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

12TH QUARTERLY REPORT: FEBRUARY - APRIL 1984

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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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RESEARCH AND DEVELOPMENT DEPARTMENT
SPECIALTY CHEMICALS DIVISION

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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 neighborhood of 40% of the lower 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 fuel.

Engelhard has successfully completed the first two phases of this program. The culmination of the pre-commercialization program will be the integration of the fuel cell system into a total energy system for multi-family residential and commercial buildings. The mandate of the current Phase III effort is to develop a full-scale 50kW breadboard power plant module and to identify a suitable type of application site. An accomplished objective in Phase III was the integration and testing of the 5kW system whose components were developed during Phase II. In addition to the development and testing of this sub-scale system, scale-up activities have been carried out under Phase III. Throughout this program, continuing technology development activity will be maintained to assure that the performance, reliability, and cost objectives are attained.

SECTION II. TECHNICAL PROGRESS SUMMARY

TASK I - 5kW POWER SYSTEM DEVELOPMENT

The objective of this task was to complete integration of the 5kW components and sub-systems developed during Phase II.

Steady-load testing of the 5kW integrated system, with regular shutdowns, was completed during August 1983. Subsequently, load-following testing was carried out successfully, as the system was operated in the fully-automatic mode. (See the August-October 1983 Quarterly Report.)

Further testing of this integrated system will be conducted as time permits.

TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS

The purpose of this task was to develop an application model for on-site integrated energy systems. The model considers fuel availability, 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 was carried out under subcontract by Arthur D. Little, Inc. (ADL), and this work has been completed. The main conclusions are summarized in the May-July 1983 Quarterly Report.

TASK III - ON-SITE SYSTEM DEVELOPMENT

This task forms the core of the Phase III contract effort. 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 units, while the 50kW fuel cell will comprise two 25kW stacks. This task is accordingly broken down into four sub-tasks as follows:

III-1. Large Stack Development
III-2. Large Fuel Processor Development
III-3. Overall System Analysis
III-4. Overall System Design and Development

The 1984 activities under this contract will focus on Sub-Task III-1. Further effort on the other sub-tasks will be carried out under private sponsorship.

A. LARGE STACK DEVELOPMENT

Preparations for 1984 Stack No. 1 are nearing completion, and assembly will take place in early May. This stack will comprise 25 cells of the 13 inch x 23 inch size and six non-metallic cooling plates, spaced at five-cell intervals and at the ends of the stack. The stack will be operated in the shutdown/start-up mode throughout most of 1984.

B. LARGE FUEL PROCESSOR DEVELOPMENT

Test activity for the 50kW fuel processing sub-system is currently in abeyance. This activity will be resumed later in 1984 in conjunction with the 25kW stack test program.

SECTION II. - CONTINUED

C. OVERALL SYSTEM ANALYSIS

The Physical Sciences Inc. subcontract has been completed. Final reports involving the off-design and transient analysis portions of the work have been received. The corresponding computer modules have been integrated into the overall fuel cell system program, and these have been successfully utilized in-house.

D. OVERALL SYSTEM DESIGN AND DEVELOPMENT

The Trane Co. has completed work under its subcontract to Engelhard. The main conclusions of Trane's study with respect to the HVAC sub-system and the utilization of waste heat are summarized in the May-July 1983 Quarterly Report.

TASK IV - STACK TECHNOLOGY

The purpose of this task, which will continue throughout the contract, is to investigate new materials and component concepts through bench-testing and stack trials. The criteria for selecting activities under this task are the prospects for improved performance, reduced costs, or improved reliability. Improvements in the performance of electrocatalysts, generated under Engelhard-sponsored Task VI, will be reported under Task IV.

A. PERFORMANCE OPTIMIZATION

CATALYSTS

Larger batches (750g.) of developmental cathode catalysts E-3 and E-7 were prepared for use in the 1984 stack series. Single-cell qualification tests have been conducted on portions of these catalyst batches.

Two cathodes with this latest E-3 catalyst are currently under test. Both are showing performance levels at or near that expected for E-3. This is illustrated in Figures 1 and 3 for cells that have run about 1000 hours and 850 hours, respectively. The corresponding voltage-current performance curves are shown in Figures 2 and 4, respectively.

Two cathodes with the latest E-7 catalyst have also been tested. These, too, have shown performance reasonably in keeping with that obtained earlier for smaller batches. The steady-load performance is shown in Figures 5 and 7 for cells that have run about 200 hours and 800 hours, respectively. The corresponding voltage-current performance curves are shown in Figures 6 and 8, respectively.

Performance comparison between cathode catalysts E-1 (baseline) and E-7 continues to be provided through the on-going testing of 1983 Stack No. 3. Figure 9 indicates that, on average, the performance differential (about 15mV in favor of E-7) continues to hold through more than 2600 hours of operation. (The gap actually appears to be widening, but this is for the most part due to anomalous losses in the bottom cell, possibly reflecting corrosion at the current-collecting plate interface.)

REDUCED CELL IR-LOSS

Stack No. 4 was built at the end of January to evaluate a cell configuration that had provided reduced IR-loss in single-cells (2.75 in. x 2.75 in. and 10.7 in. x 14 in.). The cell configuration entailed a modification of the electrolyte-matrix, and the details of the modification are presented in the Appendix.

Stack No. 4 started on test with each of the 10 cells (10.7 in. x 14 in.) performing reasonably well, but three of these cells showed signs of serious electrolyte deficiency after three days of operation. The stack had to be shut down shortly thereafter.

A "rebuild" of 1983 Stack No. 4 has been carried out, and testing was started as of the end of March. As in the original build, this stack comprises cells with electrolyte-matrix configurations that are modified in order to attain lower IR-loss (see Appendix). The rebuild involves altered procedures that are primarily related to sustaining electrolyte inventory in the matrix through the first few days, during which time the demand for acid by other cell components is greatest.

Although the start-up of this stack was more successful than that of the original build, two of the 10 cells were particularly weak, apparently due once again to electrolyte deficiency. Because of this, operation at the normal current density (161mA/cm^2) was delayed.

The stack was run at low current density (54mA/cm^2) and on hot-stand by (120°C, no load) throughout most of April. The two weak cells improved over this period, and full load was applied during the last week of the month. These cells remain very low in voltage (less than 0.5V), but there appear to be signs of further slow improvement. The open-circuit voltage of the stack overall has been acceptable, though erratic, to date as shown in Figure 10.

Some progress has been achieved with this stack in the area of cell IR-loss. The individual cells range from 30 to 36mV IR-loss at 161mA/cm^2, an improvement of about 15mV compared to a typical stack.

Testing at the normal load will be continued into May. The behavior of the two weak cells will be closely monitored, and the effect of the modified cell configuration on overall stability characteristics will start to be determined.

New approaches to IR-loss reduction are also under test in single-cells. Two approaches that have shown encouraging results in the early stages of testing (24-26mV IR-loss @ 161mA/cm^2) are described in the Appendix.

B. COST REDUCTION

LARGER CELL SUB-STACKS BETWEEN COOLING PLATES

In light of the satisfactory thermal profiles obtained using five cells per cooling plate in 1983 Stacks No. 2 and No. 3, this approach will be adopted for the 1984 stack series (see Section C., below).

C. RELIABILITY

AUTOMATED ELECTROLYTE-REPLENISHMENT SYSTEM

1983 Stack No. 3 continues to operate with the automated electrolyte-replenishment system that had been successfully demonstrated in 1983 Stack No. 1. This system is also performing successfully to date in Stack No. 3. This is illustrated in Figure 11, which shows the open-circuit voltage stability of this stack.

NON-METALLIC COOLING PLATES

Stack No. 3 (11-cell, 10.7 in. x 14 in.) continues to operate successfully with non-metallic cooling plates (see above). The steady-load performance history to date (over 2600 hours) is shown in Figure 12.

The heat-transfer performance of the non-metallic cooling plates has exceeded the goals that were established for this component. Under realistic operating conditions (see Figures 13 and 14) the effective temperature difference (log mean) from the cooling fluid to the adjacent cell element is only 9.4°F, compared to the goal of 18°F. The corresponding overall heat transfer coefficient is 116 Btu/hr-ft^2-°F, compared to the goal of 60 Btu/hr-ft^2-°F.

TASK V - FUEL PROCESSING SUPPORT

The intent of this task was 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.

TASK VI - IMPROVED ELECTROCATALYSTS

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

Development work is being pursued on both cathode and anode catalysts; however, the major activity at the present time is directed toward improved cathode activity (see Task IV).

SECTION III. CURRENT PROBLEMS

NONE.

SECTION IV. WORK PLANNED

TASK IV - STACK TECHNOLOGY

- Initiate testing of 1984 Stack No. 1.

- Continue evaluation of non-metallic cooling plates in 1983 Stack No. 3.

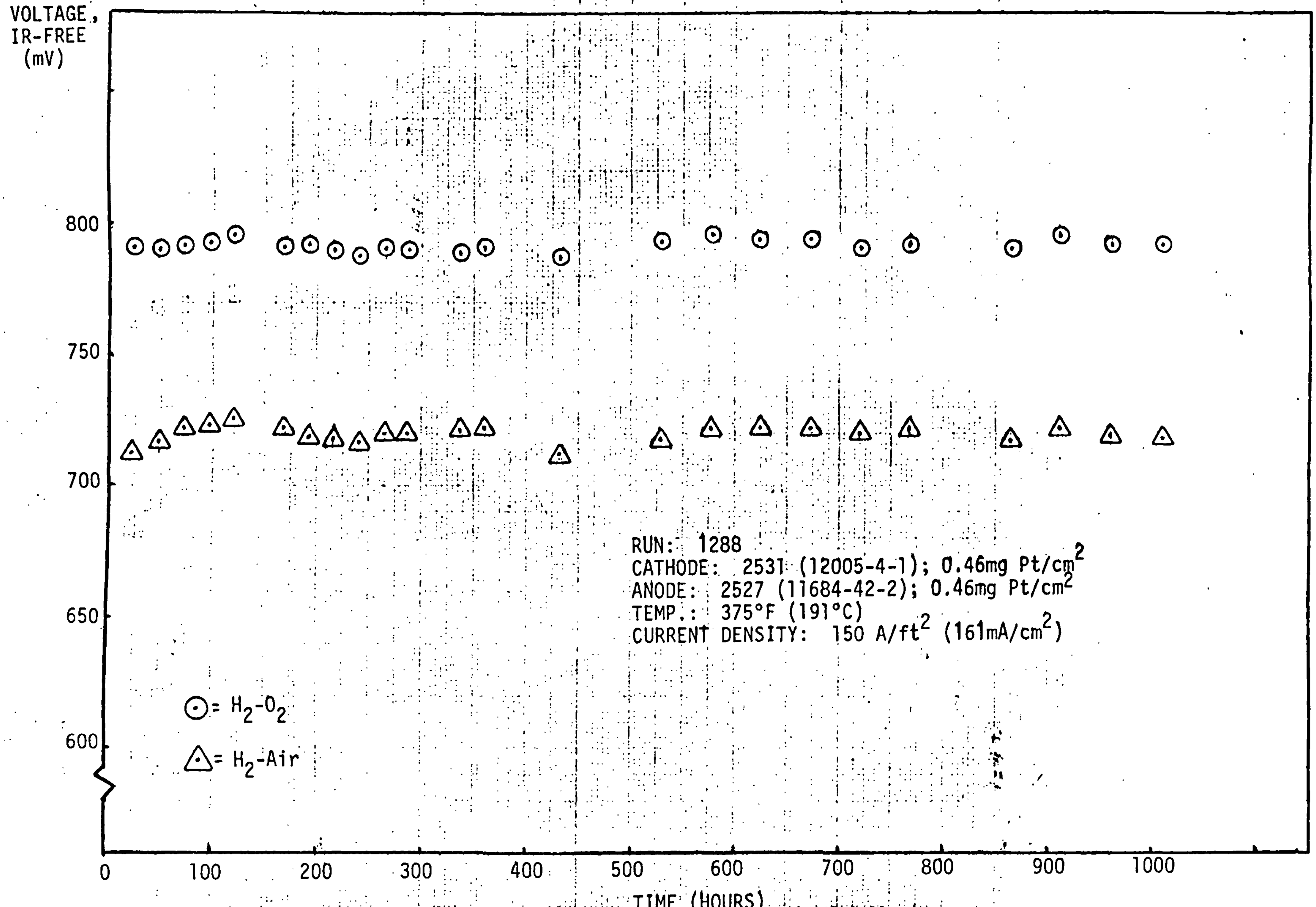


FIGURE 1 STEADY-LOAD PERFORMANCE OF SINGLE-CELL UTILIZING E-3 CATHODE CATALYST

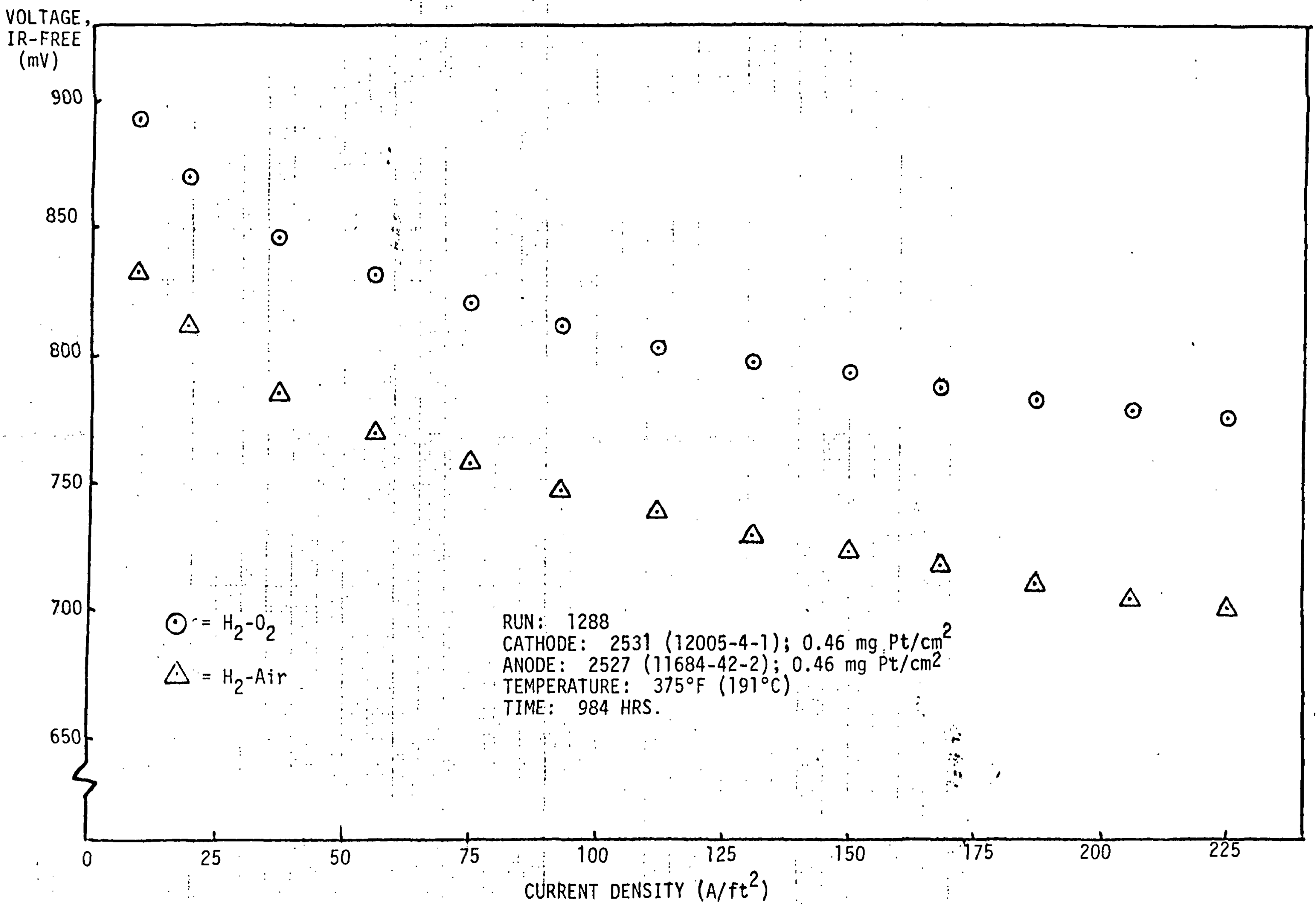


FIGURE 2 PERFORMANCE OF SINGLE-CELL UTILIZING E-3 CATHODE CATALYST

SKS 5-

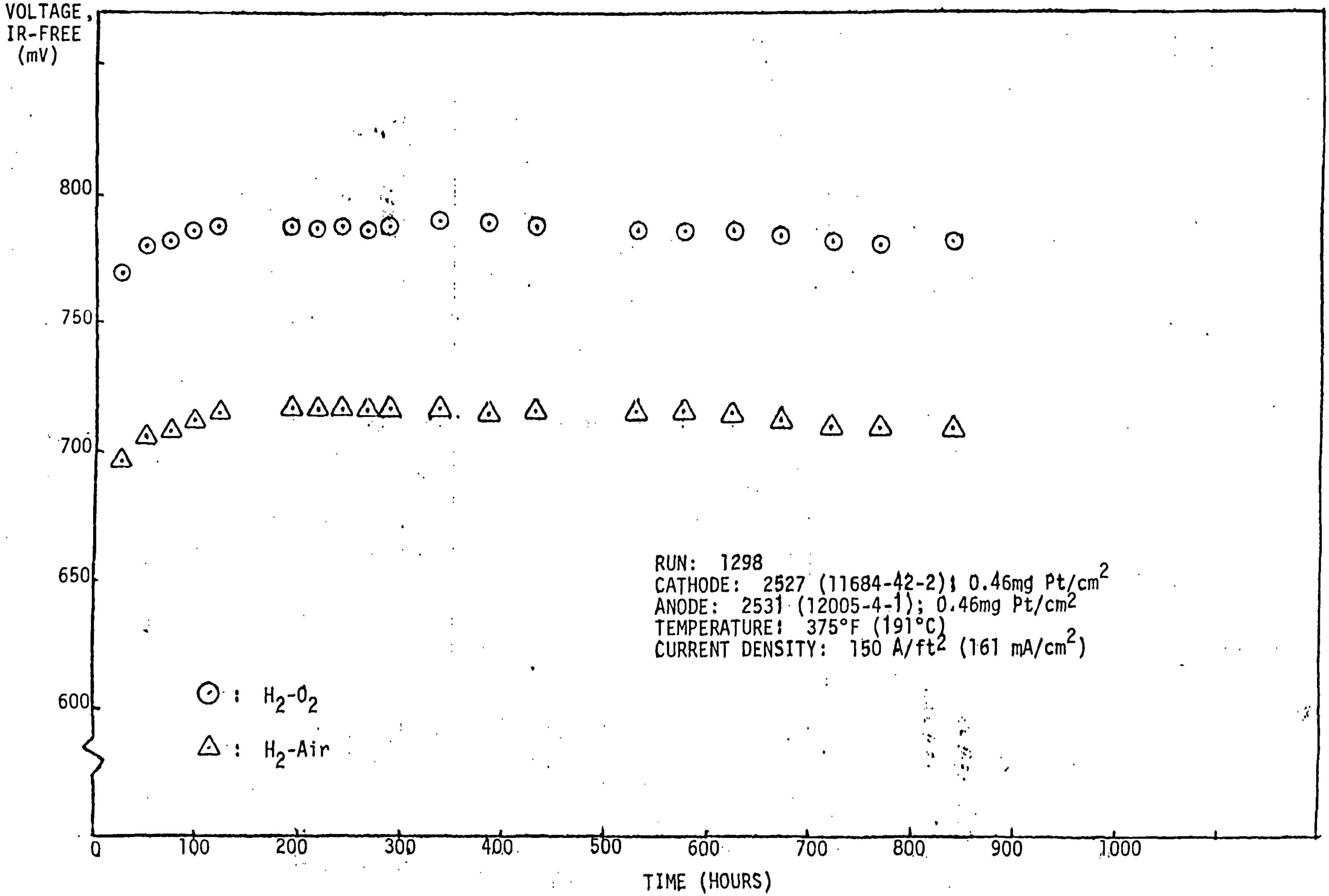


FIGURE 3 STEADY-LOAD PERFORMANCE OF SINGLE-CELL UTILIZING E-3 CATHODE CATALYST

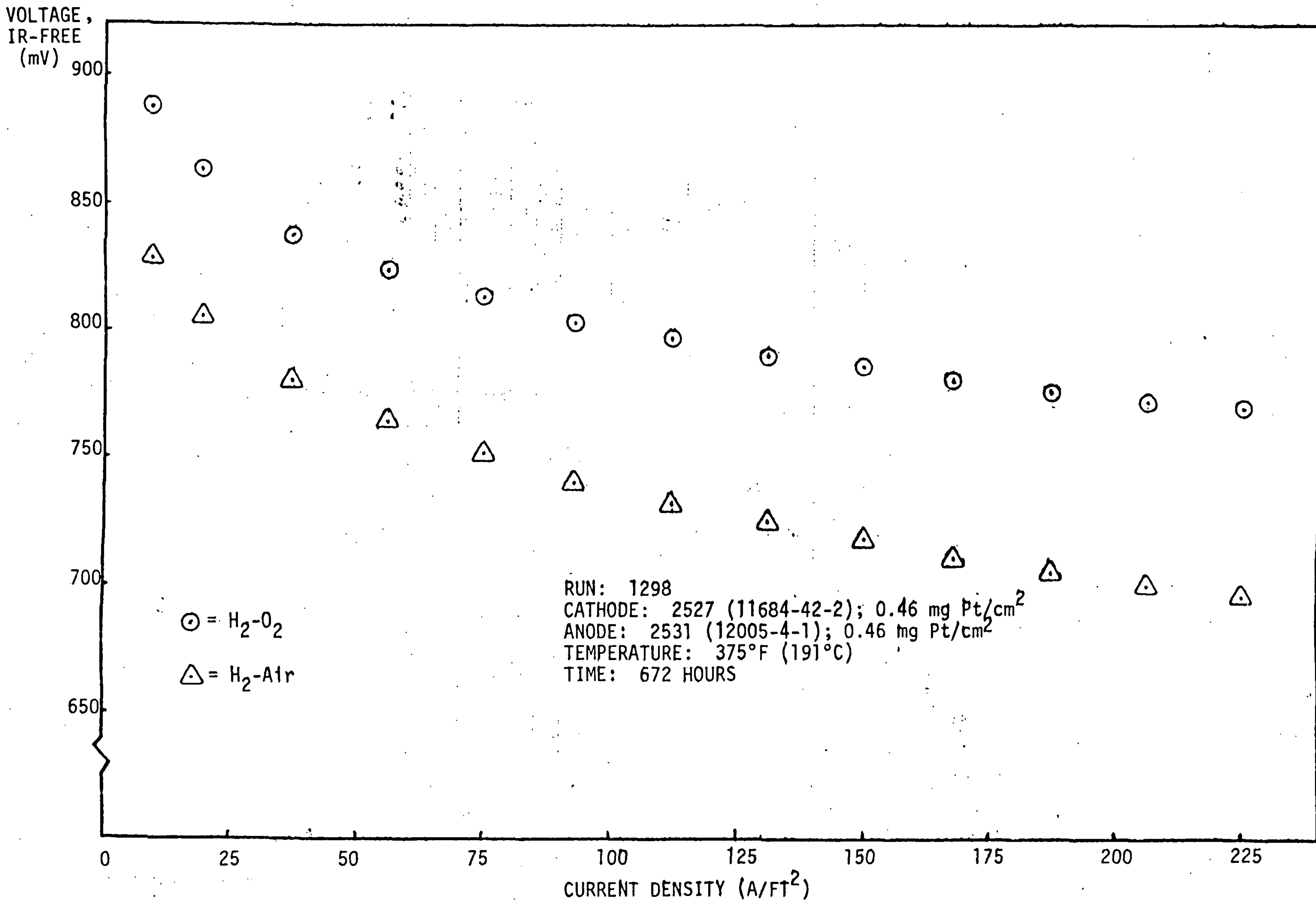


FIGURE 4 PERFORMANCE OF SINGLE-CELL UTILIZING E-3 CATHODE CATALYST

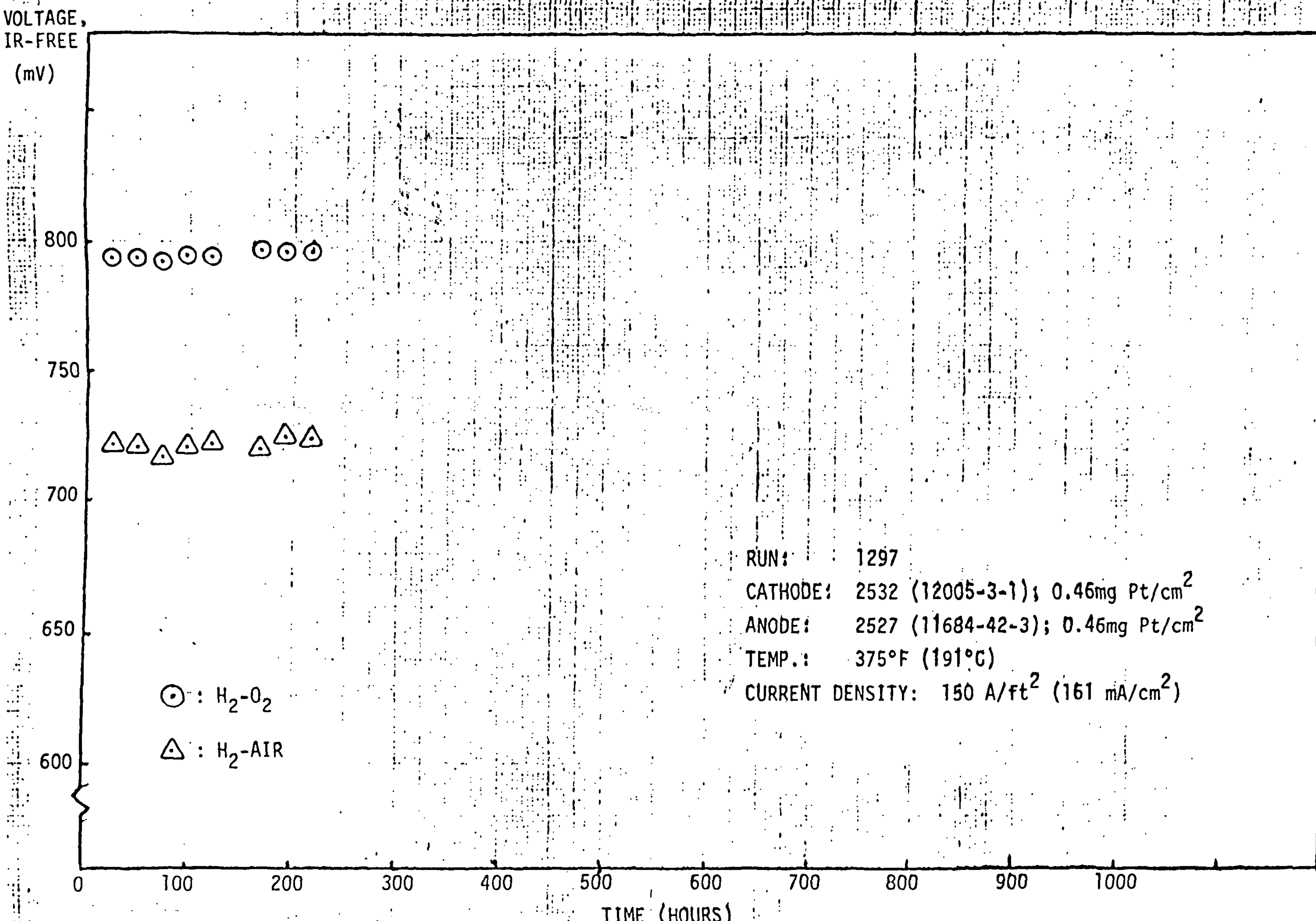


FIGURE 5 STEADY-LOAD PERFORMANCE OF SINGLE-CELL UTILIZING E-7 CATHODE CATALYST

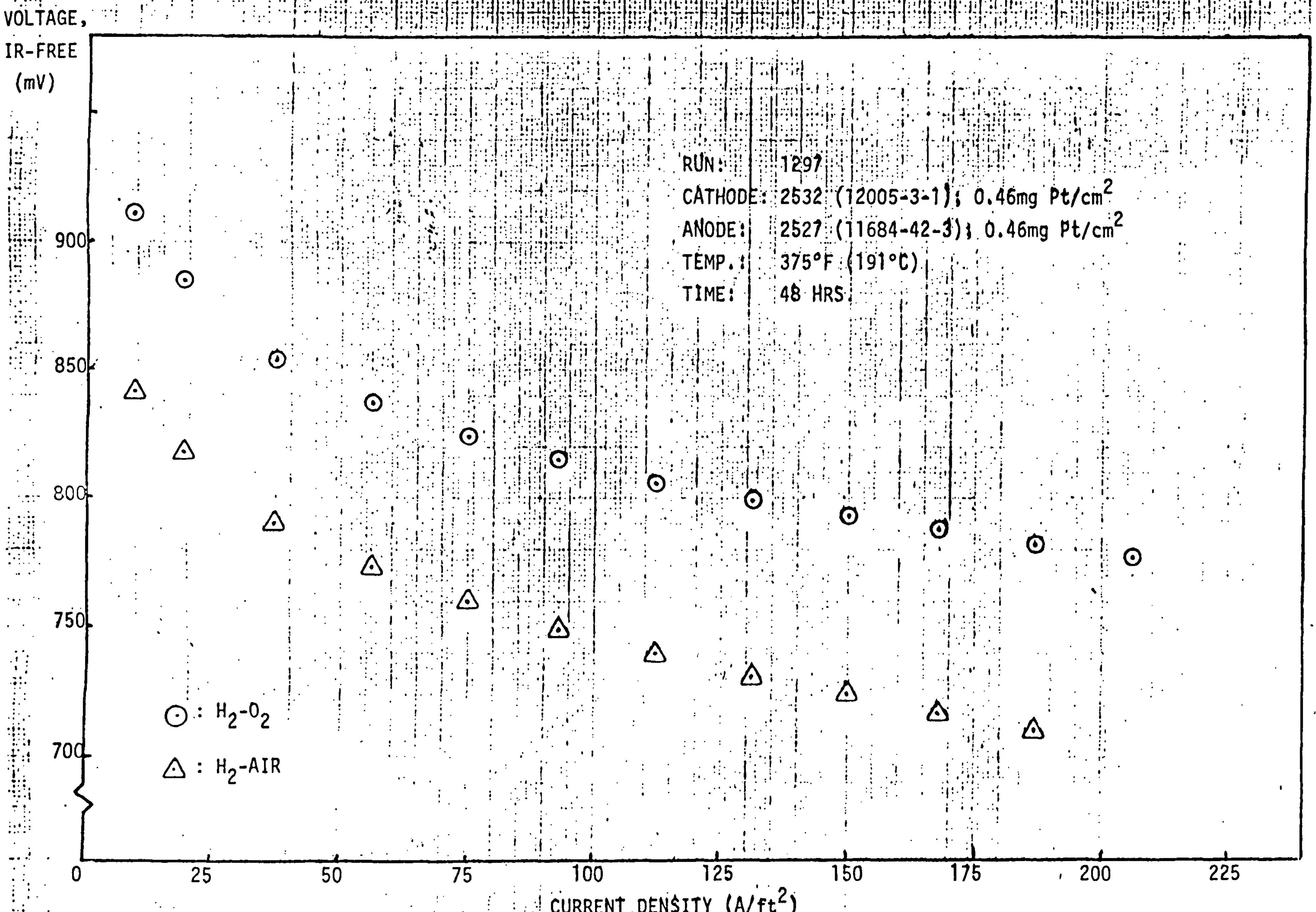


FIGURE 6 PERFORMANCE OF SINGLE-CELL UTILIZING E-7 CATHODE CATALYST

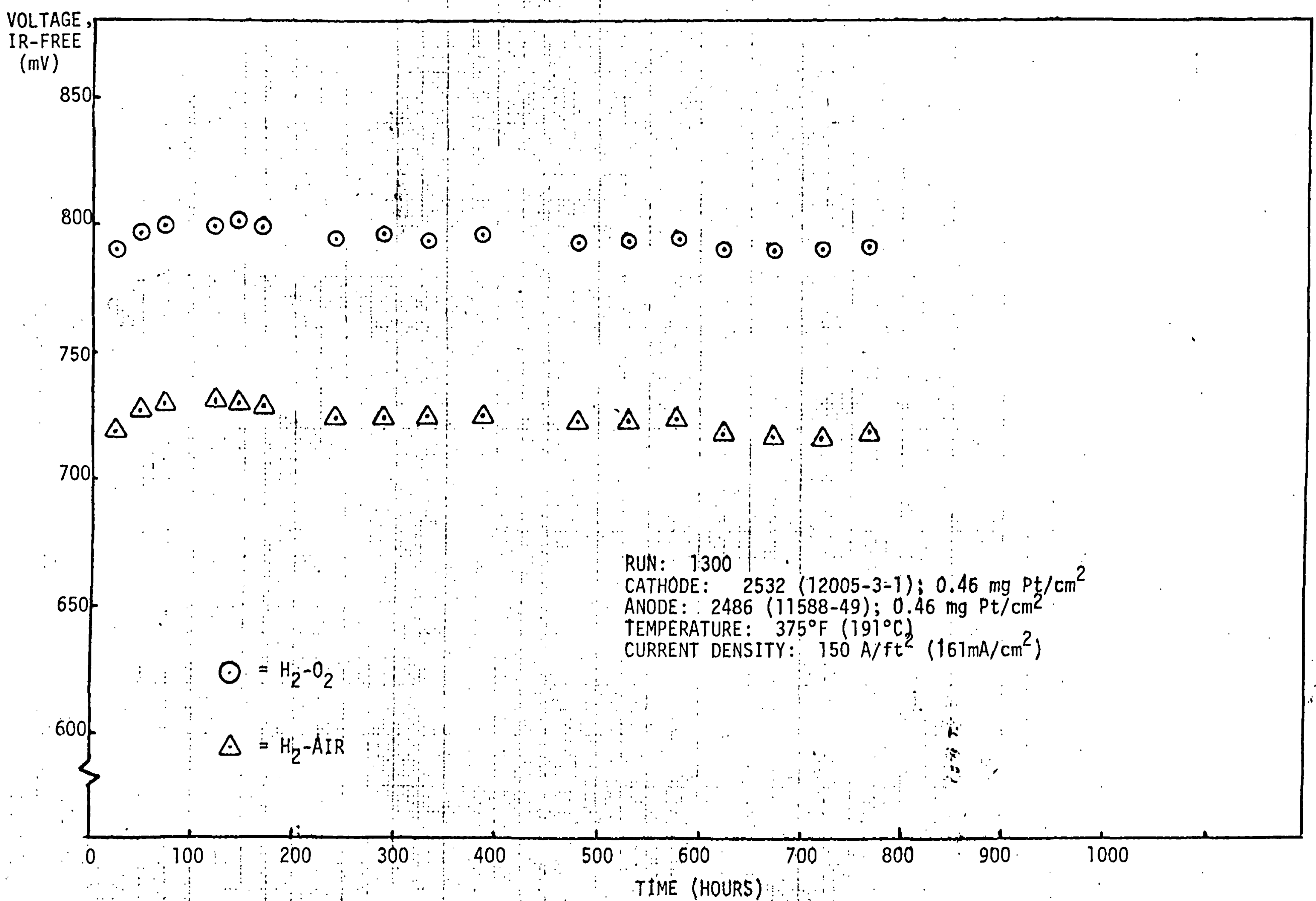


FIGURE 7 STEADY-LOAD PERFORMANCE OF SINGLE-CELL UTILIZING E-7 CATHODE CATALYST

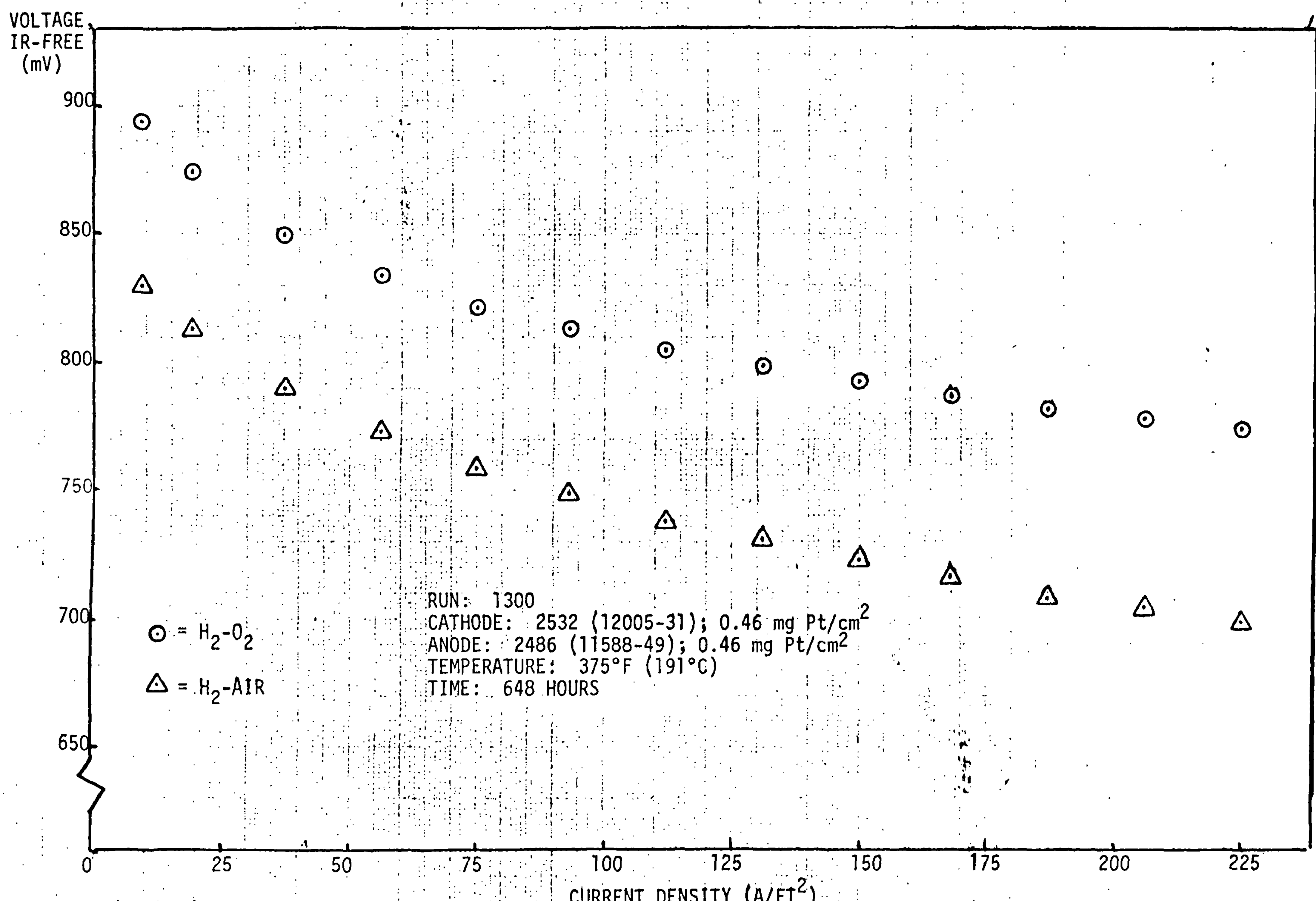


FIGURE 8 PERFORMANCE OF SINGLE-CELL UTILIZING E-7 CATHODE CATALYST

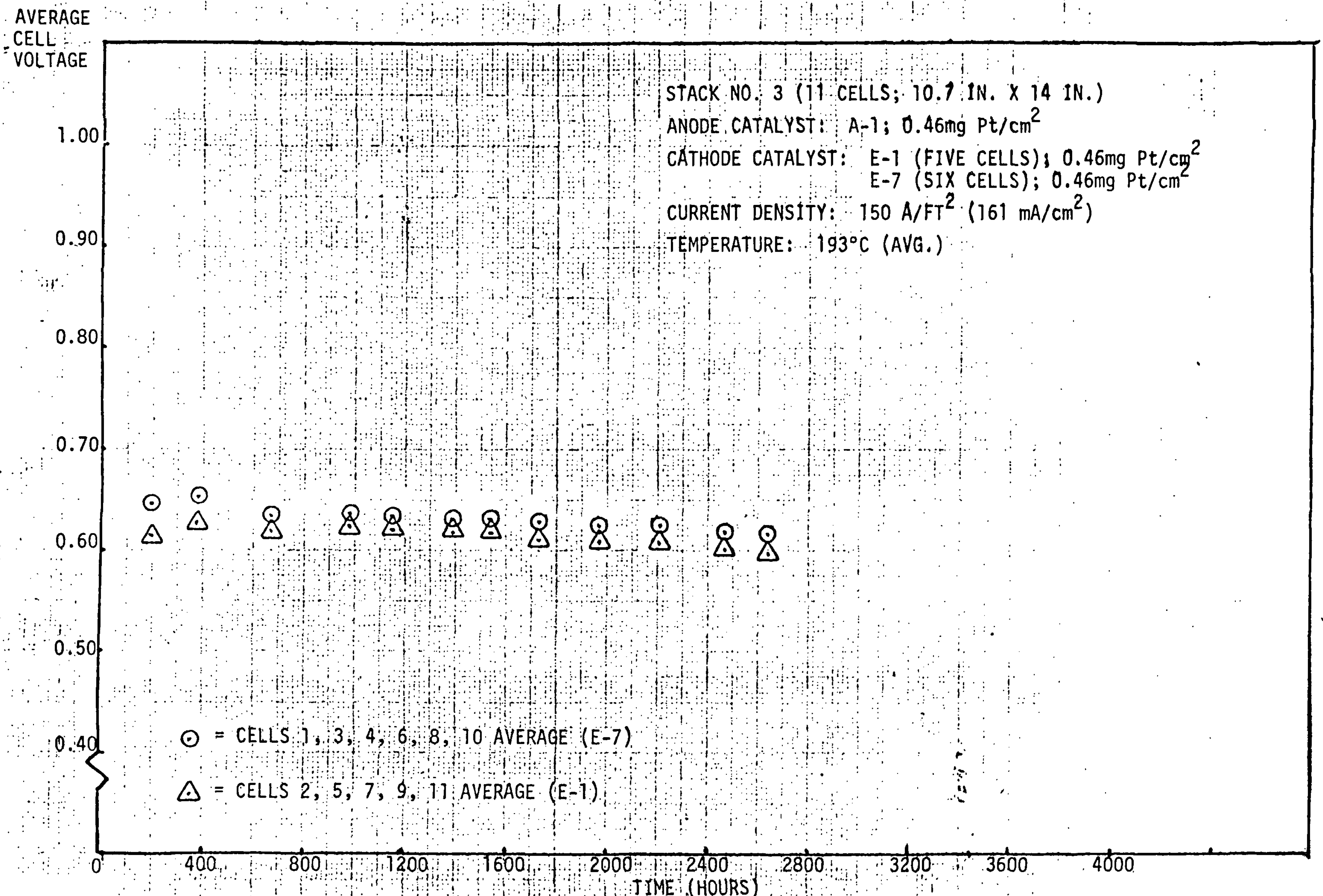


FIGURE 9 AVERAGE CELL VOLTAGE FOR CATHODE CATALYSTS IN STACK NO. 3

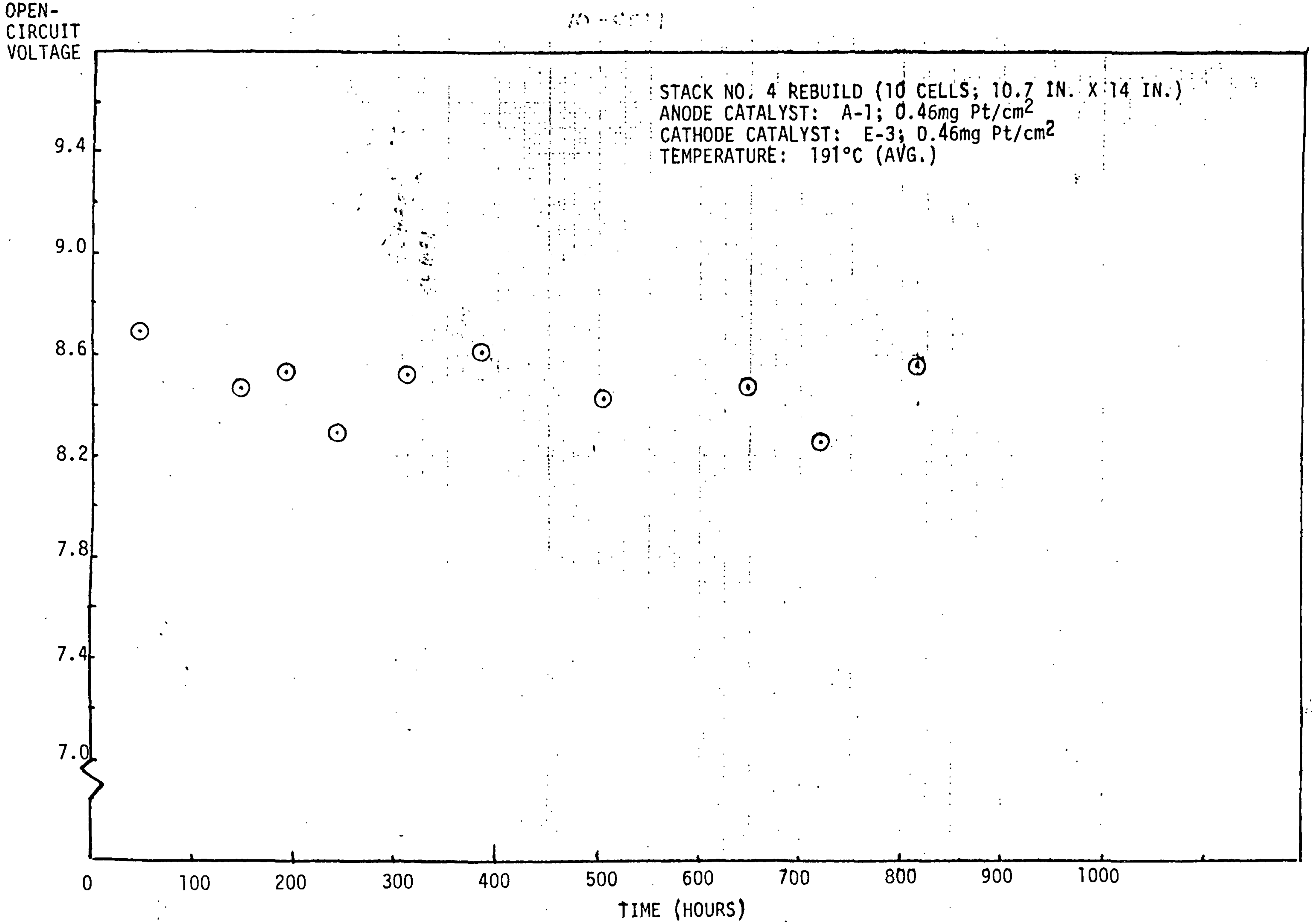


FIGURE 10 OPEN-CIRCUIT VOLTAGE OF STACK NO. 4 REBUILD

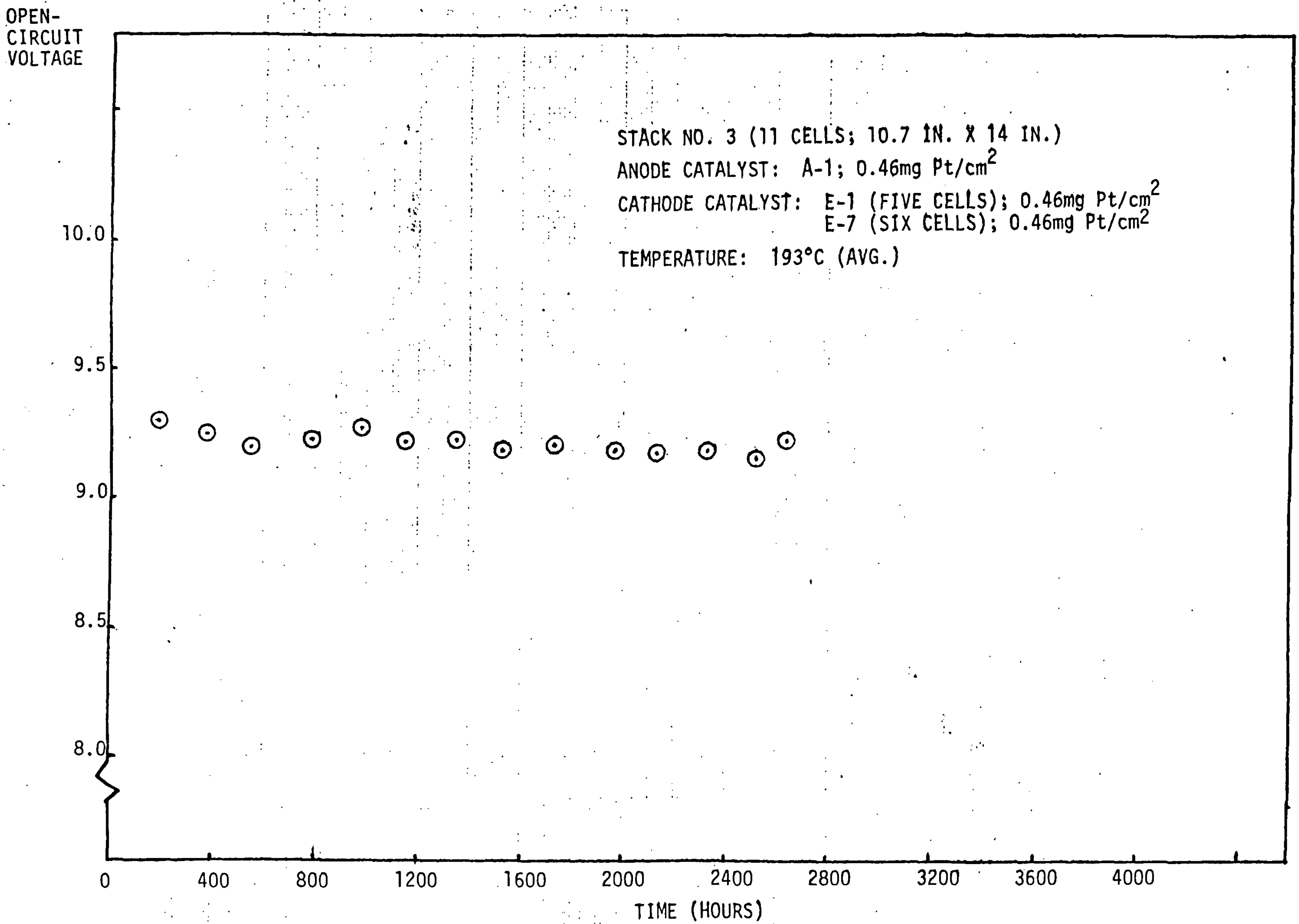


FIGURE 11 OPEN-CIRCUIT VOLTAGE OF STACK NO. 3

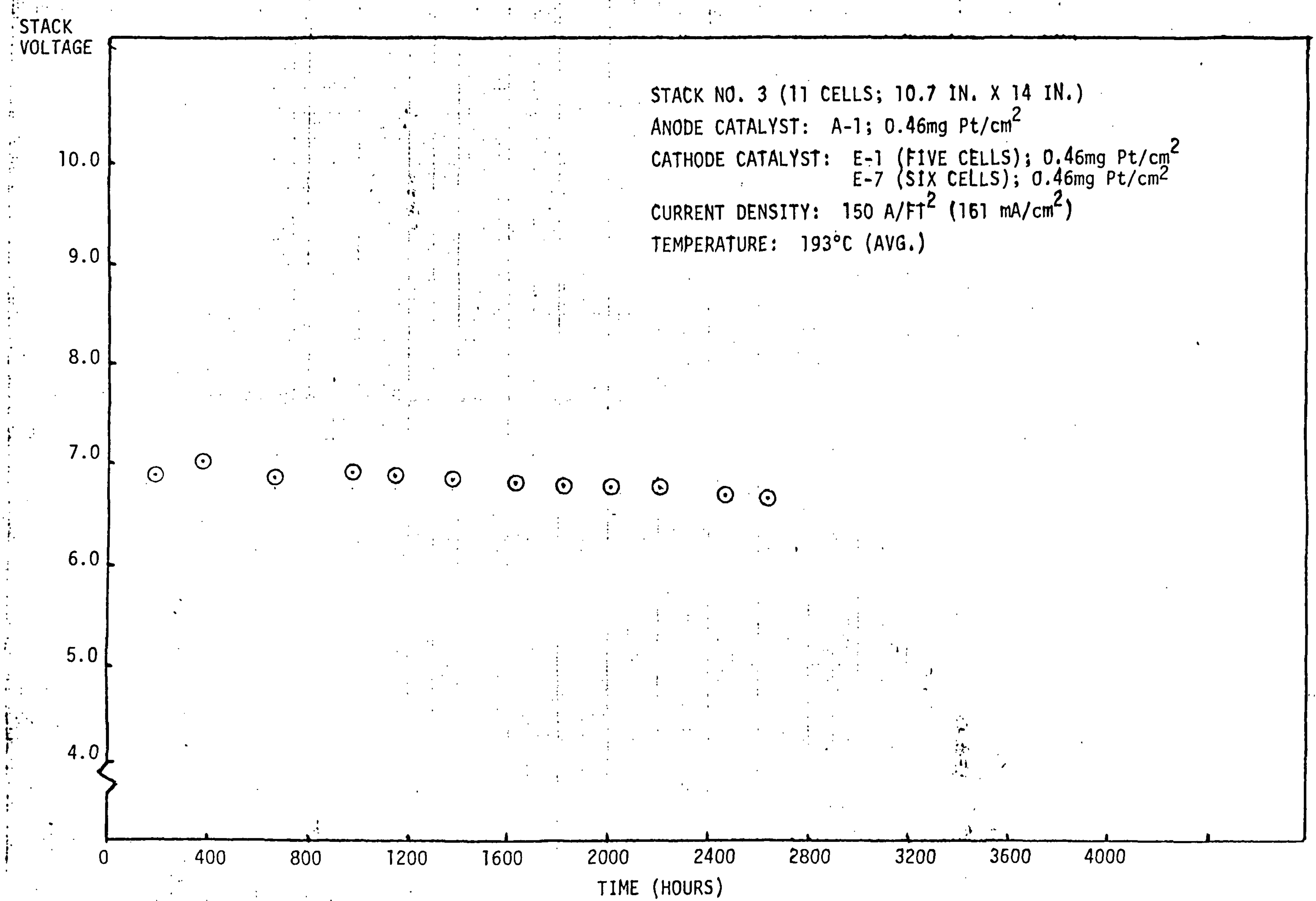
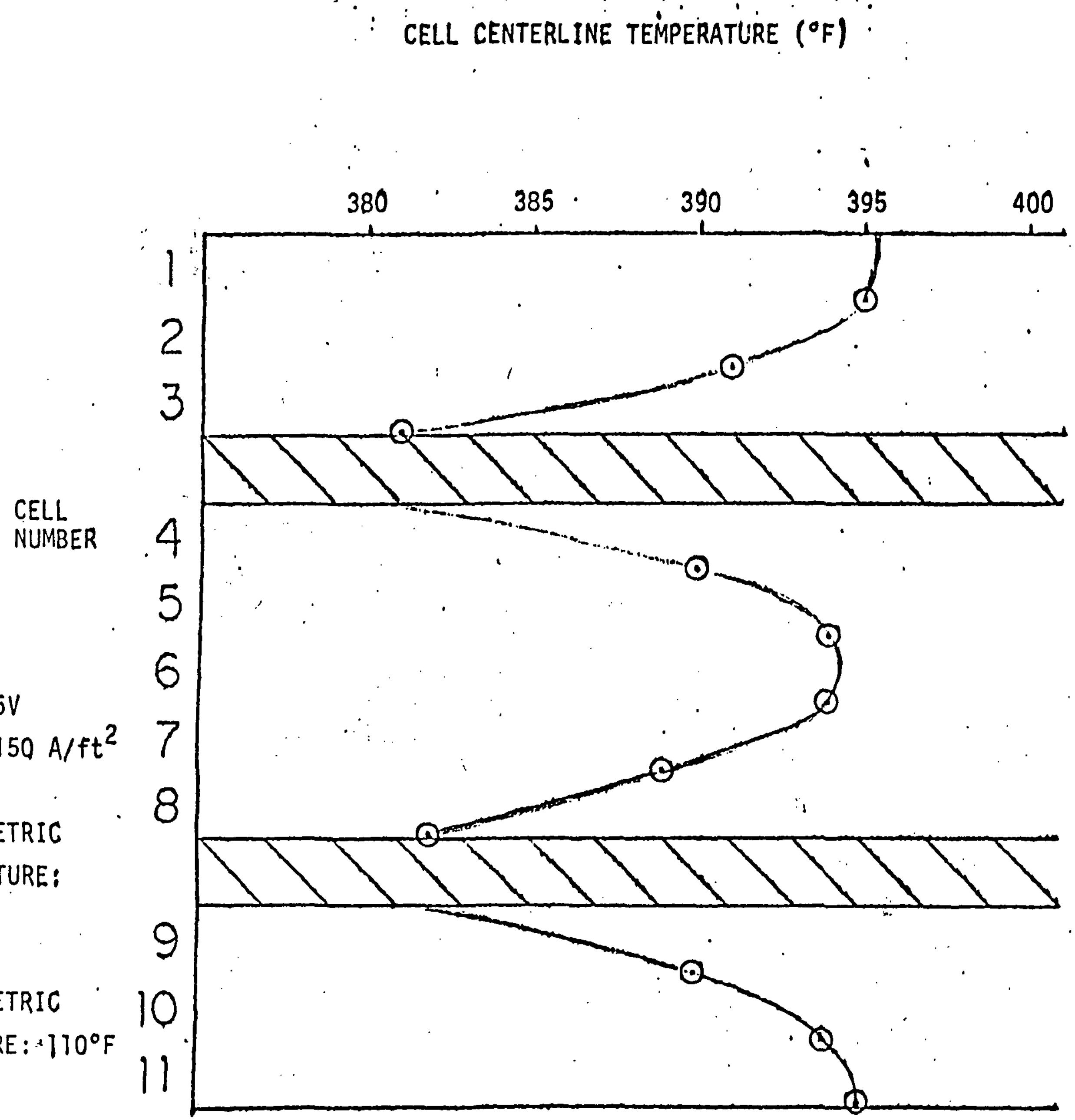


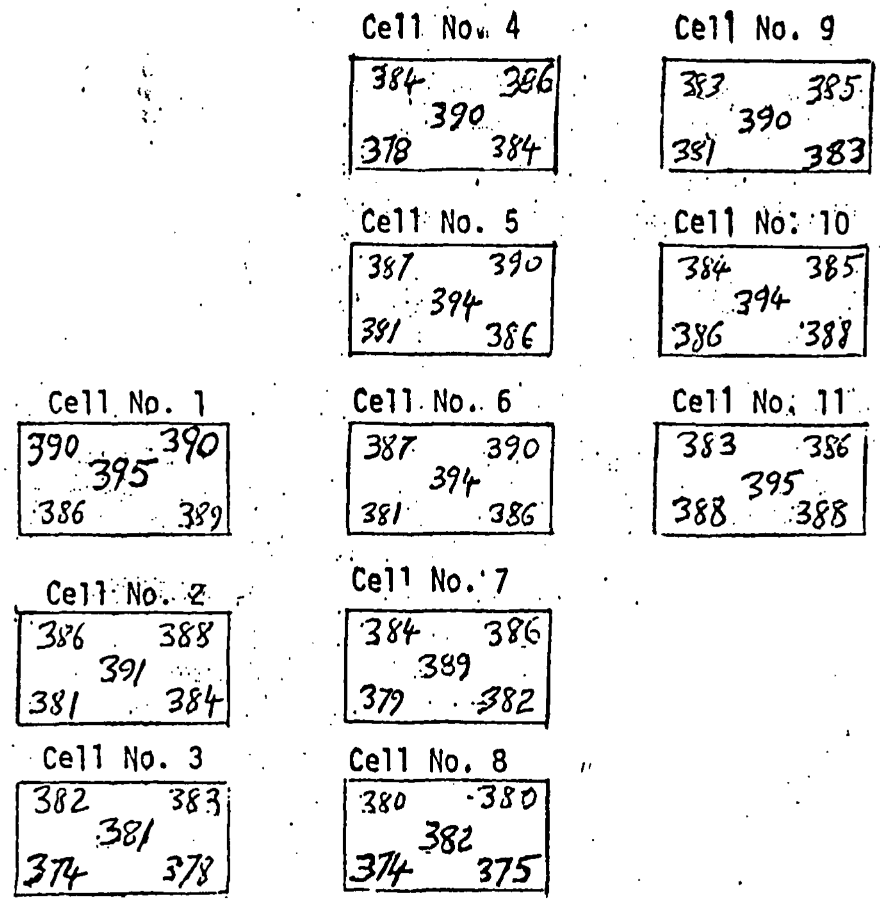
FIGURE 12 STEADY-LOAD PERFORMANCE OF STACK NO. 3



STACK NO. 3

- 11 CELLS
- 10.7 IN. X 14 IN.
- STACK VOLTAGE: 6.76V
- CURRENT DENSITY: 150 A/ft^2
- AIR FLOW RATE: 2.5 x STOICHIOMETRIC
- AIR INLET TEMPERATURE: 300°F
- H_2 FLOW RATE: 1.2 X STOICHIOMETRIC
- H_2 INLET TEMPERATURE: 110°F

FIGURE 13 TEMPERATURE DISTRIBUTION IN STACK NO. 3



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- AIR INLET TEMPERATURE: 300°F
- H_2 FLOW RATE: 1.2 X STOICHIOMETRIC
- H_2 INLET TEMPERATURE: 110°F
- COOLANT INLET TEMPERATURE: 343°F
- COOLANT EXIT TEMPERATURE: 380°F
- TEMPERATURES SHOWN IN °F.

FIGURE 14 TEMPERATURE DISTRIBUTION IN STACK NO. 3

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16. Abstract

On-going testing of an 11-cell, 10.7 in. x 14 in. stack (about 1kW) reached 2600 hours on steady load. Non-metallic cooling plates and an automated electrolyte-replenishment system continued to perform well.

A 10-cell, 10.7 in. x 14 in. stack was constructed with a modified electrolyte-matrix configuration for the purpose of reducing cell IR-loss. The desired effect was achieved, but the general cell performance level was irregular. Evaluation is continuing.

Preparations for a long-term 25-cell, 13 in. x 23 in. test stack (about 4 kW) approached completion. Start-up in early May 1984 is expected.

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