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FINAL REPORT

INTEGRATED REGENERATIVE FUEL CELL EXPERIMENTAL EVALUATION

By

R. E. Martin
International Fuel Cells Corporation
South Windsor, Connecticut

Prepared for
National Aeronautics and Space Administration

Contract No. NAS3-22234
Task XXI

NASA-Lewis Research Center
Cleveland, Ohio

Mr. Norman Hagedorn, Project Manager

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FOREWORD

This Final Report summarizes the work completed under Task XXI - Integrated Regenerative Fuel Cell Experimental Evaluation to the Long-Life, High Performance Fuel Cell Program, NASA Contract No. NAS3-22234 from 11 January 1988 through 30 June 1989 by International Fuel Cells Corporation.

The NASA Project Manager for this contract was Mr. Norman Hagedorn. The contributions of Mr. Hagedorn and other members of the staff at the NASA-Lewis Research Center are gratefully acknowledged.

The Project Manager for International Fuel Cells was Mr. Ronald E. Martin. Technical assistance for assembling and testing the laboratory regenerative fuel cells was provided by Mr. Paul A. Plasse and Mr. Charles S. Sherwin.

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ABSTRACT

An experimental test program was conducted to investigate the performance characteristics of an Integrated Regenerative Fuel Cell (IRFC) concept. The IRFC consists of a separate fuel cell unit and electrolysis cell unit in the same structure, with internal storage of fuel cell product water and external storage of electrolysis cell produced hydrogen and oxygen. The fuel cell unit incorporates an enhanced Orbiter-type cell capable of improved performance at reduced weight. The electrolysis cell features a $NiCo_2O_4$ catalyst oxygen evolution electrode with a porous Teflon cover to retard electrolyte loss. Six complete, IRFC assemblies were assembled and performance tested at an operating temperature of 200°F (93.3°C) and reactant pressures up to 170 psia (117.2 n/cm^2) on IRFC No. 4. Anomalous pressure charge/discharge characteristics were encountered during performance evaluation. A reversible fuel cell incorporating a proprietary bi-functional oxygen electrode operated satisfactorily at 200°F (93.3°C) at reactant pressures up to 60 psia (41.4 n/cm^2) as a regenerative fuel cell for one cycle, before developing an electrical short in the fuel cell mode. Electrolysis cell 300-hour endurance tests demonstrated the electrolyte retention capability of the electrode Teflon cover and the performance stability of the bi-functional oxygen electrode at high potential.

I. SUMMARY

This final report documents the activities and results of an experimental program to characterize the performance of the Integrated Regenerative Fuel Cell (IRFC) concept. Five complete IRFC laboratory size units, featuring a separate fuel cell and separate electrolysis cell in a common assembly were fabricated and tested. An exploratory test of a new dual function electrochemical cell, with a bi-functional oxygen electrode for application to future Regenerative Fuel Cell applications was tested. 300-hour endurance tests of two electrolysis cells were conducted.

A. Task Objectives and Scope

- Demonstrate that the Integrated Regenerative Fuel Cell (IRFC) is a simple and efficient energy storage device that can be repeatedly cycled with stable performance.
- Conduct two laboratory electrolysis cell endurance tests to define performance characteristics and demonstrate operability of the selected electrolyte management approach.
- Assemble and prepare for test, five laboratory 2 inch x 2 inch (5.1 cm x 5.1 cm) IRFC units with internal storage of product water and external storage of oxygen and hydrogen.
- Test each of five units to determine performance characteristics of the IRFC at cell temperatures up to 200°F (93.3°C) and reactant pressures up to 200 PSIA (137.9 n/cm^2).

B. Results

- Demonstrated performance stability of an electrolysis cell with a $NiCo_2O_4$ catalyst oxygen electrode during a 300-hour endurance test at 170°F (76.7°C) and atmospheric pressure with a cell voltage of 1.55V at 100 ASF (107.6 ma/cm^2).
- Eliminated electrolyte loss during operation of the electrolysis cell by the use of a thin porous Teflon membrane cover of the oxygen electrode.
- Demonstrated performance improvement in a 300-hour endurance test of an electrolysis cell at 170°F (76.7°C) and atmospheric pressure with a noble Alloy B catalyst oxygen electrode, with cell voltage at 100 ASF (107.6 ma/cm^2) at least 50 mV better than the electrolysis cell with the $NiCo_2O_4$ catalyst oxygen electrode.
- Assembled and attempted evaluation of five complete functioning laboratory-size Integrated Regenerative Fuel Cell units.
- Demonstrated individual functionality of the fuel cell and electrolysis cell of the IRFC in a 140-hour open cycle test at 200°F (93.3°C) and atmospheric pressure.

- Achieved satisfactory electrolysis cell performance with a $NiCo_2O_4$ oxygen electrode at 170 psia (117.2 n/cm^2) during IRFC evaluation with a cell voltage of 1.582V at 200 ASF (215.3 ma/cm^2).
- The unbalanced reactant pressure charge/discharge rates of the laboratory IRFC evaluation system are believed to be associated with cell internal product water management or elevated reactant pressure operation, leading to reactant cross leakage, which is related to the specific test configuration.
- Demonstrated potential advantages of regenerative fuel cell operation with a dual function electrochemical cell with a bi-functional oxygen catalyst electrode.
- Demonstrated performance benefits (relative to $NiCo_2O_4$) from the half-cell performance tests of the bi-functional noble Alloy B catalyst for oxygen generation.

II. INTRODUCTION

Future applications for orbiting satellites will require significantly higher power and higher energy density storage systems than employed in the past. The Regenerative Fuel Cell System (RFCS) shown in Figure 1 is an energy storage system which offers benefits of high specific energy density, increased system reliability, and extended life. The RFCS can incorporate dedicated or integrated cell stack systems. The dedicated system consists of individual fuel cell and electrolysis cell stacks while the integrated system option assumes the fuel cell and electrolyzer cells are contained in a single stack, either as interleaved individual cells or as dual function single cells.

This report describes the experimental work to assemble and to performance evaluate a laboratory-size Integrated Regenerative Fuel Cell (IRFC). The report is divided into five sections. Section I is a summary of the experimental work and gives a brief description of the test article, significant results and conclusions, and recommendations. Section III presents a description of the six IRFCs assembled, a summary of test results, and a discussion of the individual unit tests. Section IV presents a description of the two laboratory electrolysis cells assembled and a summary of endurance test results at a current density of 100 ASF (107.6 ma/cm^2), at a 170°F (76.7°C) cell temperature and 14.7 psia (10.1 n/cm^2) reactant pressure. Section V presents a general discussion of the half-cell performance tests used to identify electrode configurations for the IRFC test units. The appendix concludes the report and contains the half-cell performance curves of electrodes characterized under the task.

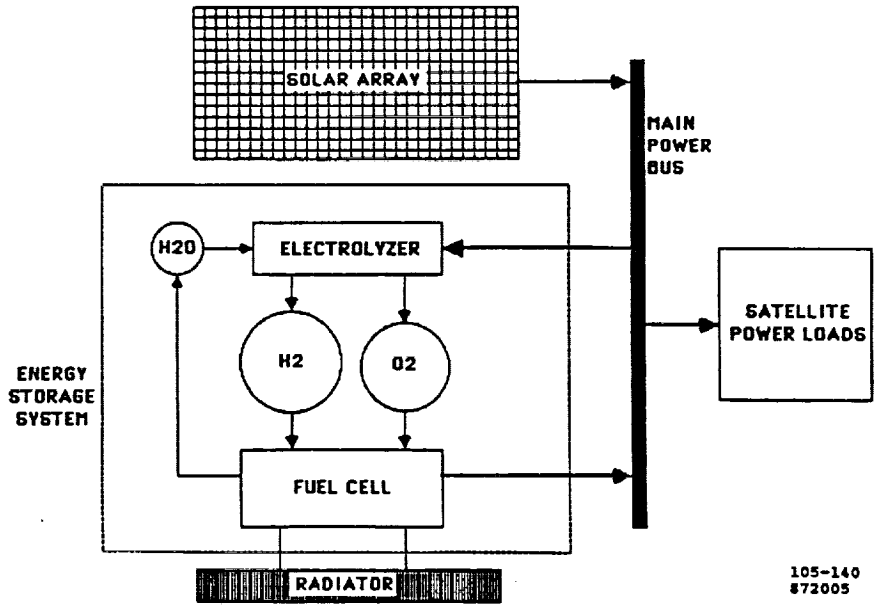

Figure 1. Satellite Regenerative Fuel Cell Energy Storage System

III. INTEGRATED REGENERATIVE FUEL CELL TEST UNITS

The Integrated Regenerative Fuel Cell (IRFC) incorporates in a single unit, an individual fuel cell and an individual electrolysis cell unit, with a common hydrogen reactant cavity. Fuel cell product water is stored internally within the cell Electrolyte Reservoir Plates (ERP) with water diffusing through the common hydrogen cavity to the electrolysis cell for reactant production. Oxygen and hydrogen are stored in tanks external to the IRFC. The IRFC assembly is shown in Figure 2.

A summary of the six IRFC configurations assembled for performance evaluation is presented in Table I. Build Nos. 1, 2 and 3 incorporated 8-mil (.2 mm) thick potassium titanate matrices. Build Nos. 4, 5, and 6 incorporated 20-mil (.5 mm) thick asbestos matrices for improved cross-pressure tolerance. To eliminate reactant leakage "O-ring" seals were incorporated into the nickel spacer plates and research cell plate hardware, following Build No. 1. Strengthened Teflon tube electrical isolators were employed following Build No. 2. Nickel port bridges on internal hydrogen ports were incorporated in Build No. 6 to prevent gasket creep into the ports.

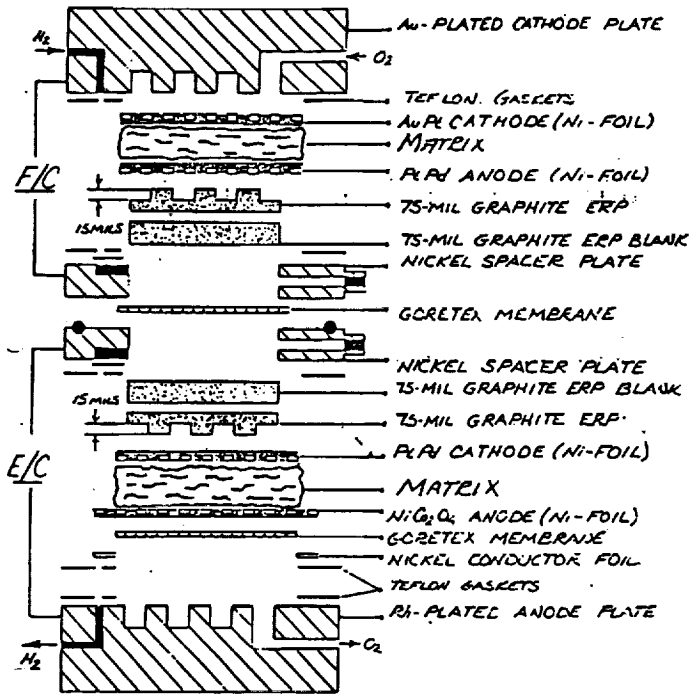

Figure 2. IRFC Cell Assembly

Table I. IRFC Configuration Summary

IRFC	Fuel Cell					Membrane	Electrolysis Cell						Reactant
	O_2 Elec.	Matrix	H_2 Elec.	ERP			ERP	H_2 Elec.	Matrix	O_2 Elec.	Barrier	Manifolding
1	AuPt	8 Mil PKT	PtPd	150 Mil C	TFE		150 Mil C	PtPd	8 Mil PKT	$NiCo_2O_4$	TFE	• O_2 Cell Hardware • H_2 Feed Tubes
2	AuPt	8 Mil PKT	PtPd	150 Mil C	TFE		150 Mil C	PtPd	8 Mil PKT	$NiCo_2O_4$	TFE	• O_2 Cell Hardware • H_2 Cell Hardware
3	AuPt	8 Mil PKT	PtPd	150 Mil C	TFE		150 Mil C	PtPd	8 Mil PKT	$NiCo_2O_4$	TFE	• O_2 Cell Hardware • H_2 Cell Hardware • Improved Isolators
4	AuPt	20 Mil ASB	PtPd	150 Mil C	TFE		150 Mil C	PtPd	20 Mil ASB	$NiCo_2O_4$	TFE	• O_2 Cell Hardware • H_2 Cell Hardware • Improved Isolators
5	Diagnostic Reversible Cell Alloy B	20 Mil ASB	PtPd	150 Mil C	-		-	-	-	-	TFE	• O_2 Cell Hardware • H_2 Cell Hardware • Improved Isolators
6	AuPt	20 Mil ASB	PtPd	150 Mil C	TFE		150 Mil C	PtPd	20 Mil ASB	$NiCo_2O_4$	TFE	• O_2 Cell Hardware • H_2 Cell Hardware • Improved Isolators • Internal Reactant Port Bridges

IIIA. TEST SUMMARY

Performance evaluation of five Integrated Regenerative Fuel Cell units demonstrated anomalous system pressurization characteristics during charge (electrolysis cell operation), and during discharge (fuel cell operation). Typically at 200 amps/ft^2 (215.3 ma/cm^2), the electrolysis cell charged the reactant system at 42.5 psi/hr (29.3 n/cm^2 hr) and the fuel cell discharged the reactant system at 67.5 psi/hr (46.5 n/cm^2 hr), compared to an expected charge/discharge rate of 55.5 psi/hr (38.3 n/cm^2 hr). A summary of the IRFC charge/discharge characteristics is presented on Figure 3. The IRFC pressure disparity is equivalent to reactant consumption at a 45 ASF (48.4 ma/cm^2) rate.

Inspection and testing of the IRFC test units did not identify the mechanism or source for the anomalous system pressurization characteristics. Pressure tests of the IRFC units found there to be no reactant leaks to external. Electrical isolation tests of all test instrumentation, cell tierods, and reactant plumbing isolators did not identify a shorting path. Checkout of the power supply load system showed the unit to be functioning properly.

A Reversible Cell, incorporating a bi-functional oxygen electrode, performing both fuel cell and electrolysis cell functions, operated satisfactorily in the regenerative mode for one cycle, before developing an electrical short as a fuel cell. In addition, IRFC-6 operated satisfactorily in the open cycle mode at atmospheric pressure.

The anomalous pressurization characteristics of the closed system integrated unit appears to be associated with the specific test configuration. The observed pressure characteristics appear to be due to internal reactant cross leakage with reactant back pressure and internal water management characteristics during closed cycle operation being contributing factors.

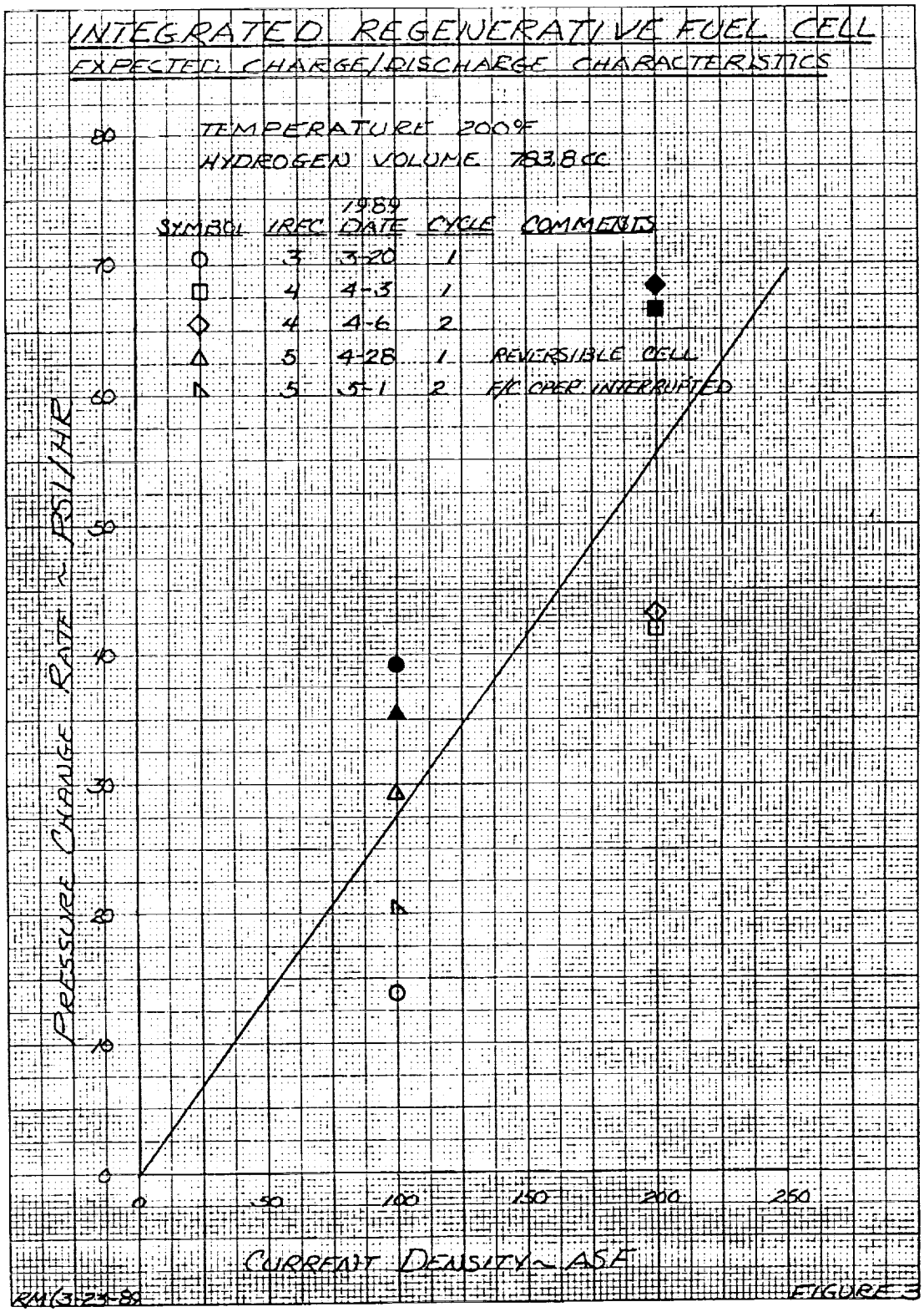

Figure 3. IRFC Charge/Discharge Characteristics

IIIB. IRFC NO. 1

The unit featured 8-mil (0.2 mm) thick potassium titanate (PKT) matrices in both the fuel cell and electrolysis cell units. Electrolysis cell produced hydrogen was delivered to the storage tank and fuel cell through small tubes in the nickel spacer plate. Details of cell construction are presented at the beginning of Section III. A photograph of IRFC-1 is shown on Figure 4.

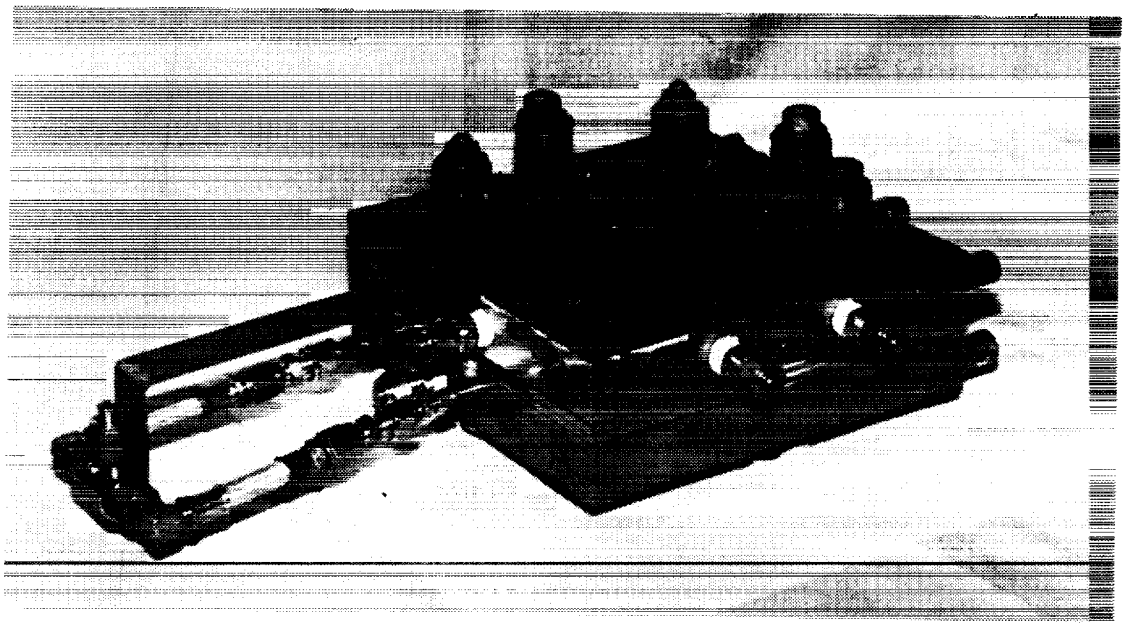

Figure 4. IRFC-1 Fuel Cell/Electrolysis Cell Assembly

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A performance checkout test of the unit was conducted in the laboratory at atmospheric pressure. The unit was charged with hydrogen and oxygen by pulse pressure purging. At a cell temperature of 200°F (93.3°C), about 90-minutes of electrolysis cell operation was completed. Water stored in the cell electrolyte reservoir plates was electrolyzed to produce hydrogen and oxygen. During the test, generated reactants were vented from the system. The fuel cell was operated for about 85-minutes on dry reactants supplied to the IRFC system. A summary of test results at 200°F (93.3°C) and atmospheric pressure is presented in Table II.

Table II. IRFC-1 Checkout Performance Summary

Cell	Time - Min.	Performance ASF	Initial V/C	Final V/C
Fuel Cell	85	100	.867	.877
Electrolysis Cell	90	100	1.522	1.505

Test results from the fuel cell performance calibration is shown on Figure 5. The performance calibration of the electrolysis cell is shown on Figure 6.

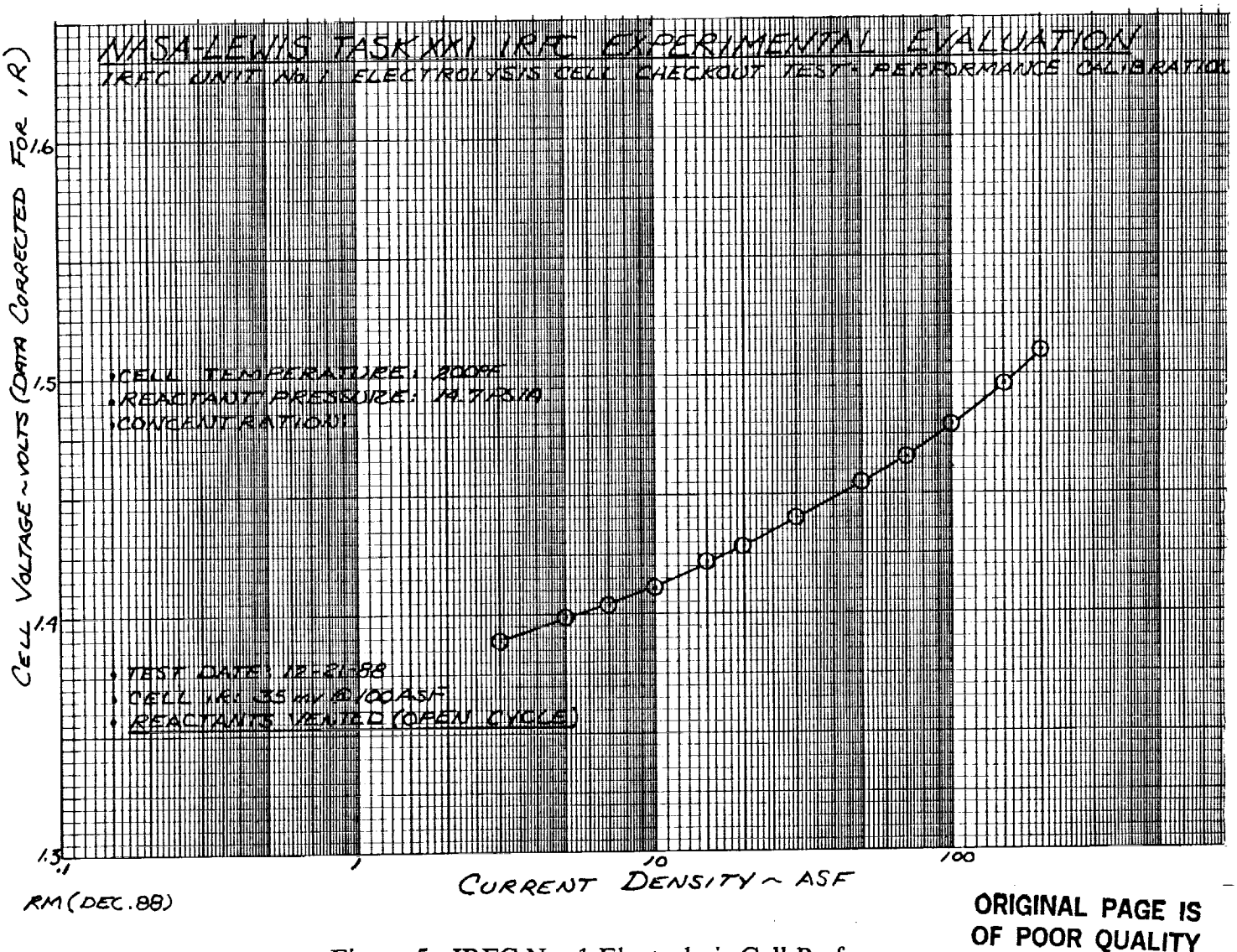

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Figure 5. IRFC No. 1 Electrolysis Cell Performance

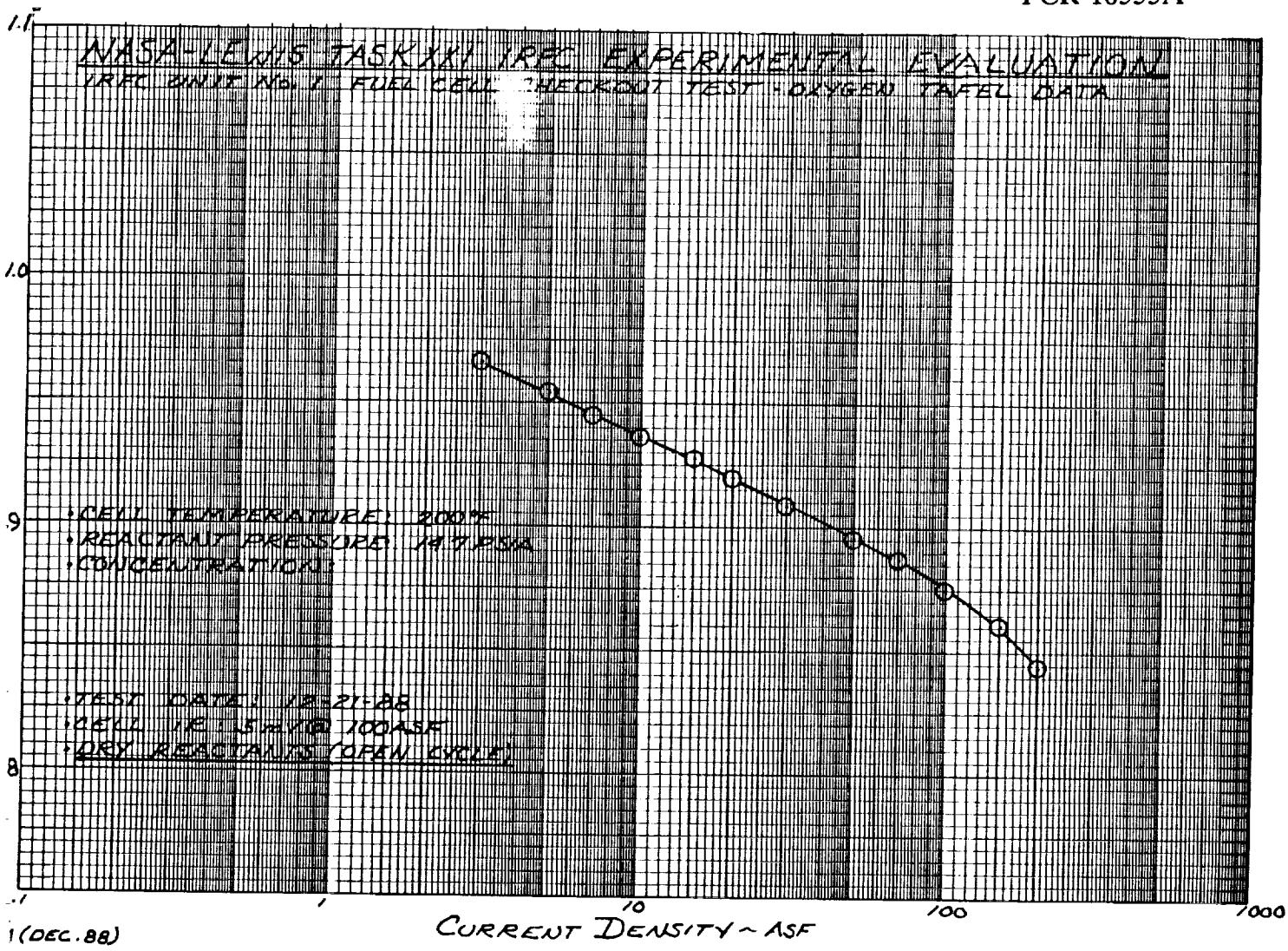

Figure 6. IRFC No. 1 Fuel Cell Performance

Upon completion of the checkout test, IRFC-1 was evaluated as an integrated unit. The cell assembly was heated to 200°F (93.3°C) and the reactant system was heated to 180°F (82.23°C). In preparation for the integrated test, the reactant tanks were pressurized to 60 psia (41.4 n/cm^2). At this point, the hydrogen tank was observed to be losing pressure.

Inspection of the unit, found hydrogen to be leaking from between the nickel spacer plates. The spacer plates were modified to eliminate reactant leakage and improve H_2 purging and pressurization. In all subsequent builds of the IRFC, O-rings were employed to seal the nickel spacer plates, and H_2 inlet and exit manifolds were machined into the spacer plates to match with existing cell hardware manifolding.

IIIC. IRFC No. 2

IRFC No. 2 incorporated 8-mil (.2 mm) thick PKT matrices in the fuel cell and electrolysis cell. The IRFC unit incorporated O-ring seals in the nickel spacer plates and internal hydrogen manifolding to match with existing cell hardware. Details of cell construction are presented at the beginning of Section III.

The integrated test unit was purged with hydrogen and oxygen to remove inerts at atmospheric pressure. The hydrogen and oxygen systems were pressurized from external sources to 60 psia (41.4 n/cm^2). At this point, there was no evidence of reactant leakage to external. During the heating of the cell assembly to 200°F (93.3°C), an electrical isolation line in the hydrogen inlet line ruptured, resulting in a 45 psid (31 n/cm^2) cross-pressure. Laboratory testing confirmed the presence of internal reactant cross-leakage.

Strengthened TFE® tube electrical isolators were evaluated at 200 psia (137.9 n/cm^2) at 200°F (93.3°C) for 3-hours with only a 1 psid (.7 n/cm^2) pressure loss. The strengthened TFE tube isolators were employed in all subsequent builds of the IRFC.

IIID. IRFC No. 3

The unit contained 8-mil (.2 mm) PKT matrices, nickel spacer plate O-ring seals, internal hydrogen manifolds and strengthen TFE® electrical isolators. Details of cell construction are presented at the beginning of Section III.

IRFC No. 3 was successfully pressurized from external sources to 60 psia (41.4 n/cm^2) and heated to 200°F (93.3°C). A modified charge cycle was initiated by operating the electrolysis cell for 1-hour at 100 ASF (107.6 ma/cm^2). The fuel cell unit was then operated for 30-minutes at 100 ASF (107.6 ma/cm^2). A graphic log of the test is shown on Figure 7. The pressure charge/discharge rates experienced on IRFC No. 3 were equivalent to a 45 ASF (48.4 n/cm^2) electrical short as shown on Figure 8. There was no evidence of an internal electrical short in the performance data of the fuel cell unit and electrolysis cell unit as shown on Figures 9 and 10 respectively. Following the test, IRFC No. 3 was shut down with the pressure of the reactants at 60 psia (41.4 n/cm^2).

The following day, the hydrogen and oxygen system pressure was at atmospheric pressure. An attempt to operate the IRFC unit revealed low fuel cell and electrolysis cell voltages and all further testing was stopped. Cross-pressure testing in the laboratory identified internal reactant cross-leakage on both the fuel cell and electrolysis cell.

To improve the cell reactant cross-pressure tolerance of IRFC, build nos. 4, 5, and 6 incorporated 20-mil (.5 mm) thick asbestos matrices in the fuel cell unit and electrolysis cell units.

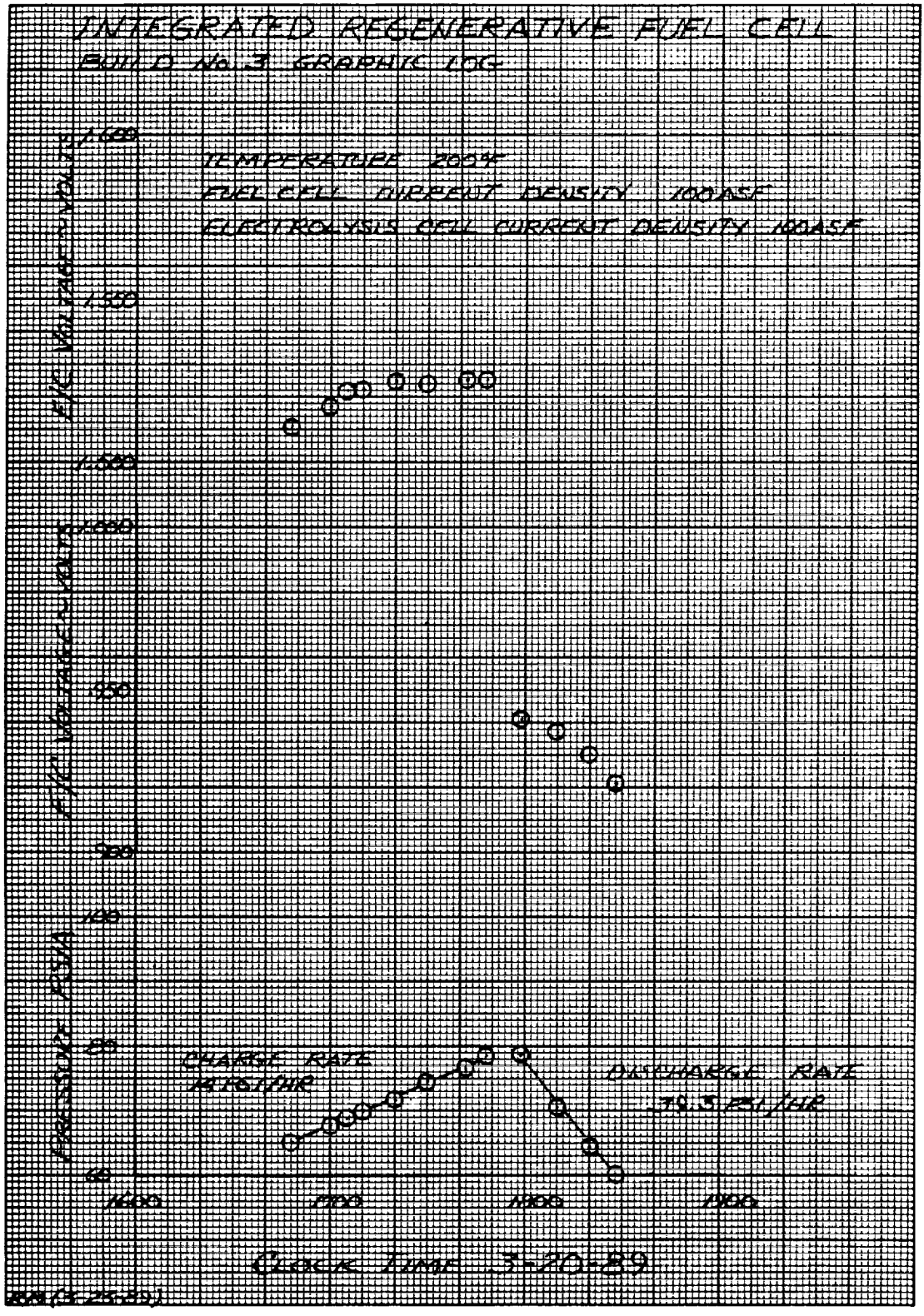

Figure 7. IRFC No. 3 Performance History

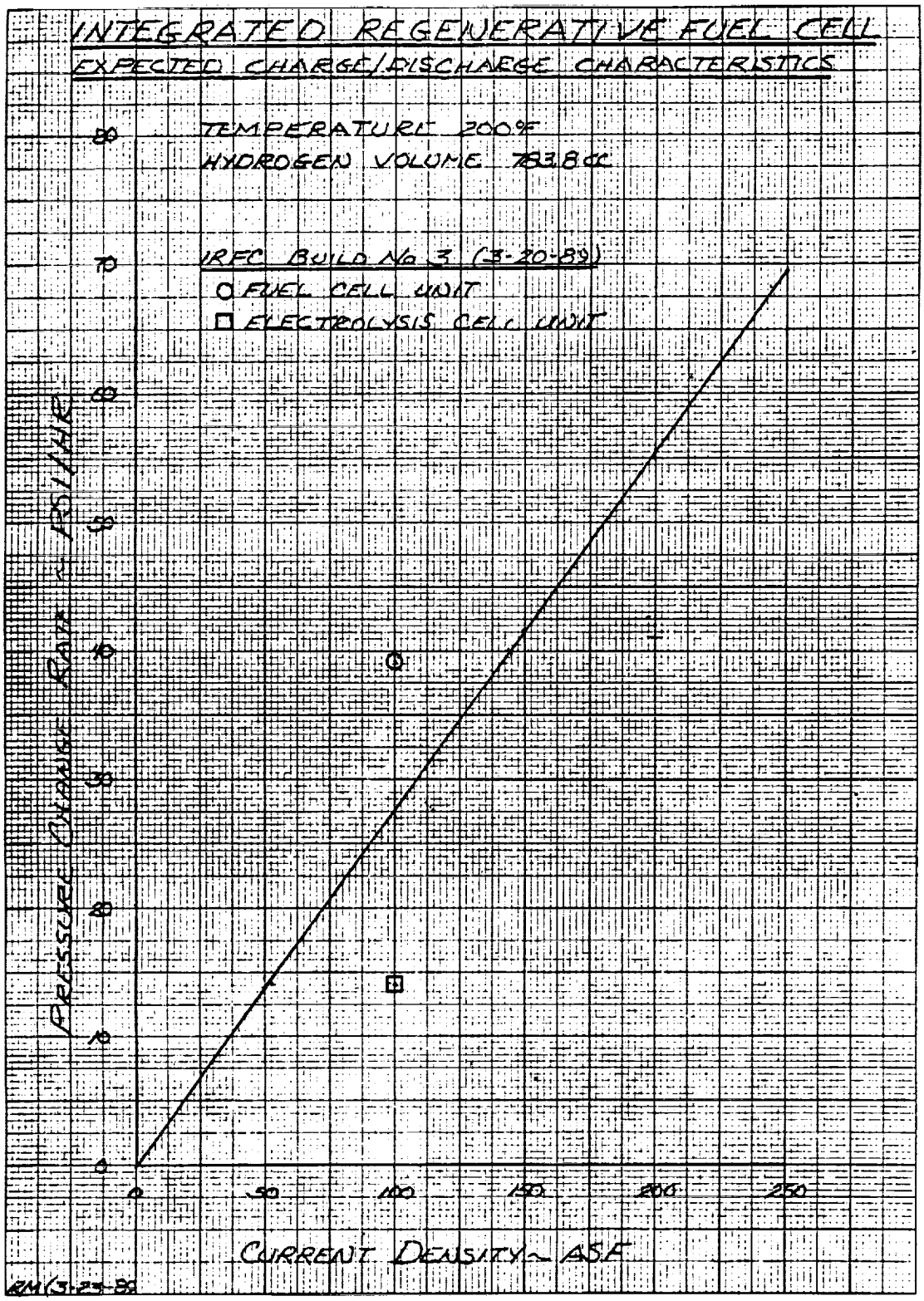

Figure 8. IRFC No. 3 Charge/Discharge Characteristics

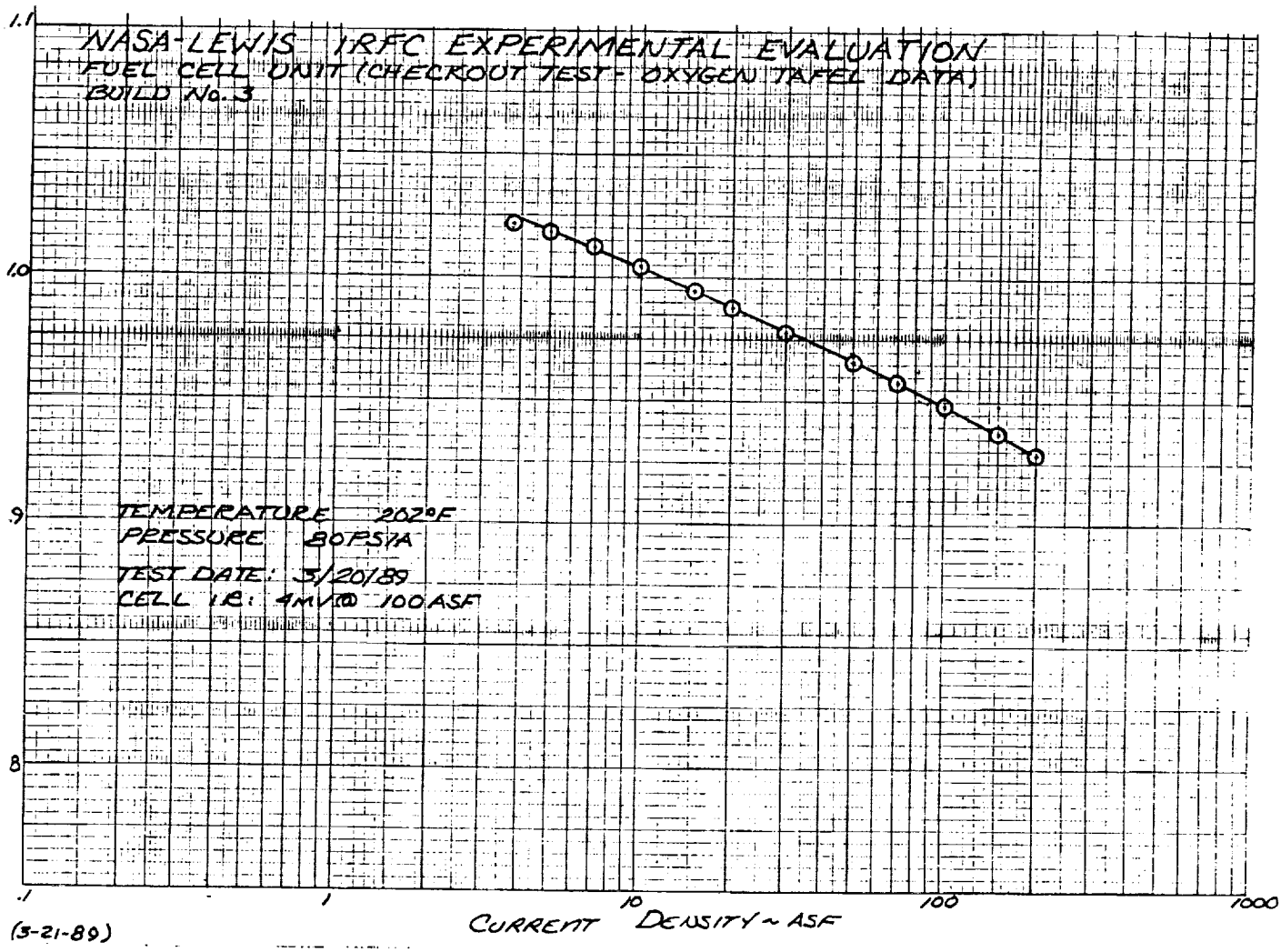

Figure 9. IRFC No. 3 Fuel Cell Oxygen Tafel Data

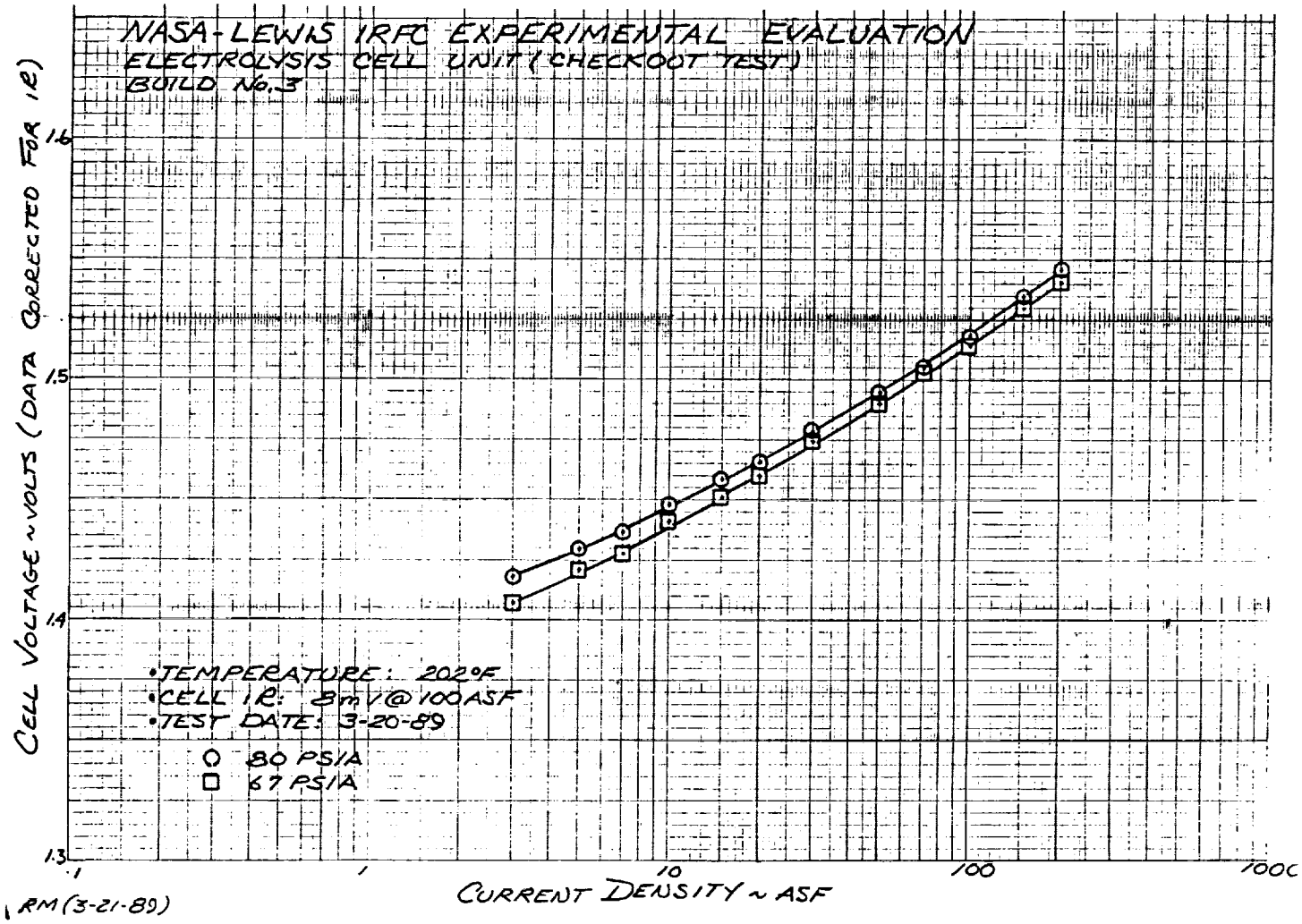

Figure 10. IRFC No. 3 Electrolysis Cell Performance

IIIE. IRFC No. 4

The integrated unit incorporated 20-mil (.5 mm) thick asbestos matrix in the fuel cell unit and electrolysis cell unit. Other than the matrix, the configuration of IRFC No. 4 was identical to IRFC No. 3. Details of the unit construction are presented at the beginning of Section III.

Following external pressurization to 60 psia (41.4 n/cm^2) and heatup to 200°F (93.3°C), a charge cycle was initiated by operating the electrolysis cell for 2.5 hours at 200 ASF (215.3 ma/cm^2). The fuel cell unit then operated for about 1.5 hours at 200 ASF (215.3 ma/cm^2). A graphic log of the test is shown on Figure 11. As shown on Figure 11, the open circuit voltage (OCV) of the electrolysis cell fell below 1.0V during discharge. As experienced on IRFC No. 3, the pressure charge/discharge rates experienced on IRFC No. 4 suggests an equivalent 45 ASF (48.4 ma/cm^2) electrical short. However, there was no evidence of an internal electrical short in the performance data of the fuel cell and electrolysis cell as shown on Figures 12 and 13 respectively. Electrical isolation tests of the instrumentation, tierods, and plumbing isolators did not locate a shorting path. Checkout of the load system, showed the unit to be functioning properly. Following the tests, IRFC No. 4 was shut down and depressurized to ambient.

A second charge/discharge operating cycle was conducted on IRFC No. 4. Upon pressurization to 60 psia (41.4 n/cm^2) and heatup to 200°F (93.3°C), the charge cycle was initiated by operating the electrolysis cell for 2.5 hours at 200 ASF (215.3 ma/cm^2). The fuel cell unit was next operated for about an hour at reduced loads because of decreasing cell voltage as shown on Figure 14. Fuel cell OCV following the testing was stable at above 1.10 volts.

Four significant observations can be made from the test. During electrolysis cell operation, fuel cell open circuit voltage remained above 1.0 volt and improved as system pressure increased. Reactant pressure increase with electrolysis operation, or charge rate was 43.2 psi/hr (29.8 n/cm^2 hr) consistent with past test experience. During fuel cell operation, the open circuit voltage of the electrolysis cell approached the operating voltage of the fuel cell. There was no consumption of reactants during a 35-minute period without load on the fuel cell and electrolysis cell as reactant pressure held at 132 psia (91.0 n/cm^2). The initial performance of the fuel cell unit during cycle No. 2 was consistent with cycle No. 1, however, continued operation during cycle No. 2 contributed to a reduction of fuel cell performance. After the second charge/discharge cycle, all testing of IRFC No. 4 was stopped.

Electrical isolation tests of the instrumentation, tierods, and plumbing isolators did not identify a shorting path. Laboratory checkout of the power supply load system again showed the unit to be functioning properly.

The anomalous pressurization characteristics appears to be due to internal reactant cross leakage, with reactant back pressure and internal water management characteristics during closed cycle operation being contributing factors.

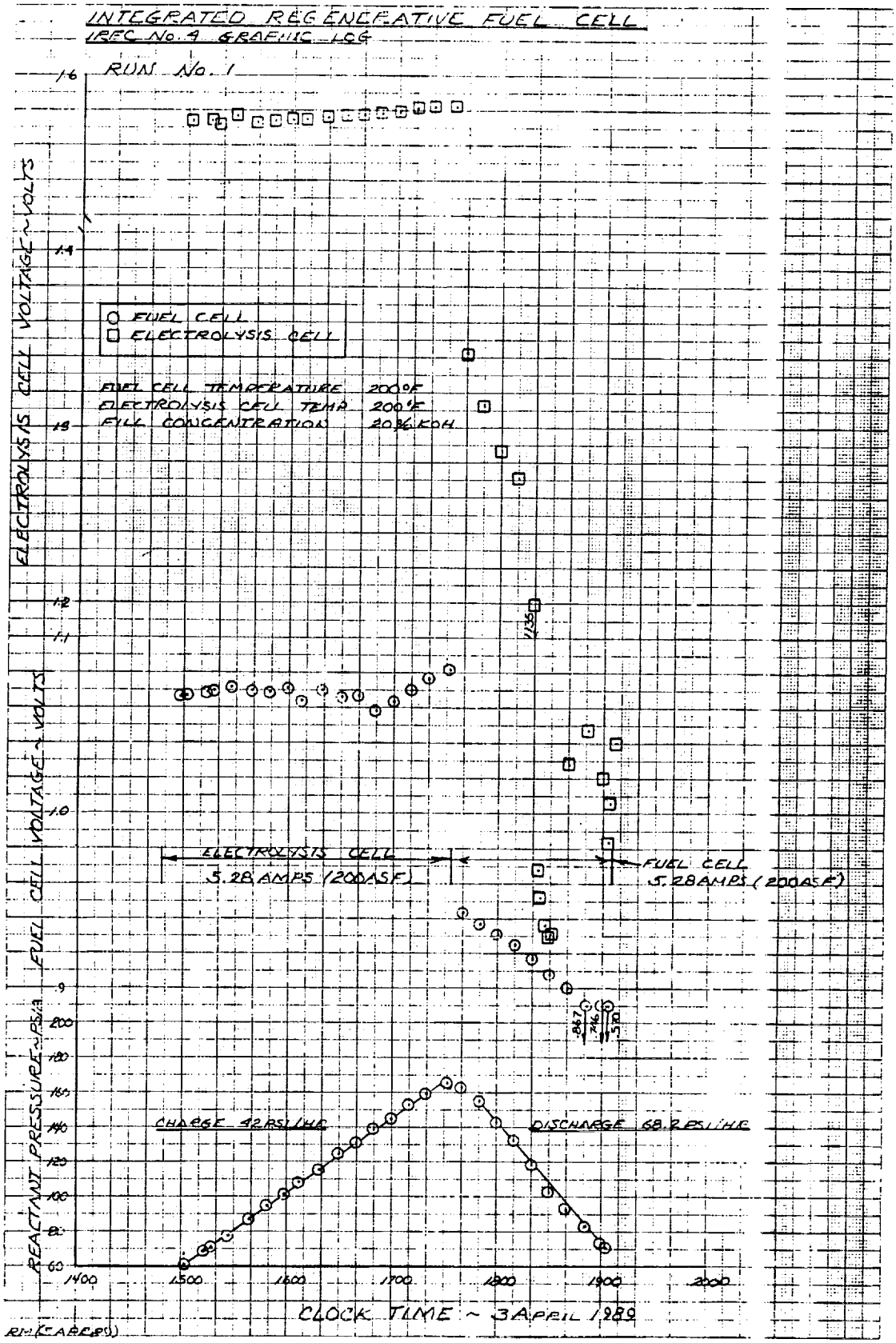

Figure 11. IRFC No. 4 Performance History

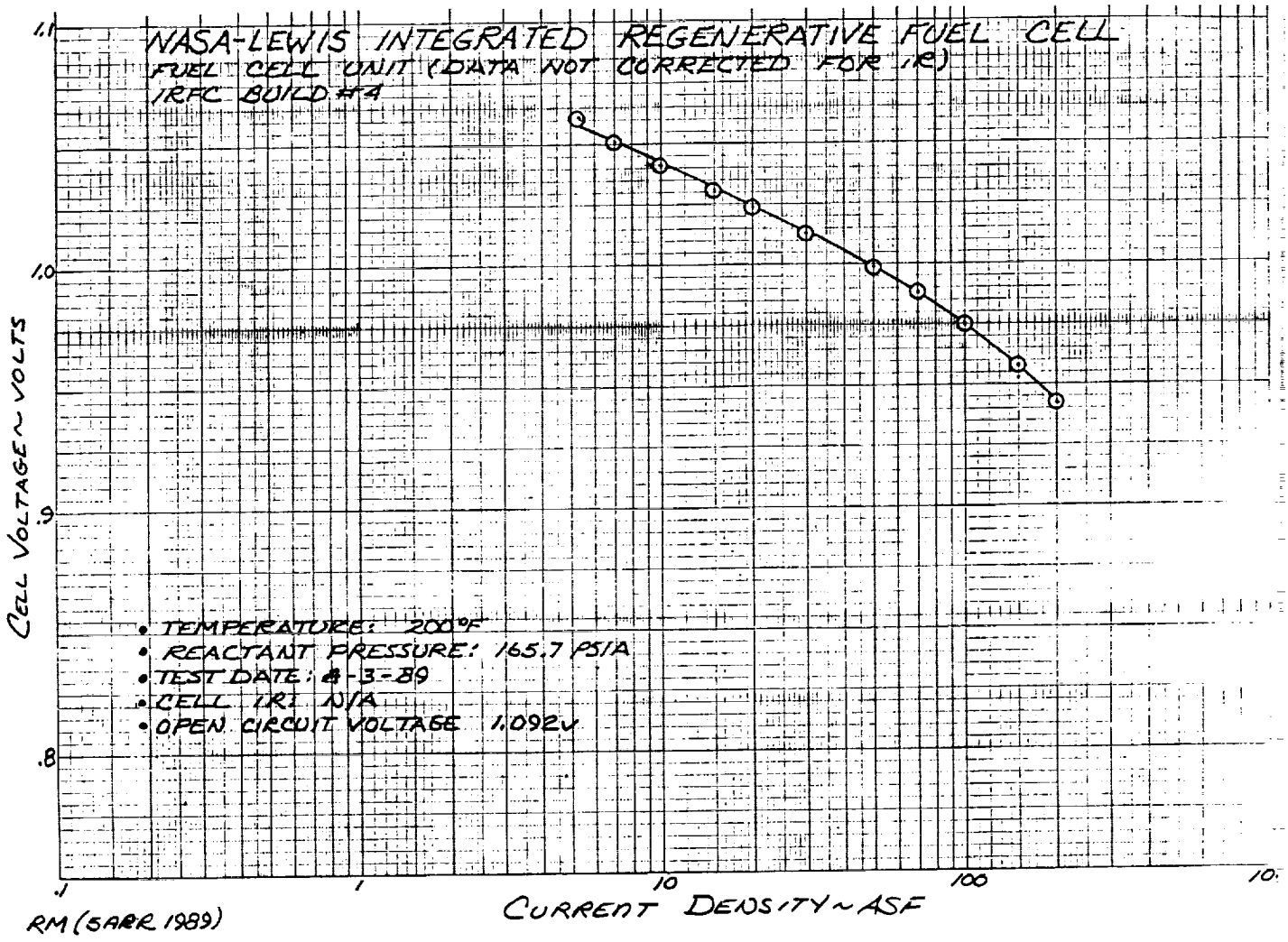

Figure 12. IRFC No. 4 Fuel Cell Oxygen Tafel Data

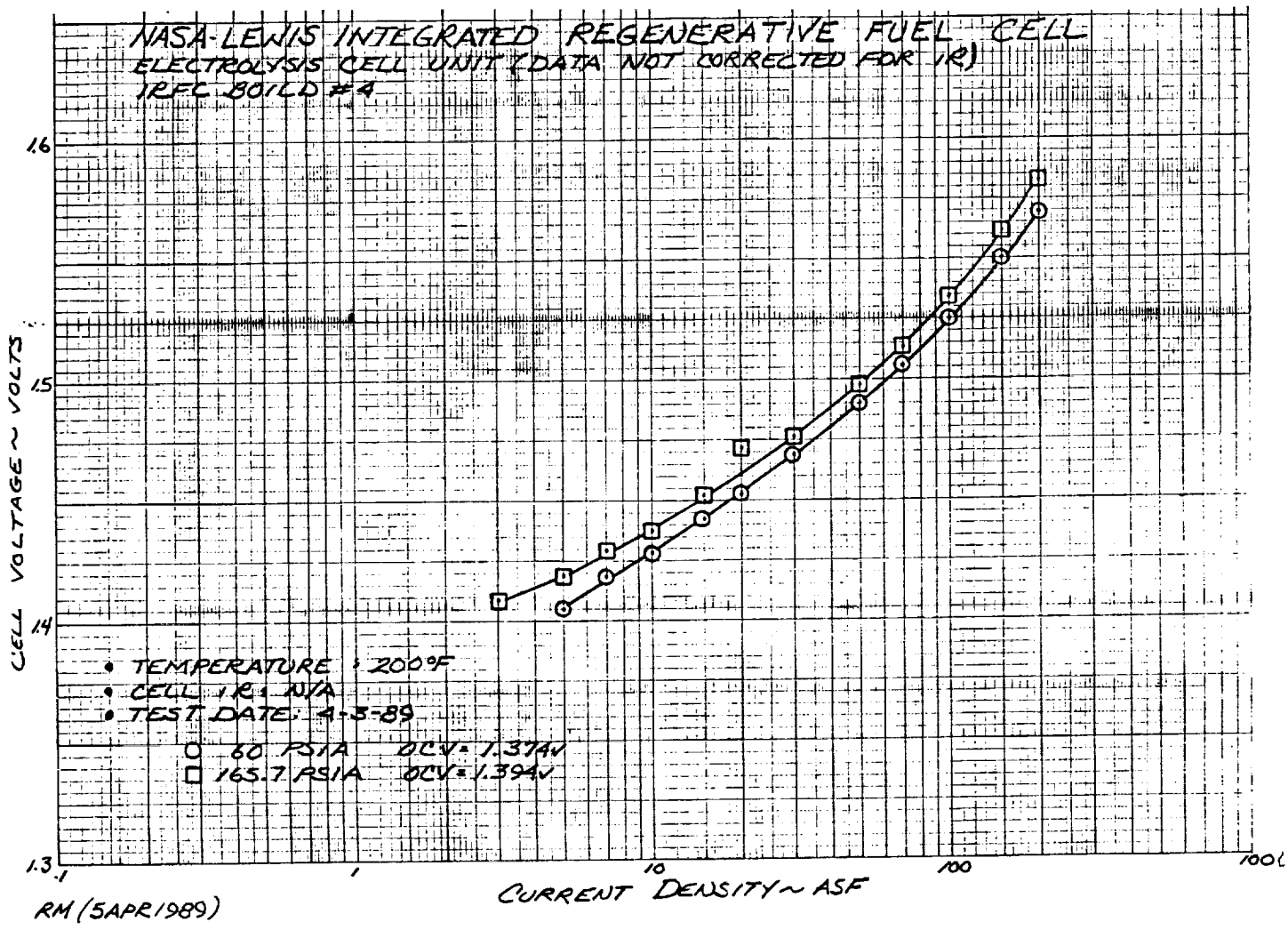

Figure 13. IRFC No. 4 Electrolysis Cell Performance

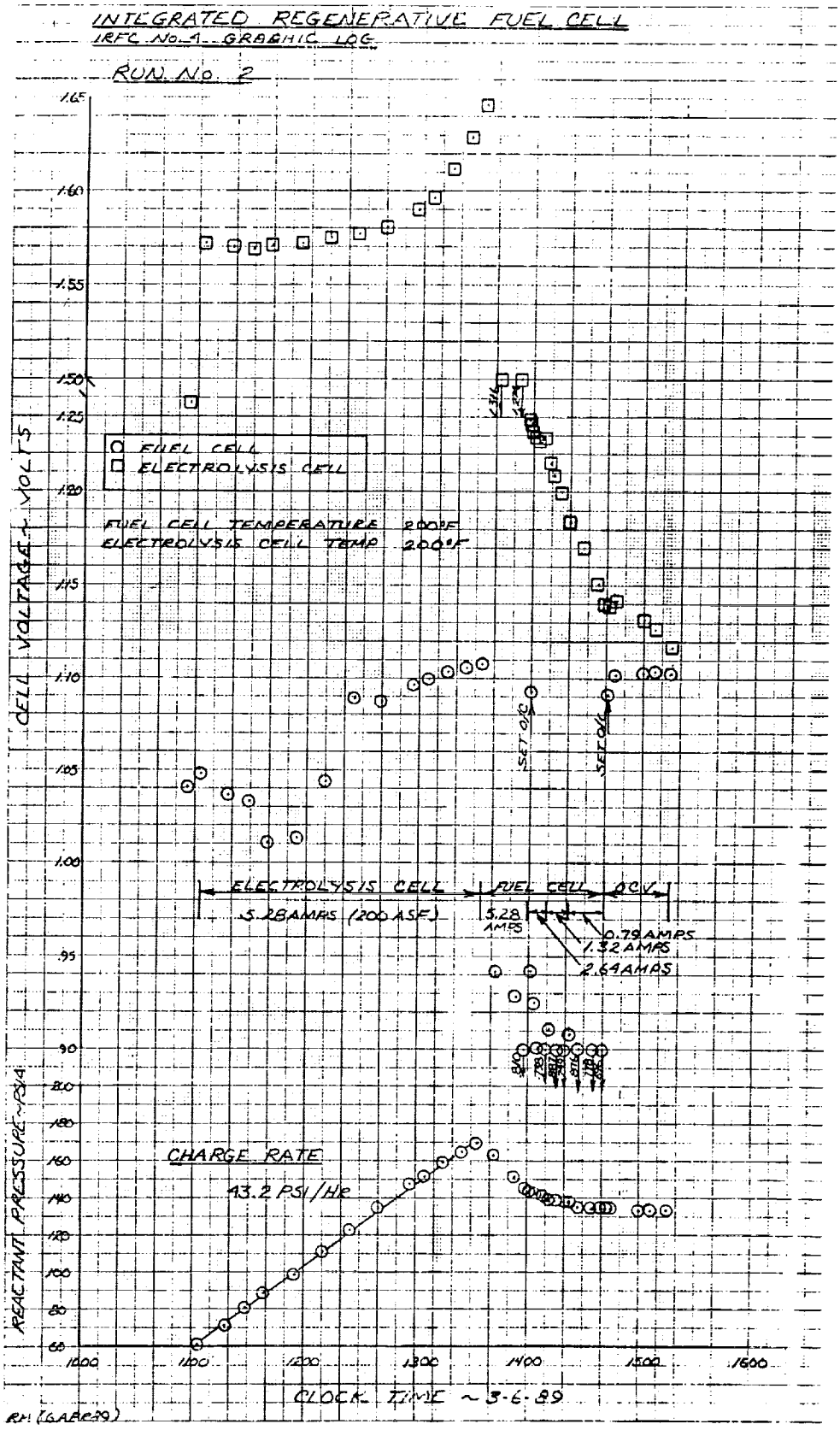

Figure 14. IRFC-4 Graphic Log Cycle No. 2

IIIF. IRFC No. 5

An exploratory Reversible Fuel Cell was assembled as IRFC No. 5. The purpose of IRFC No. 5 was to determine if the performance anomalies were caused by the IRFC configuration. IRFC No. 5 incorporated into a single unit both the electrolysis cell and fuel cell functions, simplified reactant manifolding, reduced water transport requirements, and reduced operational complexity. Details of the cell construction are presented at the beginning of Section III.

The graphic log of run No. 1 of IRFC Build No. 5 is presented on Figure 15. Following heat-up to 200°F (93.3°C), the electrolysis cell was operated for about 1.6 hours at 100 ASF (107.6 ma/cm^2) with a normal pressurization rate of 29 psi/hr (20 n/cm^2 hr). The fuel cell unit was operated for about an hour at 100 ASF (107.6 ma/cm^2) with a normal depressurization rate of 31.6 psi/hr (21.8 n/cm^2 hr). The pressure charge/discharge rates experienced for IRFC No. 5 suggests that the performance anomalies experienced on previous IRFC units was associated with the two unit integrated laboratory regenerative fuel cell.

The differential pressure imbalance (oxygen above hydrogen) experienced during run 1 was due to overboard leakage of hydrogen. In order to eliminate the pressure imbalance, oxygen was vented overboard during operation in the fuel cell mode. Leaking hydrogen system hydrogen fittings were repaired and the performance test was resumed.

The graphic log of the second run of IRFC No. 5 is shown on Figure 16. As shown on Figure 16, during electrolysis cell operation the pressurization rate was 24.8 psi/hr (17.1 n/cm^2 hr). The lower than expected pressurization rate was due to the development of an internal short during electrolysis cell operation. The magnitude of the cell short, at about 5 ASF (5.4 ma/cm^2) can be determined from the fuel cell unit Tafel data presented on Figure 17. Electrolysis cell unit performance is summarized on Figure 18. Performance of the fuel cell during discharge operation was low and unstable, possibly due to internal reactant crossleakage. In addition, to expedite shutdown of the IRFC, both reactants were periodically vented overboard as shown on Figure 16.

Due to the internal cell short, IRFC No. 5 was reassembled with new cell components and refilled with electrolyte. The test plan was to performance evaluate the unit in an open cycle mode with external supply of reactants and water. However, the NASA Project Manager directed the test not be conducted. At this point all testing of IRFC No. 5, Reversible Cell was stopped.

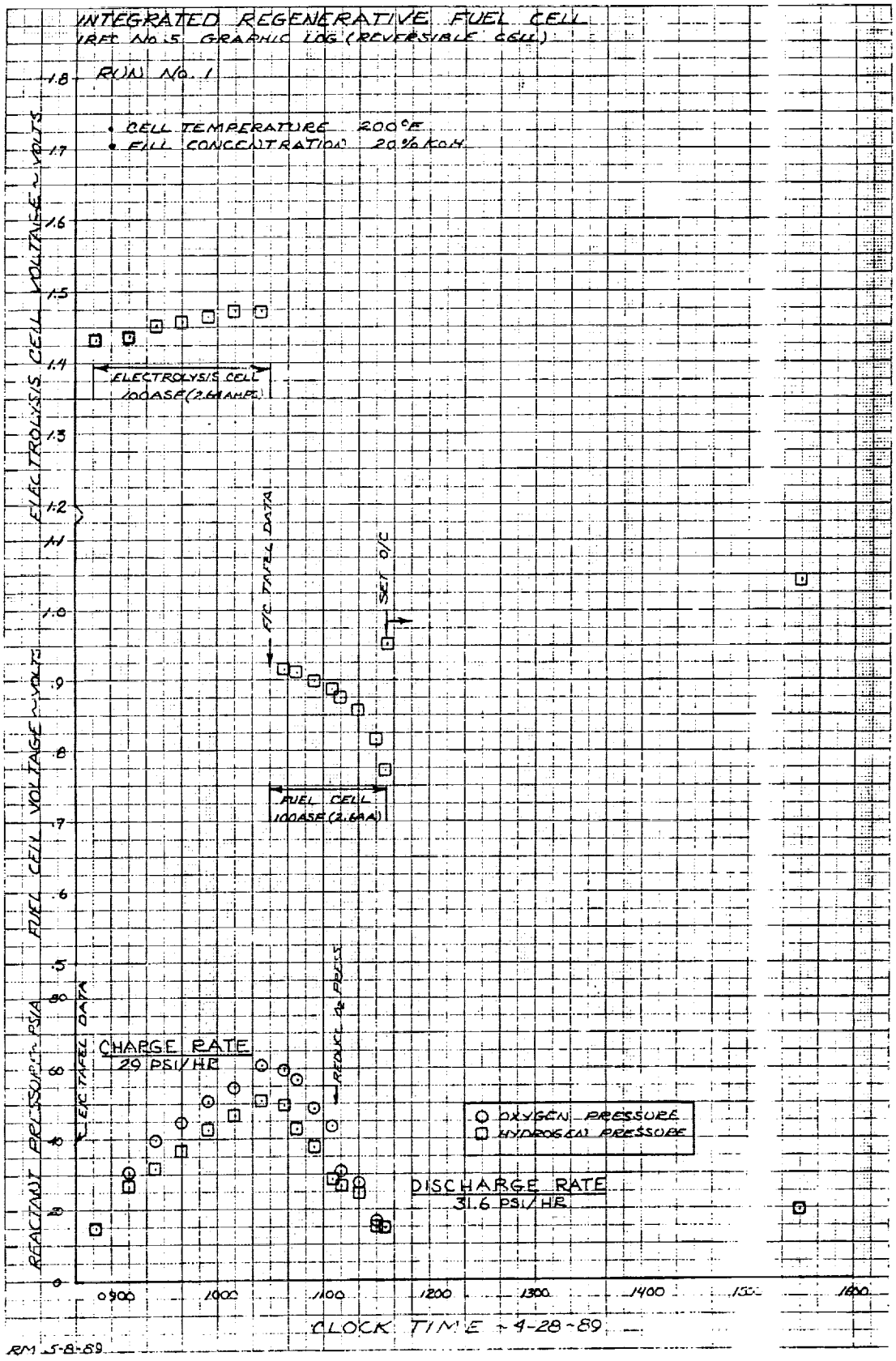

Figure 15. IRFC-5 Graphic Log Cycle No. 1

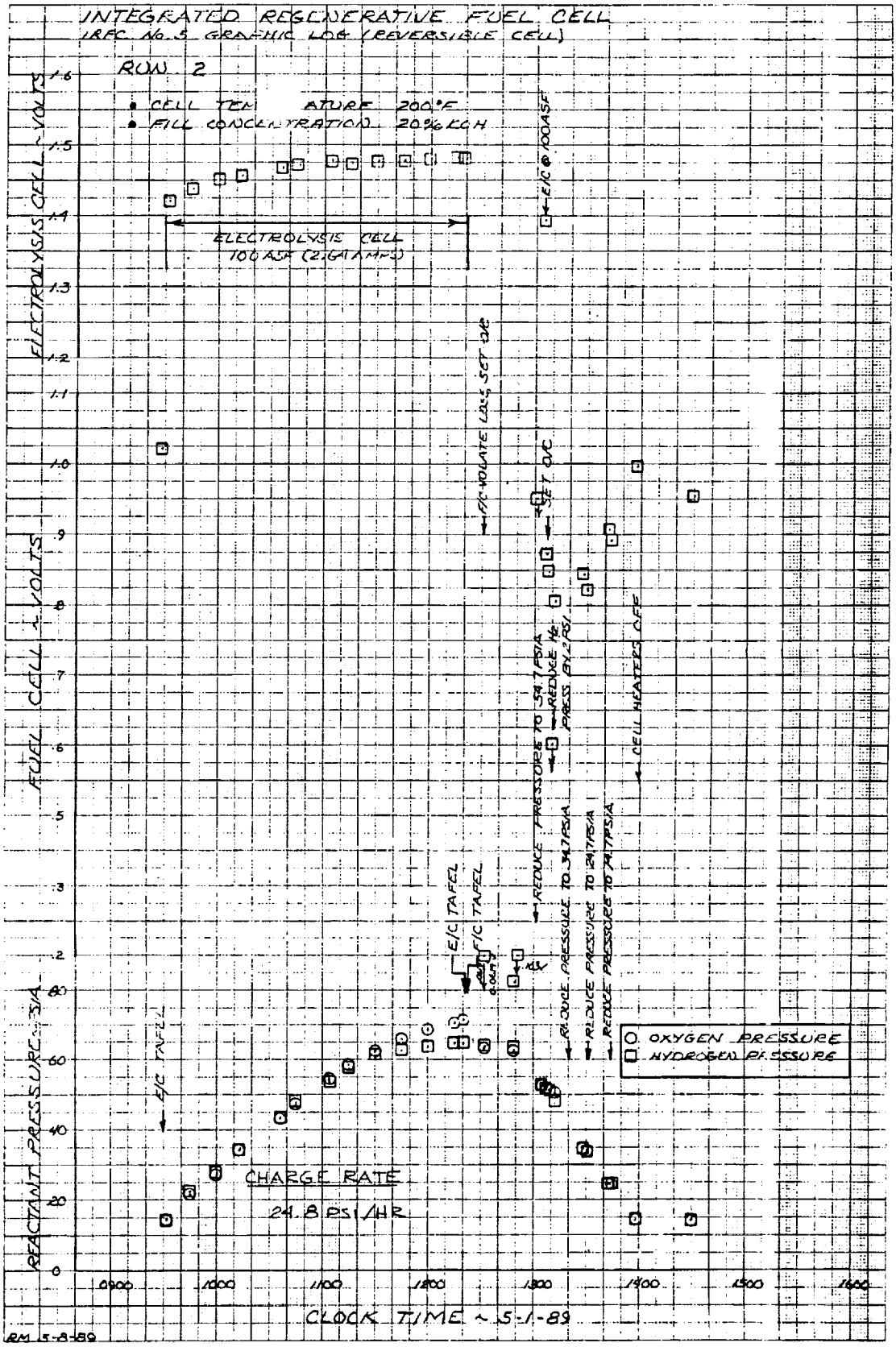

Figure 16. IRFC-5 Graphic Log Cycle No. 2

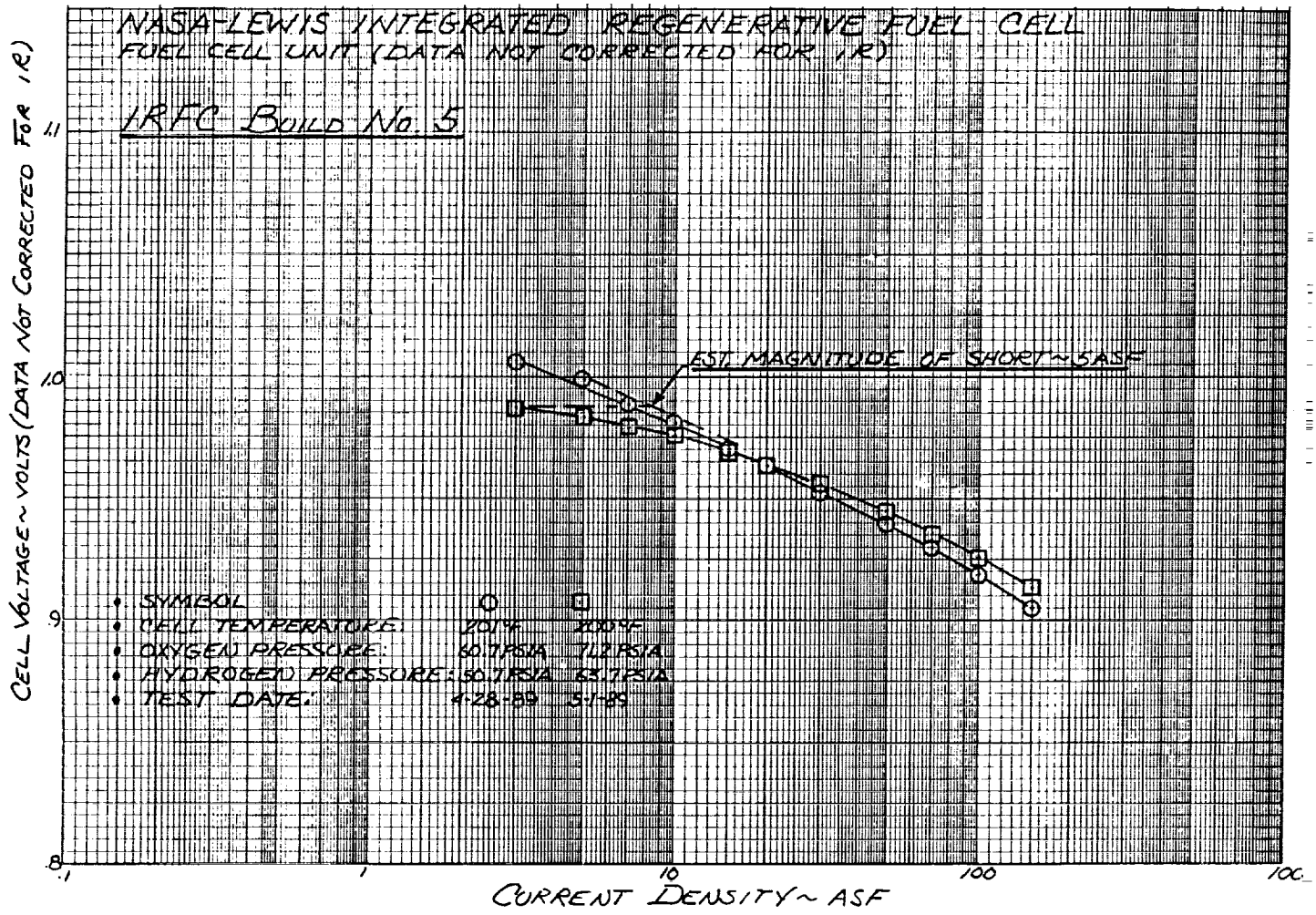

Figure 17. IRFC-5 Fuel Cell Oxygen Tafel Data

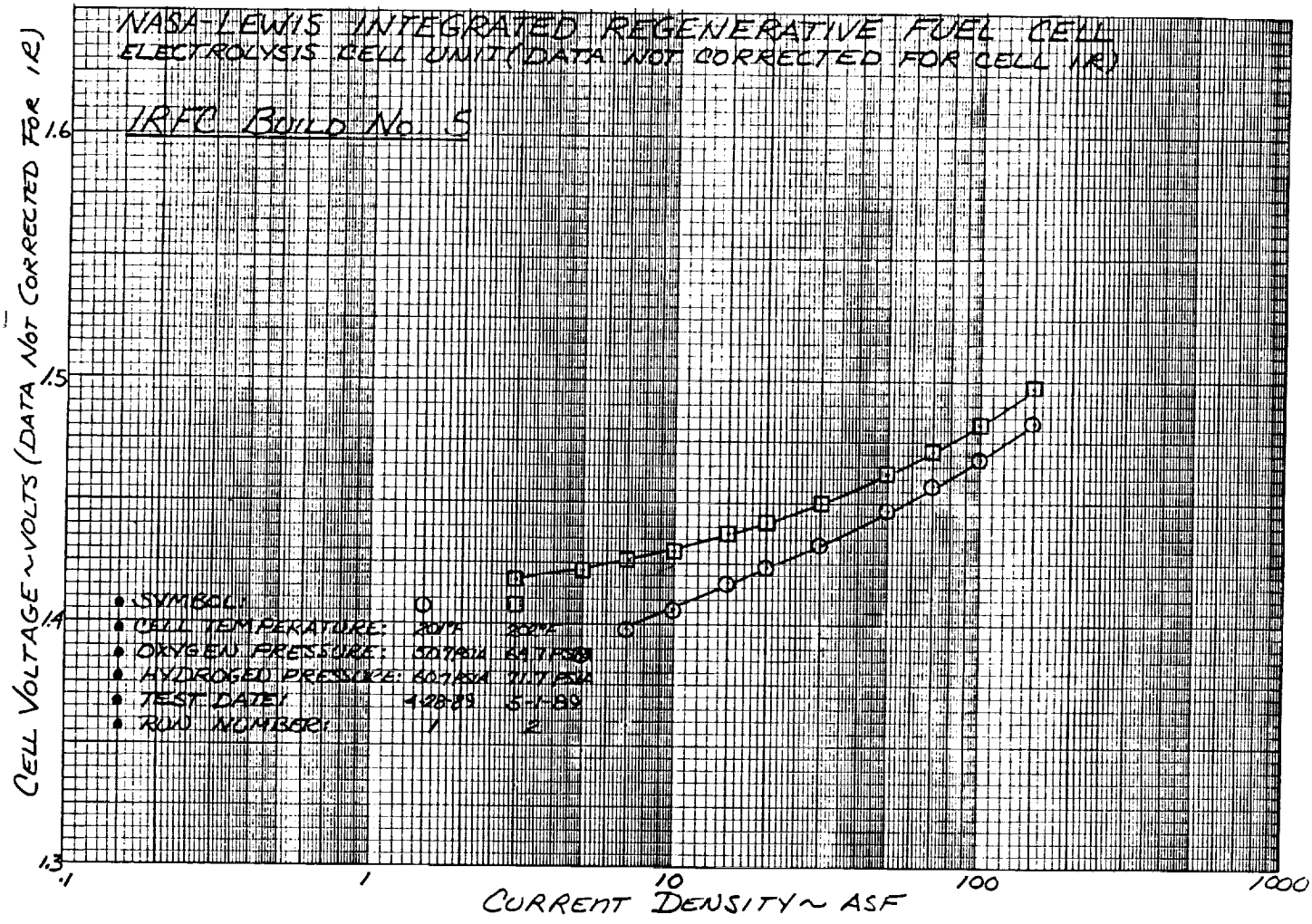

Figure 18. IRFC-5 Electrolysis Cell Performance

IIIG. IRFC No. 6

IRFC No. 6 was assembled with nickel foil bridges over the internal hydrogen ports as shown on Figure 19. The bridge will prevent Teflon gasket creep into these ports. The NASA Project Manager suggested that blockage of these ports could result in a reactant cross-pressure during electrolysis cell and fuel cell operation. The resulting reactant crossover would explain the anomalous pressurization charge/discharge rates experienced on past IRFC test unit.

Details of cell construction are presented in Section III.

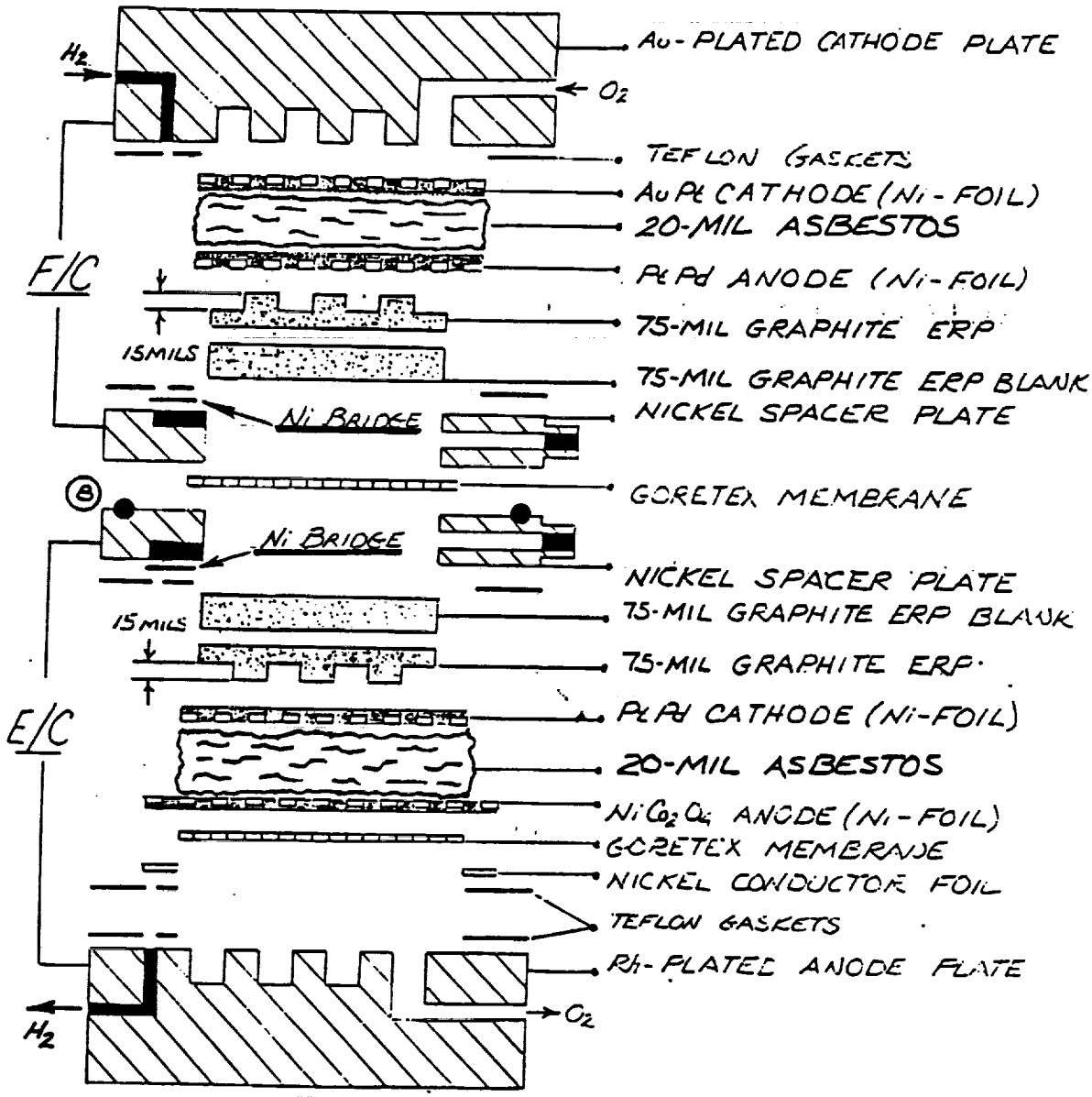

Figure 19. IRFC-6 Cell Configuration

IRFC No. 6 was tested in the open cycle mode for over 140-hours at 200°F (93.3°C) and 14.7 psia (10.1 n/cm^2) without incident. In the open cycle mode, water for electrolysis cell operation was provided from externally supplied humidified reactants. The performance history of the test is shown on Figure 20. The performance of the fuel cell and electrolysis cell was invariant during the test as shown on Figures 21 and 22 respectively.

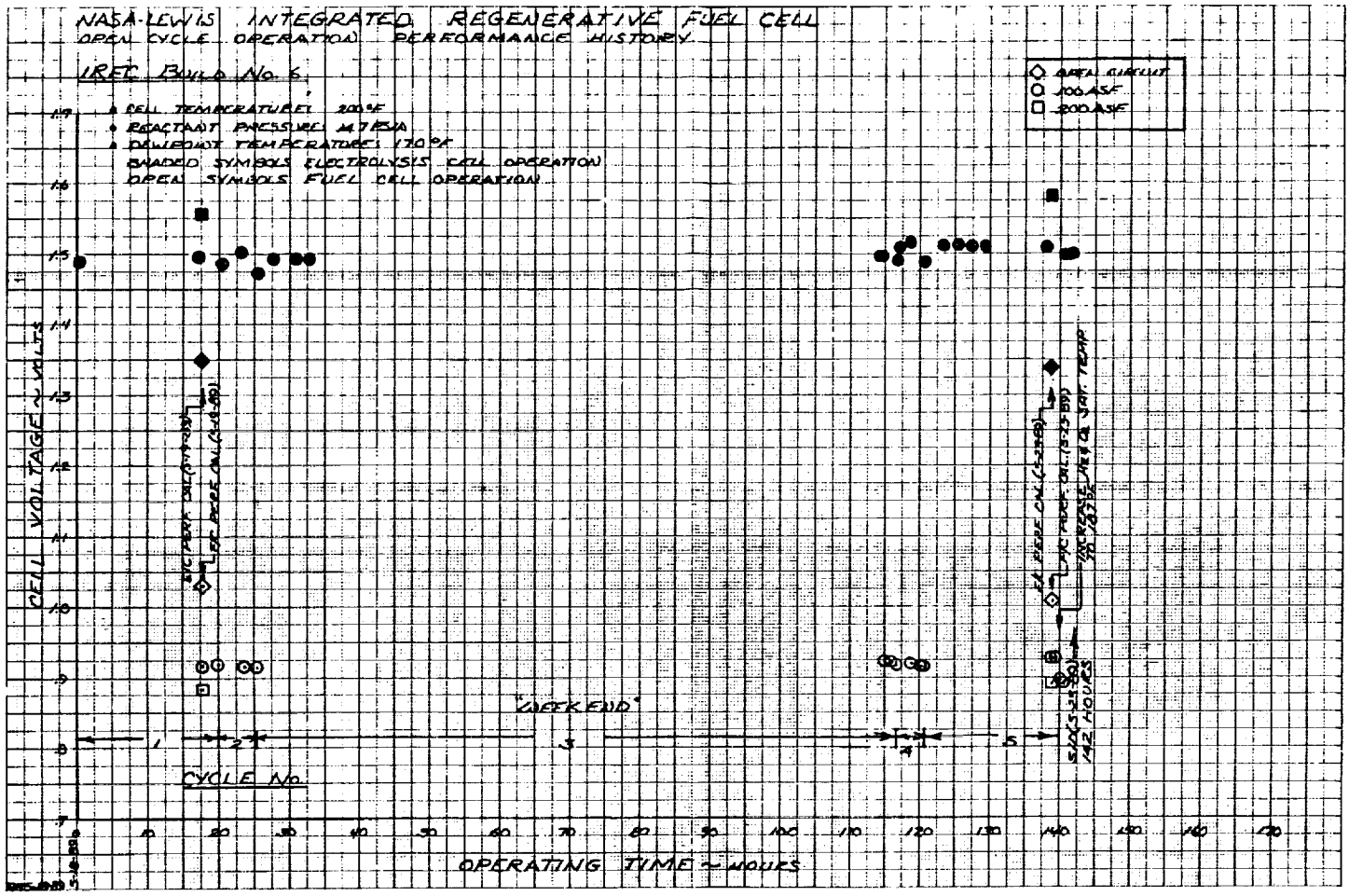

Figure 20. IRFC-6 Open Cycle Performance History

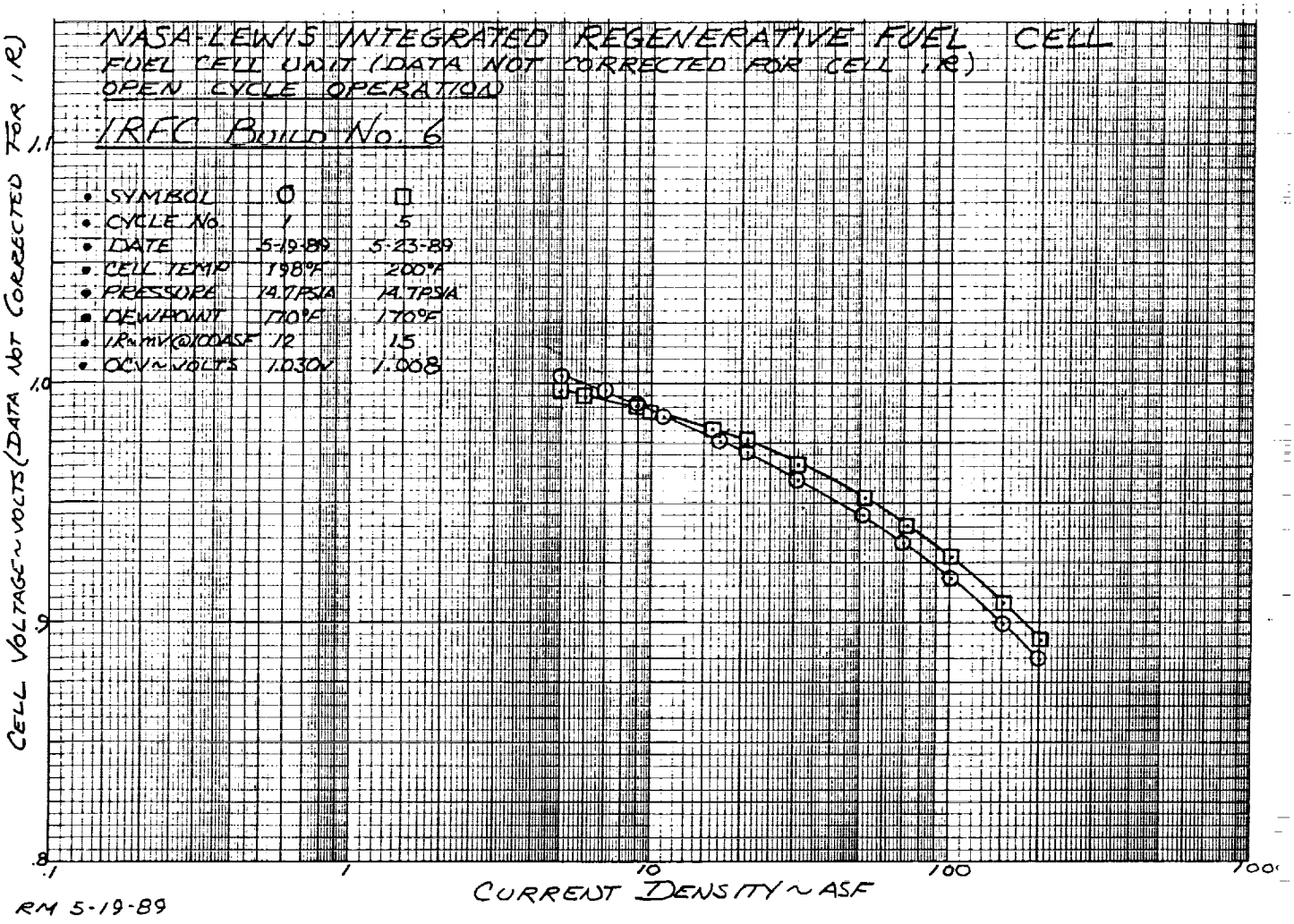

Figure 21. IRFC-6 Electrolysis Cell Performance (Open Cycle)

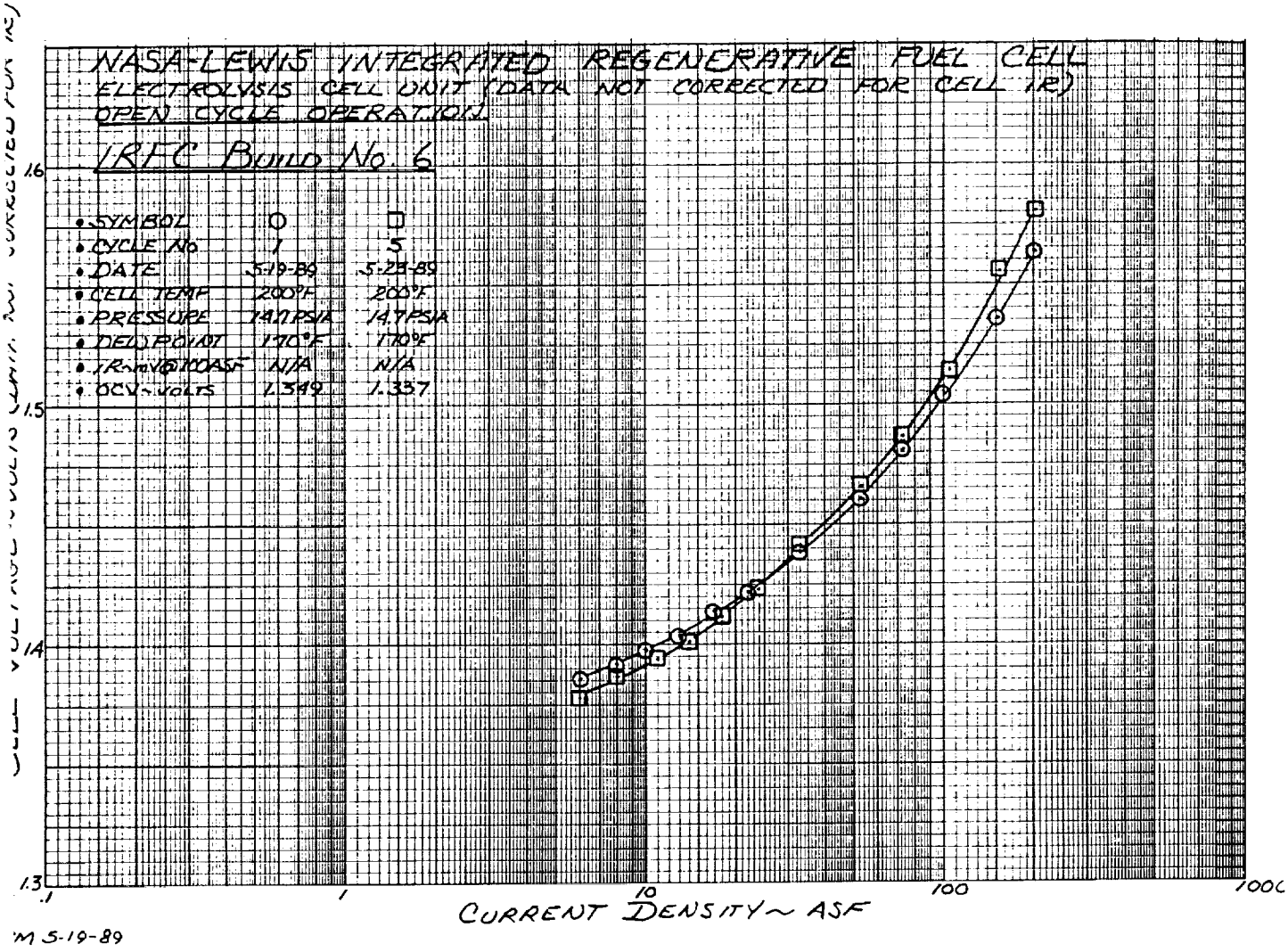

Figure 22. IRFC-6 Electrolysis Cell Performance (Open Cycle)

Open cycle test results on IRFC-6 verify the functional capability of the fuel cell and electrolysis cell units, individually.

Prior to operating IRFC No. 6 as an integrated unit, the power supply load system and IRFC test bench were reinspected. As before, no ground loss or external shorting paths were identified. Following heat-up to 200°F (93.3°), the electrolysis cell was operated closed cycle for nearly 40 minutes at 100 ASF (107.6 ma/cm^2) with no increase in reactant pressure. Electrolysis cell voltage at 100 ASF (107.6 ma/cm^2) was 1.503V consistent with open cycle test results. The fuel cell open circuit voltage was about 0.950V. Based upon open cycle Tafel data, this voltage was equivalent to a 50 ASF (53.8 ma/cm^2) short. At this point, testing on IRFC No. 6 was concluded.

IV. ELECTROLYSIS CELL ENDURANCE TESTING

Two laboratory 2-inch x 2-inch (5.1 cm x 5.1 cm) active area electrolysis cells were endurance tested at a current density of 100 ASF (107.6 ma/cm^2), at a 170°F (76.7°C) cell temperature and 14.7 psia (10.1 n/cm^2) reactant pressure. The test setup of the laboratory electrolysis cell is shown on Figure 23.

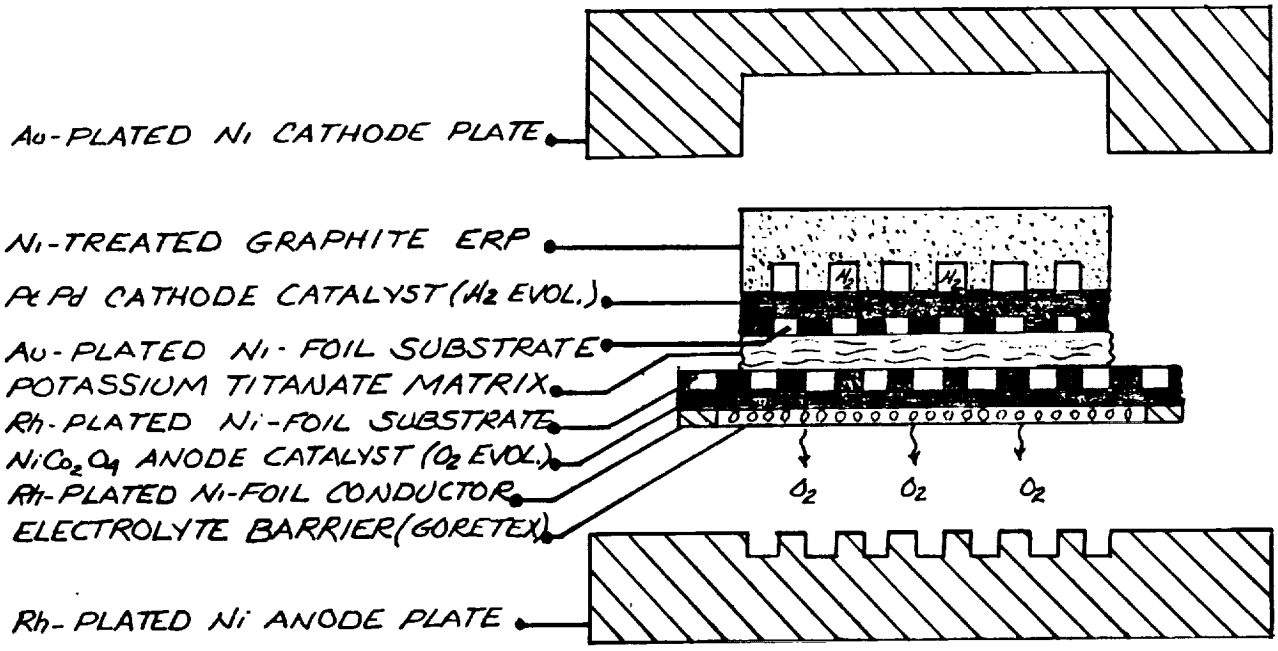

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Figure 23. Laboratory Electrolysis Cell Test Setup

The configurations of the two electrolysis cells is presented in Table III.

Table III. Electrolysis Cell Configuration Summary

Electrolysis Cell No.	ERP	H_2 Elec.	Matrix	O_2 Elec.
1	75 mil C	PtPd/Ni-Foil	8-mil PKT	$NiCo_2O_4$/Ni-Foil
2	75 mil C	PtPd/Ni-Foil	8-mil PKT	Noble Alloy/Ni-Foil

The nickel foil substrate employed at the H_2 electrode was gold-plated and the nickel foil at the O_2 electrode was Rh-plated. Both cells incorporated a porous Teflon membrane cover on the anode to prevent electrolyte loss during O_2 evolution.

IV.A Electrolysis Cell No. 1

The performance history of electrolysis Cell No. 1 is presented on Figure 24. The endurance test was voluntarily stopped after 307 hours of testing at 170°F (76.7°C) and ambient pressure. The initial cell voltage at a current density of 100 ASF (107.6 ma/cm^2) was 1.538V and after 307 hours of testing, cell voltage was 1.549V.

Test results from performance calibrations at 20 load hours and 233 load hours is summarized on Figure 25. During the endurance test cell iR was stable at 16 mV at 100 ASF (107.6 ma/cm^2).

Teardown inspection of electrolysis cell No. 1 found all components to be in good condition. There was no evidence of free electrolyte on the oxygen side of the anode Teflon cover membrane.

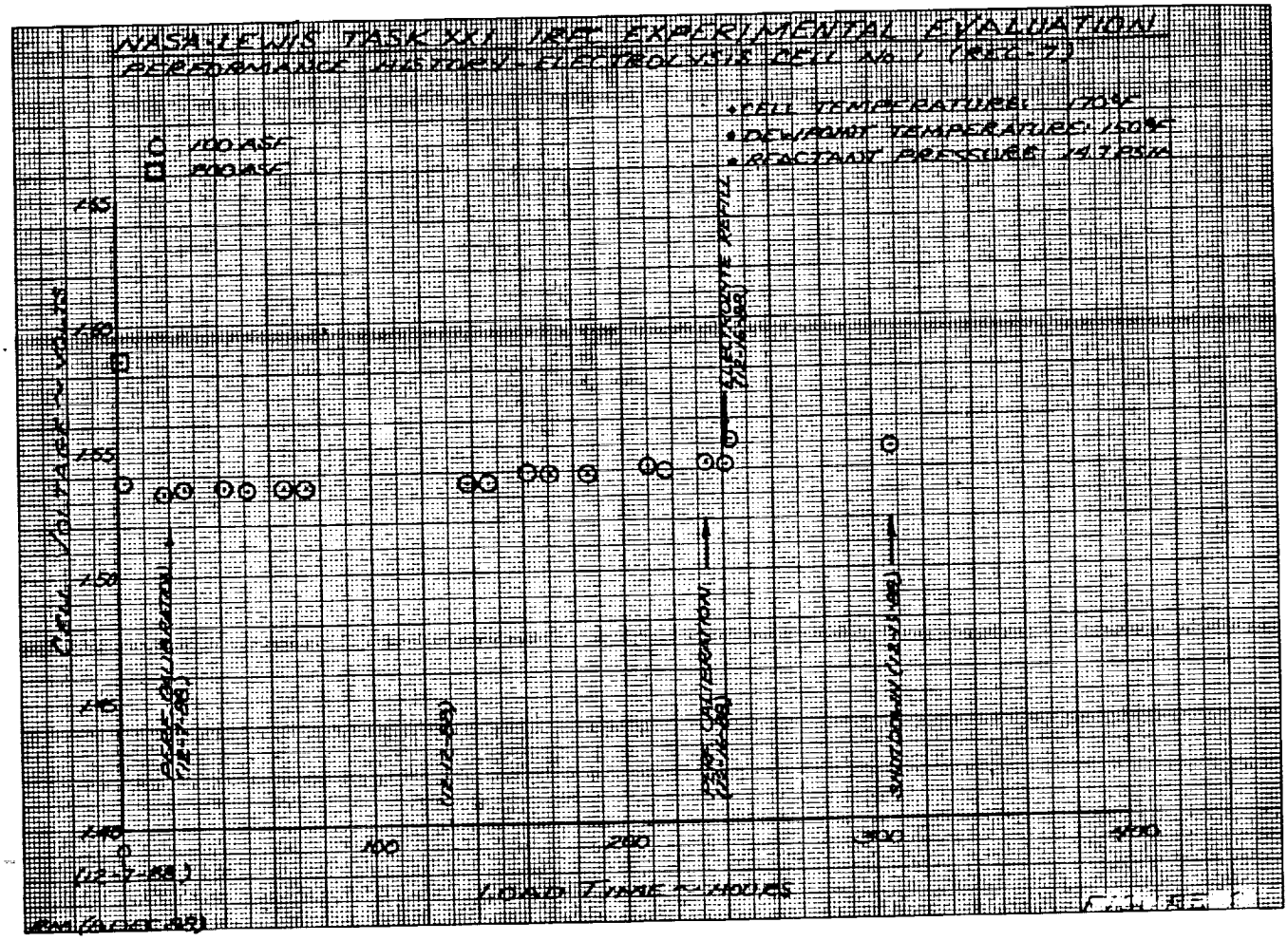

Figure 24. Electrolysis Cell No. 1 Performance History

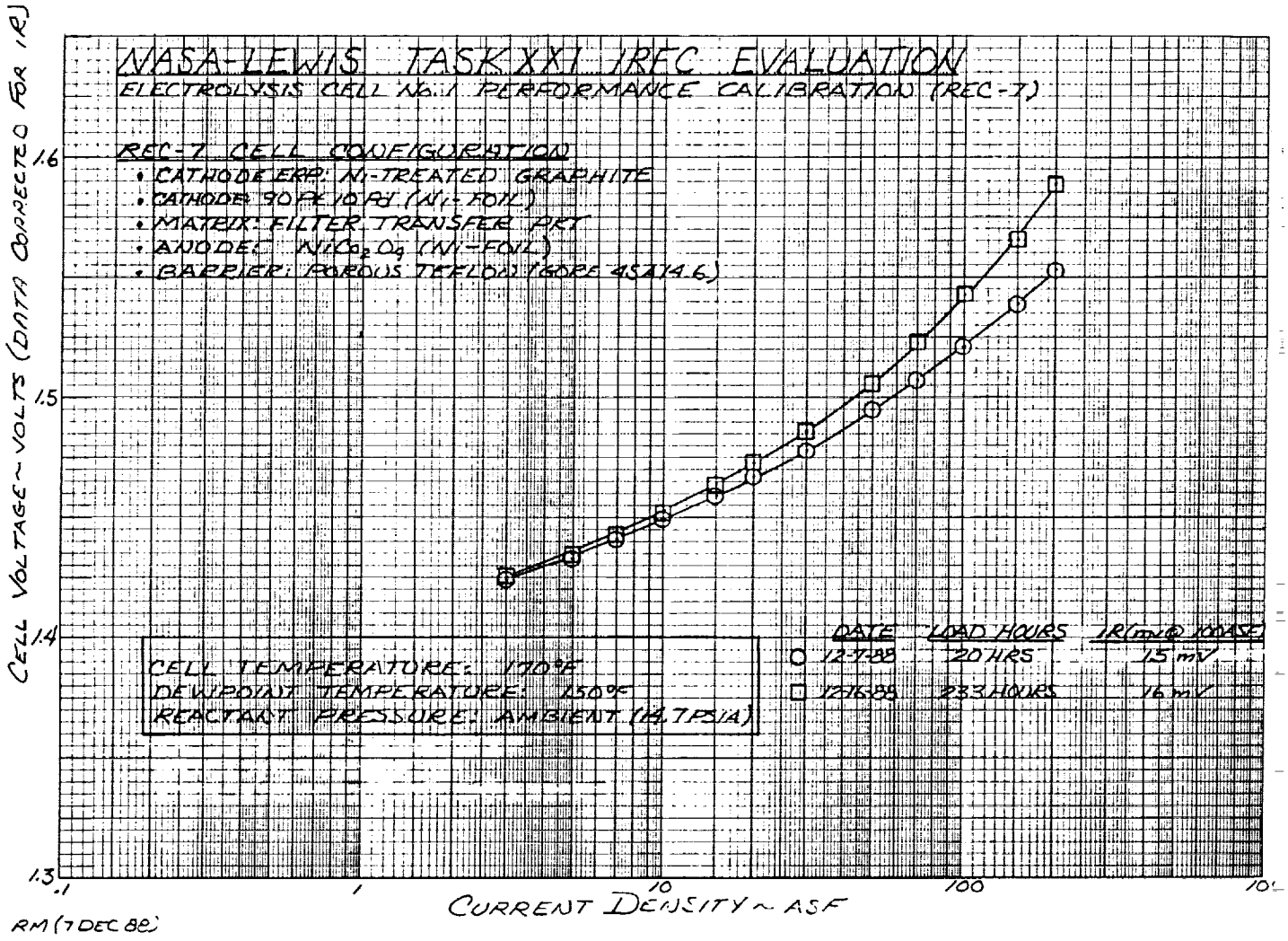

Figure 25. Electrolysis Cell No. 1 Performance Calibration

IV.B Electrolysis Cell No. 2

The performance history of Electrolysis Cell No. 2 is presented on Figure 26. The endurance test was voluntarily stopped after 312-hours of testing at 170°F (76.7°C) and ambient pressure. The initial cell voltage at a current density of 100 ASF (107.6 ma/cm^2) was 1.434V and after 312-hours of testing, cell voltage was 1.492V.

Test results from four performance calibrations are summarized on Figure 27. During the endurance test, cell iR was stable at 6 mV at 100 ASF (107.6 ma/cm^2). The stable performance of Electrolysis Cell No. 2 over a period of 200-hours of operation represented a 50 mV improvement over Electrolysis Cell No. 1 which contained a $NiCo_2O_4$ catalyst O_2 electrode.

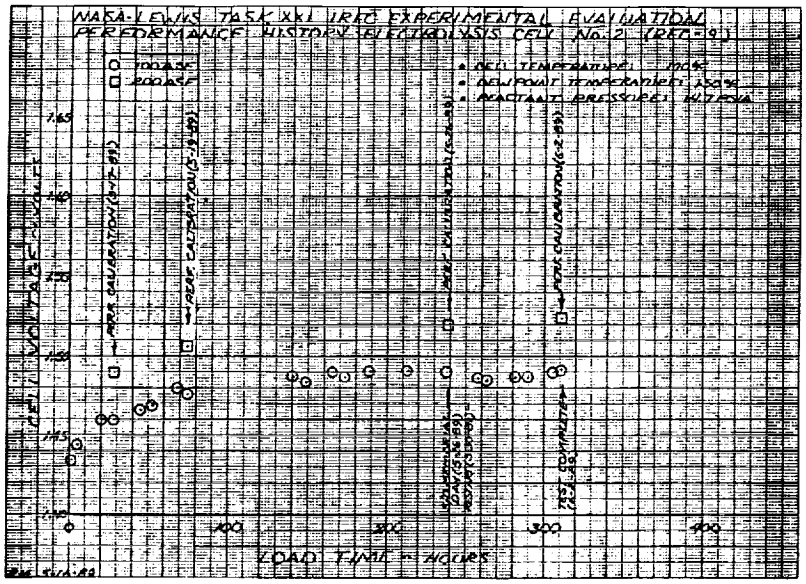

Figure 26. Electrolysis Cell No. 2 – Performance History

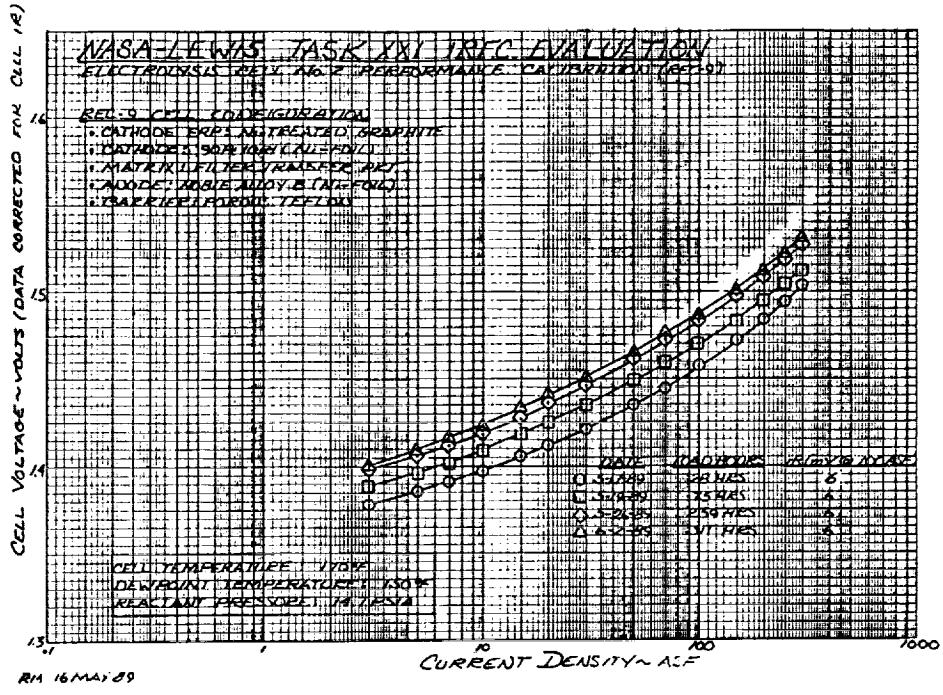

Figure 27. Electrolysis Cell No. 2 – Performance Calibration

V. HALF-CELL PERFORMANCE TESTING

Half-cell performance evaluation tests were conducted to evaluate the performance characteristics of the electrolysis cell and fuel cell electrodes to be employed in the IRFC test units. In addition, several alternate electrode configurations were evaluated to identify potential performance benefits. A summary of half-cell test results is presented in Table IV. Voltages presented are referenced to a dynamic hydrogen electrode.

Table IV. Half-Cell Performance Test Summary

Electrolysis Cell Electrodes Nominal			**Performance (mV @ 900 mA/cm²)**	
Catalyst	**Loading (mG/cm²)**	**Substrate**	**Cathodic (Under H_2)**	**Anodic (Under O_2)**
PtPd	10	Ni–Screen	–35	1641
PtPd	10	Ni–Foil	–20	1630
Alloy A	24	Ni–Foil	–40	1500
Alloy B	15	Ni–Foil	–35	1470
$NiCo_2O_4$	24	Ni–Foil	–	1560
Fuel Cell Electrodes				
			Cathodic (Under O_2)	**Anodic (Under H_2)**
AuPt	24	Ni–Foil	900	–
PtPd	10	Ni–Screen	–	20

The half-cell tests were conducted at 158°F (70°C) cell temperature and ambient pressure at 35 wt% KOH. The half-cell performance curves are presented in the Appendix.

APPENDIX

ELECTRODE HALF-CELL PERFORMANCE CURVES

APPENDIX

The half-cell performance of the fuel cell AuPt catalyst cathode and PtPd catlayst anode was consistent with current production cell performance characteristics. The performance of the $NiCo_2O_4$ catalyst O_2 evolution electrode and PtPd catalyst H_2 evolution electrode was consistent with previous IFC exploratory test results. Table V identifies the curves for the complete half-cell performance test results for the eleven electrodes tested.

Table V. Electrode Half-Cell Performance Curves

Figure No.	Description
28	PtPd (Ni-Screen) O_2 Evolution Electrode
29	PtPd (Ni-Foil) O_2 Evolution Electrode
30	Alloy A (Ni-Foil) O_2 Evolution Electrode
31	Alloy B (Ni-Foil) O_2 Evolution Electrode
32	$NiCo_2O_4$ (Ni-Foil) O_2 Evolution Electrode
33	PtPd (Ni-Screen) H_2 Evolution Electrode
34	PtPd (Ni-Foil) H_2 Evolution Electrode
35	Alloy A (Ni-Foil) H_2 Evolution Electrode
36	Alloy B (Ni-Foil) H_2 Evolution Electrode
37	AuPt (Ni-Foil) O_2 Consumption Electrode
38	PtPd (Ni-Screen) H_2 Consumption Electrode

Results from the half-cell tests confirm the suitability of the fuel cell and electrolysis cell electrodes baselined for use in the IRFC test units.

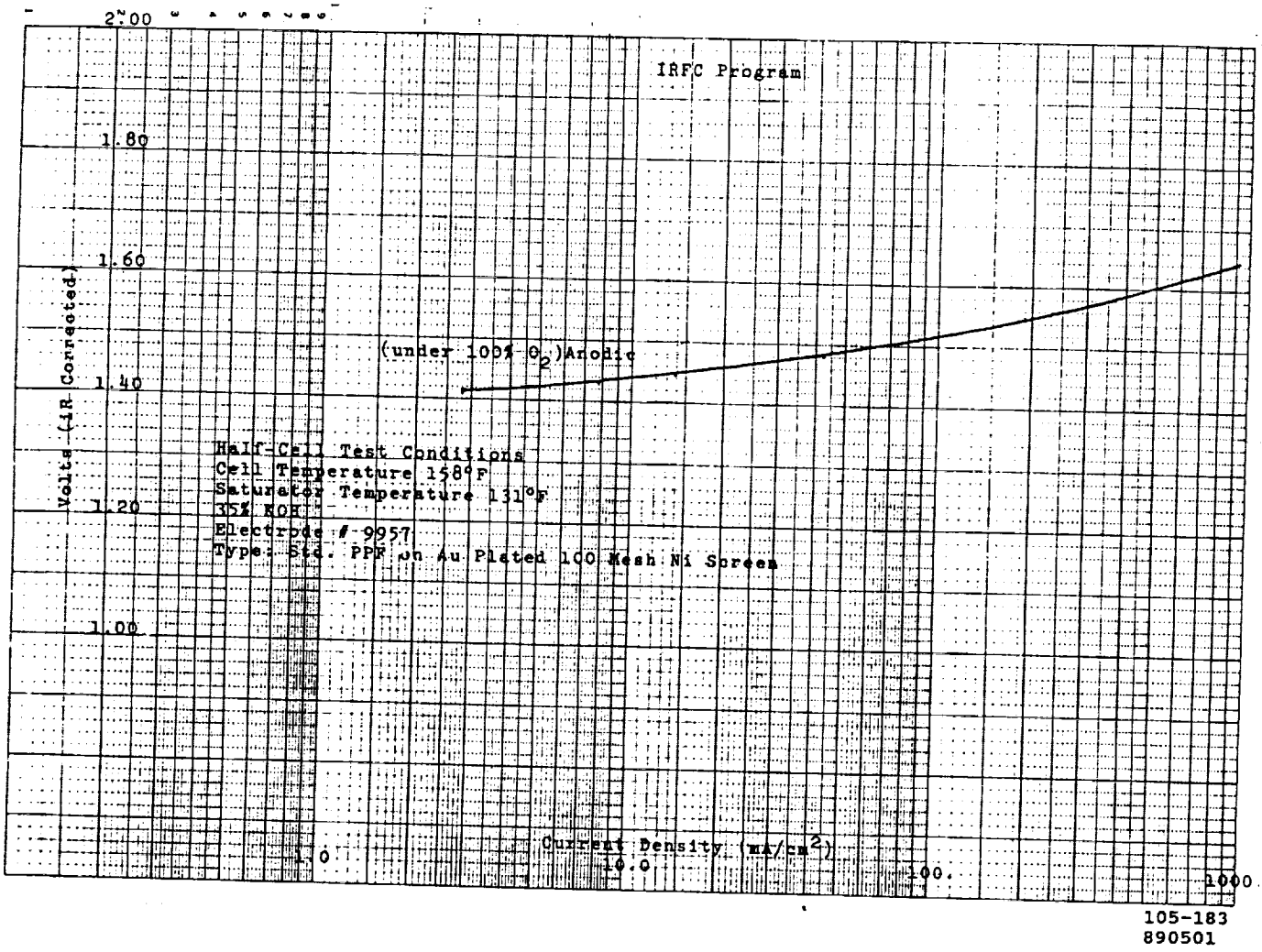

Figure 28. *Half Cell Performance – PtPd (Ni–Screen) O_2 Evolution Electrode*

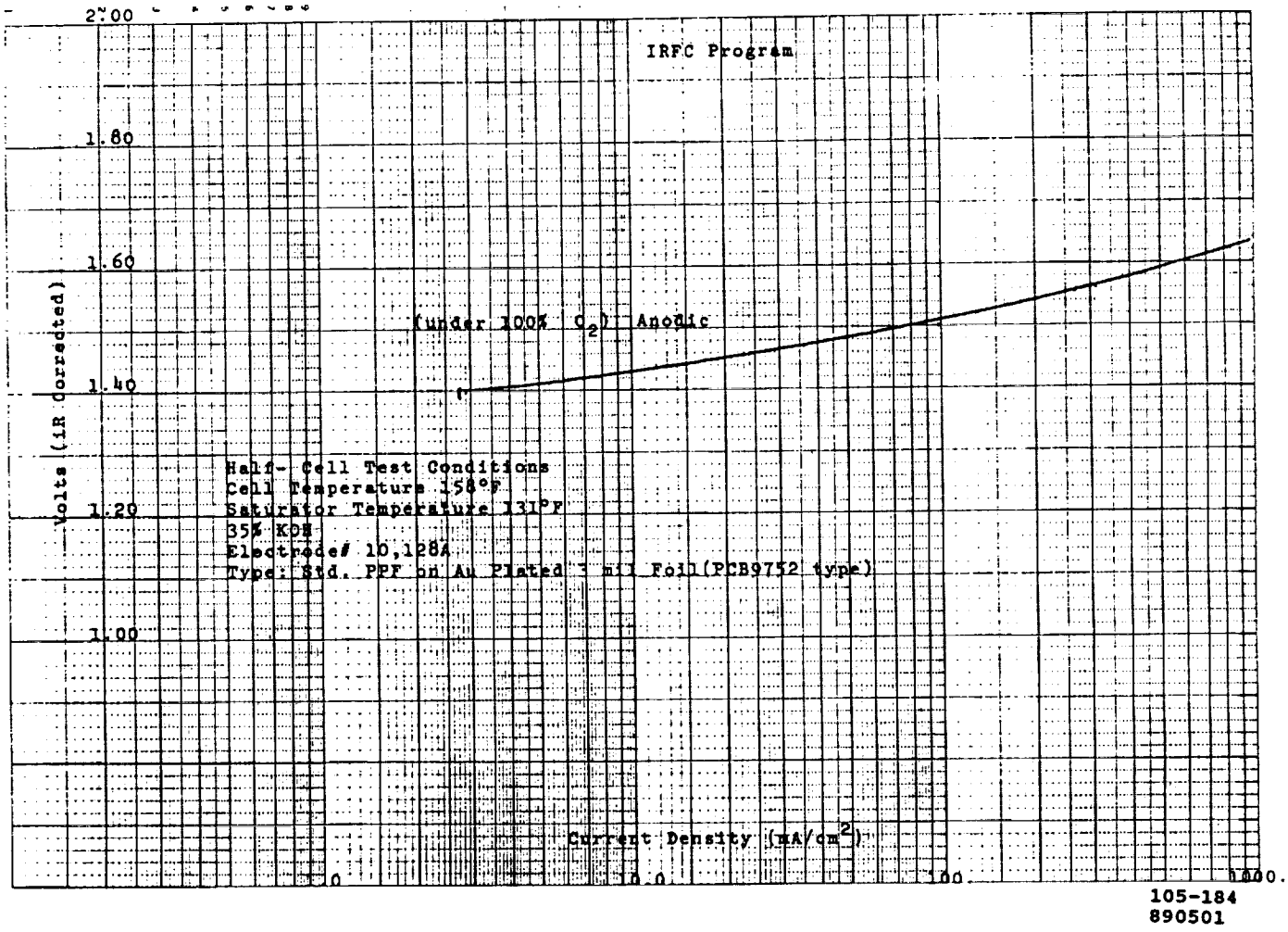

Figure 29. *Half Cell Performance – PtPd (Ni–Foil) O_2 Evolution Electrode*

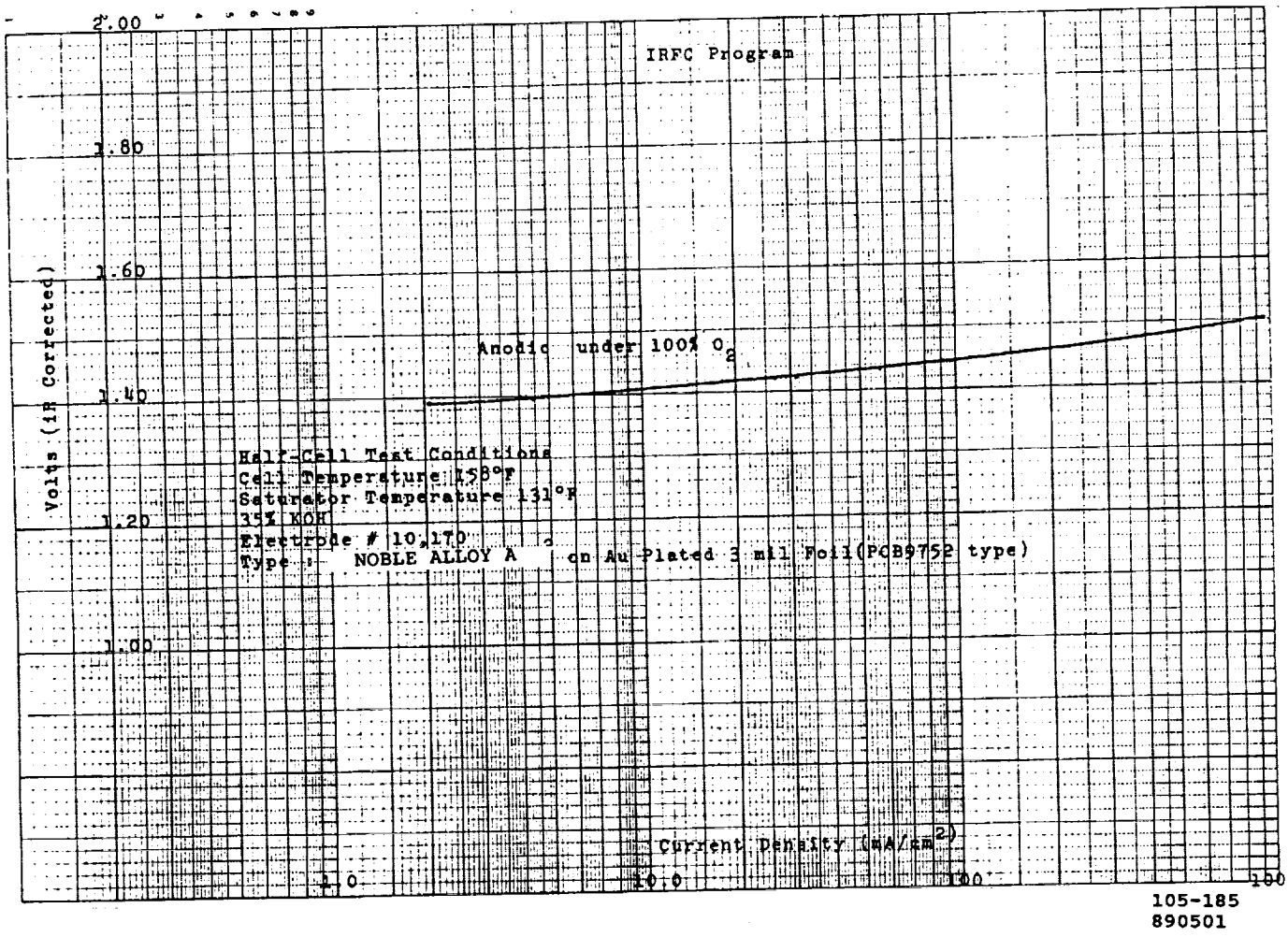

Figure 30. *Half Cell Performance – Alloy A (Ni–Foil) O_2 Evolution Electrode*

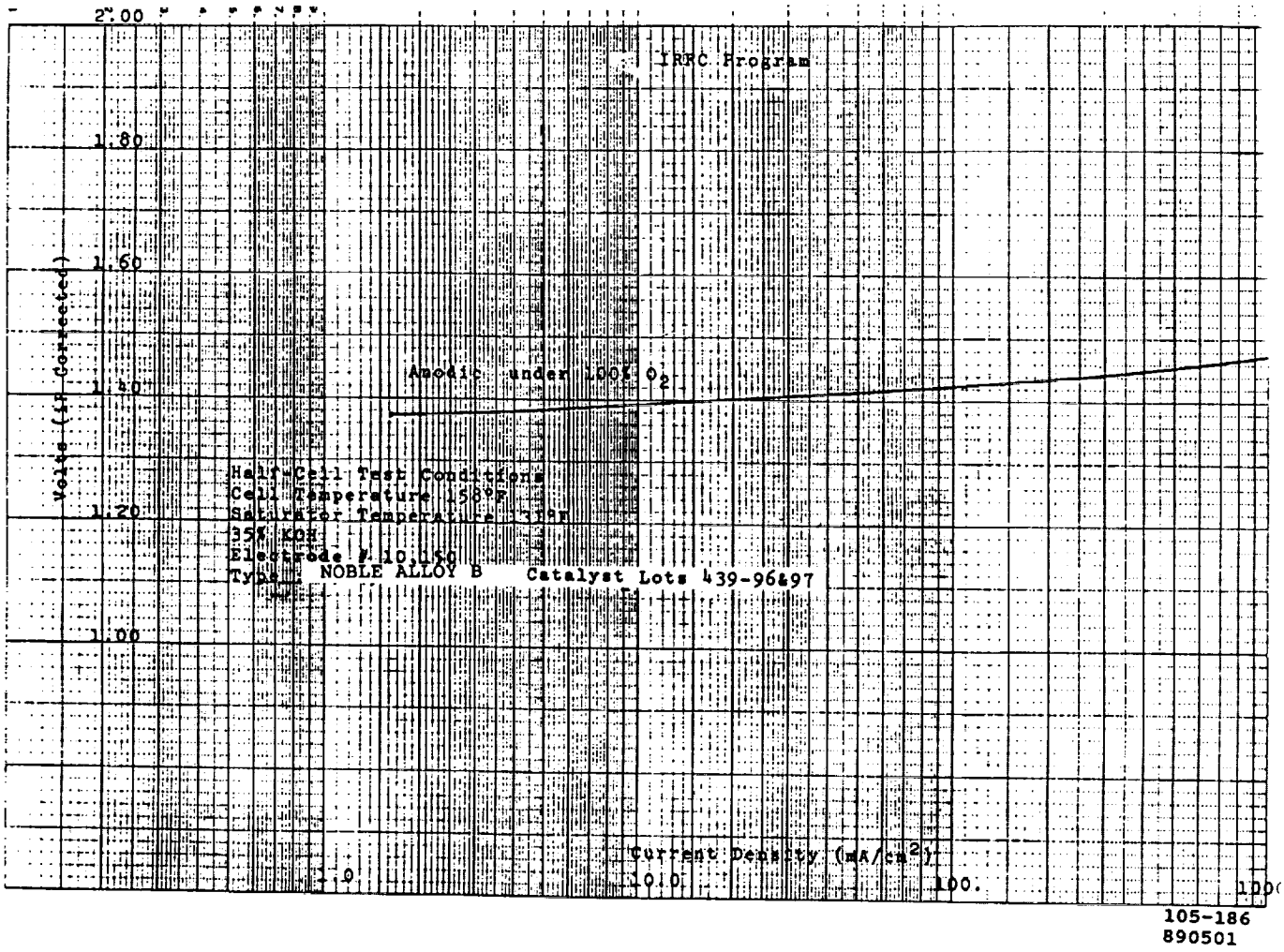

Figure 31. *Half Cell Performance – Alloy B (Ni–Foil) O_2 Evolution Electrode*

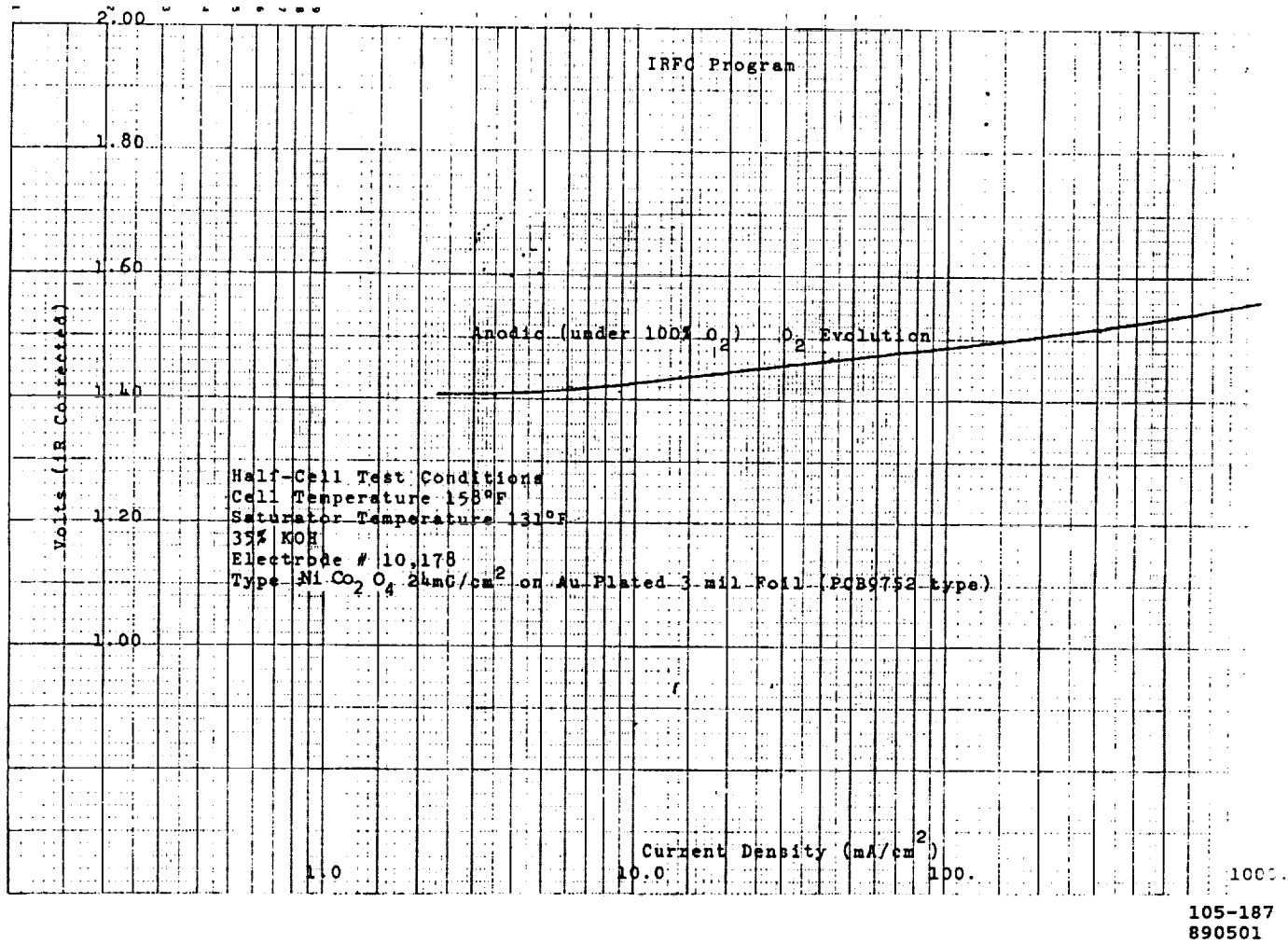

Figure 32. *Half Cell Performance – $NiCo_2O_4$ (Ni–Foil) O_2 Evolution Electrode*

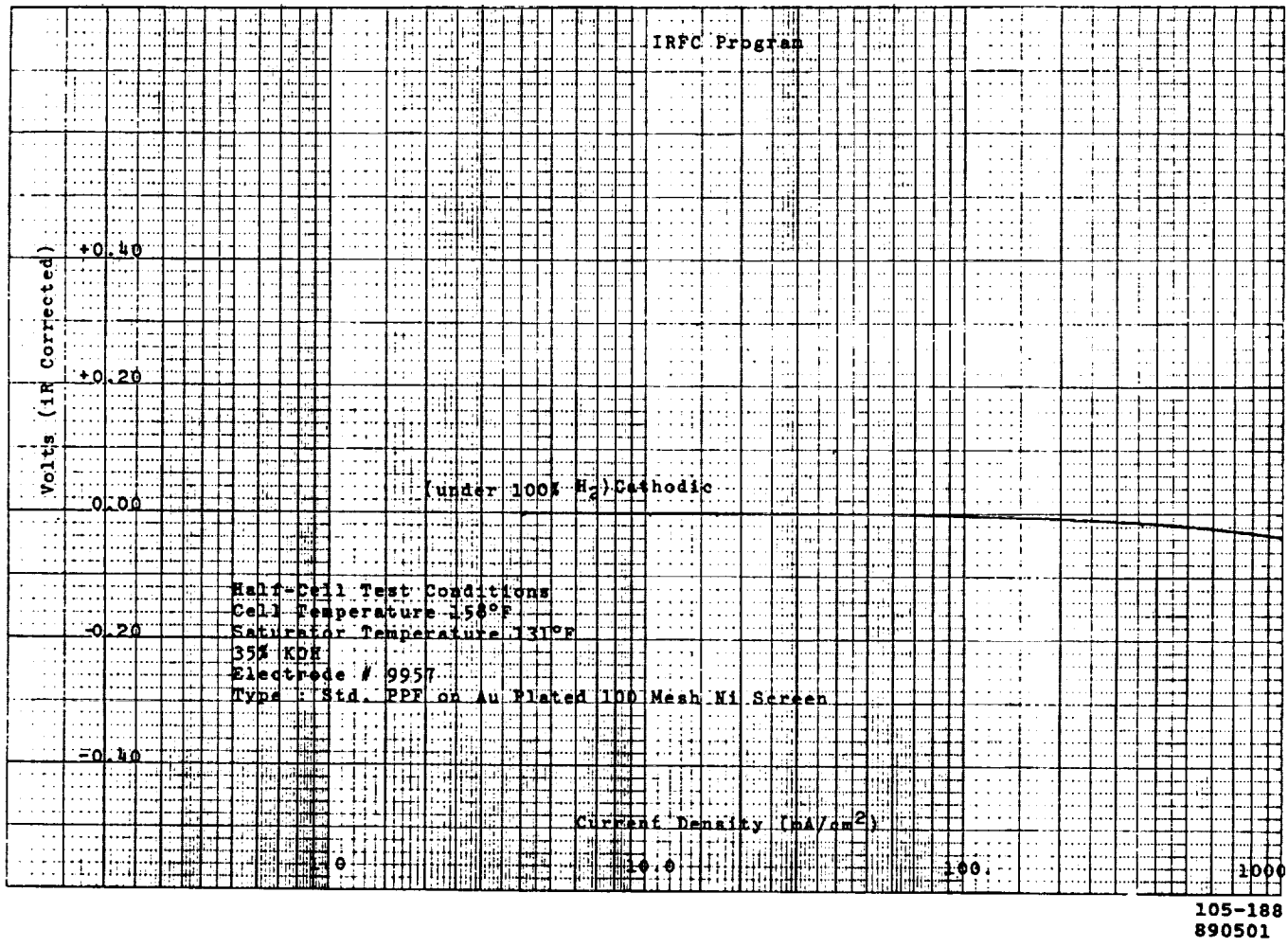

Figure 33. *Half Cell Performance – PtPd (Ni–Screen) H_2 Evolution Electrode*

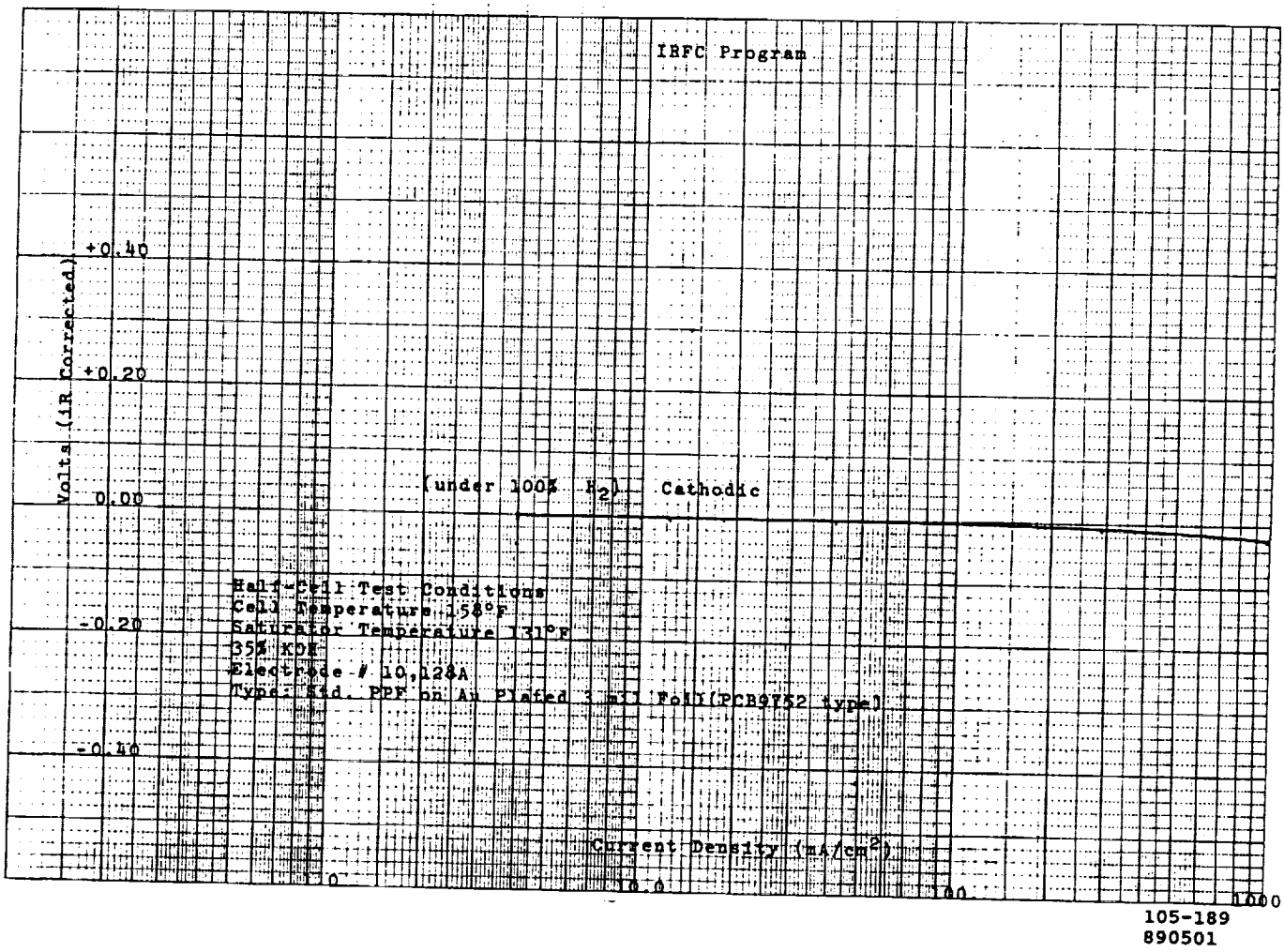

Figure 34. *Half Cell Performance – PtPd (Ni–Foil) H_2 Evolution Electrode*

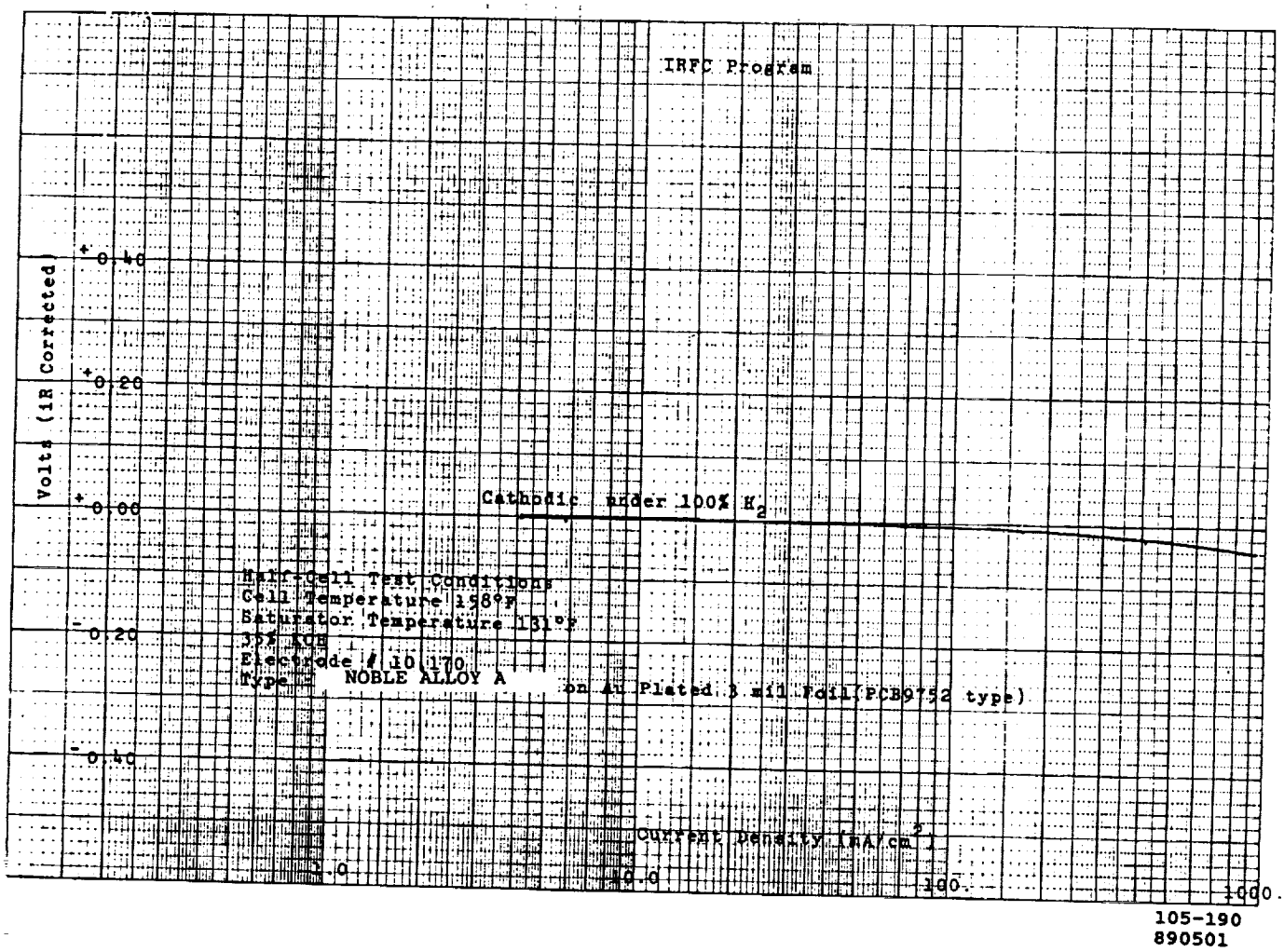

Figure 35. *Half Cell Performance – Alloy A (Ni–Foil) H_2 Evolution Electrode*

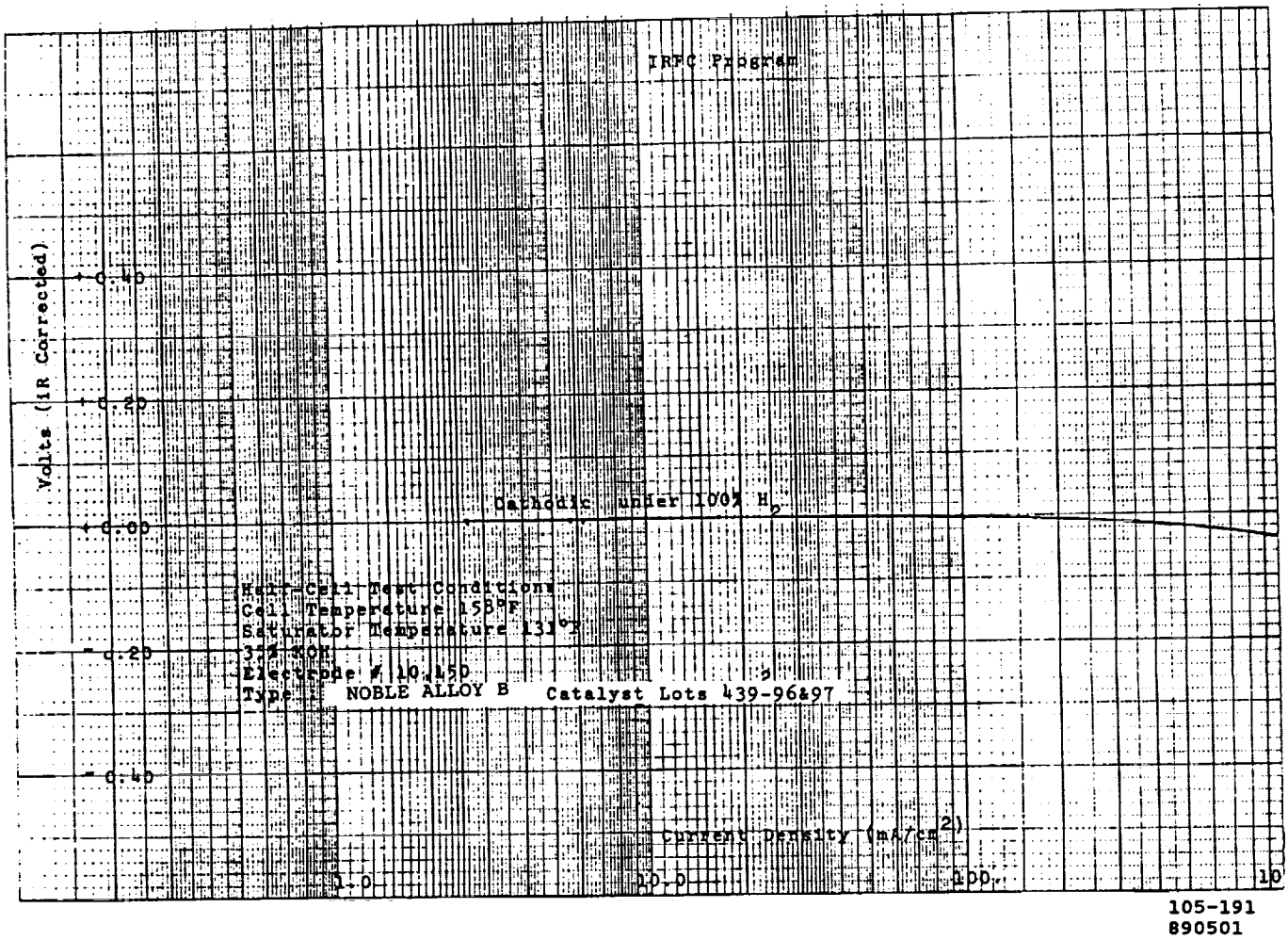

Figure 36. *Half Cell Performance – Alloy B (Ni–Foil) H_2 Evolution Electrode*

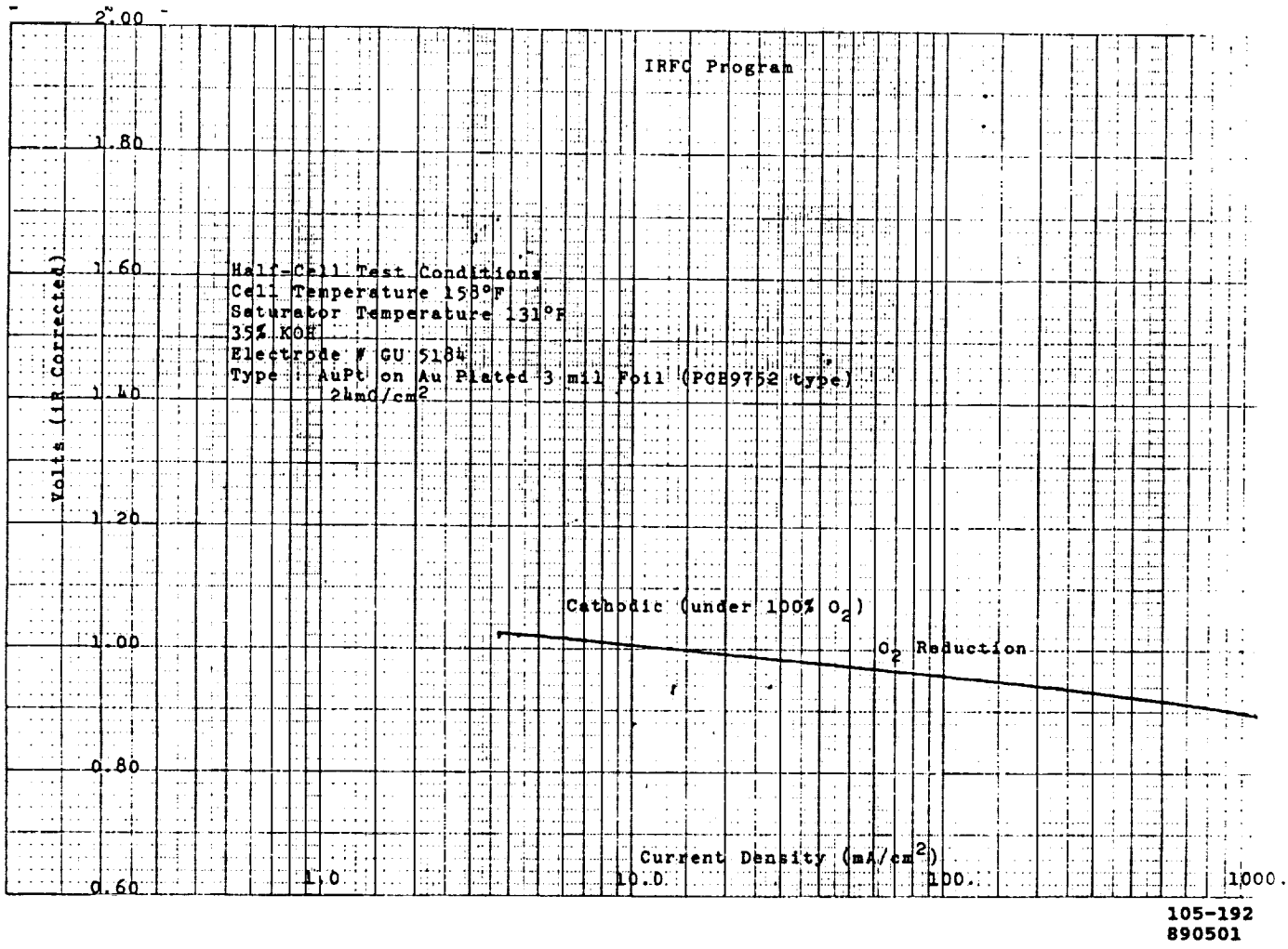

Figure 37. *Half Cell Performance – AuPt (Ni–Foil) O_2 Consumption Electrode*

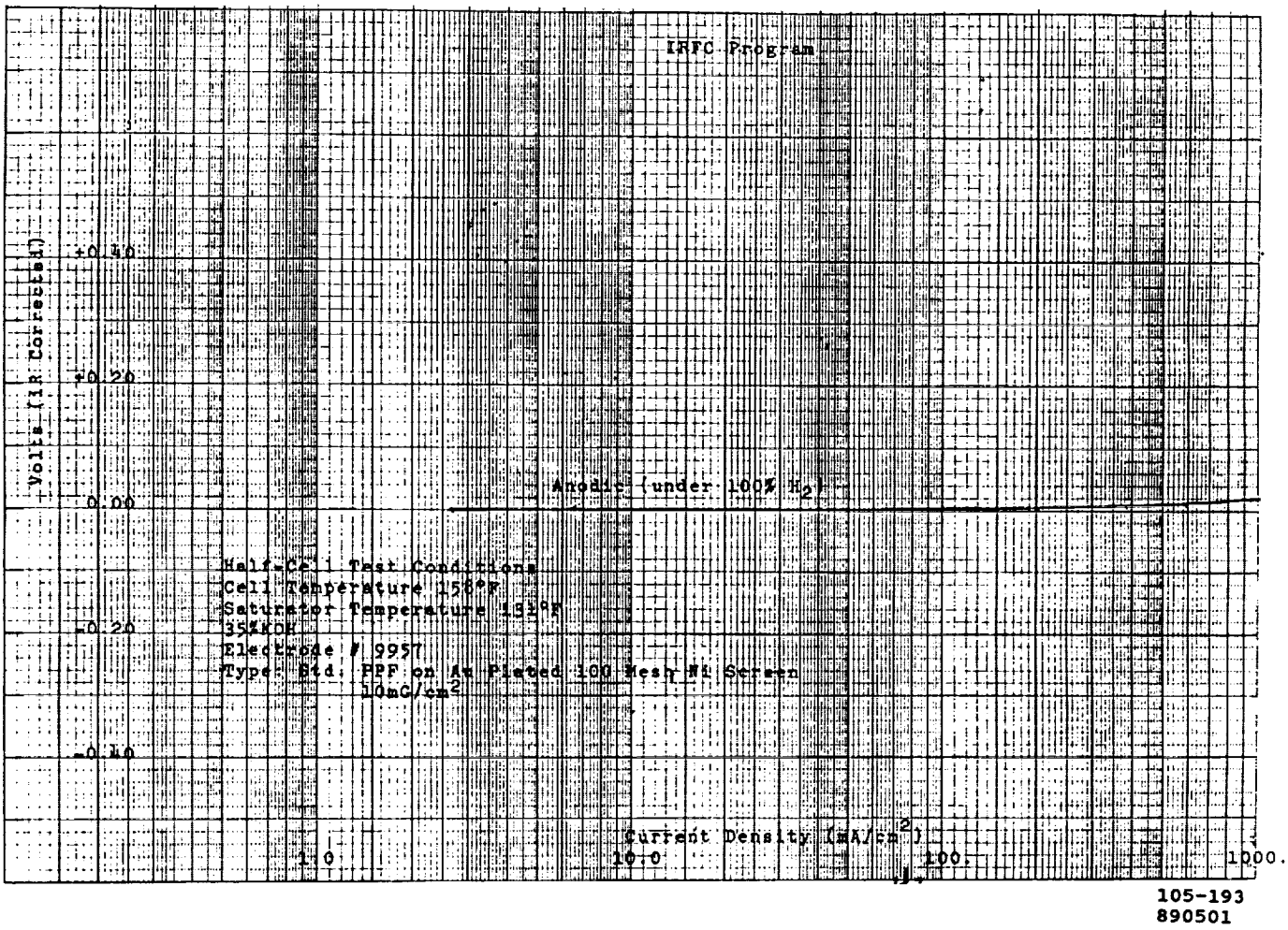

Figure 38. *Half Cell Performance – PtPd (Ni-Screen) H_2 Consumption Electrode*

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16. Abstract

An experimental test program was conducted to investigate the performance characteristics of an Integrated Regenerative Fuel Cell (IRFC) concept. The IRFC consists of a separate fuel cell unit and electrolysis cell unit in the same structure, with internal storage of fuel cell product water and external storage of electrolysis cell produced hydrogen and oxygen. The fuel cell unit incorporates an enhanced Orbiter-type cell capable of improved performance at reduced weight. The electrolysis cell features a $NiCo_2O_4$ catalyst oxygen evolution electrode with a porous Teflon cover to retard electrolyte loss. Six complete IRFC assemblies were assembled and performance tested at an operating temperature of 200°F (93.3°C) and reactant pressures up to 170 psia (117.2 n/cm^2) on IRFC No. 4. Anomalous pressure charge/discharge characteristics were encountered during performance evaluation. A reversible fuel cell incorporating a proprietary bi-functional oxygen electrode operated satisfactory at 200°F (93.3°C) at reactant pressures up to 60 psia (41.4 n/cm^2) as a regenerative fuel cell for one cycle, before developing an electrical short in the fuel cell mode. Electrolysis cell 300-hour endurance tests demonstrated the electrolyte retention capability of the electrode Teflon cover and the performance stability of the bi-functional oxygen electrode at high potential.

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