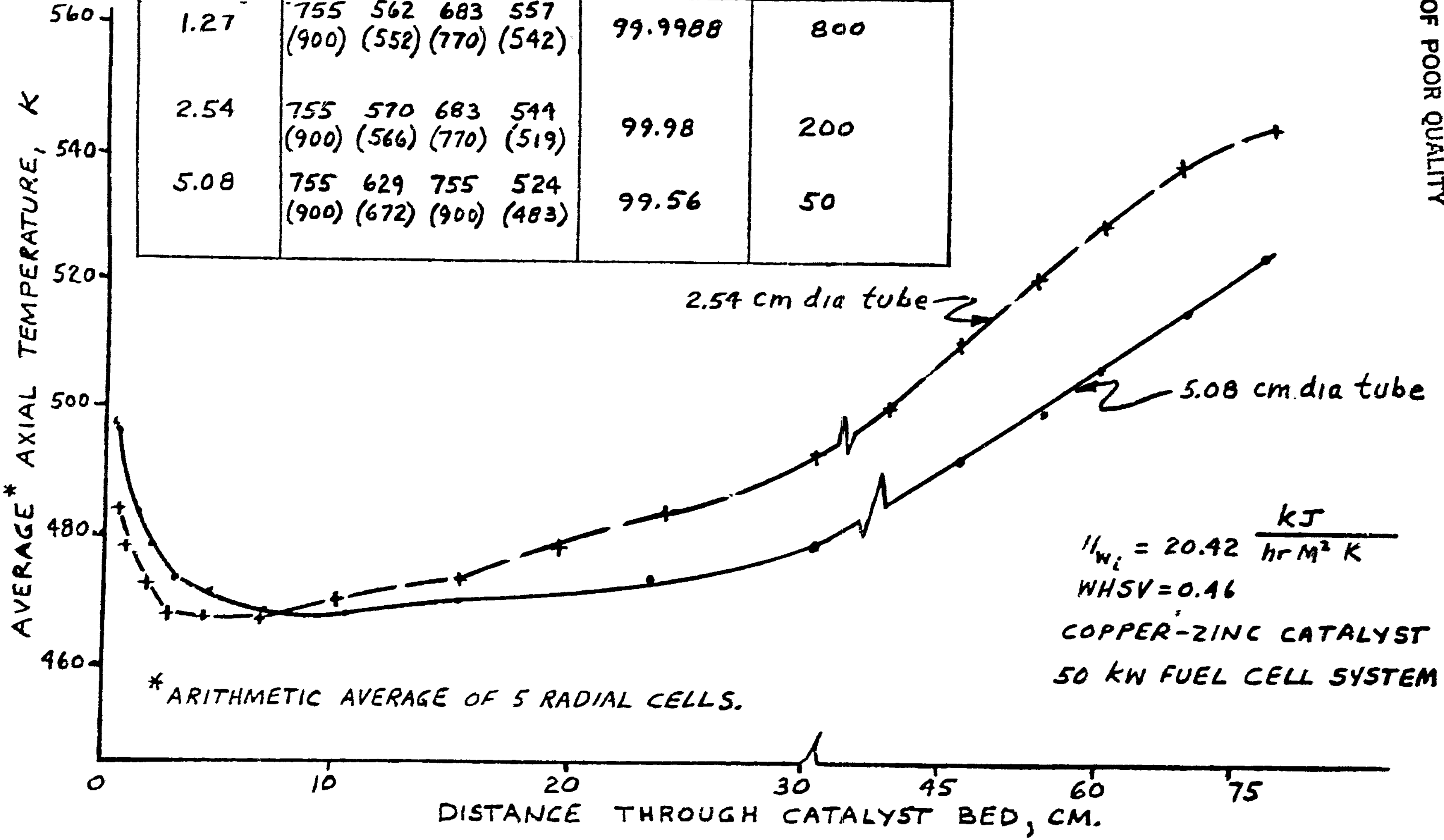

FIGURE 5 TEMPERATURE PROFILES IN SINGLE REFORMER TUBES (2-D MODEL PREDICTIONS)

J.A. WHELAN
10-1-81

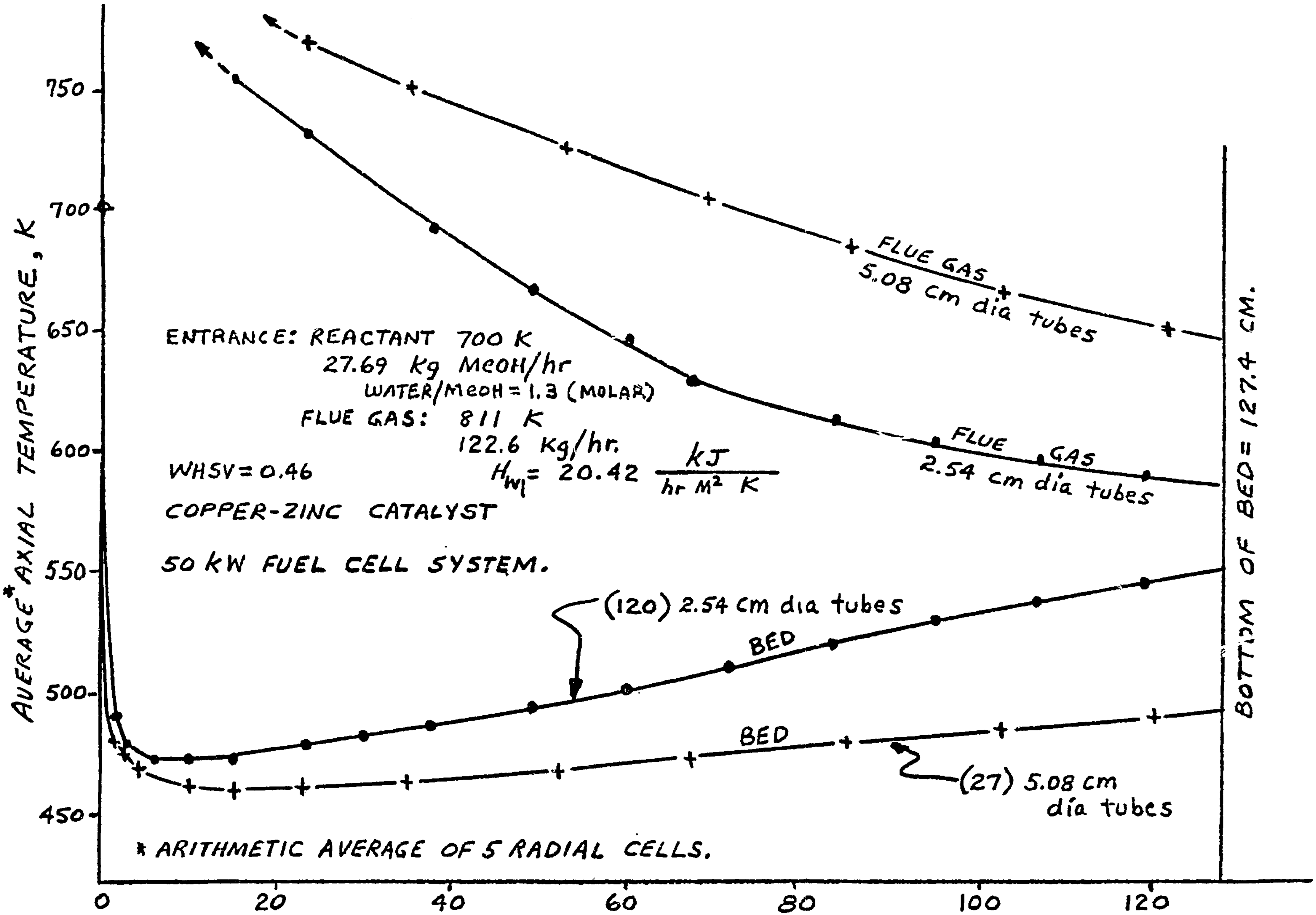

FIGURE 6 AXIAL TEMPERATURE PROFILES IN METHANOL/STEAM REFORMER. (PREDICTION BY TWO-DIMENSIONAL MATH MODEL)

J.A. WHELAN
10-26-81

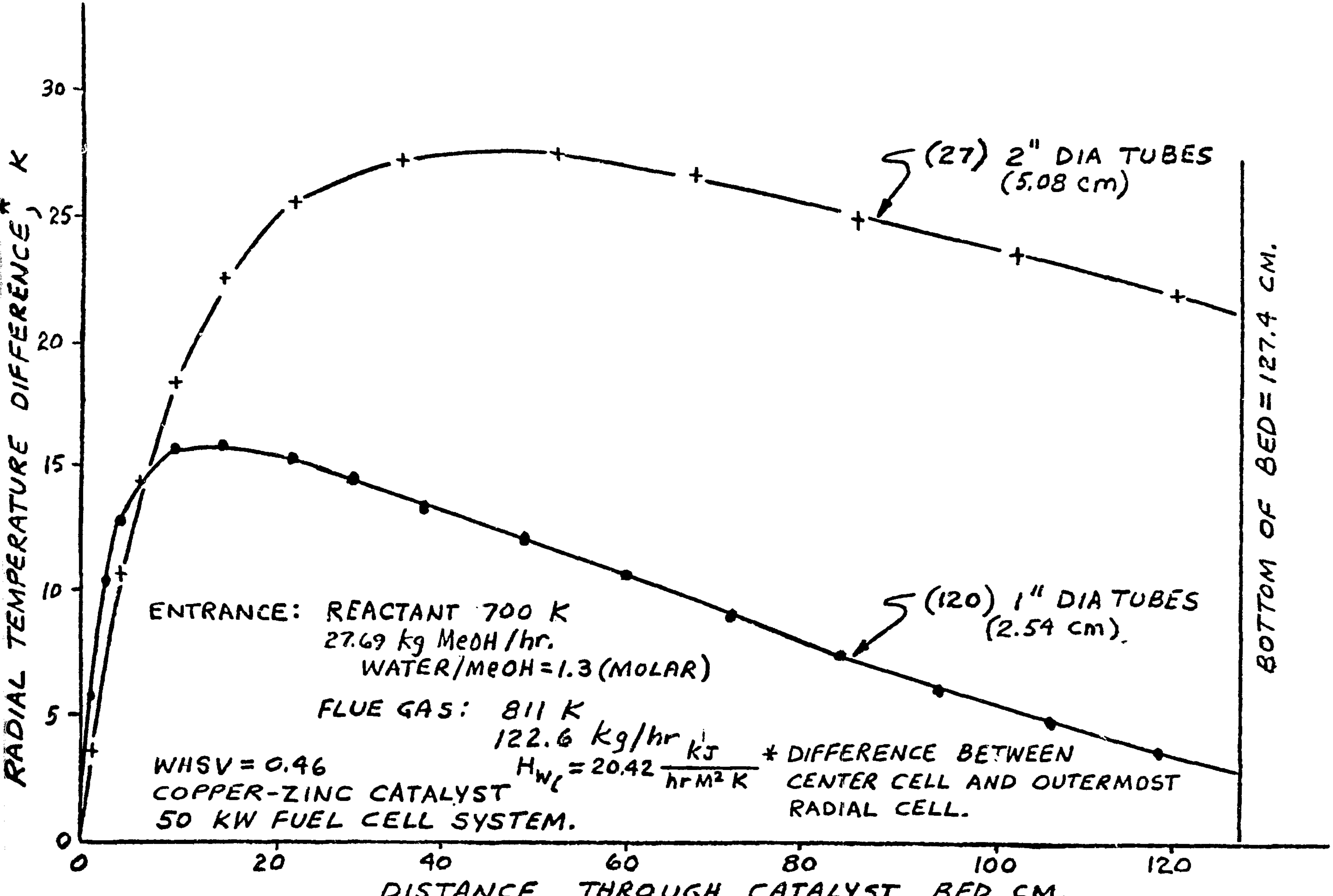

FIGURE 7 RADIAL TEMPERATURE DIFFERENCE PROFILES. IN METHANOL/STEAM REFORMER. PREDICTION BY TWO-DIMENSIONAL MATH MODEL

J.A WHELAN
10-26-81

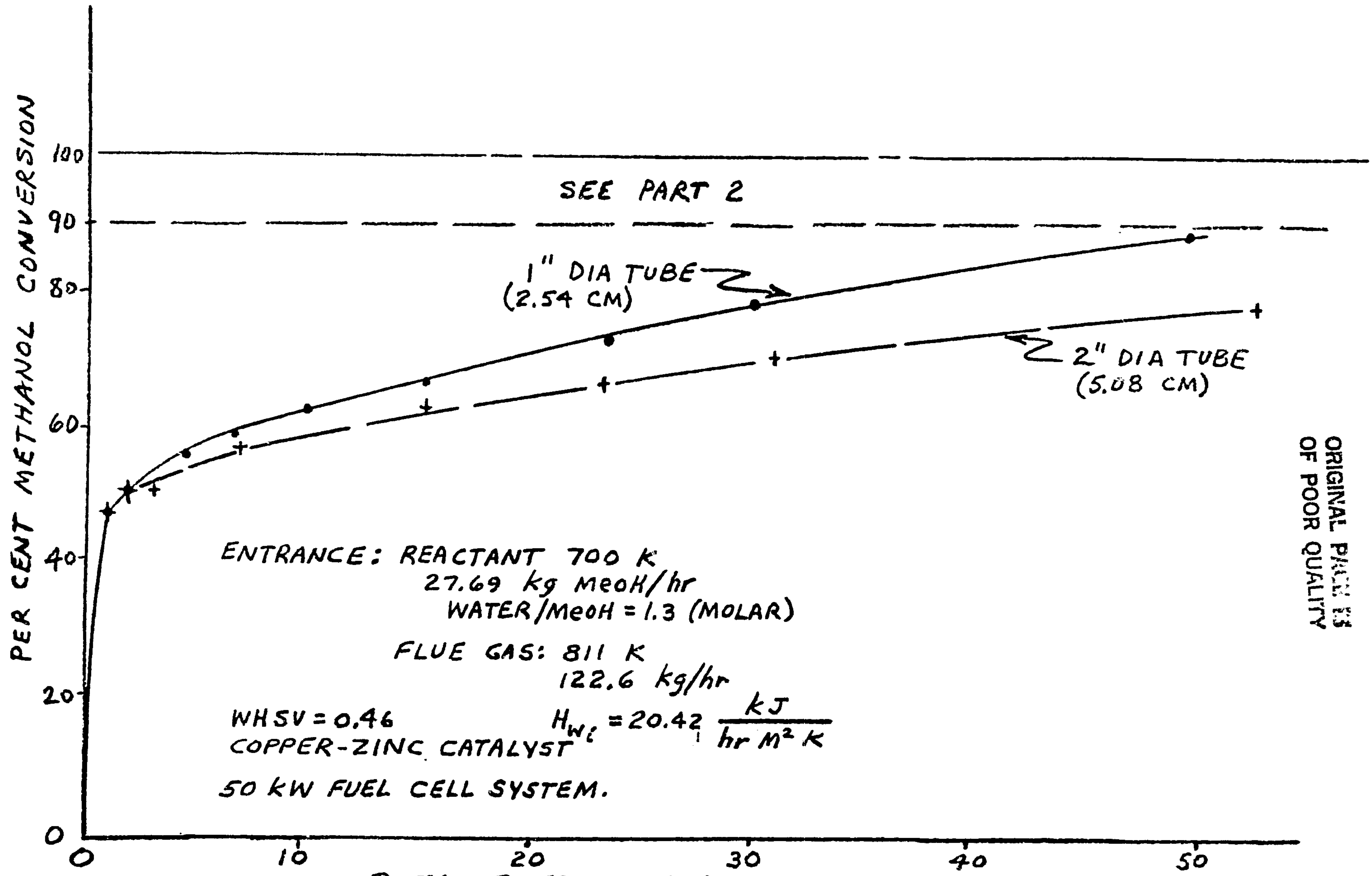

FIGURE 8 CONVERSION PROFILE IN METHANOL/STEAM REFORMER (PREDICTION BY TWO-DIMENSIONAL MATH MODEL) PART 1

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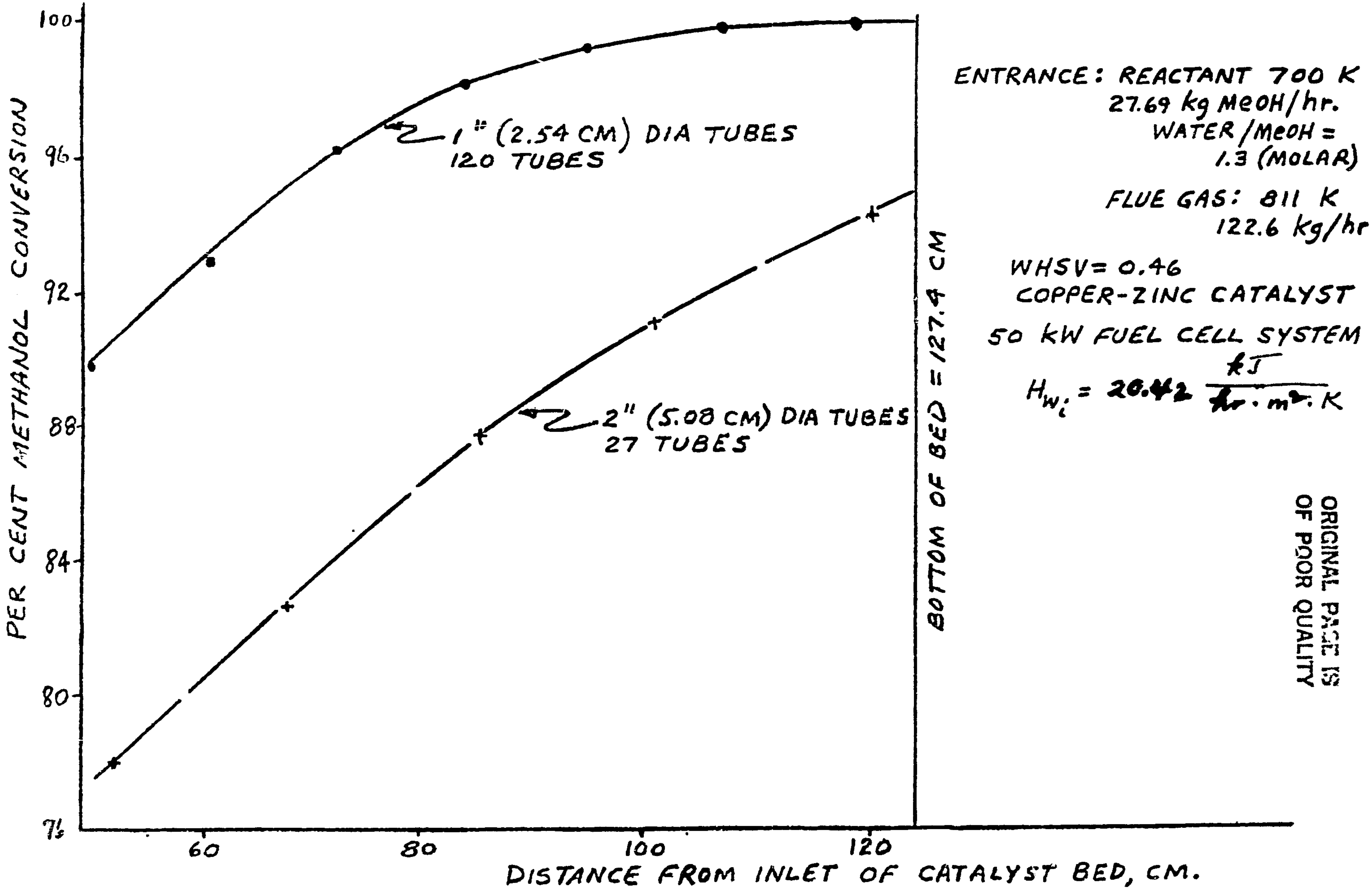

FIGURE 9 CONVERSION PROFILE IN METHANOL/STEAM REFORMER (PREDICTION BY TWO-DIMENSION MATH MODEL) PART 2.

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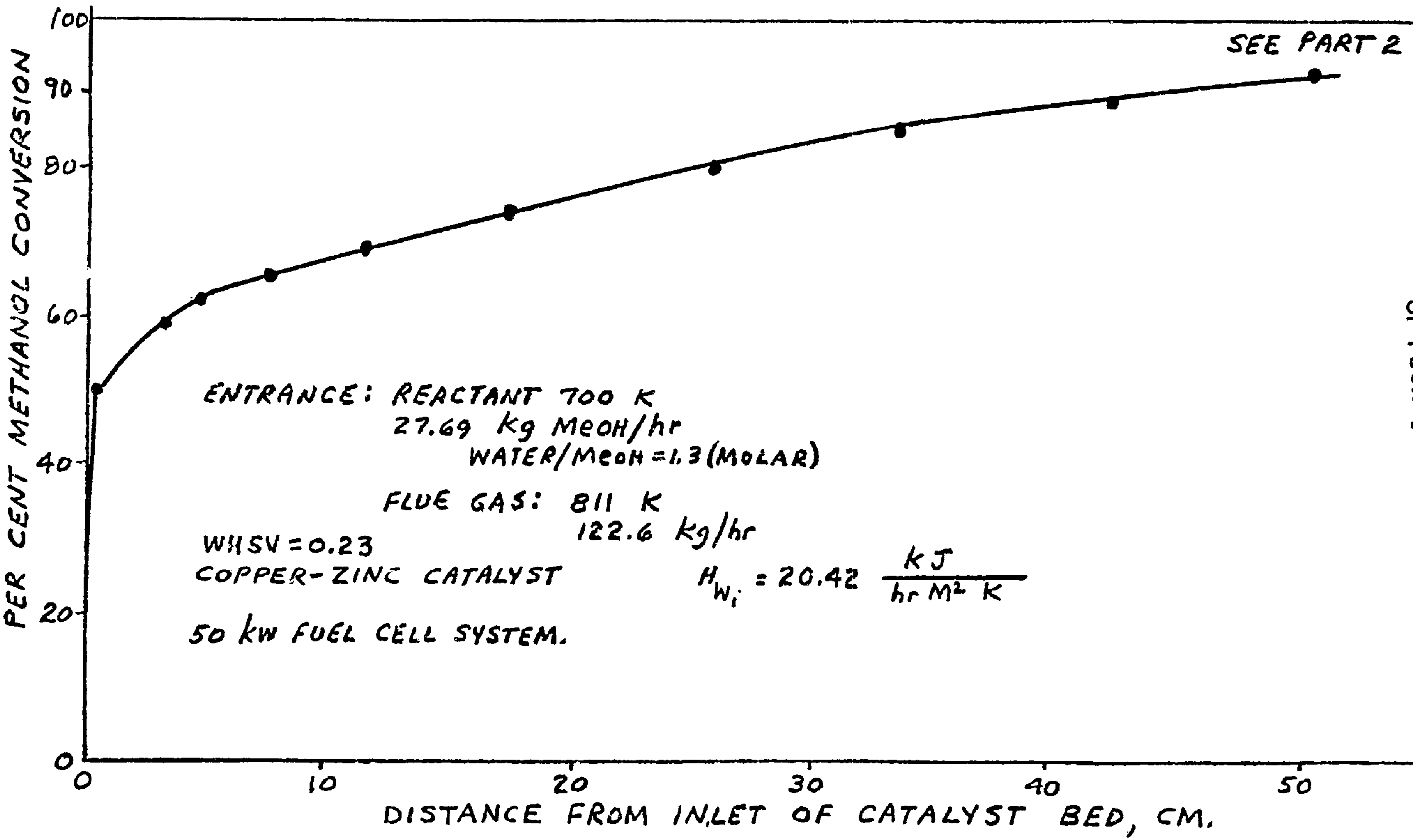

FIGURE 10 CONVERSION PROFILE IN LENGTHENED 2" (2.54 CM) TUBE METHANOL/STEAM REFORMER. (PREDICTION BY TWO-DIMENSIONAL MATH MODEL.) PART 1

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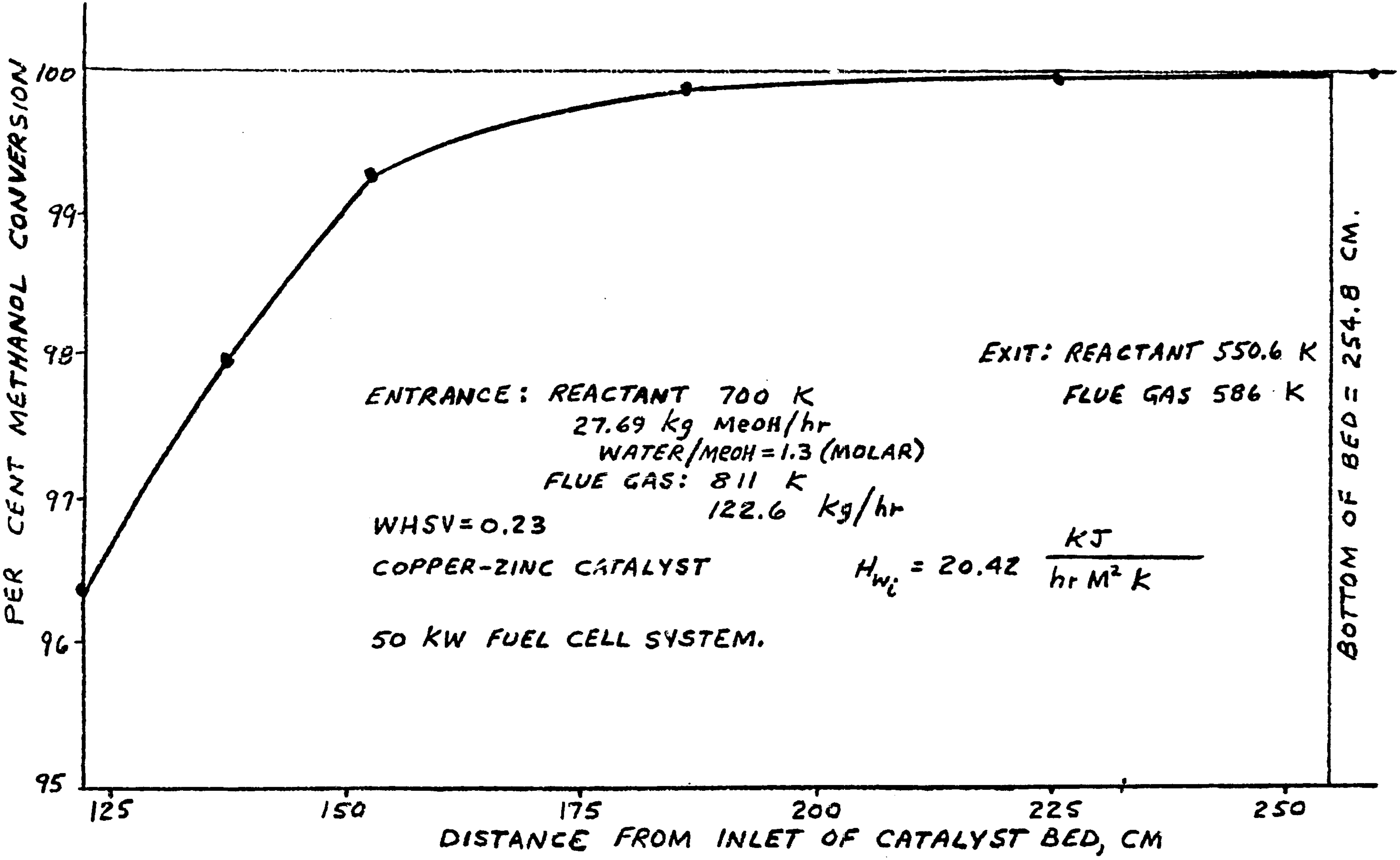

FIGURE 11 CONVERSION PROFILE IN LENGTHENED 2" (2.54CM) TUBE, METHANOL/STEAM REFORMER. (PREDICTION BY TWO-DIMENSIONAL MATH MODEL.) PART 2

J.A. WHELAN 10-30-81

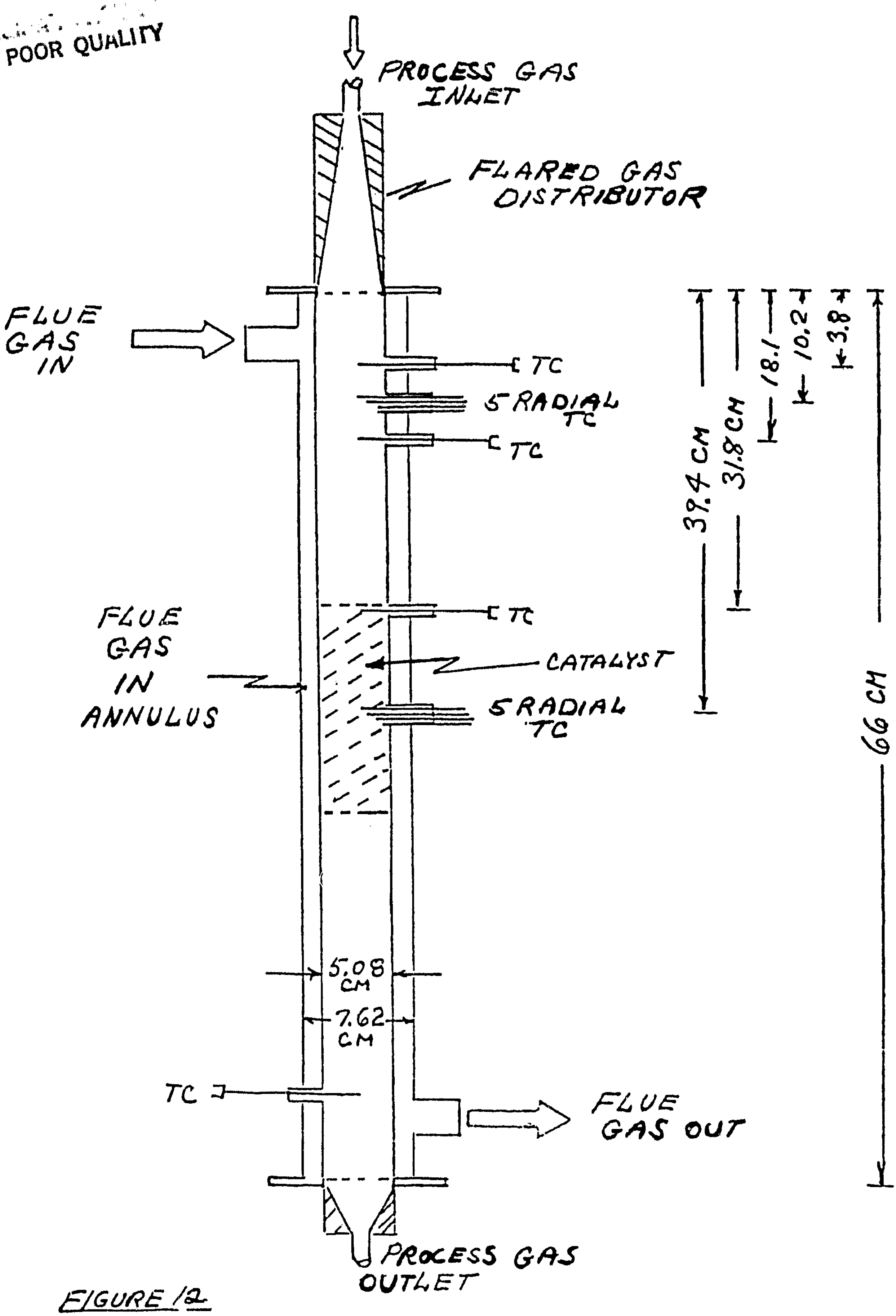

FIGURE 12

REACTOR FOR SINGLE-TUBE STUDIES

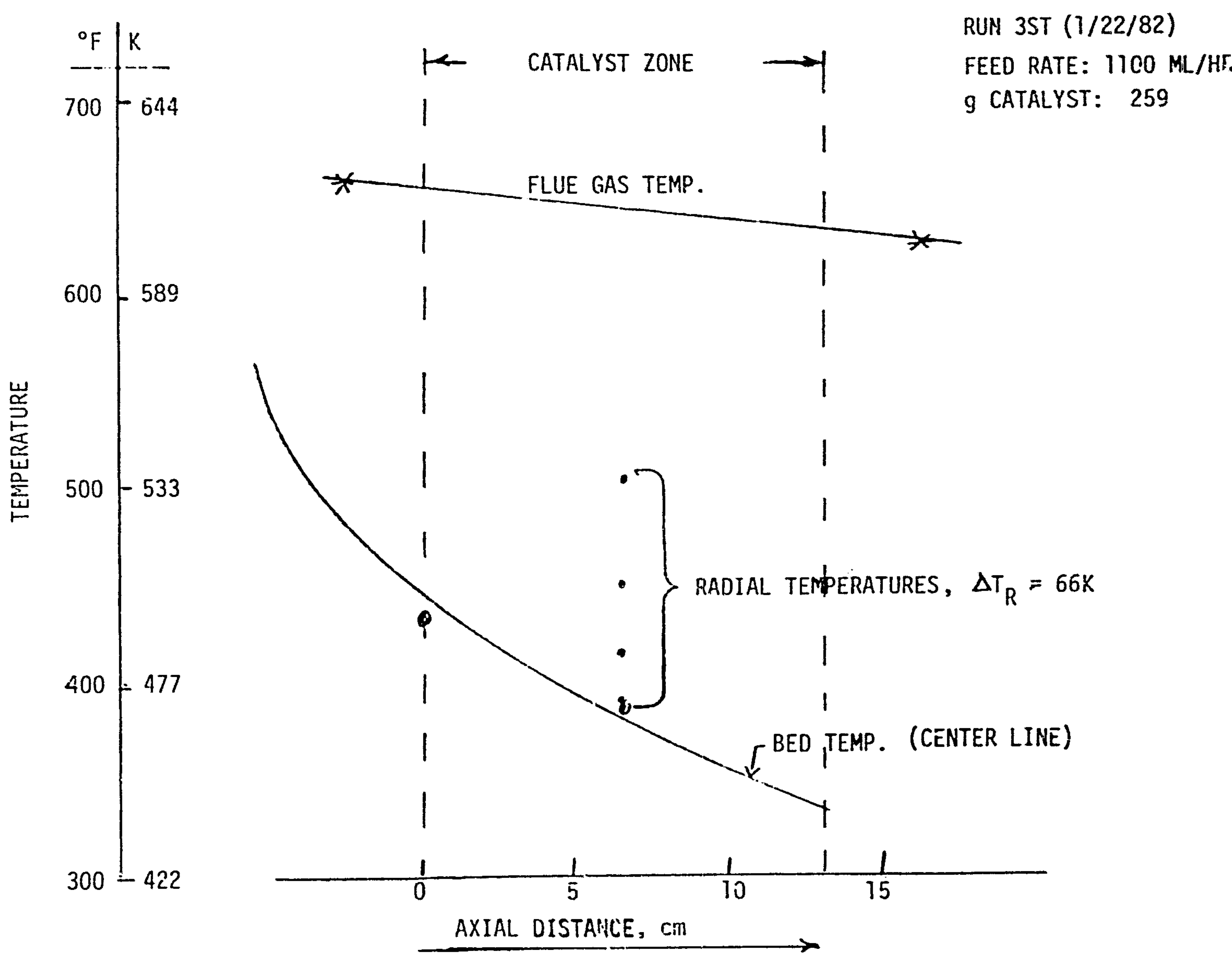

FIGURE 13 TEMPERATURE PROFILES: 50mm D. TUBE

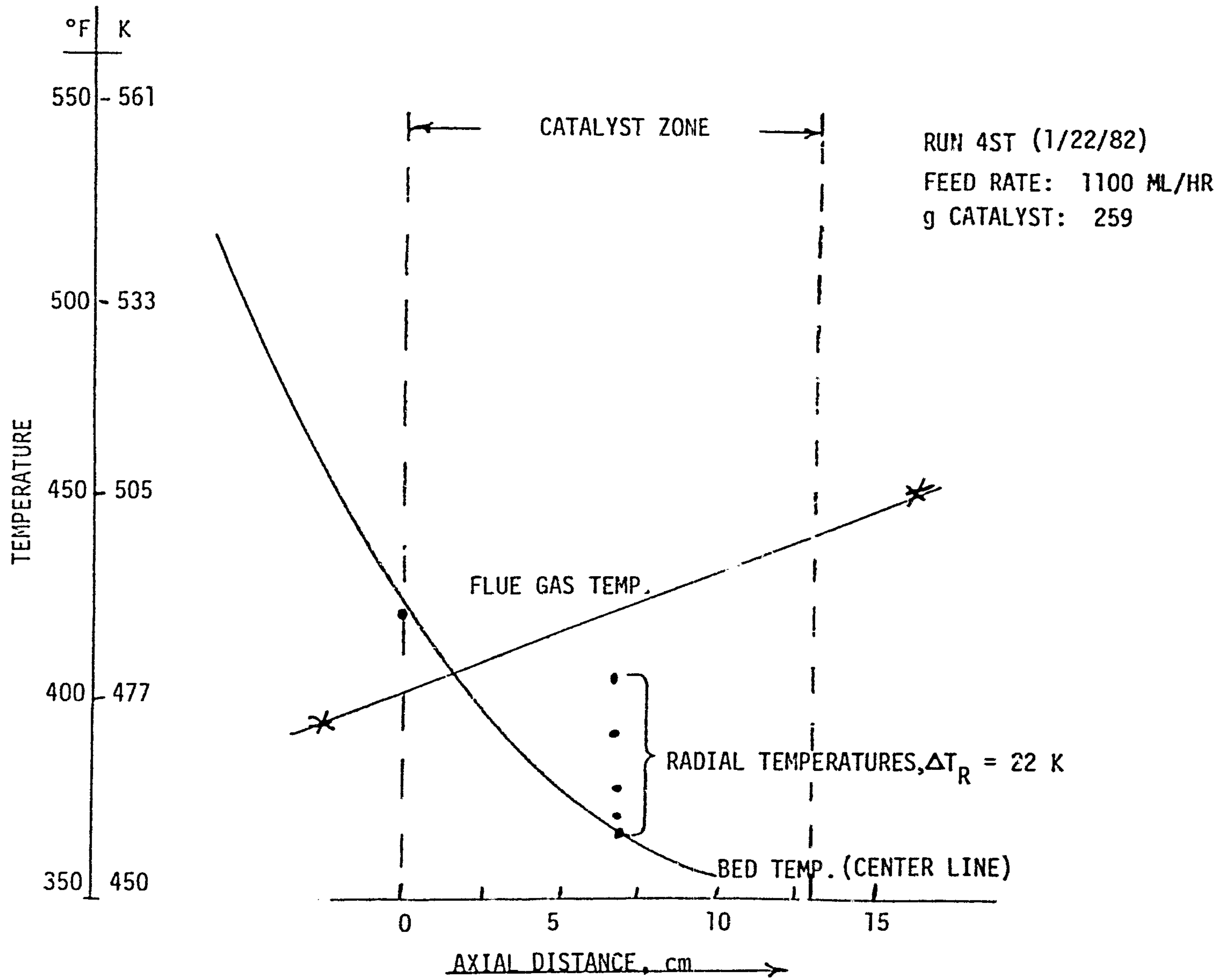

FIGURE 14 TEMPERATURE PROFILES: 50mm D. TUBE

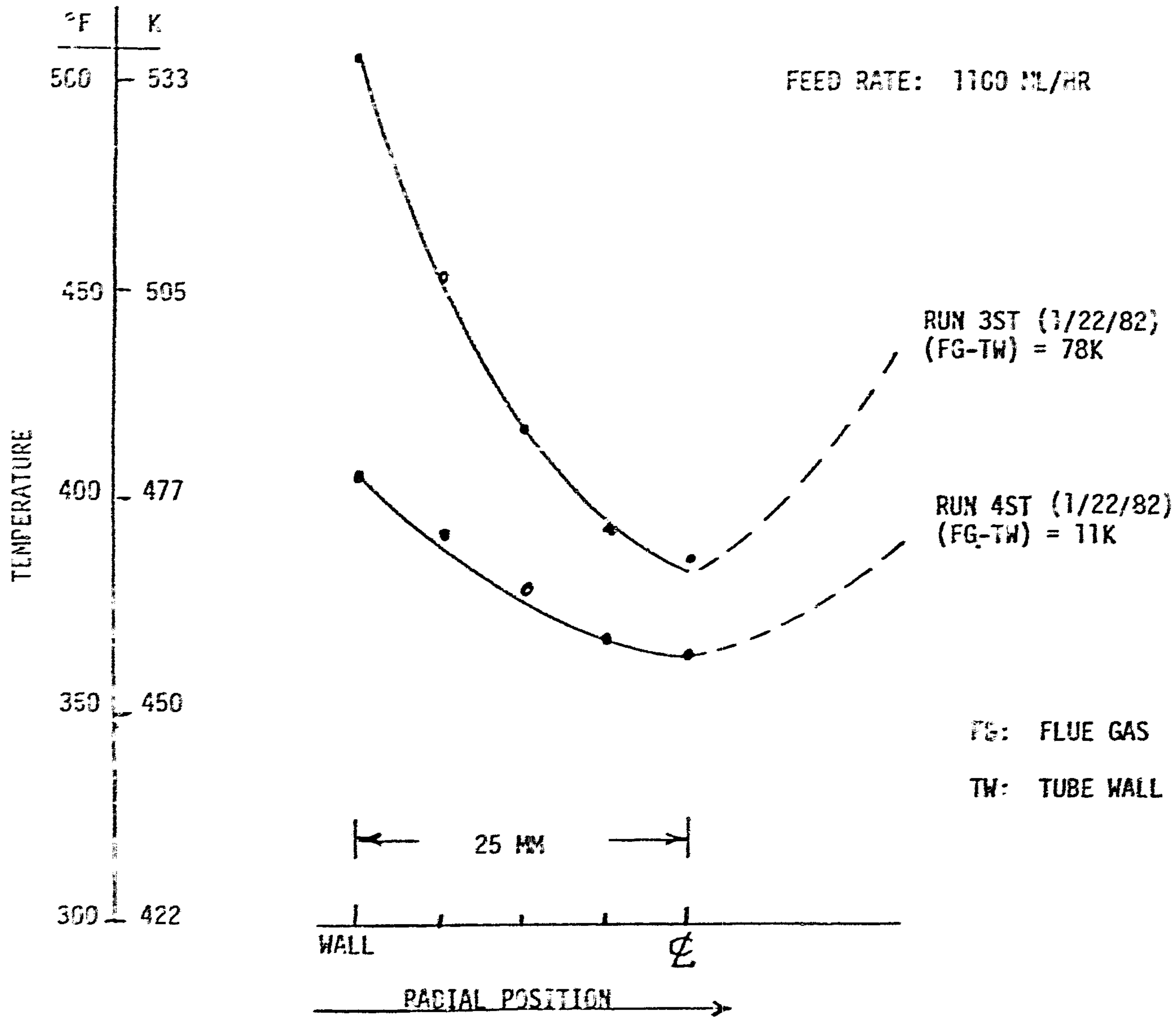

FIGURE 15 RADIAL TEMPERATURE PROFILES: 50 mm D. TUBE

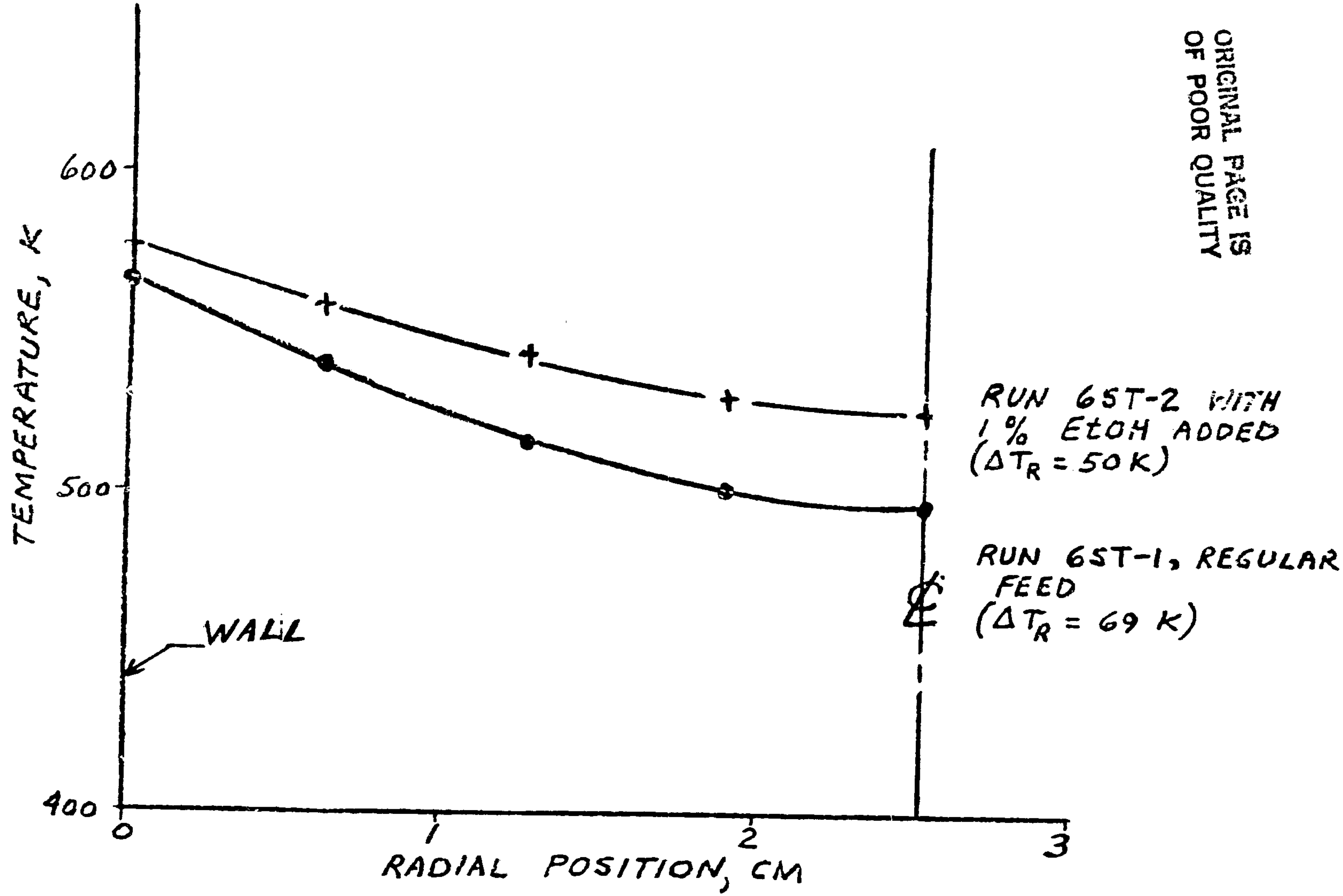

FIGURE 16 AFFECT OF ETHANOL POISONING ON RADIAL TEMPERATURE PROFILE.

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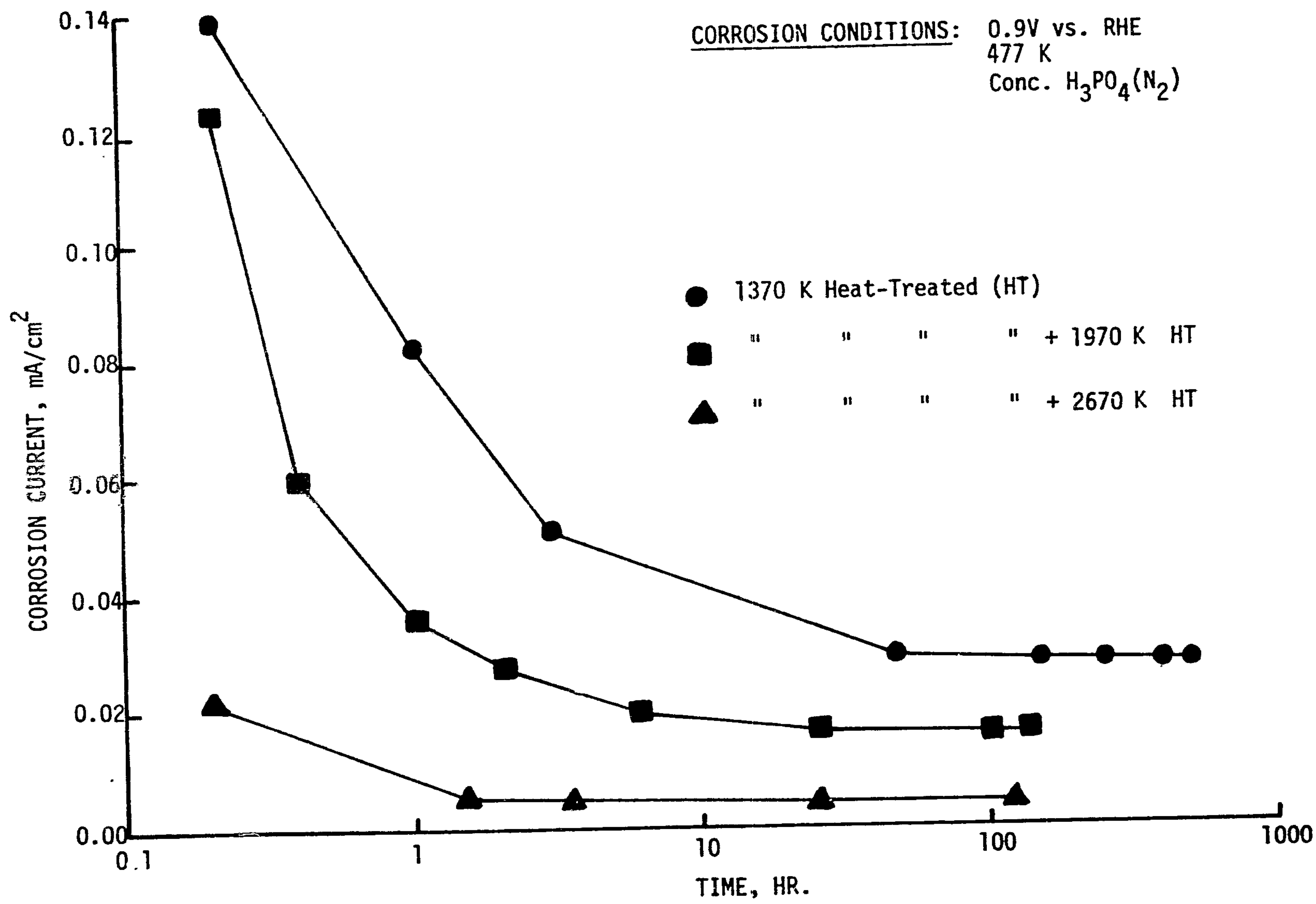

FIGURE 17 CORROSION CURRENTS OF HEAT-TREATED GRAPHITE ADHESIVE

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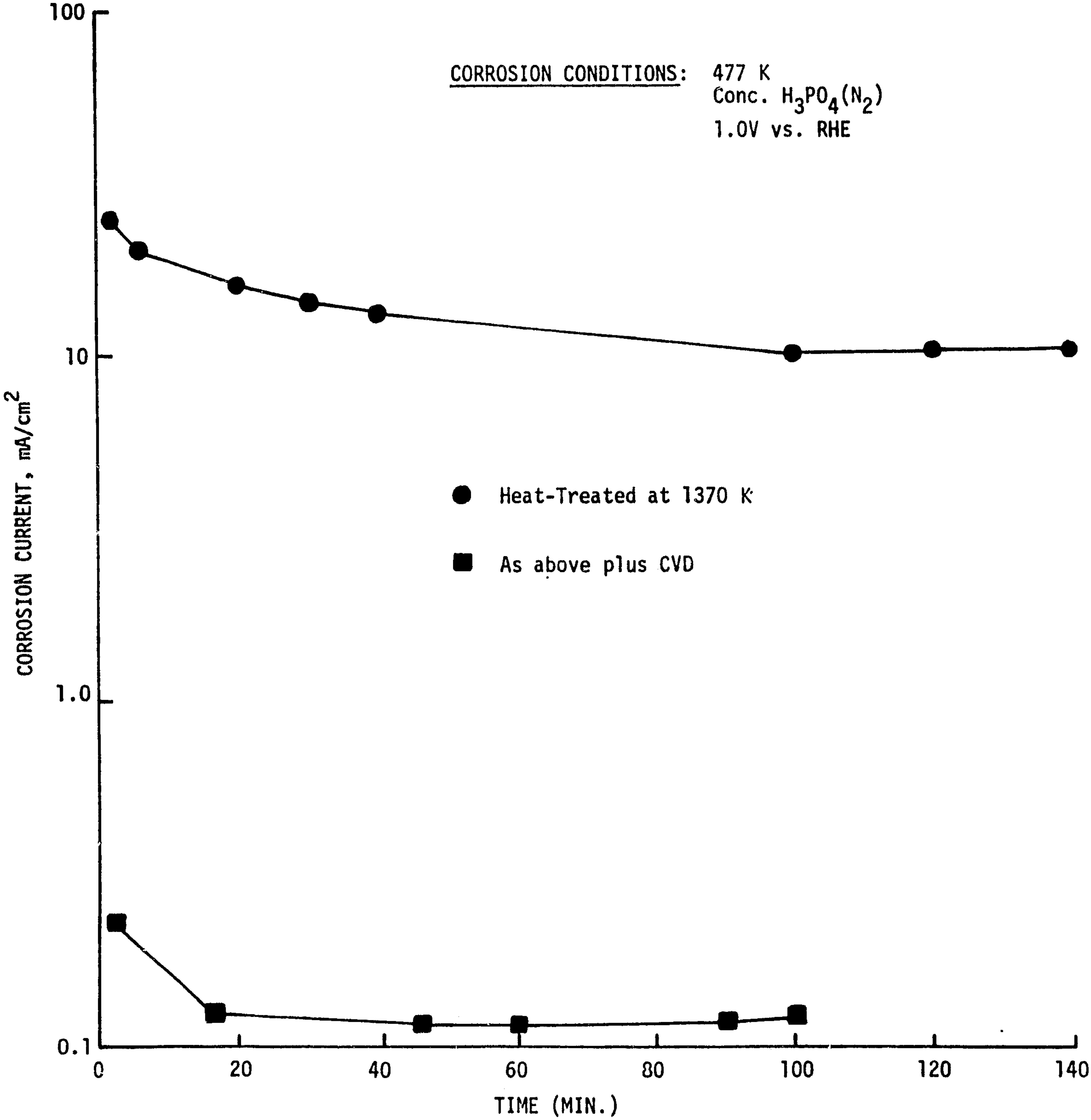

FIGURE 18 CORROSION CURRENTS OF HEAT-TREATED GRAPHITE ADHESIVE

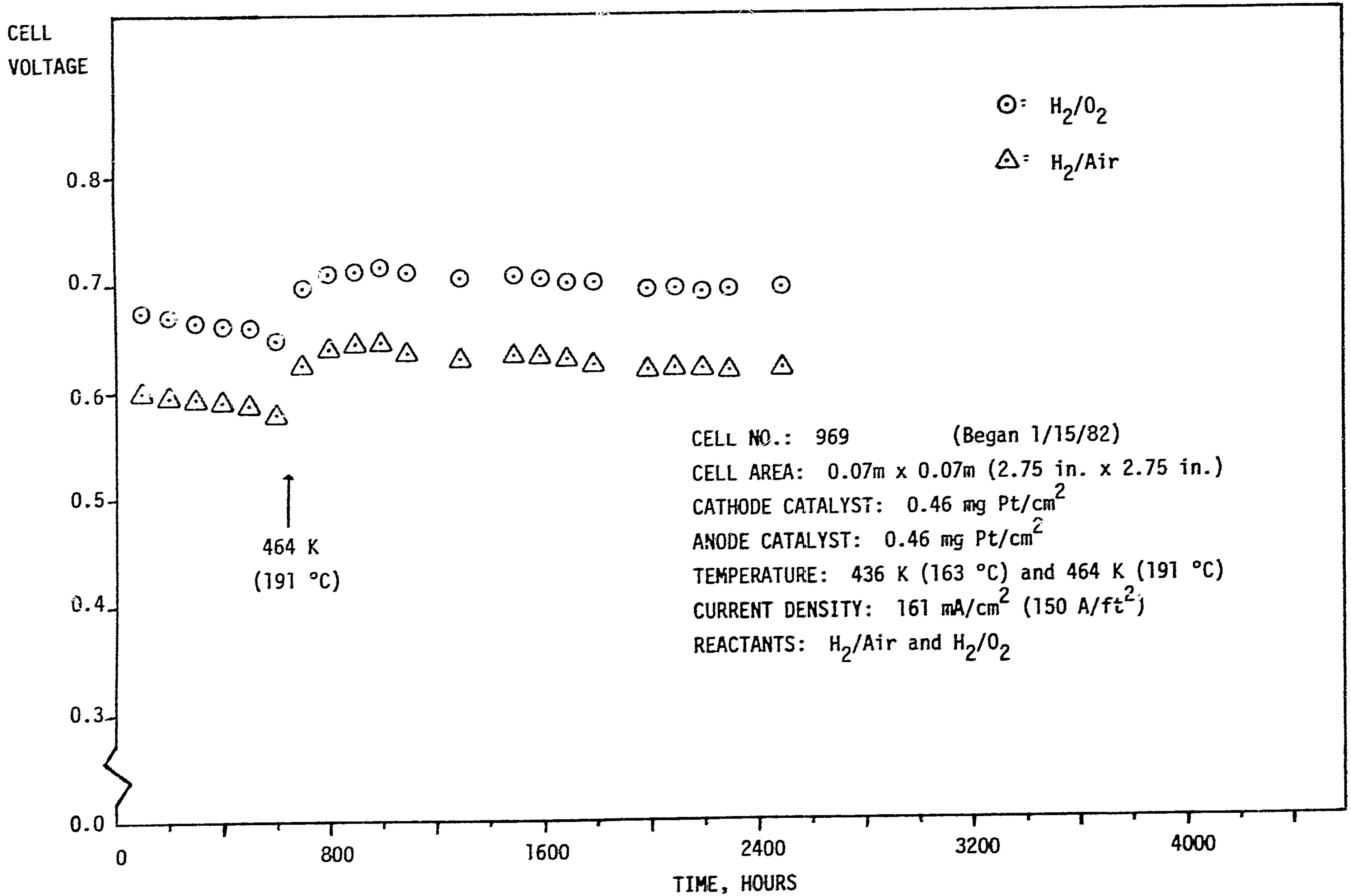

Figure 19 Voltage Stability of Single-Cell Utilizing an Electrolyte Replenishment System