CR-172002

DEVELOPMENT OF AN ALKALINE FUEL CELL SUBSYSTEM

Final Program Summary Report

for the Period

April 10, 1986 - March 31, 1987

FCR-8590

CONTRACT NO. NAS 9-17613

Prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Prepared by

International Fuel Cells
South Windsor, CT 06074

International Fuel Cells

P.O. Box 739
195 Governors Highway
South Windsor, Connecticut 06074

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INTRODUCTION

The Space Station electrical power system will include an energy storage capability. The function of the energy storage system is to store electrical energy generated during the daylight portion of the orbit and to deliver electrical power during the night portion of the orbit. Several NASA and NASA-sponsored studies of energy storage systems for Space Station applications have shown that Regenerative Fuel Cell Systems offer significant benefit over current state-of-the-art energy storage devices. NASA-JSC plans to integrate an electrolyzer subsystem and fuel cell subsystem into a Space Station Prototype (SSP) regenerative fuel cell to demonstrate this energy storage function.

The fuel cell subsystem for the SSP will contain an advanced power section mated with a government-furnished Orbiter Powerplant accessory section modified with improved components to provide extended life and greater capacity. A microprocessor controller will be used to operate, control, and integrate the fuel cell power plant and the electrolyzer into a Space Station Prototype (SSP) regenerative fuel cell system.

The fuel cell subsystem for the SSP is to have the following features: a nominal output power of 10 kW, a minimum electrical efficiency of 55 percent, one-square foot active area cells and accessory section components with projected life times of 20,000-hours or greater.

Under Contract No. NAS9-17613, International Fuel Cells initiated a two task program to develop advanced fuel cell components which could be assembled into an alkaline power section for the SSP fuel cell subsystem. The first task was to establish a preliminary SSP power section design to be representative of the 200-cell Space Station power section design begun under NAS9-15990. The power section design was to incorporate technology improvements for extended endurance and low weight identified under the NASA-Lewis fuel cell programs. The second task of the program was to conduct tooling and fabrication trials and fabrication of selected cell stack components.

All work associated with the development of an alkaline SSP fuel cell system was terminated following receipt of a stop work order issued by JSC on 24 July 1986.

Prototype Power Section Design

Cell Requirements and Area Selection - The prototype power section design requirements were established based upon the requirements of the Statement of Work and supplementary information from NASA and Space Station Phase B studies. Studies were conducted that evaluated alternative cell configurations. The results indicated that significant improvements in fuel cell system efficiency and reliability could be achieved by developing a one-square foot cell configuration. Specifically a ten percentage point improvement in power plant could be obtained by use of a one-square foot cell rather than the Orbiter-sized half-square foot cell configuration. This efficiency improvement could be accomplished by operating two 0.5-ft^2 Orbiter-type stacks electrically in parallel; however, the doubling of the number of cells results in a factor of two lower MTBF and nearly a 5 percent heavier cell stack when compared to the 1.0-ft^2 cell stack configuration. As a result of 1.0-ft^2 cell active area was selected for the prototype stack design.

Repeating Unit Design - The repeating unit of the power section is a group of individual fuel cells together with the cooler for removing waste heat from the group of cells. This unit repeats throughout the entire stack.

For the prototype power section the repeating unit design is comprised of five parts which are repeatedly "stacked." A cross-section of the repeating unit is shown in Figure 1. Starting at the top of figure the parts are a nickel cell-separator plate, a ribbed graphite electrolyte reservoir plate, a unitized cell assembly, and a silver-plated polyphenylene sulfide cell holder frame. This pattern repeats for three cells. Between the third and fourth cell a silver-plated polyphenylene sulfide cooler plate is inserted to form a coolant flow cavity. This 3-cell unit with a cooler is the repeating unit. It repeats again and again to form the power section.

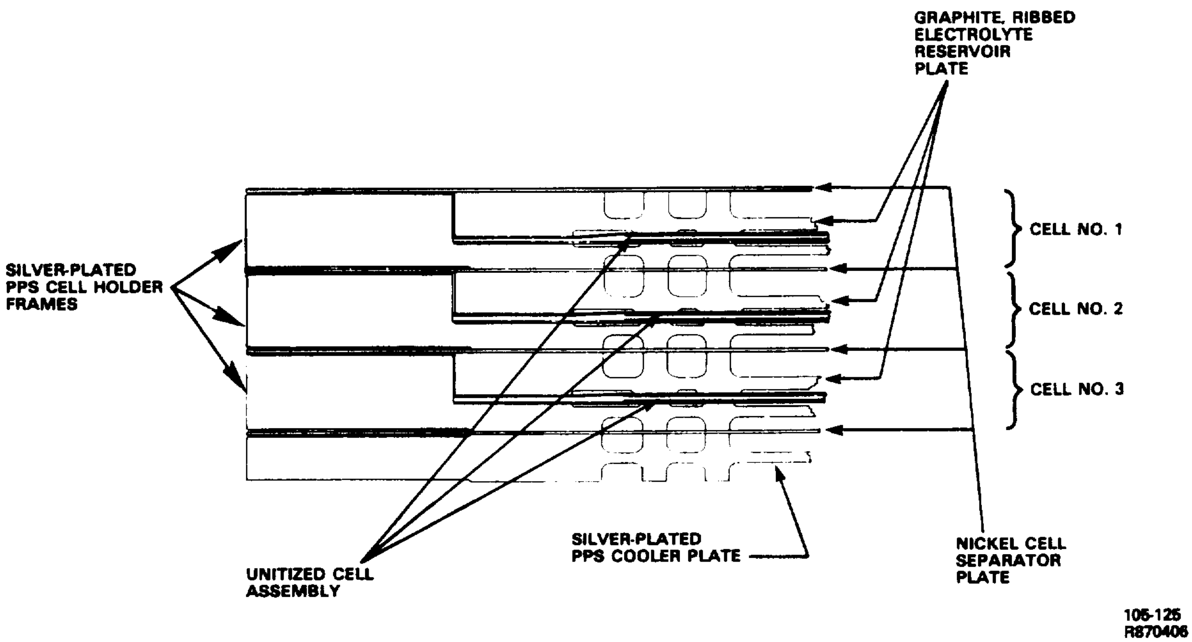


Figure 1. Repeating Unit Advanced Fuel Cell Power Section

The function of each parts is as follows: The bipolar cell holder frame conducts electrical current through the silver plating to the adjacent cell. A 5-mil thick nickel separator plate isolates the oxygen and hydrogen cavities of adjacent cells. An identical separator isolates the cooler plate from the three-cell repeating element. A flow field in the cell holder frame and the ribbed carbon anode electrolyte reservoir plate (ERP) provide for the circulation of oxgen and hydrogen; a flow field in the cooler plate provides for the circulation of coolant. The advanced 1.0-ft2 cell design incorporates internal reactant and coolant manifolds. Metering ports in the plastic plates ensure the uniform distribution of hydrogen, oxygen, and coolant in the respective flow fields. These plates contain molded seals that seal the spaces between plates, separators, and electrode assemblies to prevent mixing of hydrogen, oxygen or coolant and leakage of these fluids from the fuel cell power section.

The cell and repeating unit designs incorporate the advanced material and component technology developed under NASA-LeRC sponsored programs. This includes corrosion-resistant polyphenylene sulfide frames and coolant plates, stable butyl rubber bonded potassium titanate matrices, extended endurance platinum-on-carbon catalyst anodes, light-weight anode carbon electrolyte reservoir plates (ERP), low-weight perforated nickel foil electrode substrates, and thin nickel coolant separator plates.

The planform of the 1.0-ft^2 advanced fuel cell design is compared to the Orbiter production cell in Figure 2. The specific weight of the repeating unit based on this planform and the improved corrosion resistant materials is 2.3 lbs/ft^2. For the Orbiter repeating unit the weight is 2.9 lbs/ft^2. A six-cell stack of 1/2 ft^2 area cells incorporating all of the 1.0-ft^2 cell configuration technology improvements was endurance tested to a simulated Regenerative Fuel Cell load profile under the NASA-Lewis Long-Life, High Performance Fuel Cell Program, Contract No. NAS3-22234 and successfully completed over 6000 hours of operation with no loss in performance.

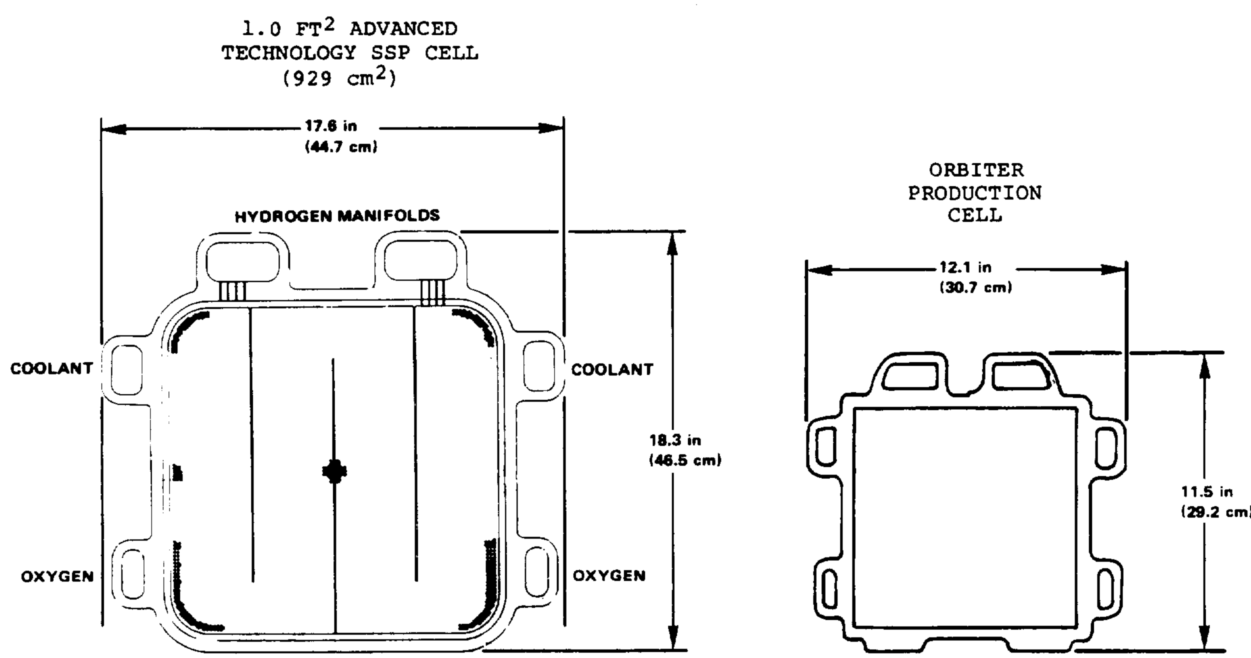


Figure 2. Fuel Cell Planform Comparison

105-126
R872703

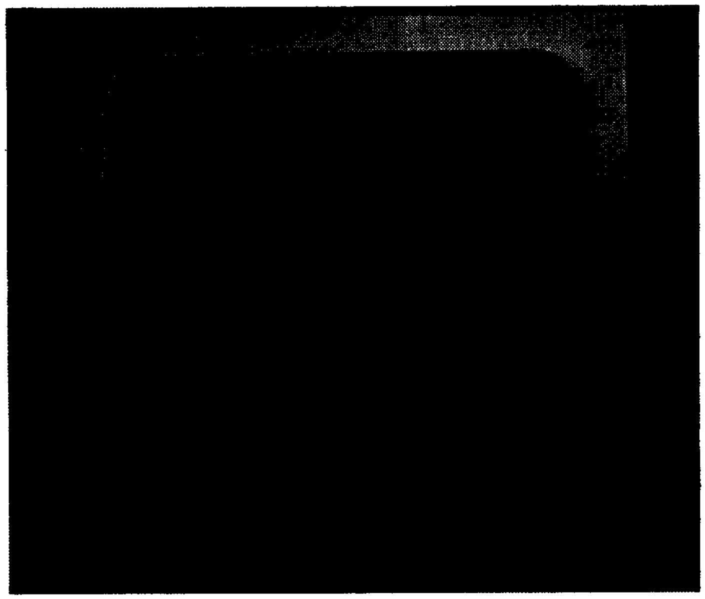
Prototype Power Section Design and PDR

The prototype power section design was based on the 3 cells/1 cooler repeating unit. It consists of 66 repeating units for a total of 198 cells and 67 coolers. One additional cooler unit is added on one end of the power section to make the cooler arrangement symmetrical and the thermal profiles throughout all repeating units the same. The power section output is 25 kW at 180 to 200 volts. Its operating pressure is 60 psia and its nominal operating temperature is 180°F.

A Preliminary Design Review of the power section, repeating unit and cells was conducted with NASA-JSC. Design documentation, including drawings of the power section assembly and individual cell components, was prepared and provided to NASA. Fuel cell background information on endurance of the power section design were also provided at the PDR. The Design Review Data Package is attached in Appendix I.

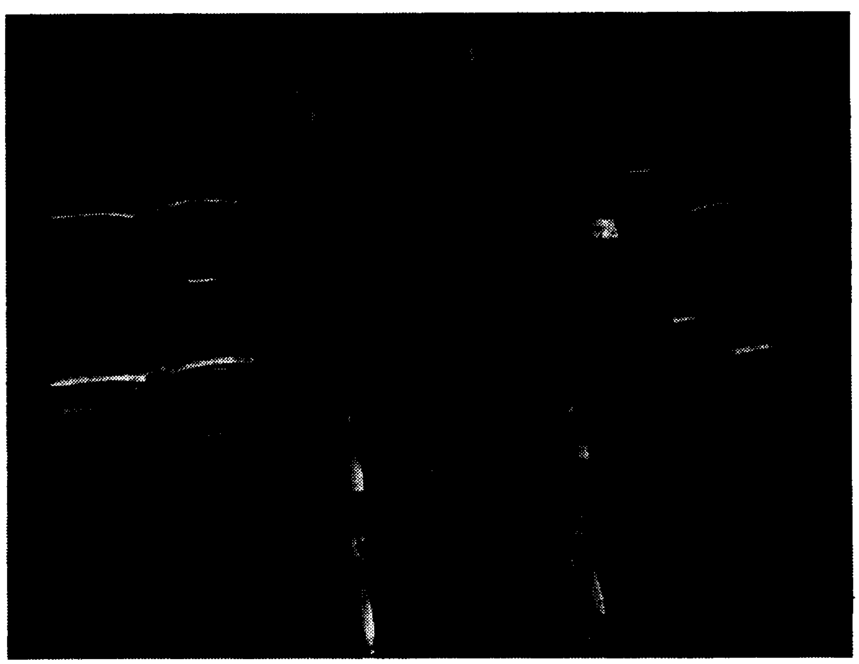
Development of Fuel Cell Stack Components

Fabrication trials were conducted to define manufacturing procedures for the platinum-carbon anode, cathode and potassium titanate matrix of the 1.0-ft^2 cell. Special tooling was designed and constructed for the manufacture of these components. Supported platinum catalyst anodes and gold-platinum catalyst cathodes were successfully fabricated from the defined procedures. A photograph of the gold-plated photo fabricated nickel, foil electrode substrate is shown on Figure 3. Performance evaluation of electrode test samples satisfied IFC specifications for production cells with cathode exceeding the 850 mV @ 800 mA/cm^2 established for Orbiter-gold-platinum cathodes. Employing the established manufacturing procedures, large 15-inch by 15-inch "mat-type" butyl-rubber bonded potassium-titanate matrices were fabricated. The cross-pressure tolerance of these matrices was determined to be in excess of 20 psid. The matrix and electrode fabrication tooling is shown in Figure 4. This tool is used for vacuum filtration of matrix raw material into a "mat" or to deposit catalyst layers on finished matrices.



(WCN-13823)

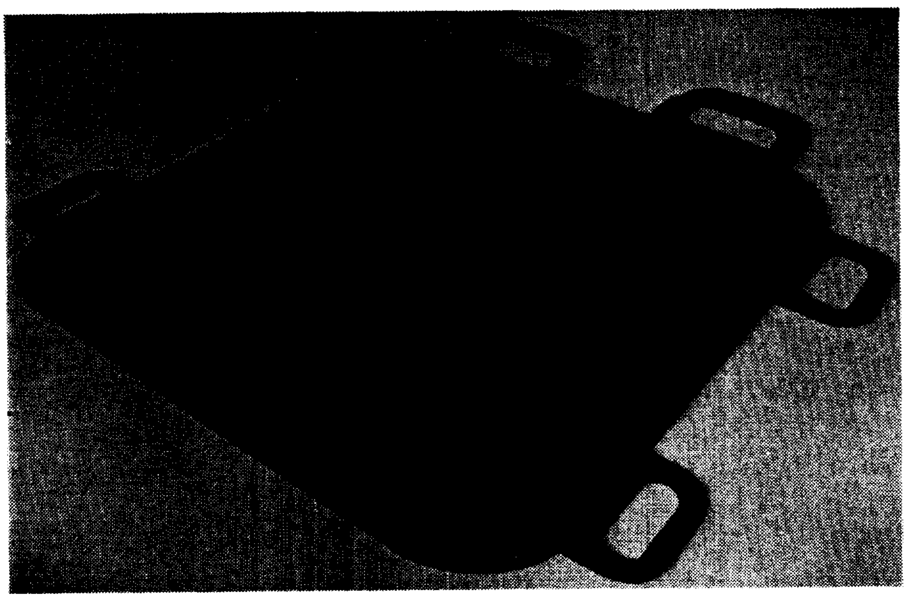
Figure 3. 1.0-ft2 Gold-Plated Photofabricated Nickel Foil Electrode Substrate



(WCN-13819)

Figure 4. 1.0-ft2 Matrix-Electrode Vacuum Filtration Tooling

Cell holder and cooler plates molded from corrosion-resistant polyphenylene sulfide (PPS) have the benefits of reduced cost and extended endurance. Initially, the plan was to machine the plates from molded PPS blanks, eventually completely molding the parts in a one-step operation. Full-size PPS blanks were molded for machining trials. A cell holder produced in an initial machining trial is shown in Figure 5. The part is a full-size 1.0-ft^2 PPS cell holder. The completed plate had oxygen flow fields, edge seal grooves, reactant and coolant manifolding and full exterior contouring.



(WCN-14065)

Figure 5. 1.0-ft^2 Polyphenylene Sulfide Cell Holder Plate

CONCLUSIONS

- A lightweight, reliable cell stack design suitable for the space station prototype regenerative fuel cell power plant has been completed. The design meets NASA's preliminary requirements for future multi-kilowatt Space Station missions.
- Cell stack component fabrication and tooling trials demonstrated cell components of the SSP stack design of the 1.0-ft^2 area can be manufactured using techniques and methods evaluated and developed under this and previous technology development programs sponsored by NASA.

RECOMMENDATIONS

- Development of the 1.0-ft^2 cell stack components should be completed to permit single cell and substack testing of the components to demonstrate that they meet SSP power plant design requirements and specifications.

APPENDIX

CELL STACK ASSEMBLY

PRELLIMINARY DESIGN REVIEW

DEVELOPMENT OF AN ALKALINE FUEL CELL SUBSYSTEM

NASA-JSC CONTRACT NAS 9-17613

CELL STACK ASSEMBLY

PRELIMINARY DESIGN REVIEW

R. E. MARTIN

JUNE 1986

AGENDA

- INTRODUCTION
- SUMMARY
- ASSUMED DESIGN GUIDELINES AND GOALS
- CELL STACK ASSEMBLY/COMPONENT DESIGN REQUIREMENT
- ALKALINE FUEL CELL AREA COMPARISON
- DESIGN STATUS AND FEATURES
- TECHNOLOGY DEVELOPMENT STATUS
- SUPPLEMENTARY TASKS

INTRODUCTION

- THIS IS A PRELIMINARY DESIGN REVIEW.
- FLIGHT WEIGHT END PLATES AND INSULATORS ARE NOT INCLUDED.
- THE POWER SECTION CONFIGURATION THAT WE RECOMMEND IS PRESENTED
- THE RECOMMENDED CONFIGURATION CONTAINS ADVANCED FEATURES EVALUATED UNDER THE NASA LEWIS PROGRAM.

SUMMARY

- PREDICTED WEIGHT OF REPEATING PARTS IS 2.3 LBS/FT^3
- THE POWER SECTION HAS 1 FT^2/CELL ACTIVE AREA AND 199 CELLS.
- MAGNESIUM SEPARATOR PLATES REPLACED WITH PPS FRAME AND MONEL COVER SHEET FOR IMPROVED RELIABILITY, LIFE, AND POTENTIALLY LOWER COSTS.
- ADVANCED DETAILS INCLUDE:
  - ASBESTOS MATRIX REPLACED WITH PKT
  - Pt/Pd ANODE CATALYST REPLACED WITH SUPPORTED Pt CATALYST.
  - POROUS Ni ERP REPLACED WITH CARBON
  - Ni FOIL SUBSTRATE REPLACES FINE WIRE SCREEN ELECTRODE SUBSTRATE

ASSUMED

DESIGN GUIDELINES AND GOALS

• DESIGN POWER, kW	
• NET	25
• GROSS	25.4
• DESIGN VOLTAGE, VOLTS	
• MAXIMUM	200
• MINIMUM	180
• NUMBER OF CELLS	200
• DESIGN CURRENT DENSITY, ASF	
• INITIAL	133
• 40,000-HOURS	140
• NASA REGENERATIVE FUEL CELL EFFICIENCY	55%
• FUEL CELL SUBSYSTEM EFFICIENCY	67.8%
• EQUIVALENT FUEL CELL PERFORMANCE	0.863 @ 412 ASF (TWO-CELL RIG 39728-1)
• PEAK GROSS POWER, kW	33.5
• CELL ACTIVE AREA, FT^2	1.0
• NOMINAL COOLANT INLET TEMPERATURE	180 F
• NOMINAL REACTANT PRESSURE	60 PSIA
• (HIGHER REACTANT PRESSURE - IMPROVED PERFORMANCE 120 PSIA)	
• REPEATING UNIT SPECIFIC WEIGHT	2.2 LBS/FT^2
• LIFE GOAL	40,000 HOURS

CELL STACK ASSEMBLY

COMPONENT DESIGN REQUIREMENTS

INTERNATIONAL
FUEL CELLS

September 9, 1985

To: Mr. R. E. Martin

From: Jay Garow Ext. 2372

Subject: X708 Fuel Cell Power Plant Improvement Program - Cell Stack Assembly Requirements

The attached Component Requirements Document presents the preliminary performance requirements for the Advanced Technology Powersection Design. It is based on nominal Space Station Power Plant requirements of 25 kw, 180 to 200 volts.

Jay
Jay Garow

cc. Name

Clausi, J. V.
Davis, G. H.
Fanciullo, S.
Morganthaler, G. F.
Suljak, G. T.
Sawyer, R. D.

COMPONENT REQUIREMENTS

CELL STACK ASSEMBLY

DATE	REVISION LETTER	SYMBOL	PREPARED BY	FUNCTIONAL GROUP APPROVAL	PC24A PROJECT APPROVAL
9/9/85	Preliminary				

CELL STACK ASSEMBLY

Basis of Requirements

Figure 1 - 25 kw

Purge Rates

H_2 Purge Rate = 4 pph
O_2 Purge Rate = 8 pph

Scope

The cell stack assembly consists of, but is not limited to, the following:

Component	Quantity
Electrode Assembly (EA)	200
Includes: - Fine-Pore Carbon Anode Electrode Reservoir Plate (ERP) - Pt/C Catalyst Anode - Gold-Plated Perforated Nickel Anode Substrate - Butyl Rubber Bonded Potassium Titanate Matrix - Au/Pt Catalyst Cathode - Gold-Plated Perforated Nickel Cathode Substrate - Glass-Filled Polyphenylene Sulfide Edge Frames	
Metal Cover Sheet	300
Glass-Filled Polyphenylene Sulfide Seal Frame or Equivalent	100
Carbon Coolant Field Insert or Equivalent	100
Negative-end (H2) Load Tab Plate	1
Positive-end (O2) Load Tab Plate	1
Positive-end Insulator Plate	1
Negative-end Insulator Plate	1
Positive-end Pressure Plate	1
Negetive-end Pressure Plate	1
Tie Rods, Washers, Nuts	As Req'd

Hydrogen:	Flow (cfm)	26.8
	Humidity Ratio (lbs H_2O) / (lb dry H_2) :inlet	.589
	outlet	1.428
	Inlet Temperature (deg F)	151
	Inlet Pressure (psia)	60 (TBD)
Oxygen:	Flow (pph)	
	Dual Feed Mode	18.37 (total)
	Single Feed Mode (with purge)	26.37
	Inlet Temperature (deg F)	185
	Inlet Pressure (psia)	60 (TBD)
Coolant:	Flow (pph FC40)	3959
	Inlet Temperature (deg F)	180.0
	Inlet Pressure (psia)	60 (TBD)

Note: The coolant system will be subjected to a vacuum (TBD) in order to facilitate a complete coolant fill.

Allocated Pressure Drop:

Hydrogen (in. H_2O), max.	2.5
Coolant (psi), max.	1.5

Allocated Heat Loss: (Btu/hr), max. TBD

Abort Start Capability

The CSA should be capable of being able to start-up and go to zero net power after having aborted two starts just prior to start complete.

Applicable Documents

TBD

Operating Environment

Atmosphere	Space Vacuum or Air
Relative Humidity	Up to 100 %
Temperature (deg F)	40 to 200 (TBD)
Pressure (psia)	0 to 20 (TBD)
Attitude	TBD

Vibration

TBD

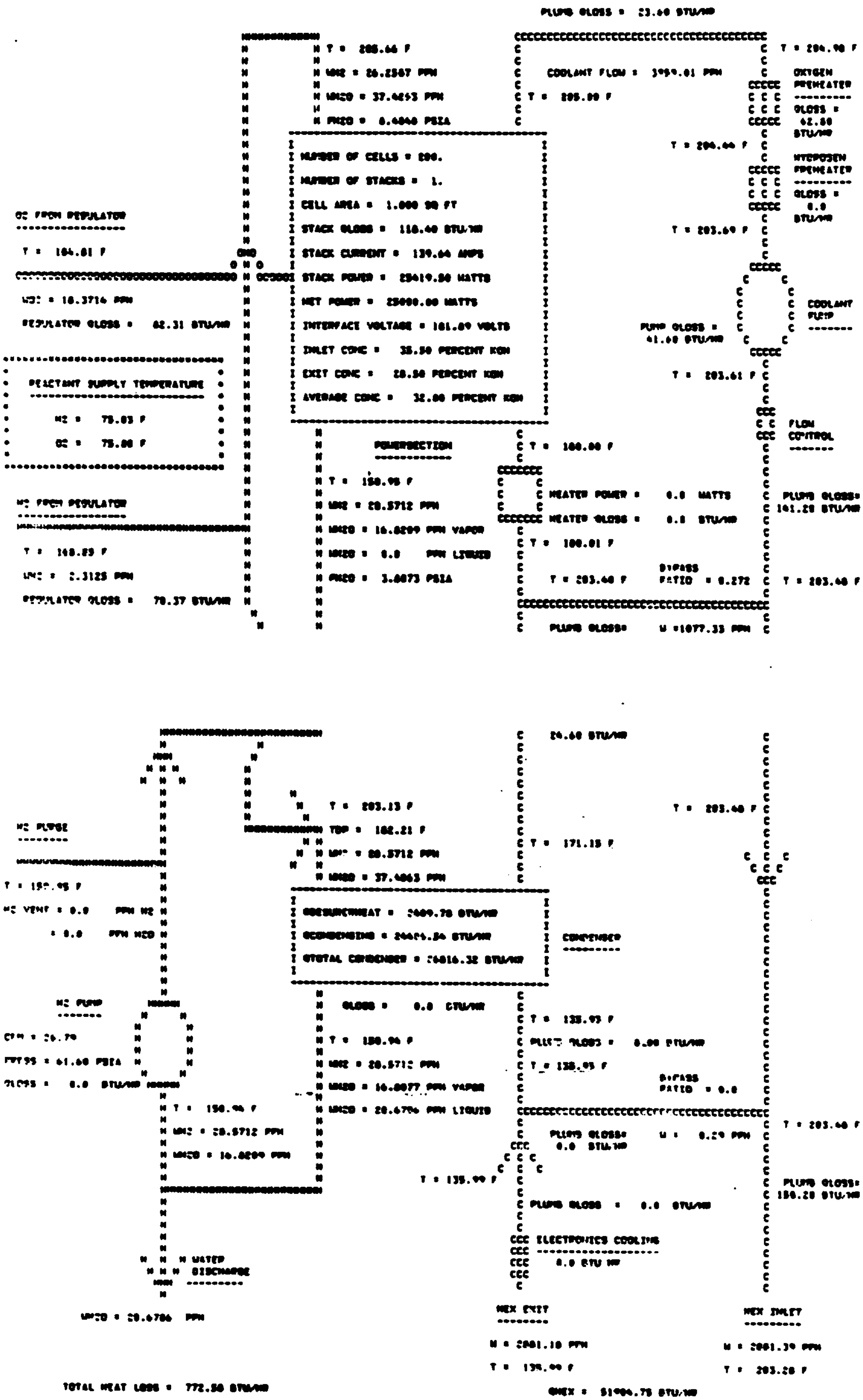
Transportation and Handling

TBD

Start/Stop Cycles TBD

HEAT AND MASS BALANCE

RUN NUMBER 0
THE DATE OF THIS RUN IS 08/30/85



ALKALINE FUEL CELL

AREA COMPARISON

ALKALINE FUEL CELL AREA COMPARISON

- SUMMARY
  - TYPICAL CONSTRAINTS - SPACE STATION APPLICATION
    - HIGH EFFICIENCY REQUIREMENT
    - VOLTAGE LEVEL REQUIREMENT
    - NO PACKAGING CONSTRAINTS
    - LOOSE VOLTAGE REGULATION BAND CONSTRAINTS
  - CON$LUSIONS
    - ANY CELL AREA CAN MEET VOLTAGE AND EFFICIENCY REQUIREMENTS.
    - ORBITER-TYPE 0.5 FT^2 CAN BE PARALLELED FOR EQUAL AREA AND SAFETY REQUIREMENTS.
    - ADVANCED 1.0 FT^2 CELL RESULTS IN A DOUBLING OF THE MTBF FOR THE STACK (ASSUMES CELL MTBF INDEPENDENT OF SIZE).
    - THERE IS A SMALL WEIGHT SAVINGS FOR THE 1.0 FT^2 CELL OVER THE .5 FT^2 CELL OF ABOUT 10%.
    - A FUEL CELL POWER PLANT INCORPORATING THE ADVANCED 1.0 FT^2 CELL HAS FEWER PARTS, PARTICULARLY AS POWER REQUIREMENTS INCREASE.

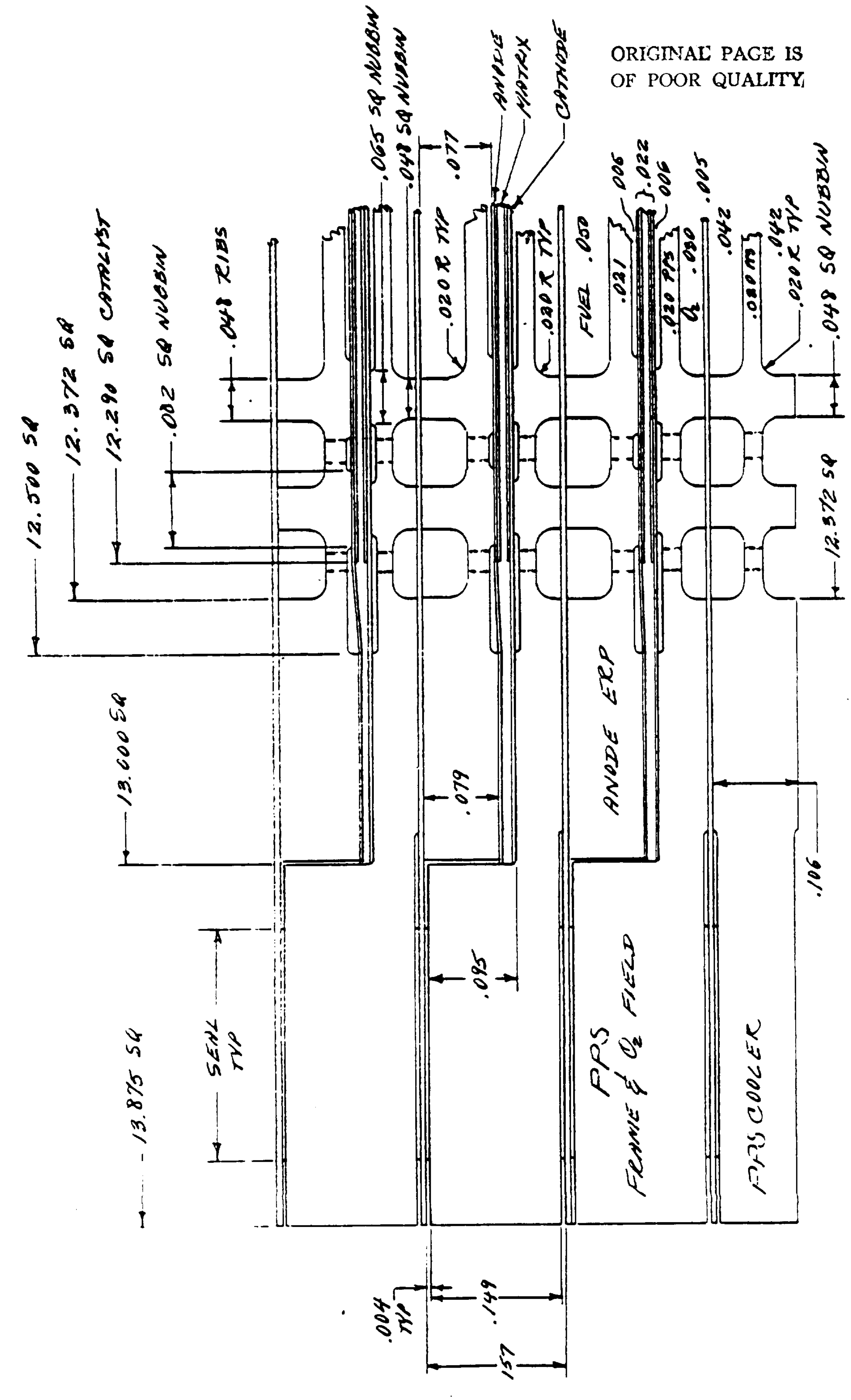
DESIGN STATUS AND FEATURES

DESIGN STATUS

- SUMMARY
  - MATERIAL AND TECHNOLOGY IMPROVEMENTS IDENTIFIED UNDER THE NASA-LEWIS PROGRAM HAVE BEEN INCORPORATED INTO AN ADVANCED CELL DESIGN.
    - POTASSIUM TITANATE MATRIX
    - PLATINUM-ON-CARBON CATALYST ANODE
    - PERFORATED Ni-FOIL ELECTRODE SUBSTRATES
    - CARBON ELECTROLYTE RESERVOIR PLATE
    - POLYPHENYLENE SULFIDE CELL EDGE FRAMES (PPS ALSO USED FOR O_2 FIELD AND COOLER CONFIGURATION)
  - CAPABILITIES OF THE ADVANCED 1.0 FT^2 POWER SECTION WERE IDENTIFIED

	DESIGN	ESTIMATED MAXIMUM
• POWER - kW	25	62
• CURRENT DENSITY - ASF	140	355
• VOLTAGE - VOLTS	180	175

  - THE ADVANCED 1.0 FT^2 CELL DESIGN WAS COMPLETED
    - STRUCTURAL ANALYSIS OF THE REPEATING ELEMENT
    - REACTANT AND COOLANT DISTRIBUTION ANALYSIS
    - THERMAL AND ELECTRICAL RESISTANCE ANALYSIS
    - END CELL HEAT LOSS ANALYSIS
  - DETAIL DESIGN PRINTS OF THE ADVANCED 1.0 FT^2 CELL CONFIGURATION COMPONENTS HAVE BEEN PREPARED
  - IDENTIFIED REMAINING CELL STACK DESIGN TASKS



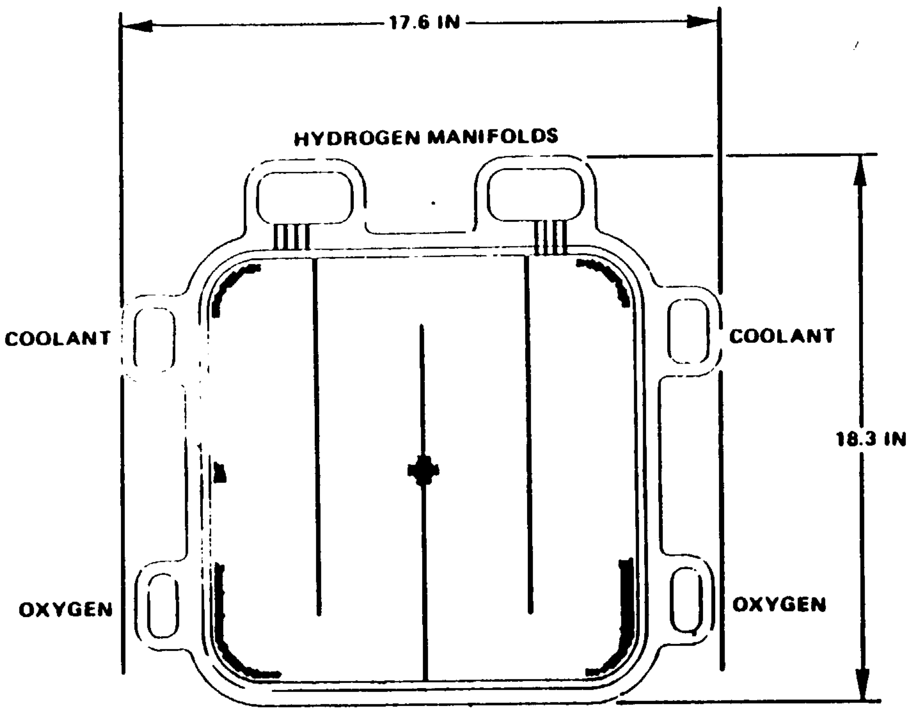
SPECIFIC WEIGHT 2.3 LBS/FT^2

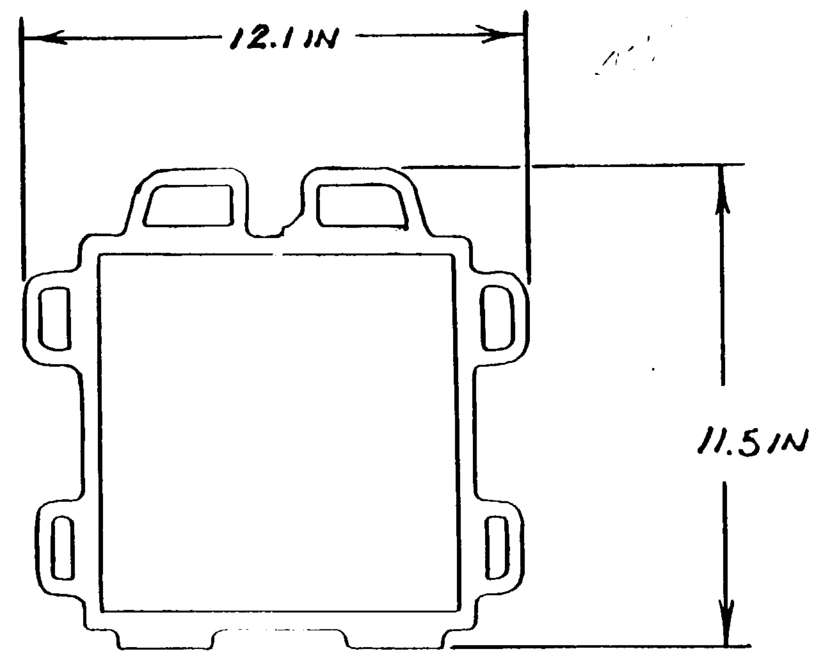
ESTIMATED WEIGHT OF REPEATING ELEMENTS

COMPONENT	WEIGHT PER FT^2 ACTIVE AREA	% CONTRIBUTION
• ELECTRODES AND MATRIX	0.31	13
• O_2 FIELD AND FRAME	0.78	34
• SEPARATOR	0.44	19
• COOLER	0.24	11
• ELECTROLYTE	0.30	13
• ANODE ERP	0.23	10
• TOTAL	2.3 LBS	100

1.0 FT^2 ADVANCED TECHNOLOGY CELL

ORBITER CELL





CELL PLANFORM AREA

1.58 FT^2

0.97 FT^2

ADVANCED TECHNOLOGY 1.0 FT^2 CELL FEATURES

- CORROSION-RESISTANT MATERIALS FOR LONG-LIFE
    - POTASSIUM TITANATE (PKT) MATRIX
    - POLYPHENYLENE SULFIDE (PPS) CELL, COOLER, AND INSULATOR PLATES
    - CARBON ELECTROLYTE RESERVOIR PLATE (ERP) - 10 MICRON FOR ELECTROLYTE RETENTION
    - SUPPORTED PLATINUM-ON-CARBON ANODE CATALYST

- ADVANCED CONFIGURATION FOR LOWER COST
    - ONE-PIECE MOLDED PPS FRAME
    - MOLDED PPS CELL PLATE
    - MOLDED PPS COOLER PLATE
    - PERFORATED Ni-FOIL ELECTRODE SUBSTRATES
    - THIN (5-MIL) NICKEL FOIL SEPARATOR
    - SIMPLE CELL EDGE SEAL

- ADVANCED CONFIGURATION FOR LOWER WEIGHT
    - CARBON ERP
    - PERFORATED Ni-FOIL SEPARATOR
    - THIN NICKEL FOIL SEPARATOR
    - MOLDED PPS CELL, COOLER, AND INSULATOR PLATES

- ADVANCED CONFIGURATION FOR IMPROVED RELIABILITY
    - FEWER CELL COMPONENT PARTS
    - PERFORATED Ni-FOIL ELECTRODE SUBSTRATE
    - CORROSION-RESISTANT CELL COMPONENT MATERIALS
    - IMPROVED CELL EDGE SEAL

1.0 FT^2 CELL ELECTRODE ASSEMBLY

- CATHODE
  - CATALYST -90% GOLD-10% PLATINUM
  - LOADING -20 mg/cm^2
  - SUBSTRATE * - - - - - - - - - - - - - - - - - -GOLD-PLATED, PHOTOETCHED NICKEL FOIL
- MATRIX
  - MATERIAL * - - - - - - - - - - - - - - - - - - - 96% POTASSIUM TITANATE - 4% BUTYL RUBBER
  - THICKNESS -20-MILS
- ANODE
  - CATALYST * - - - - - - - - - - - - - - - - - - - 10% PLATINUM-ON-CARBON
  - LOADING * -0.5 mg cm^2
  - SUBSTRATE * - - - - - - - - - - - - - - - - - -GOLD-PLATED, PHOTOETCHED NICKEL FOIL
- ELECTROLYTE RESERVOIR PLATE/HYDROGEN FLOW FIELD
  - MATERIAL * - - - - - - - - - - - - - - - - - - - POROUS CARBON

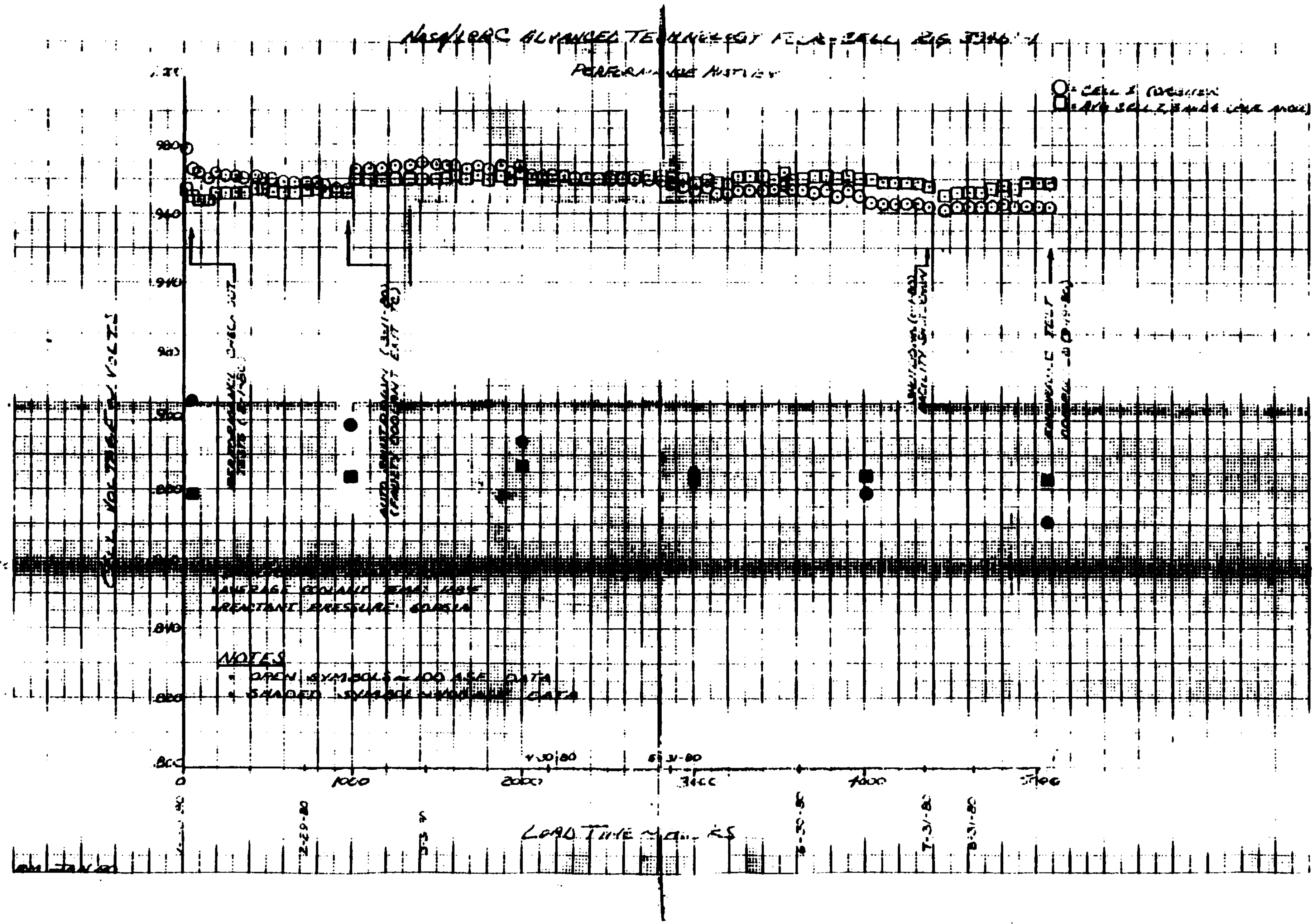
* ADVANCED TECHNOLOGY CELL COMPONENT

ENDURANCE EXPERIENCE

RIG NO.	NO. CELLS	ADVANCED TECHNOLOGY CELL COMPONENT	TEST HOURS
● 39461-1	4	SUPPORTED Pt/C CATALYST ANODE	5,000
● 39578-1	6	SUPPORTED Pt/C CATALYST ANODE	18,000
● 39493-1	4	SUPPORTED Pt/C CATALYST ANODE	3,500
		CARBON ELECTROLYTE RESERVOIR PLATE	
		HYBRID POLYSULFONE EDGE FRAME	
● 39673-1	4	SUPPORTED Pt/C CATALYST ANODE	4,500
		CARBON ELECTROLYTE RESERVOIR PLATE	
		BUTYL BONDED PKT MATRICES	
● 39678-1	4	MOLDED PPS CELL EDGE FRAMES	6,000
		BUTYL BONDED PKT MATRICES	
		PERFORATED NICKEL FOIL SUBSTRATES	
		NICKEL SEPARATOR PLATES	
● 39714-1	6	SUPPORTED Pt/C CATALYST ANODE	4,000*
		MOLDED PPS CELL EDGE FRAMES	
		BUTYL BONDED PKT MATRICES	
		PERFORATED NICKEL FOIL SUBSTRATES	
		CARBON ELECTROLYTE RESERVOIR PLATE	
		NICKEL SEPARATOR PLATE	
		CATHODE NICKEL ELECTROLYTE RESERVOIR PLATE	
● 39728-1	2	SUPPORTED Pt/C CATALYST ANODES	1,500
		MOLDED PPS CELL EDGE FRAMES	
		BUTYL BONDED PKT MATRICES	
		PERFORATED NICKEL FOIL SUBSTRATE	
		CARBON ELECTROLYTE RESERVOIR PLATE	
		NICKEL SEPARATOR PLATE	
		NICKEL OXYGEN FLOW FIELD	

* TEST CONTINUING

RIG 39461-1



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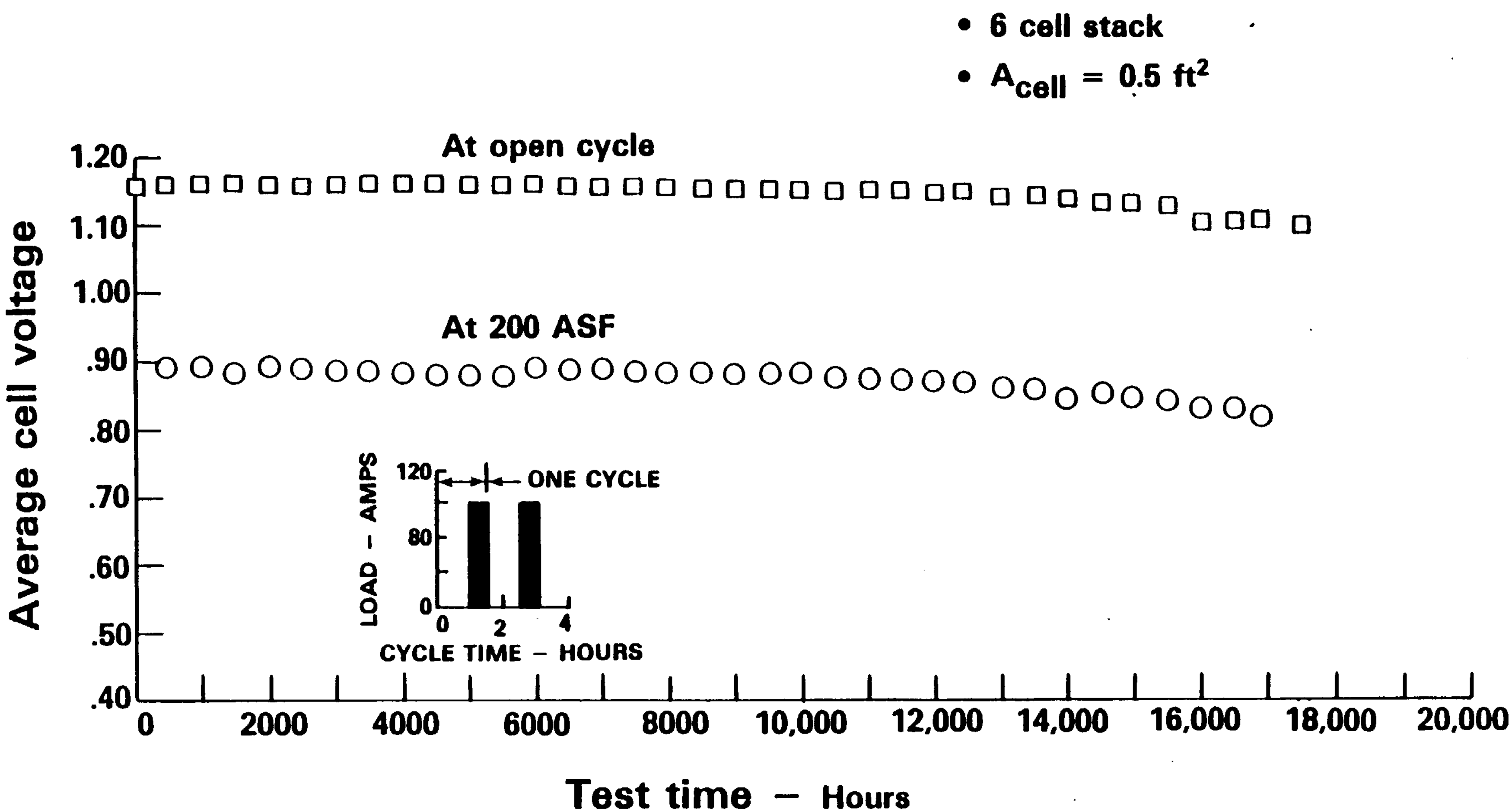
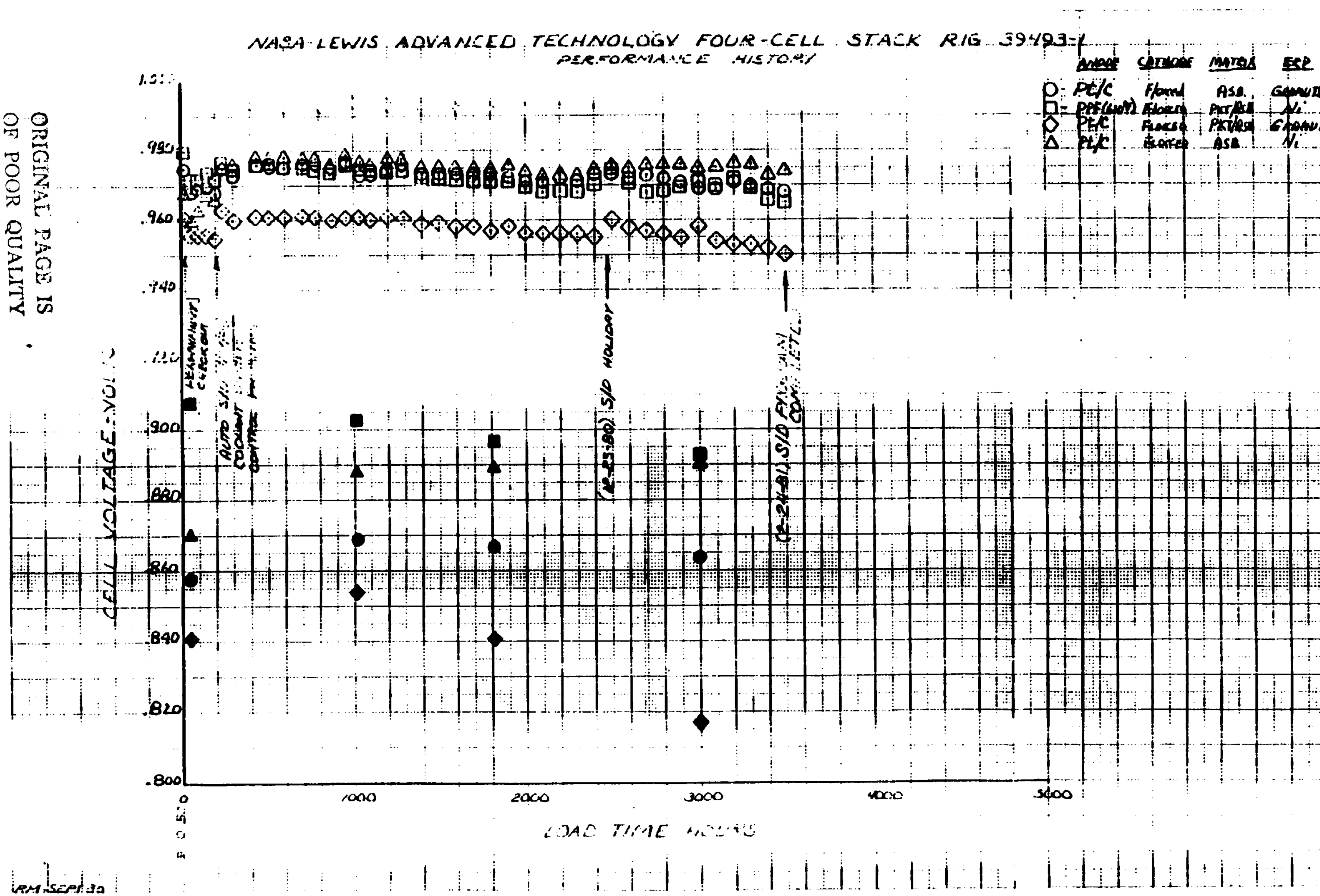
REGENERATIVE FUEL CELL ENDURANCE TEST





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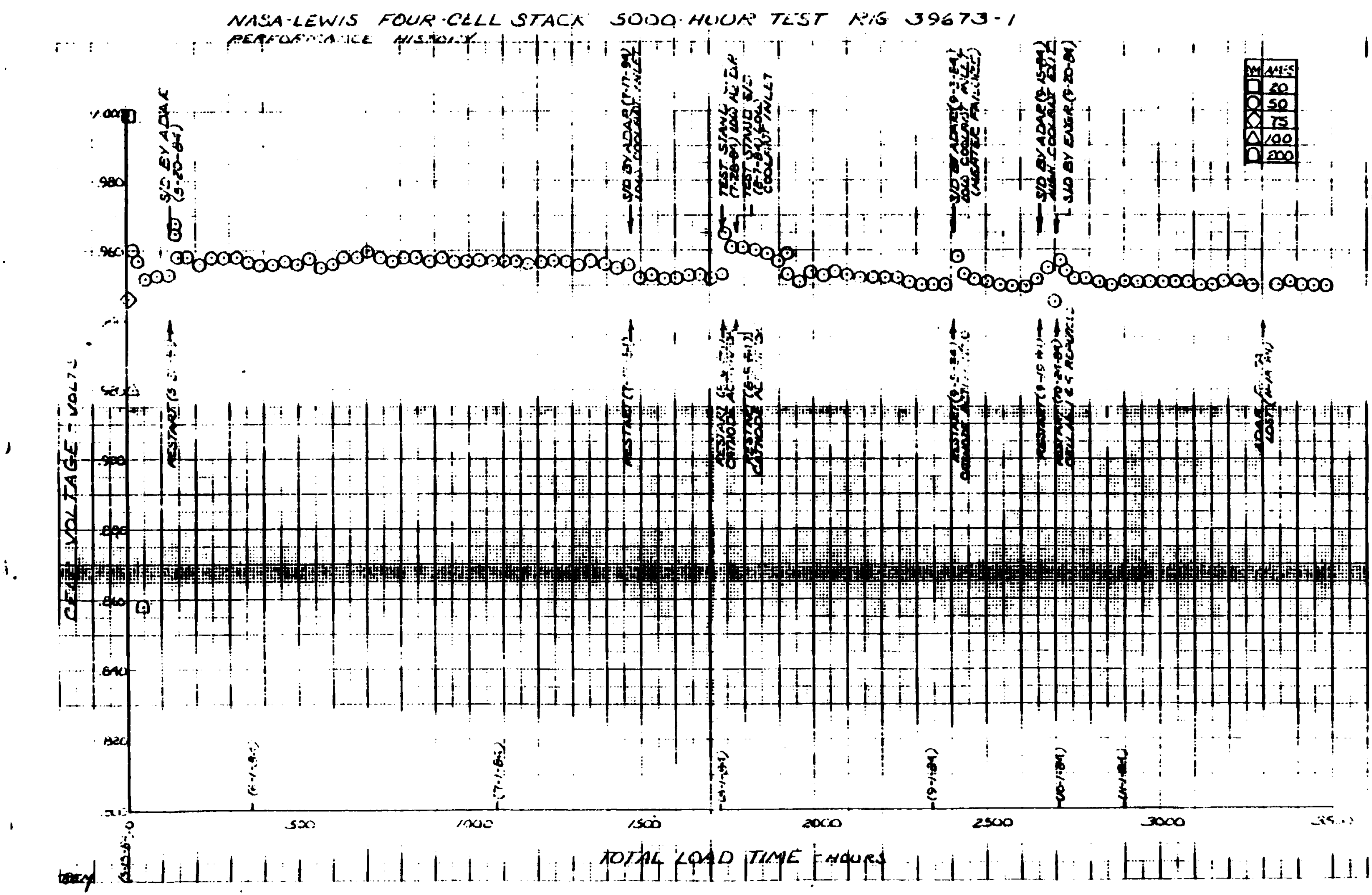
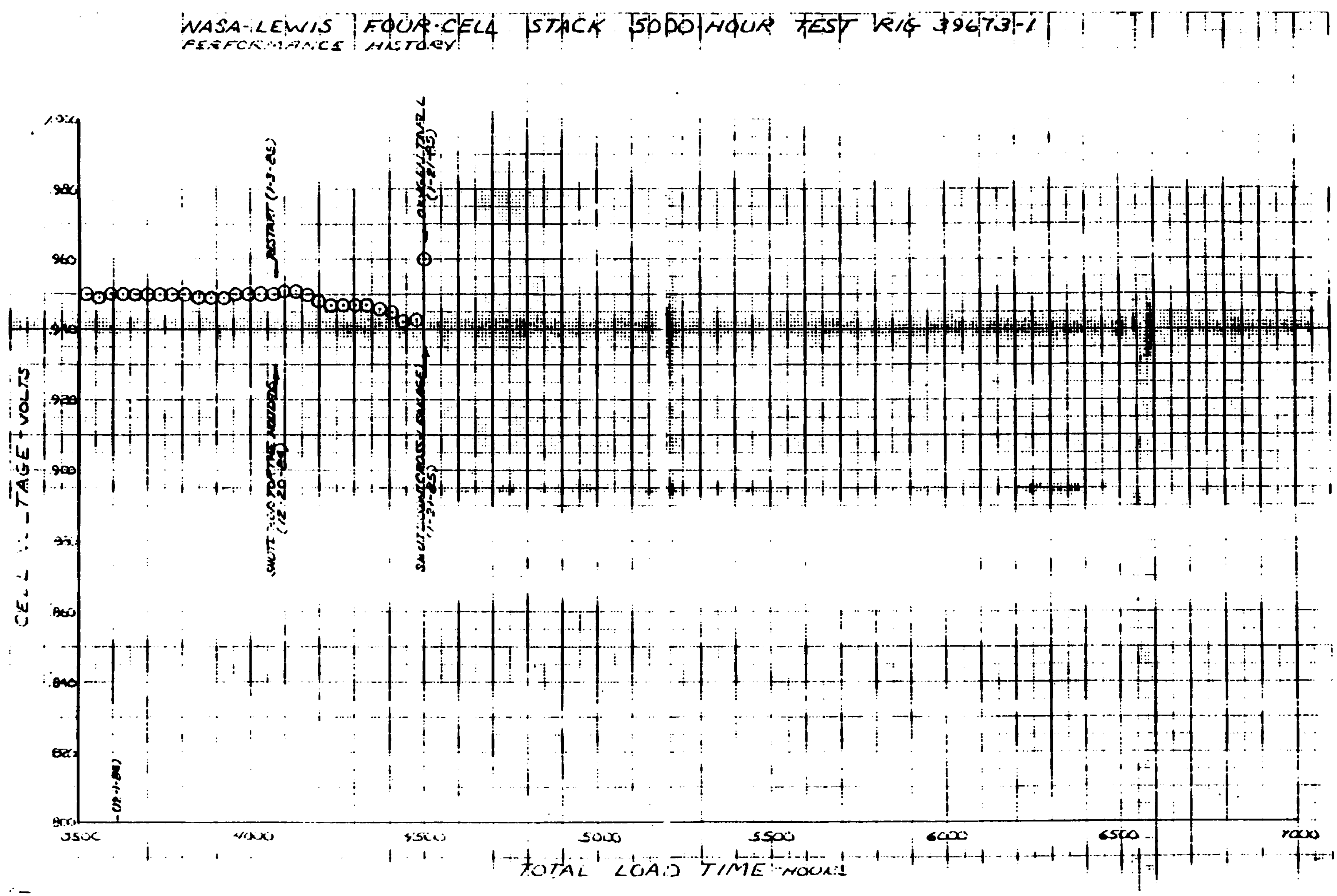
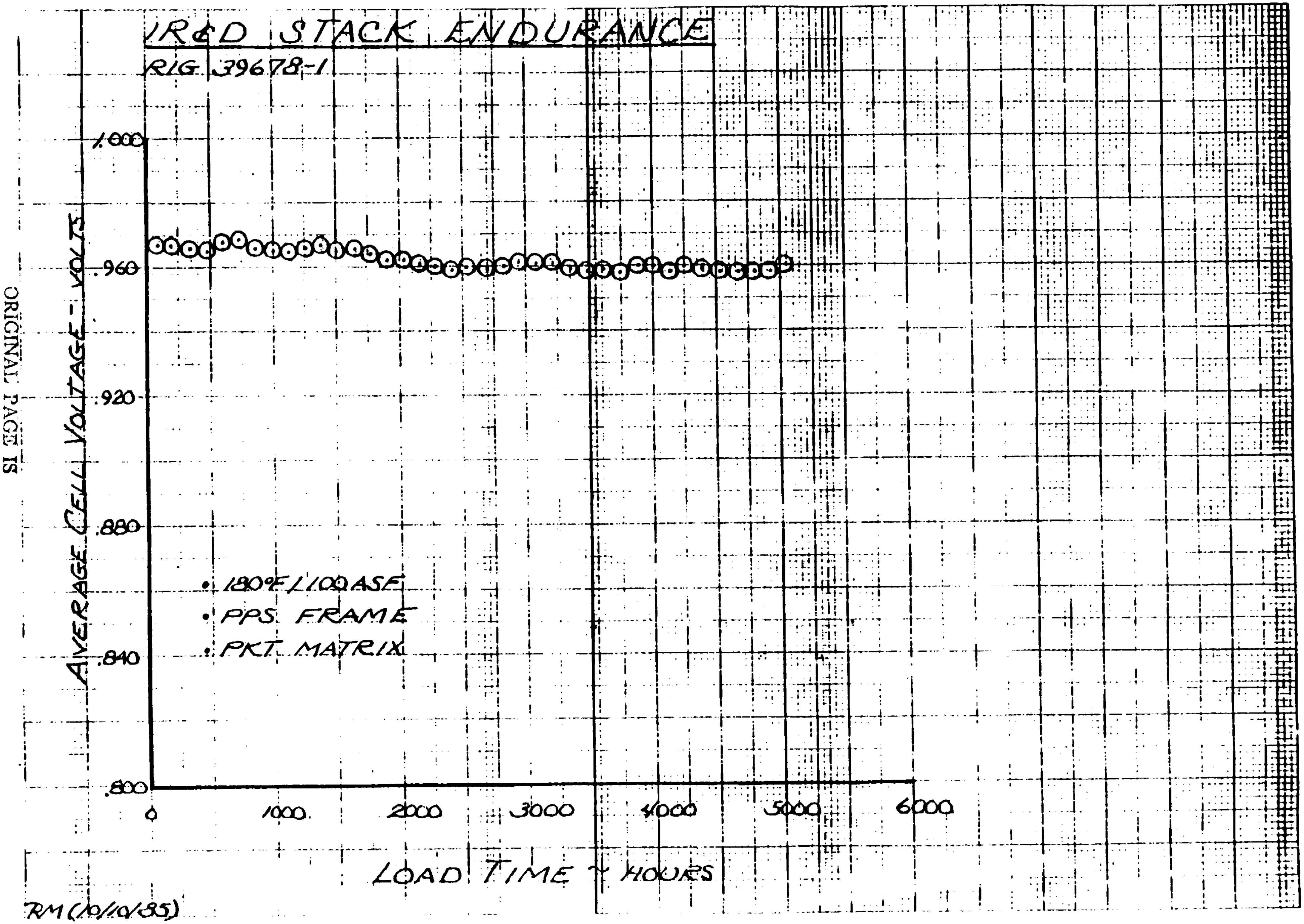
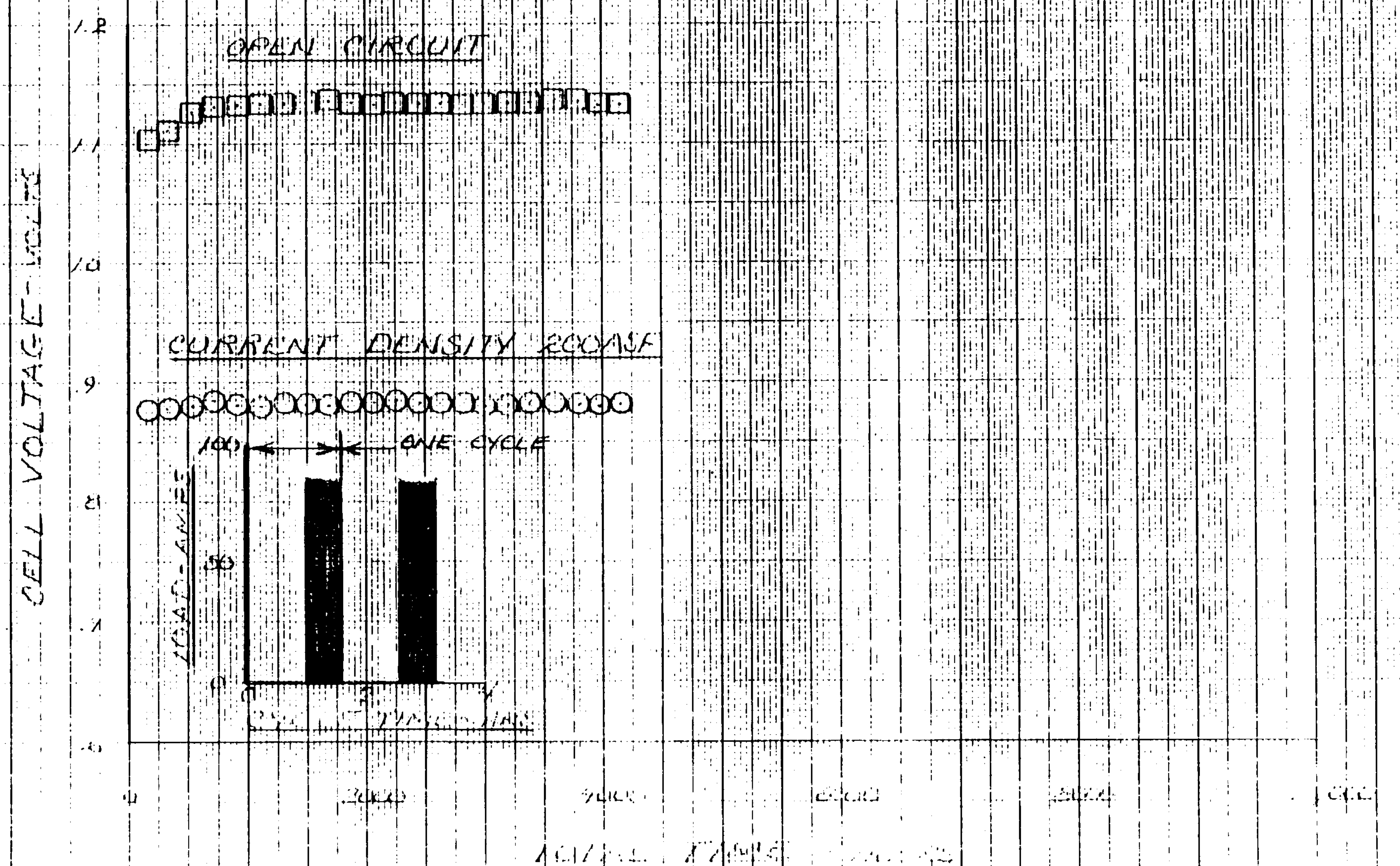
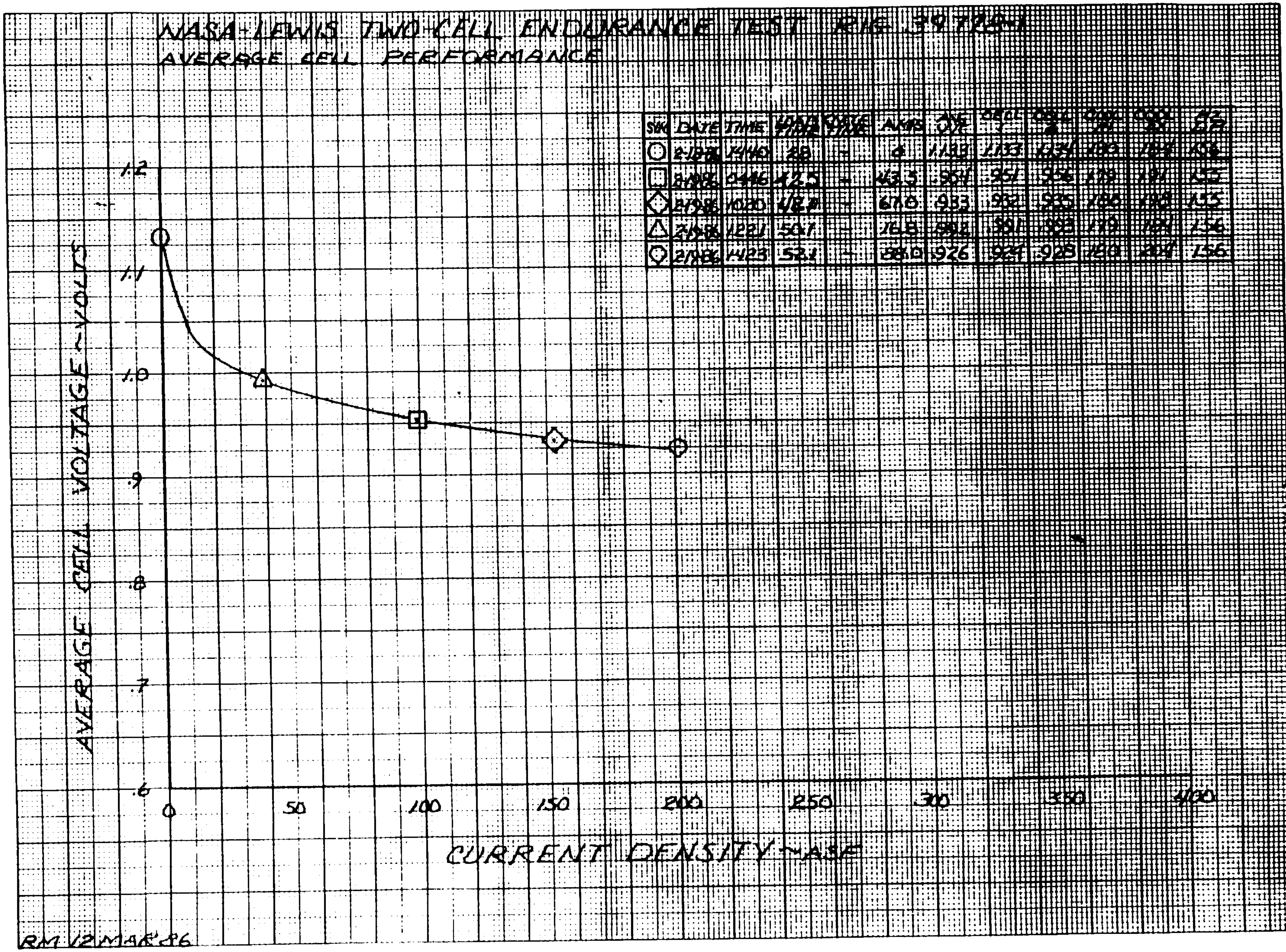



NASA-LEWIS FOUR-CELL STACK 5000 HOUR TEST RIG 39673-1
PERFORMANCE HISTORY
RESTART (1-3-85)
SHUT DOWN FOR THE HOLIDAYS (12-20-84)
SHUT DOWN CROSSLEAKAGE (1-21-85)
(12-1-84)
CELL VOLTAGE - VOLTS
.980
.960
.940
.920
.900
.860
.840
800
3500
4000
4500
5000
5500
6000
6500
7000
TOTAL LOAD TIME - HOURS


IRCD STACK ENDURANCE
RIG 39678-1
AVERAGE CELL VOLTAGE - VOLTS
1.000
.960
.920
.880
.840
.800
• 180°F / 100 ASF
• PPS FRAME
• PKT. MATRIX
0
1000
2000
3000
4000
5000
6000
LOAD TIME ~ HOURS
RM (10/10/85)

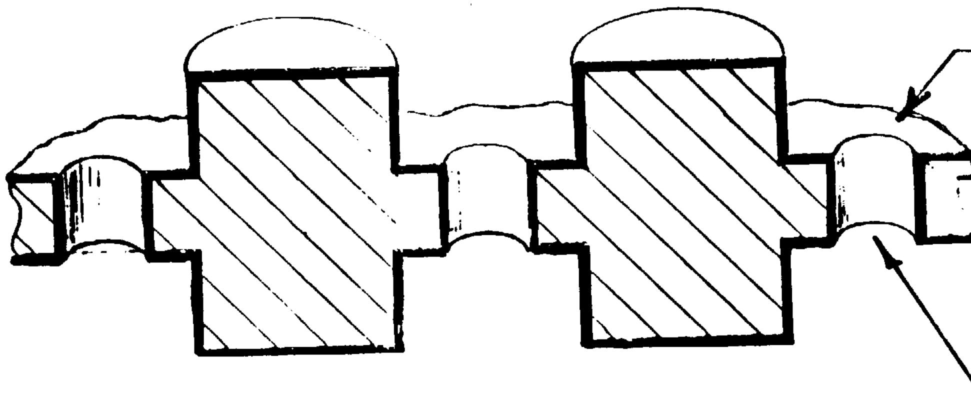
NASA LEWIS SIX-CELL STACK LONG-TERM ENDURANCE TEST
FIG 39 PERFORMANCE HISTORY





NASA-LEWIS TWO CELL ENDURANCE TEST RIG
AVERAGE CELL PERFORMANCE
AVERAGE CELL VOLTAGE ~ VOLTS
1.2
1.1
1.0
.9
.8
.7
.6
0
50
100
150
200
250
300
350
400
CURRENT DENSITY ~ ASF
RM 12 MAR 86

POLYPHENYLENE SULFIDE CELL AND COOLER PLATE



- THERMAL ANALYSIS RESULTS
  - THREE CELLS PER COOLER
  - DESIGN TEMPERATURE GRADIENT 4.2°F (ORBITER 3.1°F)
- ELECTRICAL RESISTANCE ANALYSIS RESULTS
  - ONE-MIL SILVER PLATE ON MOLDED PPS
  - DESIGN PLATE INTERNAL RESISTANCE (iR) 1.5 MV/CELL (140 AMPS) (MAXIMUM PLATE iR 3.7 mV/CELL 355 AMPS)
- POWER SECTION THERMAL AND ELECTRICAL RESISTANCE ANALYSIS VERIFIED BY DESIGN ANALYSIS

CELL/COOLER HEAT TRANSFER

* THERMAL RESISTANCE CALCULATED USING SIMPLIFIED MODEL

  * CONDUCTION THROUGH PPS FLOW FIELD
    - PPS SOLID
    - SILVER PLATE

  * CONDUCTION THROUGH MONEL SEPARATOR

  * CONDUCTION THROUGH ERP

  * CONDUCTION THROUGH CELL PACKAGE - ELECTRODES - MATRIX

  * CONVECTION TO COOLANT (FC40)

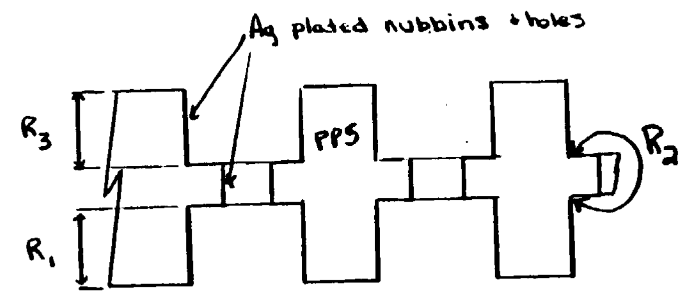
* THREE CELLS/COOLER

  T(HOT CELL) - T(FC40) = 4.2 DEG F

WORK TO DIMENSIONS GIVEN—
DO NOT SCALE

UNLESS OTHERWISE SPECIFIED

RESISTANCE CALCULATION



$$R_{TOT} = R_1 + R_2 + R_3$$

$$\frac{1}{R_{HUB}} = \frac{1}{R_{PPS}} + \frac{1}{R_{Ag}}$$

$$\frac{1}{R_{WEB}} = \frac{1}{R_{PPS}} + \frac{1}{R_{Ag,HOLES} + R_{Ag,HOLES,IN PLANE}}$$

$$R_3 = R_1$$

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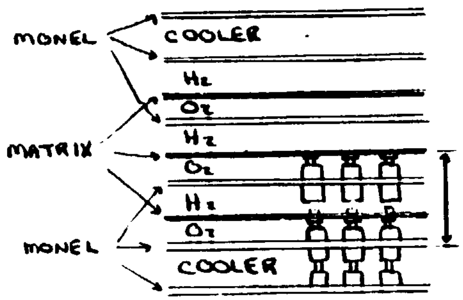
OF POOR QUALITY

NAME	APPROVED	TITLE			
DATE		MATERIAL	SPEC.	SKETCH NO.	CLASS
UNITED TECHNOLOGIES POWER SYSTEMS DIVISION				SHEET NO.	NO. OF SHEETS

WORK TO DIMENSIONS GIVEN— DO NOT SCALE UNLESS OTHERWISE SPECIFIED



$$\Delta T = .5Q(\tfrac{1}{2}R_{mat} + R_{O_2} + R_{mon} + R_{H_2} + \tfrac{1}{2}R_{mat}) + 1.5Q(\tfrac{1}{2}R_{mat} + R_{O_2} + R_{mon} + R_{film}) = 4.2°F$$

PIECE	MATERIAL	K	THERMAL RESISTANCE - hr °F/Btu
MATRIX *		.18675 $\frac{Btu}{hr\ ft\ °F}$	$R_{MATRIX} = 9.817 \times 10^{-3}$
O_2 PLATE	PPS	2.0 $\frac{Btu \cdot in}{hr\ ft^2\ °F}$	$R_{WEB} = 2.270 \times 10^{-3}$, $R_{NUBBINS} = 8.910 \times 10^{-4}$
	SILVER PLATING	2900 $\frac{Btu \cdot in}{hr\ ft^2\ °F}$	
MONEL	MONEL 400	12.6 $\frac{Btu \cdot ft}{hr\ ft^2\ °F}$	$R_{MONEL} = 3.063 \times 10^{-5}$
H_2 PLATE **	CARBON	10 $\frac{Btu}{hr\ ft\ °F}$	$R_{WEB} = 1.514 \times 10^{-4}$, $R_{NUBBINS} = 3.247 \times 10^{-3}$
FILM	FC40	FILM COEF, h 157.33 $\frac{Btu}{hr\ ft^2\ °F}$	$R_{FILM} = 8.039 \times 10^{-3}$

* ASSUMED K TO BE HALF THE K OF 35 % KOH

** CALCULATIONS USED .060 FIELD DEPTH INSTEAD OF FINAL DEPTH OF .050

NAME	APPROVED	TITLE			
DATE		MATERIAL / SPEC.	SKETCH NO.		CLASS
UNITED TECHNOLOGIES POWER SYSTEMS DIVISION			SHEET NO.	NO. OF SHEETS	

CELL IR

* PPS USED IN O_2 AND COOLER FLOW FIELDS IS AN INSULATOR
* PROVIDE ELECTRICAL CONTINUITY BY SILVER PLATING
  - HOLES THROUGH WEB
* APPROXIMATE VOLTAGE DROP CALCULATED
  - SAME MODEL AS THERMAL RESISTANCE CALCULATION
  - COOLER IR AMORTIZED OVER 3 CELLS
* CONTACT RESISTANCE IGNORED
* CALCULATIONS BASED ON 1 MIL SILVER PLATE
* 1.5 MV/CELL AT 140 AMPS, DUE TO PLATES

WORK TO DIMENSIONS GIVEN— DO NOT SCALE   UNLESS OTHERWISE SPECIFIED

IR DUE TO SEPARATOR PLATES AND FLOW FIELD COMPONENTS

THROUGH PLANE RESISTANCE = $\frac{1}{8} R_{COOLER}$ $\frac{4}{3} R_{MONEL} + R_{H_2} + R_{O_2}$

IN PLANE RESISTANCE = $\frac{1}{3} R_{COOLER, INPLANE} + R_{O_2, IN PLANE}$

TOTAL IR = $(R_{THRU} + R_{IN}) I$ = 139.64 amps $(1.065 \times 10^{-2} + 4.122 \times 10^{-3})$ = 1.49 mV

PIECE	MATERIAL	ELECTRIC RESISTIVITY	IR - mV/100 ASF
COOLER	PPS	———	$IR_{Ag, HOLES, THRU PLANE} = 5.816 \times 10^{-4}$
	SILVER PLATING	9.8 ohm-cir.mil / ft	$IR_{Ag, IN PLANE} = 3.337 \times 10^{-3}$
MONEL	MONEL 400	307 ohm-cir.mil / ft	$IR_{MONEL, THRU PLANE} = 6.975 \times 10^{-8}$
H_2 PLATE	CARBON	IR = 0.31 $\times 10^{-2}$ mV / mil of thickness at 100 ASF	$IR_{WEB, THRU PLANE} = 6.232 \times 10^{-2}$
			$IR_{NUBBINS, THRU PLANE} = 1086$
O_2 PLATE	PPS	———	$IR_{Ag, HOLES, THRU PLANE} = 7.861 \times 10^{-4}$
	SILVER PLATING	9.8 ohm-cir.mil / ft	$IR_{Ag, IN PLANE} = 3.337 \times 10^{-3}$

ORIGINAL PAGE IS OF POOR QUALITY

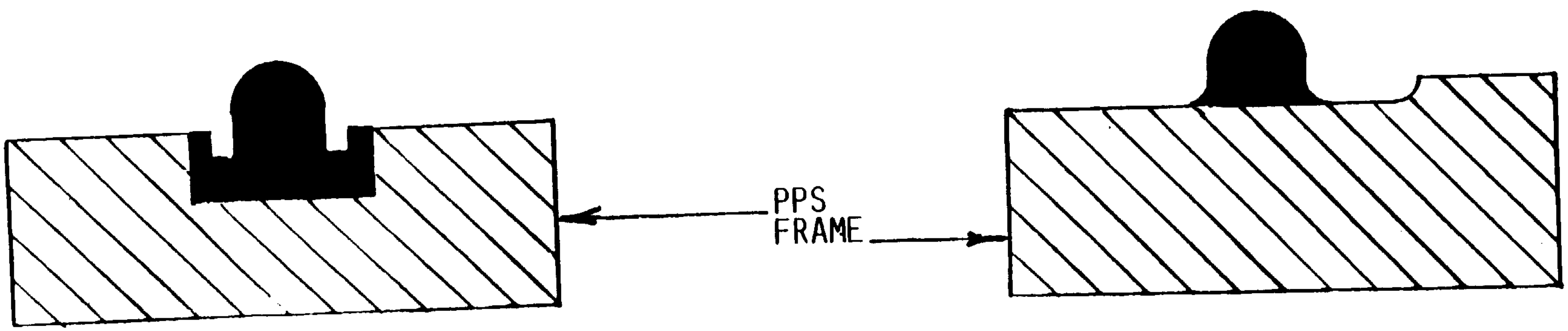
NAME	APPROVED	TITLE			
DATE		MATERIAL /	SPEC.	SKETCH NO.	CLASS
UNITED TECHNOLOGIES POWER SYSTEMS DIVISION				SHEET NO.	NO. OF SHEETS

EDGE SEAL APPROACHES

BASELINE

GASK-O-SEAL

PRINTED SEAL



PARKER SEALS

- STANDARD ORBITER SEAL
- IMPROVED SEAL MATERIAL
- IMPROVED MATERIAL AND IMPROVED CONFIGURATION

DOWTY LTD.

- SIMPLE CONCEPT WITH LOW COST POTENTIAL
- APPLICABLE TO MULTI-SEAL CONCEPTS
- CONTINUE EVALUATION UNTIL IMPACTS PROGRAM COST

STRUCTURAL DESIGN

POWER SECTION REPEATING ELEMENTS

COMPONENT	MATERIAL	STRESS DESIGN	STRESS ALLOWABLE	SF
• SEPARATOR PLATE	MONEL ALLOY 400	17.9 KSI	25.0 KSI	4
• CELL HOLDER PLATE	MOLDED A-100 (PPS/FG)	1400 PSI	1500 PSI	4
• CELL COOLER PLATE	MOLDED A-100 (PPS/FG)	1400 PSI	1500 PSI	4
• END COOLER PLATE	MOLDED A-100 (PPS/FG)	1220 PSI	1500 PSI	4
• HYDROGEN MANIFOLD	MOLDED A-100 (PPS/FG)	1300 PSI	3000 PSI	4
• ANODE ERP	PARTICULATE CARBON ERP (FINE-PORE 10 MICRON)	226 PSI	400 PSI	4

* POWER SECTION REPEATING ELEMENT DESIGN VERIFIED BY DESIGN ANALYSIS

- **DESIGN MATERIAL PROPERTIES**
  - **SEPARATOR PLATE**
    - MATERIAL: MONEL ALLOY 400

	Y.S.	U.T.S.	MODULUS
R.T.:	28.0 KSI	70.0 KSI	26,000,000 PSI
250 F:	25.0 KSI	63.6 KSI	26,000,000 PSI

COEFFICIENT OF THERMAL EXPANSION = 7.8 E-6 IN/IN/F

  - **CATHODE ELECTRODE PLATE, CELL COOLER PLATE, AND END COOLER PLATE**
    - MATERIAL: INJECTION MOLDED RYTON R-3 PPS/FG

	FLEXURE		TENSILE		COMPRESSIVE
	STRENGTH	MODULUS	STRENGTH	MODULUS	STRENGTH
R.T.:	22.5 KSI	1,530,000 PSI	15.3 KSI	1,000,000 PSI	20.7 KSI
250 F:	12.0 KSI	600,000 PSI	6.0 KSI	400,000 PSI	12.7 KSI

COEFFICIENT OF THERMAL EXPANSION = 11.0 E-6 IN/IN/F (IN-PLANE)
28.0 E-6 IN/IN/F (THRU-PLANE)

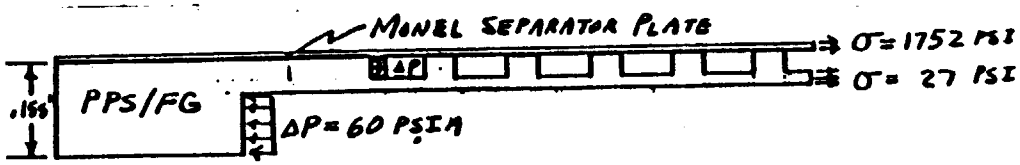
  - **ANODE ERP**
    - MATERIAL: PARTICULATE CARBON SUBSTRATE
      - DENSITY = .036 LB./CU.IN.

- **SEPARATOR PLATES**
  - MATERIAL: MONEL ALLOY 400

    R.T.: Y.S. = 28.0 KSI U.T.S. = 70.0 KSI E = 26,000,000 PSI

    250 F: Y.S. = 25.0 KSI U.T.S. = 63.6 KSI E = 26,000,000 PSI

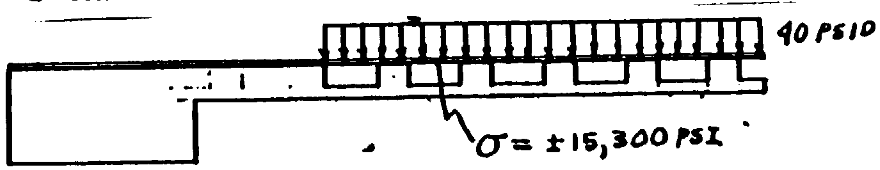
    COEFFICIENT OF THERMAL EXPANSION = 7.8 E-6 IN/IN/F
  - THICKNESS: t = .005"
  - **WORST CASE ASSUMPTION**: EDGE SEAL BONDS SEPARATOR PLATE TO PPS/FG PLATES
    - IN-PLANE PRESSURE STRESS:



DESIGN ALLOWABLE: (250 F)

TENSILE STRESS < .67×Y.S. (16.7 KSI)

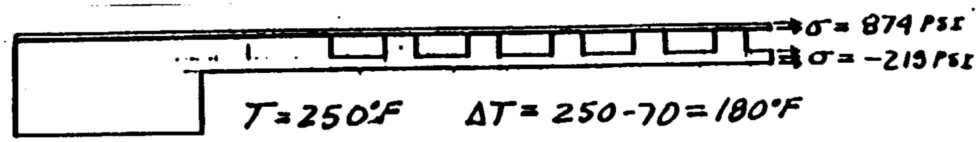
    - THRU-PLANE PRESSURE STRESS:



DESIGN ALLOWABLE: (250 F)

BENDING STRESS < 1.0×Y.S. (25.0 KSI)

    - THERMAL STRESS:



DESIGN ALLOWABLE: (250 F)

TENSILE STRESS < .67×Y.S. (16.7 KSI)

    - TOTAL STRESS:

      17.9 KSI < 25.0 KSI ALLOWABLE

- CATHODE ELECTRODE PLATE

  - MATERIAL: INJECTION MOLDED RYTON R-3 PPS/FG

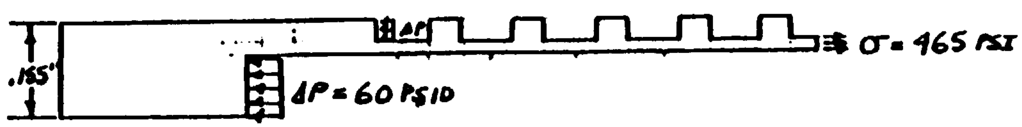
	FLEXURE		TENSILE		COMPRESSIVE
	STRENGTH	MODULUS	STRENGTH	MODULUS	STRENGTH
R.T.:	22.5 KSI	1,530,000 PSI	15.3 KSI	1,000,000 PSI	20.7 KSI
250 F:	12.0 KSI	600,000 PSI	6.0 KSI	400,000 PSI	12.7 KSI

COEFFICIENT OF THERMAL EXPANSION = 11.0 E-6 IN/IN/F (IN-PLANE)
28.0 E-6 IN/IN/F (THRU-PLANE)

  - THICKNESS: t = .020" (WEB) & t = .155" (FRAME)

  - WORST CASE ASSUMPTION: EDGE SEAL DOES NOT BOND CATHODE PLATE TO SEPARATOR PLATE

    - IN-PLANE PRESSURE STRESS: (NO THERMAL STRESS)

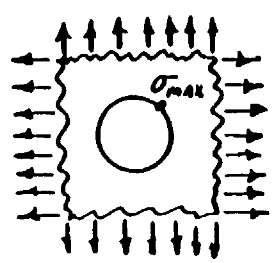


DESIGN ALLOWABLE: (250 F)

TENSILE STRESS < .25×STRENGTH
(1500 PSI)

    - STRESS CONCENTRATION:

      - Kt = 3.0 (BI-AXIAL STRESS FIELD WITH .075" DIA. HOLES AND .135" HOLE SPACING)



$\sigma_{AVG} = 465$ PSI

$\sigma_{MAX} = K_t \, \sigma_{AVG}$

  - MAXIMUM AVERAGE STRESS: 465 PSI

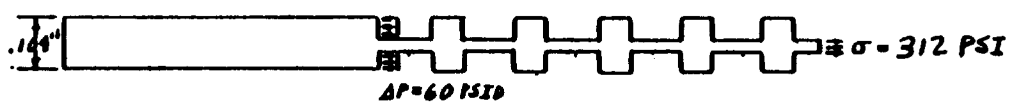
  - MAXIMUM STRESS = 1400 PSI < DESIGN ALLOWABLE

- CELL COOLER PLATE
  - MATERIAL: INJECTION MOLDED RYTON R-3 PPS/FG

	FLEXURE		TENSILE		COMPRESSIVE
	STRENGTH	MODULUS	STRENGTH	MODULUS	STRENGTH
R.T.:	22.5 KSI	1,530,000 PSI	15.3 KSI	1,000,000 PSI	20.7 KSI
250 F:	12.0 KSI	600,000 PSI	6.0 KSI	400,000 PSI	12.7 KSI

COEFFICIENT OF THERMAL EXPANSION = 11.0 E-6 IN/IN/F (IN-PLANE)
28.0 E-6 IN/IN/F (THRU-PLANE)

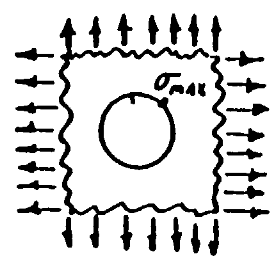
- THICKNESS: t = .020" (WEB) & t = .104" (FRAME)
- WORST CASE ASSUMPTION: EDGE SEAL DOES NOT BOND COOLER PLATE TO SEPARATOR PLATE
  - IN-PLANE PRESSURE STRESS: (NO THERMAL STRESS)



DESIGN ALLOWABLE: (250 F)

TENSILE STRESS < .25×STRENGTH (1500 PSI)

  - STRESS CONCENTRATION:
    - Kt = 4.5 (BI-AXIAL STRESS FIELD WITH .100" DIA. HOLES AND .135" HOLE SPACING)



$\sigma_{AVG} = 312$ PSI

$\sigma_{MAX} = K_t \, \sigma_{AVG}$

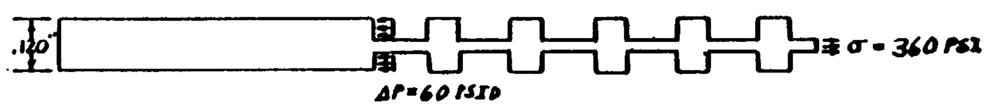
  - MAXIMUM AVERAGE STRESS: 312 PSI
  - MAXIMUM STRESS = 1400 PSI < DESIGN ALLOWABLE

- **<u>END COOLER PLATE</u>**
  - MATERIAL: INJECTION MOLDED RYTON R-3 PPS/FG

	FLEXURE		TENSILE		COMPRESSIVE
	STRENGTH	MODULUS	STRENGTH	MODULUS	STRENGTH
R.T.:	22.5 KSI	1,530,000 PSI	15.3 KSI	1,000,000 PSI	20.7 KSI
250 F:	12.0 KSI	600,000 PSI	6.0 KSI	400,000 PSI	12.7 KSI

COEFFICIENT OF THERMAL EXPANSION = 11.0 E-6 IN/IN/F (IN-PLANE)
28.0 E-6 IN/IN/F (THRU-PLANE)

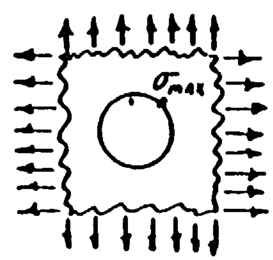
- THICKNESS: t = .020" (WEB) & t = .120" (FRAME)
- <u>WORST CASE ASSUMPTION</u>: EDGE SEAL DOES NOT BOND CATHODE PLATE TO SEPARATOR PLATE
  - IN-PLANE PRESSURE STRESS: (NO THERMAL STRESS)



DESIGN ALLOWABLE: (250 F)

TENSILE STRESS < .25×STRENGTH
(1500 PSI)

  - STRESS CONCENTRATION:
    - Kt = 3.4 (BI-AXIAL STRESS FIELD WITH .085" DIA. HOLES AND .135" HOLE SPACING)

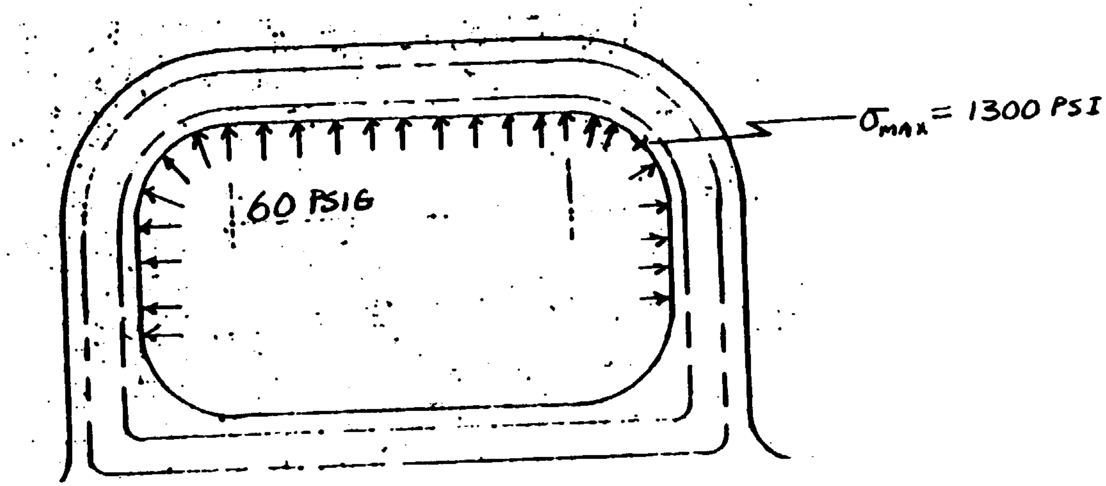


$\sigma_{AVG} = 360$ PSI

$\sigma_{MAX} = K_t \, \sigma_{AVG}$

  - MAXIMUM AVERAGE STRESS: 360 PSI
  - MAXIMUM STRESS = <u>1220</u> PSI < DESIGN ALLOWABLE

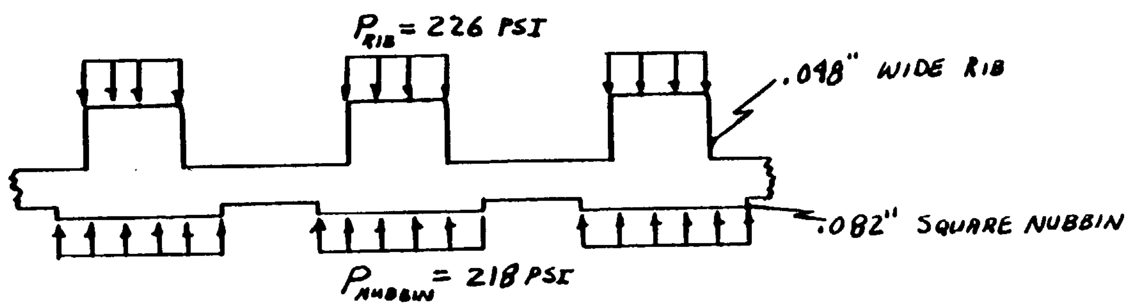
- **HYDROGEN MANIFOLD INTERNAL PRESSURE**
  - PPS/FG PLATES (CATHODE ELECTRODE, CELL COOLER, & END COOLER)
  - FLEXURE STRESS OF MANIFOLD WALL FROM 60 PSIG INTERNAL PRESSURE
  - FLEXURE DESIGN ALLOWABLE = .25*(FLEXURE STRENGTH) = 3000 PSI



  - MAXIMUM STRESS = 1300 PSI < DESIGN ALLOWABLE

o ANODE ERP

- o MATERIAL: PARTICULATE CARBON SUBSTRATE
  - o DENSITY: .036 LB./CU. IN.
  - o CRUSH STRENGTH: 400 PSI
- o ANODE LOAD: P = 80.5 PSI (AVG.) (CELL PINCH TOTAL LOAD = 12,000 #)
- o RIB LOADING: P = 226 PSI (2.81×(AVG. PRESSURE))
- o NUBBIN LOADING: P = 218 PSI (2.71×(AVG. PRESSURE))



- o MAXIMUM COMPRESSIVE STRESS = 226 PSI (CRUSH STRENGTH S.F. = 1.77)

STRUCTURAL DESIGN

POWER SECTION NON-REPEATING ELEMENTS

COMPONENT	MATERIAL	PARAMETER
• PRESSURE PLATES	300 SERIES STAINLESS STEEL	1.0" THICKNESS
• INSULATOR PLATES	A-100 (PPS/FG)	0.625" & 0.360" (ORBITER)
• TIE-RODS	AMS 4971 TITANIUM	.250" DIAMETER

POWER SECTION AXIAL LOAD ANALYSIS

- MAXIMUM STRESS 124.5 KSI
- DESIGN STRESS 125.0 KSI

POWER SECTION NON-REPEATING ELEMENT DESIGN VERIFIED BY DESIGN ANALYSIS

- CELL STACK CONFIGURATION:
  - PRESSURE PLATES
    - MATERIAL: 300 SERIES STAINLESS STEEL
    - THICKNESS: t = 1.00"
  - INSULATOR PLATES
    - MATERIAL: RYTON R-3 PPS/FG
    - THICKNESS: t = .625" & .360" (ORBITER FCP THICKNESSES)
  - SEPARATOR PLATES
    - MATERIAL: MONEL 400
    - THICKNESS: t = .005"
  - ELECTRODE PLATES
    - MATERIAL: INJECTION MOLDED RYTON R-3 PPS/FG
    - THICKNESS: t = .155" (CATHODE ELECTRODE PLATE FRAME)
  - COOLER PLATES
    - MATERIAL: INJECTION MOLDED RYTON R-3 PPS/FG
    - THICKNESS: t = .104" (CELL COOLER PLATE FRAME) & t = .120" (END COOLER PLATES)
  - TIE-RODS
    - MATERIAL: AMS 4971 TITANIUM
    - DIAMTETER: .250"-28 THREAD WITH REDUCED SHANK DIAMETER (.215") OR FULLY THREADED ROD TO GIVE CONSTANT AREA AND MAXIMUM FLEXIBILITY

- CELL STACK AXIAL LOAD
  - AXIAL LOAD MODEL
    - PRESSURE PLATES: L = 2.00" (TWO PLATES)
    - INSULATORS: L = .985" (BOTH PLATES)
    - SEPARATOR PLATES: L = 1.340" (268 PLATES)
    - ELECTRODES: L = 37.949" (199 CATHODES, 66 CELL COOLERS, & 2 END COOLERS)
    - TIE-RODS: A = .0362 SQ. IN. (CONSTANT AREA - 21 TIE-RODS)
      L = 38.000" (SHANK)
  - AXIAL LOAD ANALYSIS
    - CELL STACK LOADING
      - INTERNAL PRESSURE: 60 PSIG
      - CELL MATRIX PINCH: 12,000 # (TOTAL)
      - SEAL LOADING: 4800 # (TOTAL FOR 50 PLI)
    - TIE-ROD LOADING
      - INITIAL COLD LOAD: 3760 # (STRETCH = .279")
      - PRESSURIZED COLD: 3850 # (STRETCH = .286")
      - PRESSURIZED HOT: 4510 # (MAXIMUM LOAD)
      - MAXIMUM STRESS: 124.5 KSI < 125 KSI DESIGN STRESS
        (S.F. = 1.40 - 175 KSI U.T.S.)

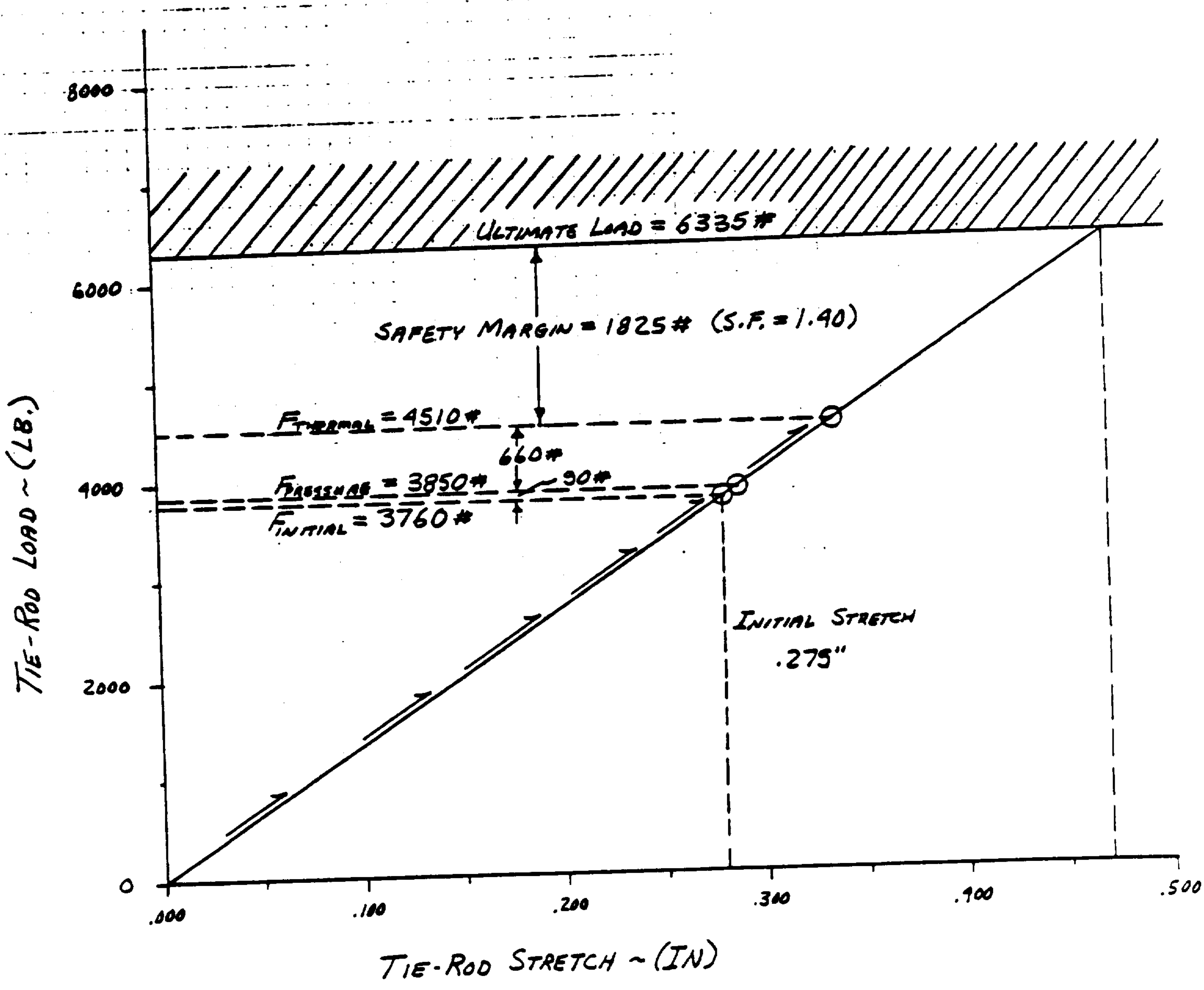
X708 CELL STACK AXIAL LOAD

TIE-ROD LOAD CYCLE – LOAD VS. STRETCH

MATERIAL: AMS 4971 TITANIUM (UTS = 175 KSI)

$A = .0362\ IN^2$ (.250-28 THD.)

$E = 16 \times 10^6$ PSI



REACTANT AND COOLANT DISTRIBUTION ANALYSIS

	FIELD DEPTH MILS	PORT DEPTH MILS	PORT WIDTH MILS	NO PORTS IN/OUT	PRESSURE LOSS – CALCULATED	ALLOCATED
• HYDROGEN	50	38	35	4/4	3.4	3.5
• OXYGEN	30	19	21	3/3	2.5	–
• CELL COOLER	40	40	30	4/4	.5	1.5
• END COOLER	50	50	39	4/4	.5	1.5

* POWER SECTION REACTANT AND COOLANT DISTRIBUTION VERIFIED BY DESIGN ANALYSIS.

REACTANT FLOW FIELD DESIGN

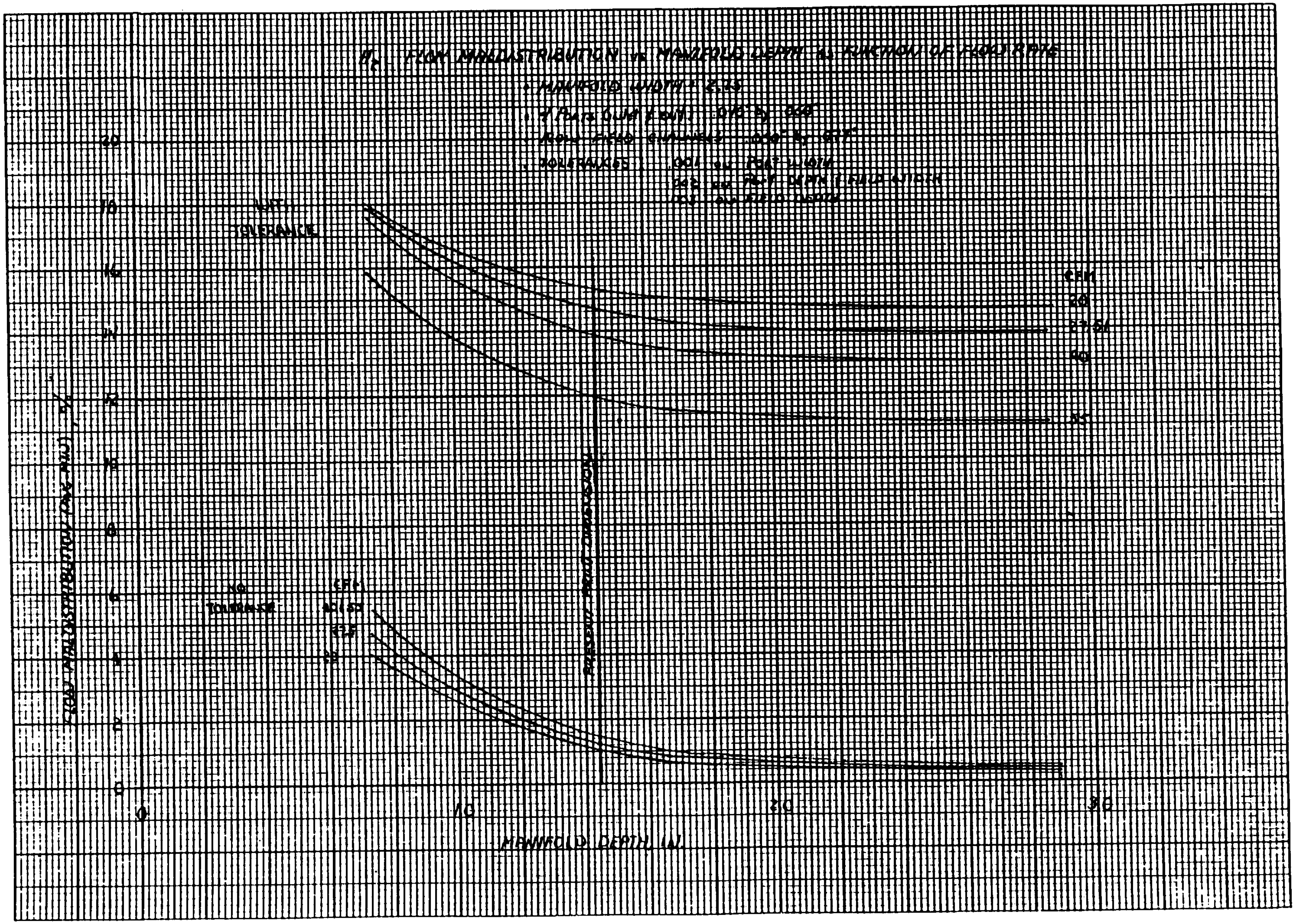
* BASIC CELL DESIGN IS FLOW FIELDS AND PORTS
  * NUBBINS FOR MINIMUM WEIGHT
  * PORTS CONTROL CELL TO CELL FLOW DISTRIBUTION
* MANIFOLDS SIZED FOR NEGLIGABLE CONTRIBUTION TO FLOW MALDISTRIBUTION
* SILVER PLATING ON PPS FLOW FIELDS TO ENHANCE HEAT TRANSFER AND PROVIDE ELECTRICAL CONTINUITY

HYDROGEN FIELDS

* FLOW DISTRIBUTION
  - SETS MANIFOLD SIZE
  - NOT A DETERMINING FACTOR IN PORT AND FIELD SIZING
  - ~ 12% AT DESIGN FLOW

* CLEARING KOH DROPS FROM PORTS
  - 4 INLET PORTS, 4 EXIT PORTS
  - INLET PORT WORST CASE
  - CAN CLEAR ANY PLUGGED PORT IN STACK AT NOMINAL FUEL FLOW
    - .038 X .035 PORTS
    - 4 INLET:4 EXIT PORTS

* PRESSURE DROP ~ 3.5 IWC


MANIFOLD DEPTH (IN)
0
10
20
30
20
18
16
14
12
10
8
6
4
2
0
CFM
20
40
NO TOLERANCE
TOLERANCE

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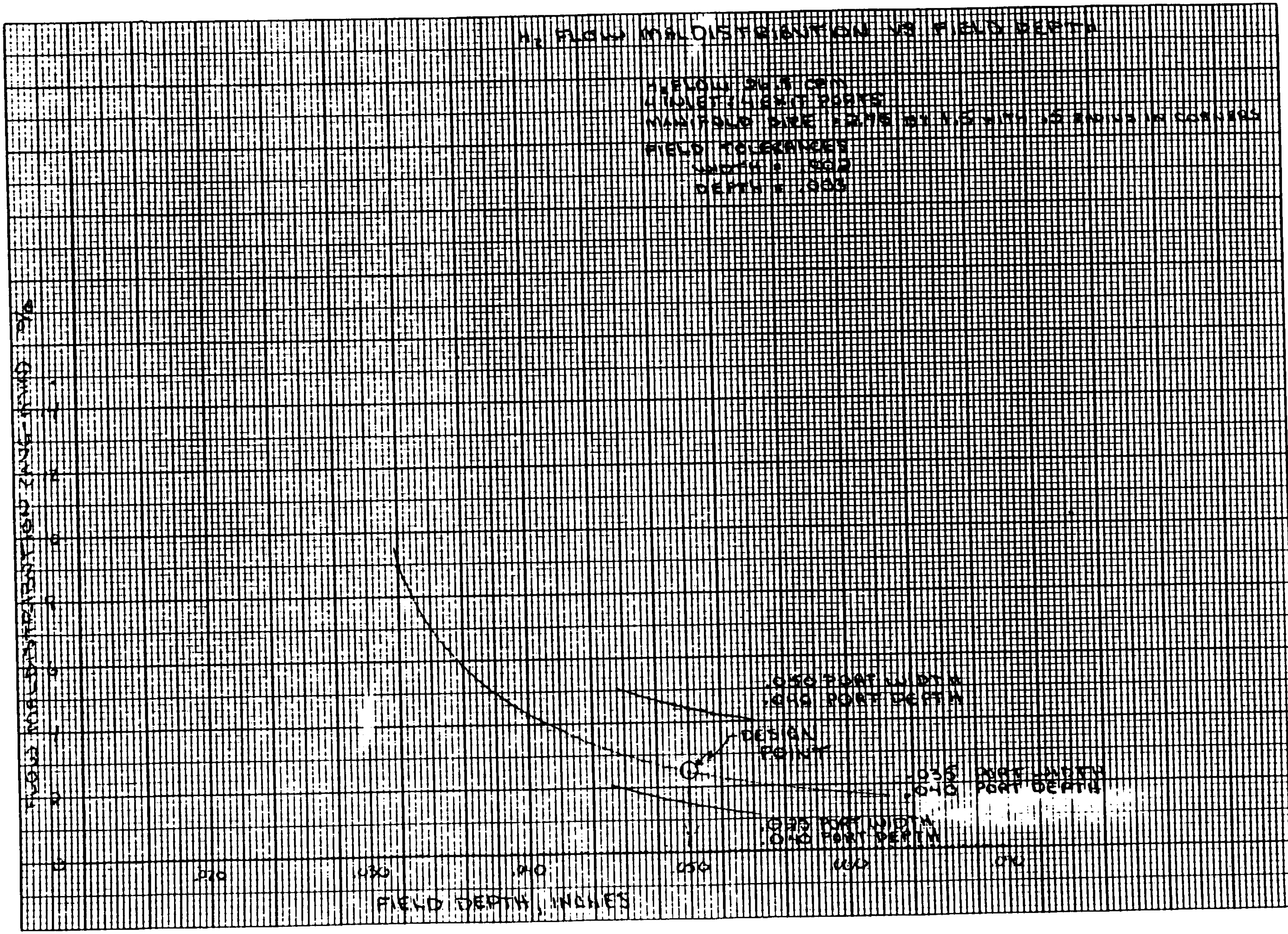

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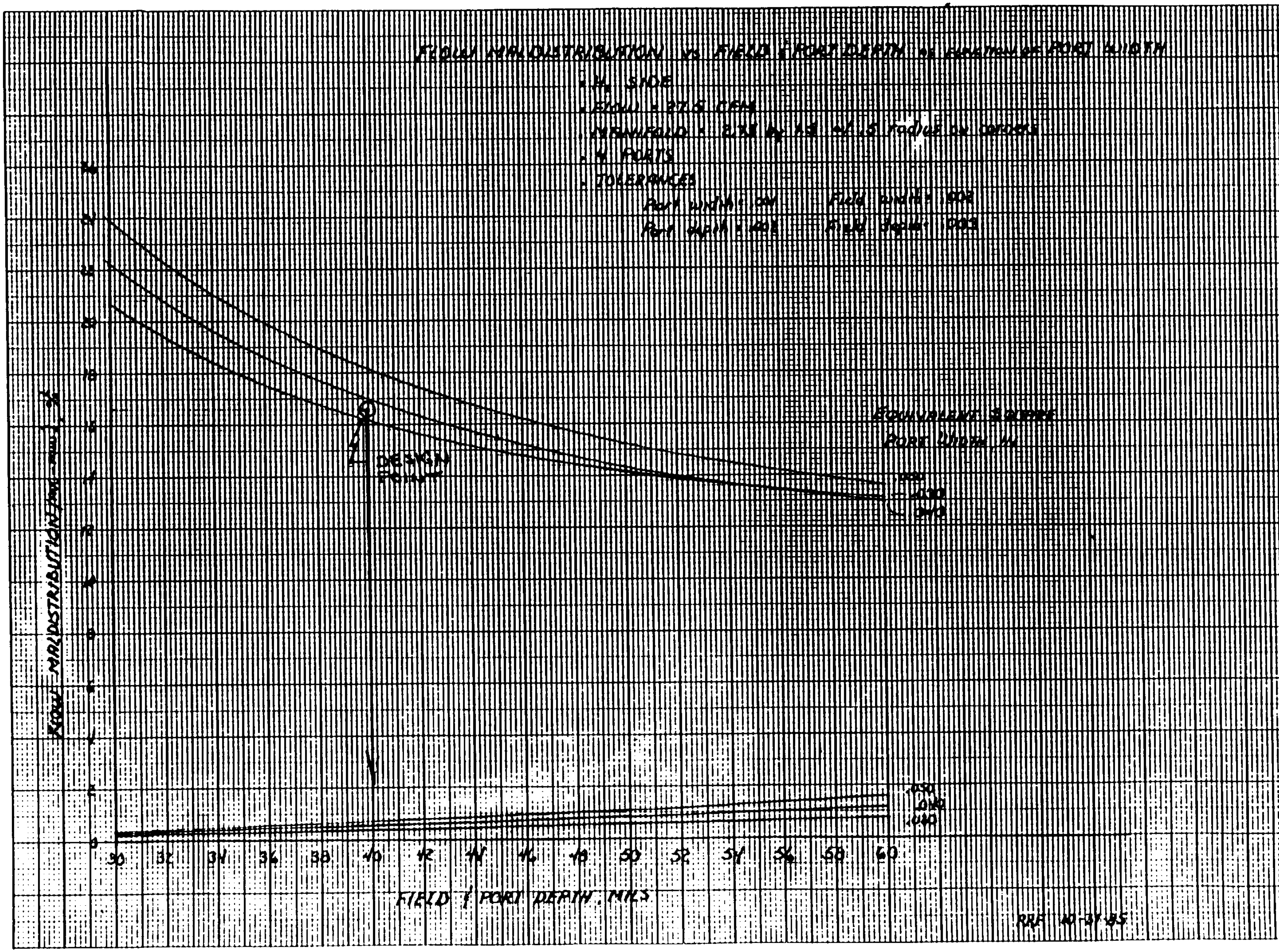
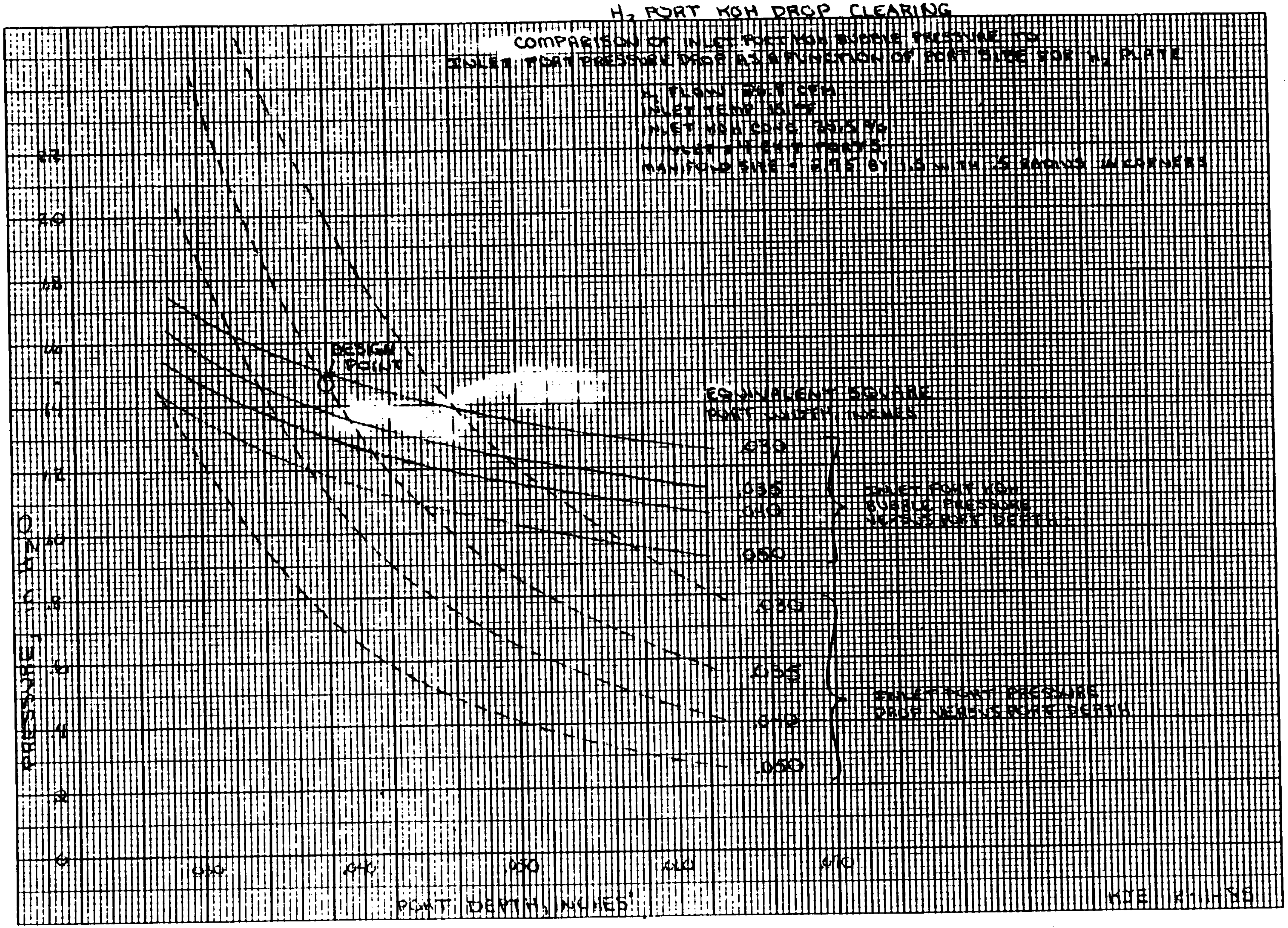
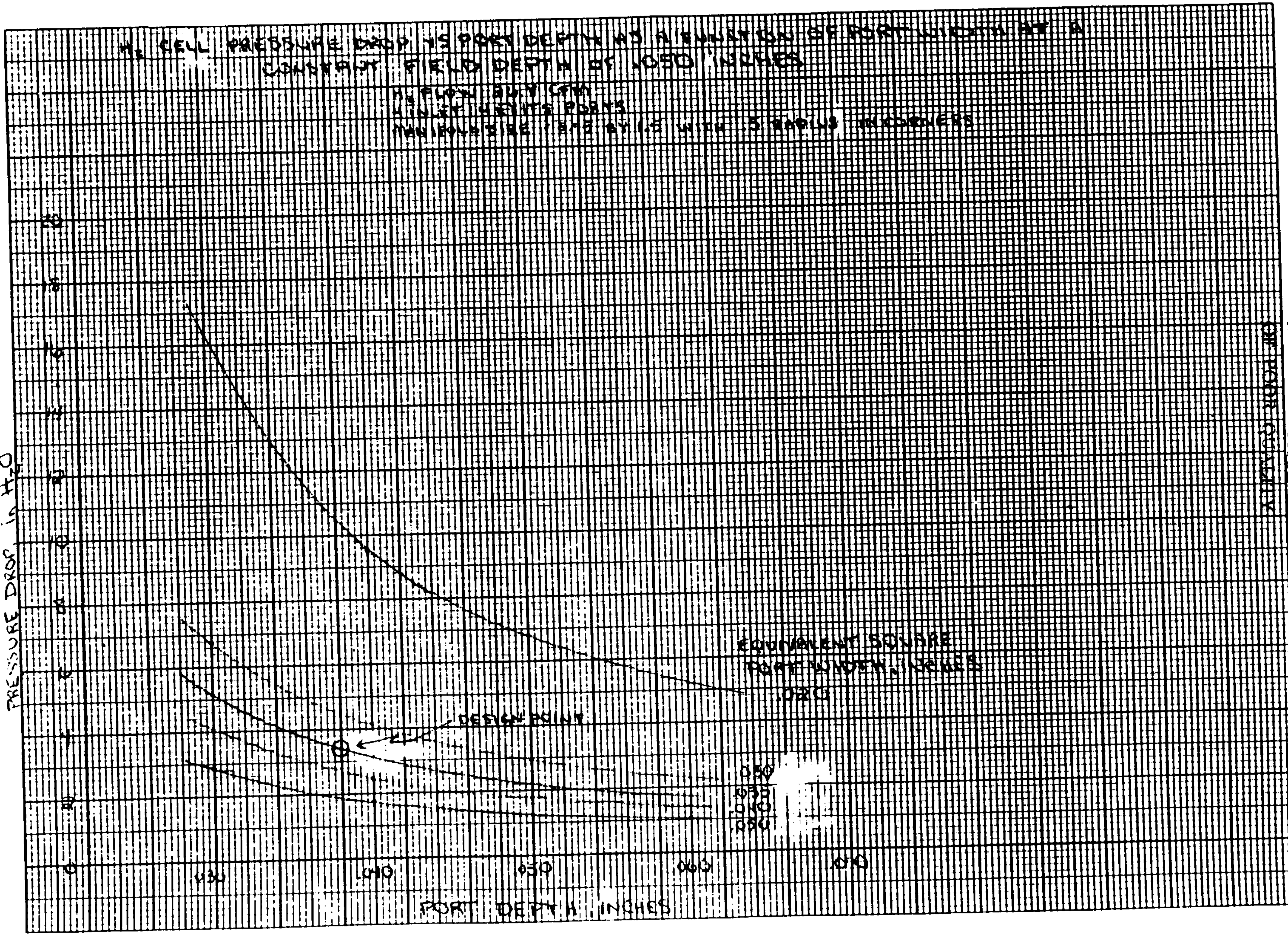



H2 PORT KOH DROP CLEARING
COMPARISON OF INLET PORT KOH BUBBLE PRESSURE TO
INLET PORT PRESSURE DROP AS A FUNCTION OF PORT SIZE FOR H2 PLATE
DESIGN POINT
EQUIVALENT SQUARE PORT WIDTH, INCHES
.030
.035
.040
.050
INLET PORT KOH BUBBLE PRESSURE VERSUS PORT DEPTH
.030
.035
.040
.050
INLET PORT PRESSURE DROP VERSUS PORT DEPTH
PORT DEPTH, INCHES
PRESSURE, IN H2O



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OXYGEN FIELDS

* FLOW DISTRIBUTION
  - SETS A MINIMUM MANIFOLD SIZE
  - NOT A DETERMINING FACTOR IN SIZING FIELDS OR PORTS
  - 26% AT DESIGN POINT

* CLEARING KOH DROPS FROM PORTS
  * NOT POSSIBLE TO CLEAR DROPS FROM AT REASONABLE PURGE RATES WITH PORTS > .020 MIL DEPTH AND WIDTH
  * DESIGN TO ENSURE CLEARING OF A LEAST ONE PORT IN EACH CELL INLET AND OUTLET
  * 4 PORTS DESIRABLE FOR BEST SWEEPING OF FLOW FIELDS
    - NEED MORE PURGE FLOW TO BLOW OUT DROPS
  * 3 PORTS WILL ALLOW PORT CLEARING AT CDR PURGE FLOW
    - .020 PORTS - NO MARGIN
  * 50% INCREASE IN PURGE FLOW ALLOWS LARGER PORTS
    - LESS SENSITIVE TO TOLERANCES

* PRESSURE DROP ~ 2.5 IWC

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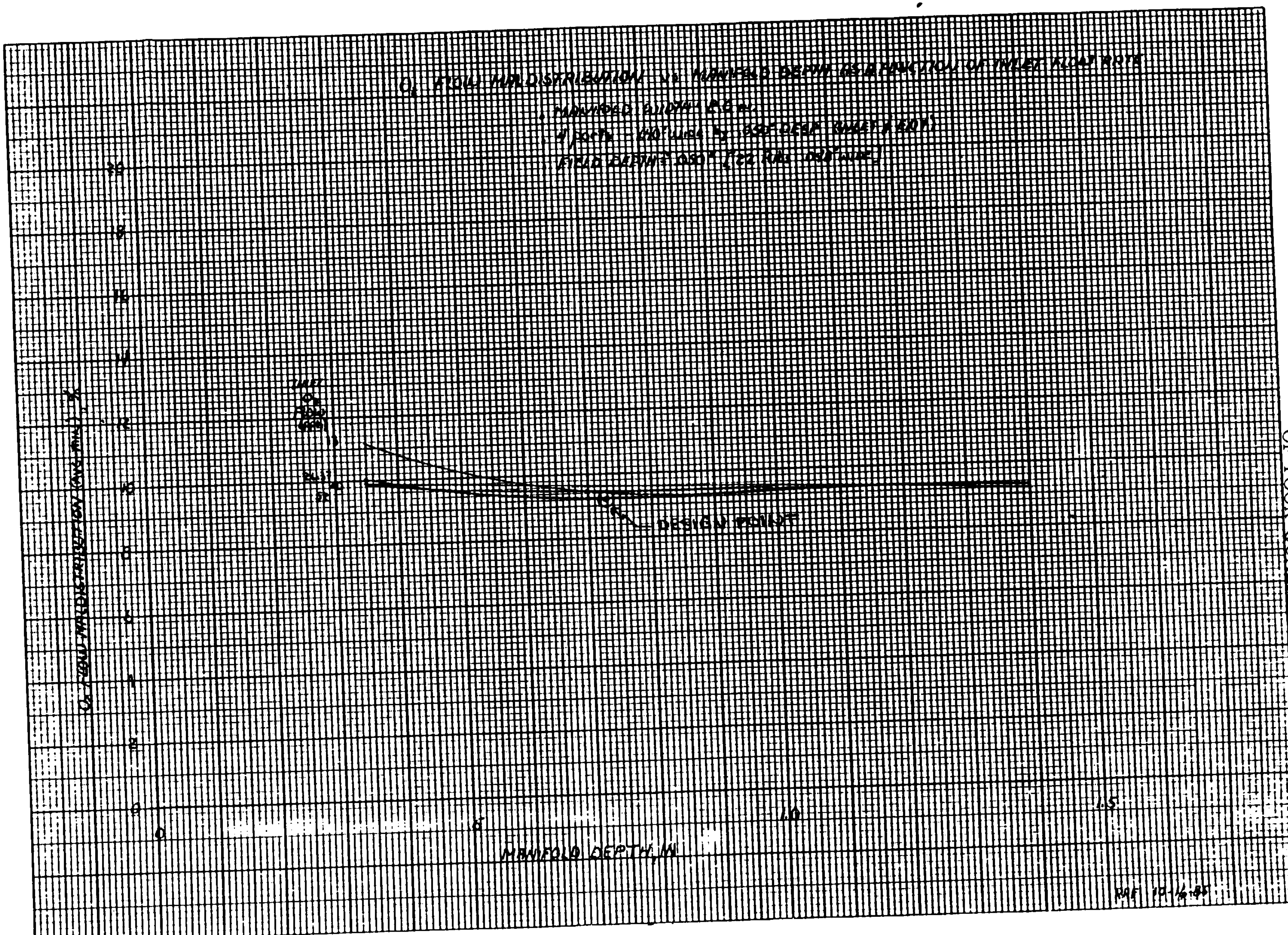
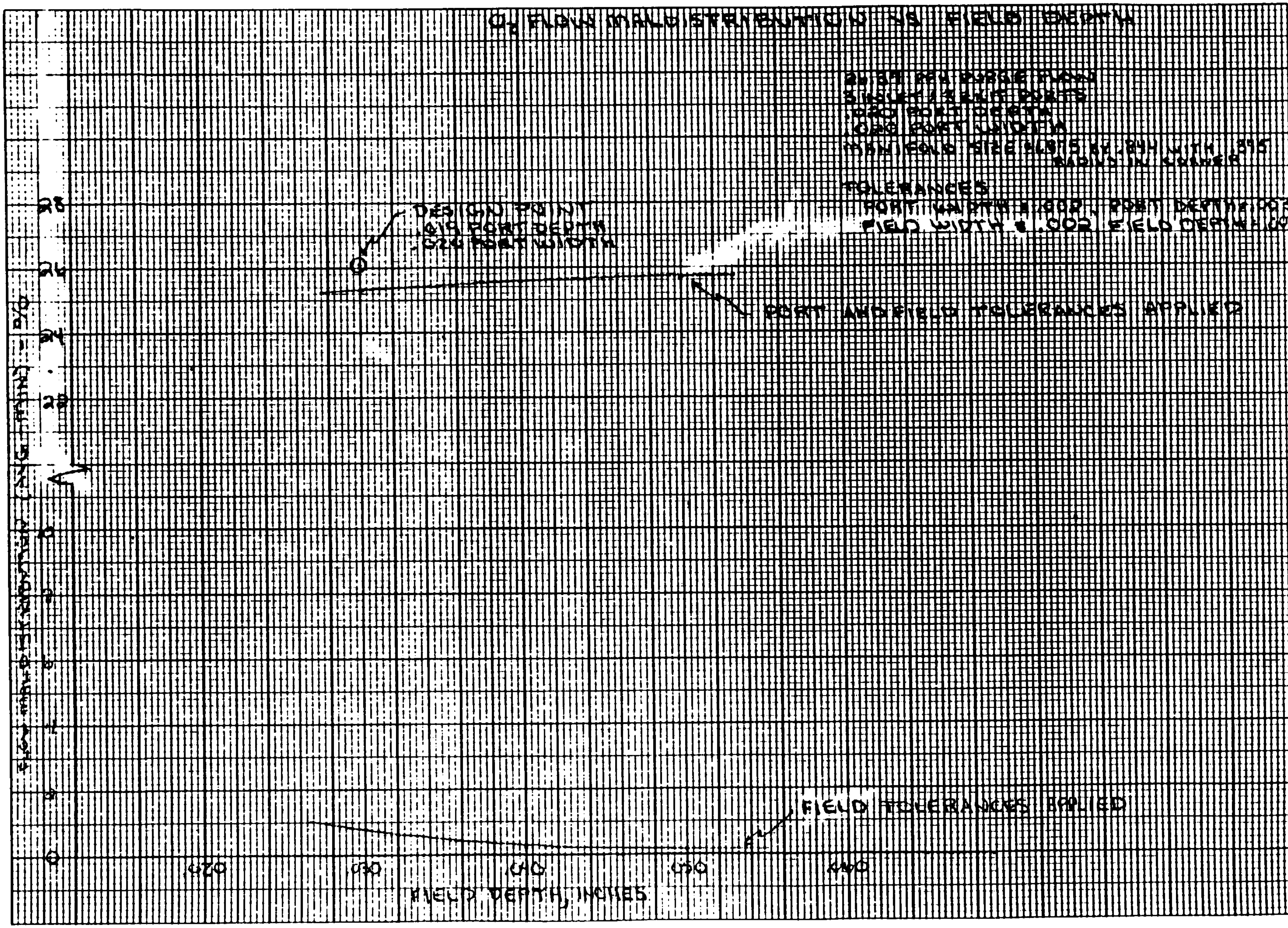
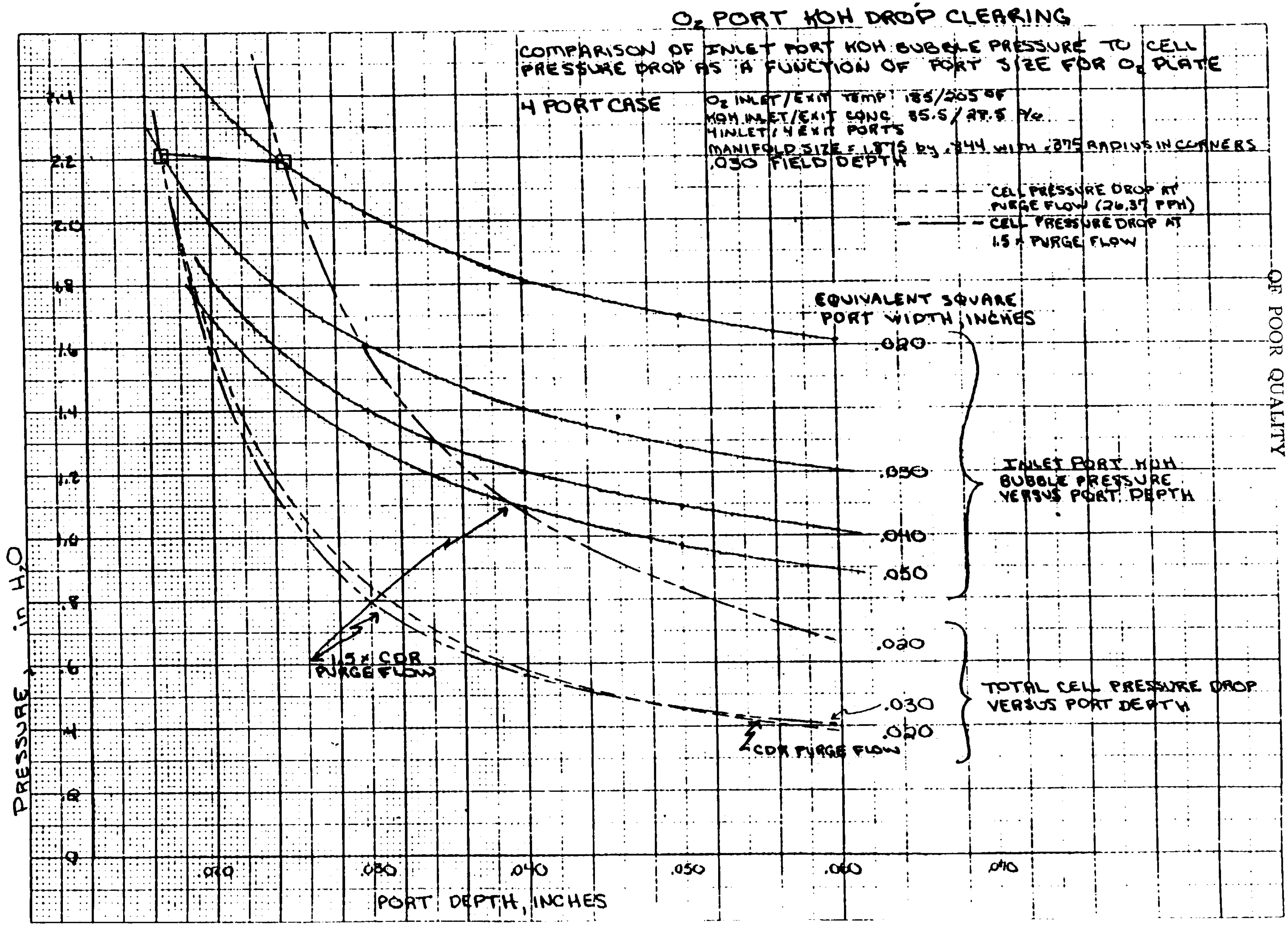
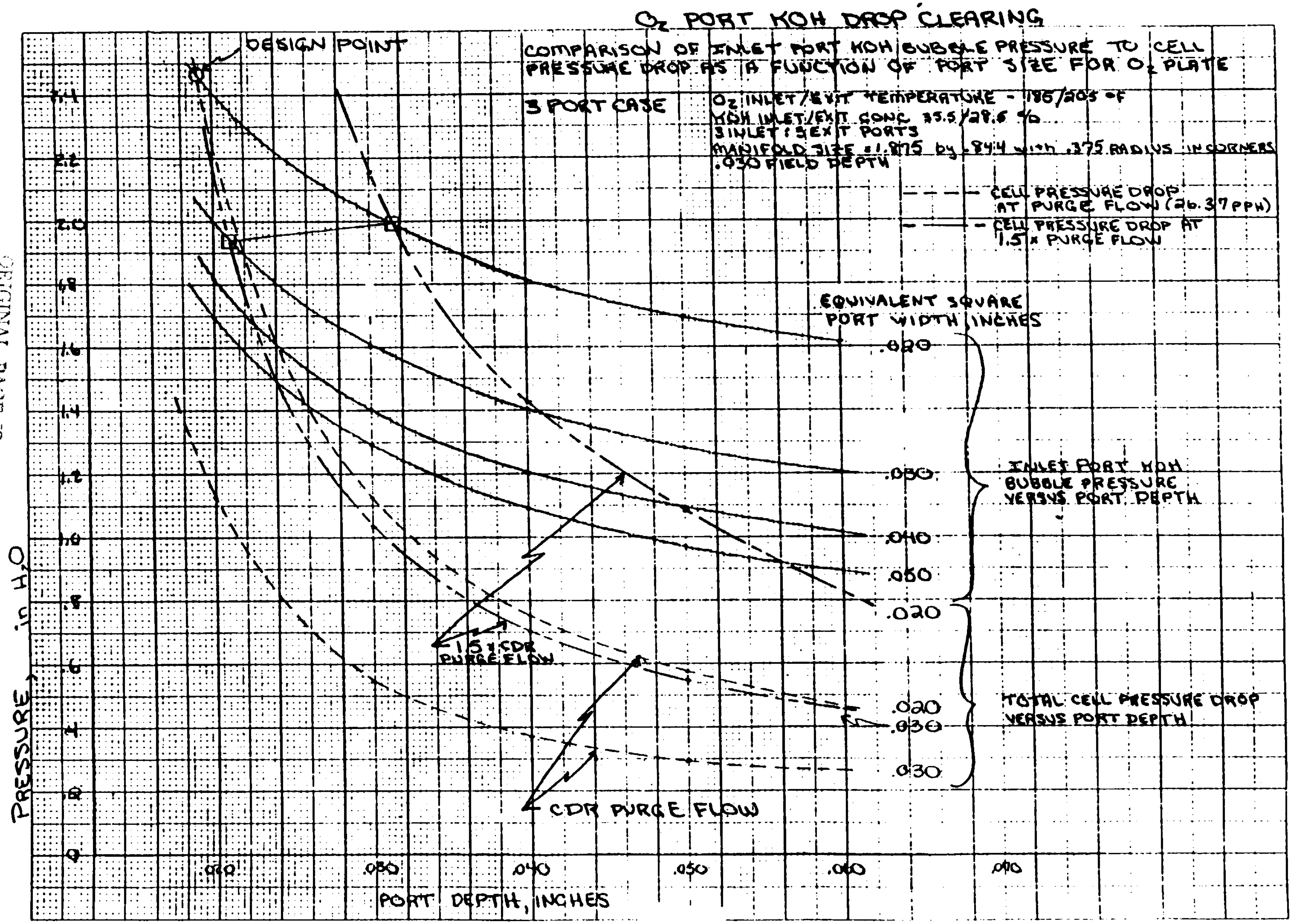


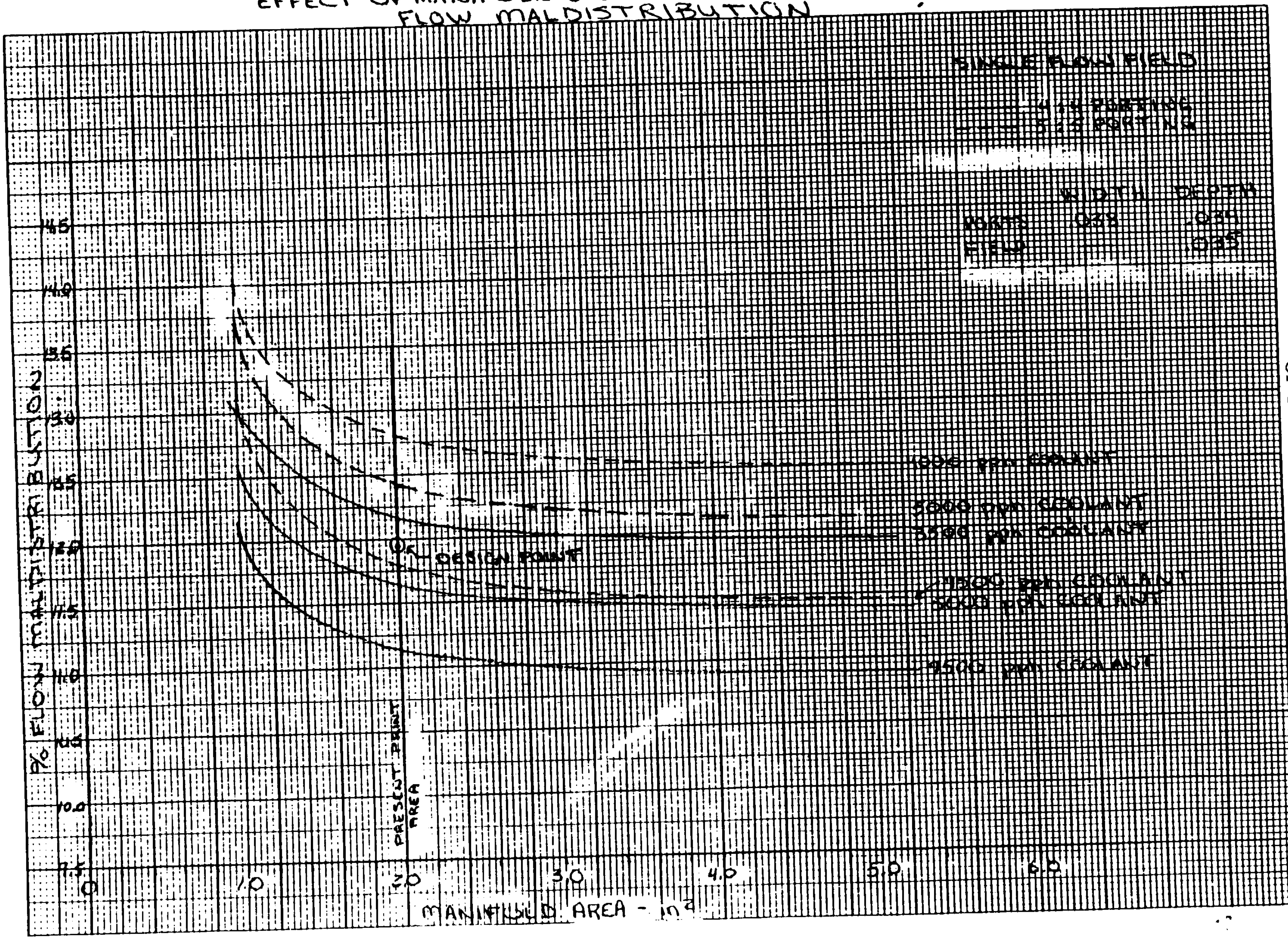

O2 FLOW MALDISTRIBUTION VS FIELD DEPTH
TOLERANCES
DESIGN POINT
.024 PORT WIDTH
PORT AND FIELD TOLERANCES APPLIED
FIELD TOLERANCES APPLIED
.020
.030
.040
.050
.060
FIELD DEPTH, INCHES

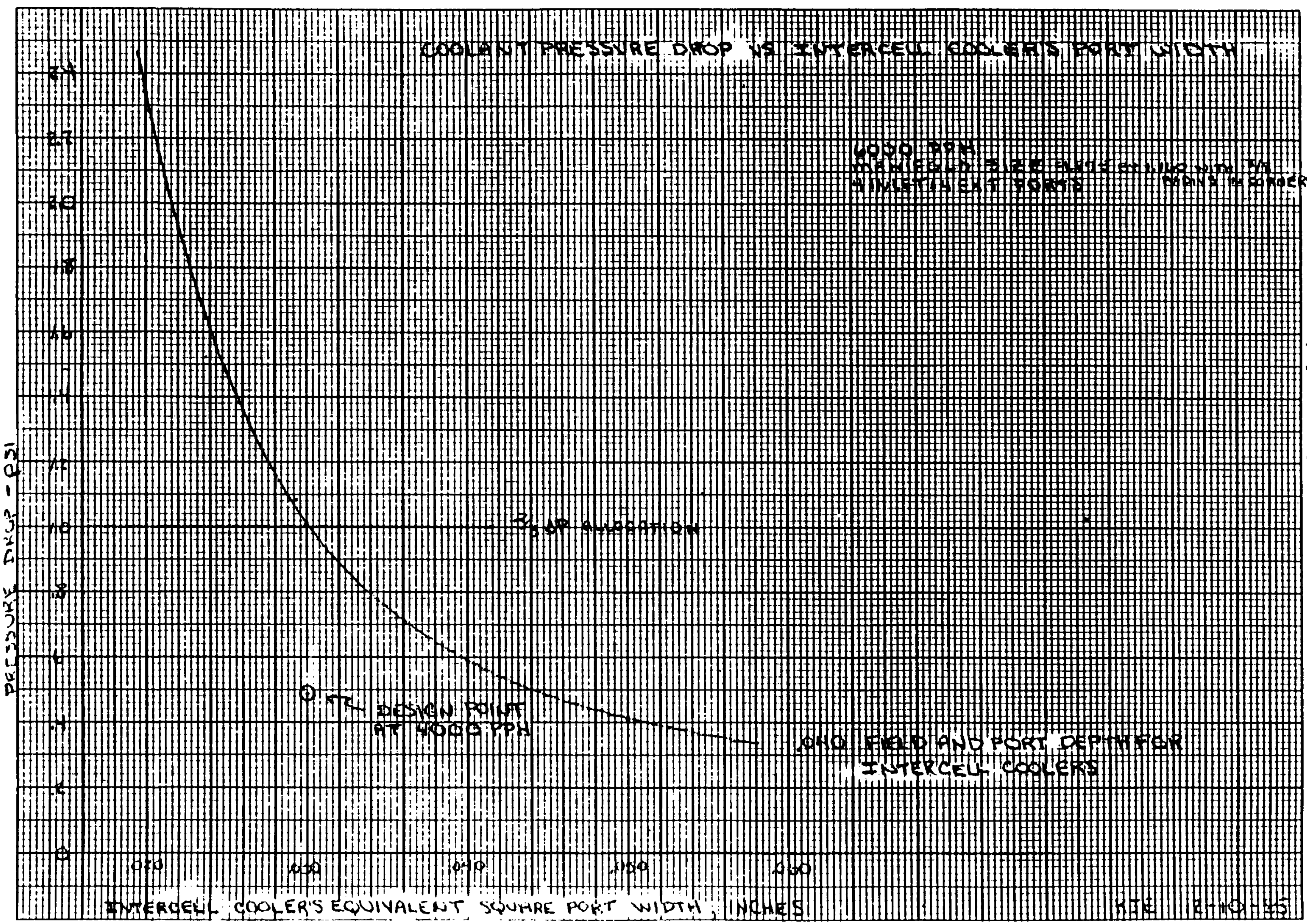


O2 PORT KOH DROP CLEARING
COMPARISON OF INLET PORT KOH BUBBLE PRESSURE TO CELL PRESSURE DROP AS A FUNCTION OF PORT SIZE FOR O2 PLATE
4 PORT CASE
O2 INLET/EXIT TEMP 185/205 °F
KOH INLET/EXIT CONC 35.5/27.5 %
4 INLET/4 EXIT PORTS
MANIFOLD SIZE = 1.875 by .344 WITH .375 RADIUS IN CORNERS
.030 FIELD DEPTH
CELL PRESSURE DROP AT PURGE FLOW (26.37 PPH)
CELL PRESSURE DROP AT 1.5 × PURGE FLOW
EQUIVALENT SQUARE PORT WIDTH INCHES
.020
.030
.040
.050
INLET PORT KOH BUBBLE PRESSURE VERSUS PORT DEPTH
.020
.030
.020
TOTAL CELL PRESSURE DROP VERSUS PORT DEPTH
1.5 × CDR PURGE FLOW
CDR PURGE FLOW
PRESSURE, in H2O
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.020
.030
.040
.050
.060
.070
PORT DEPTH, INCHES


O2 PORT KOH DROP CLEARING
COMPARISON OF INLET PORT KOH BUBBLE PRESSURE TO CELL PRESSURE DROP AS A FUNCTION OF PORT SIZE FOR O2 PLATE
3 PORT CASE
O2 INLET/EXIT TEMPERATURE - 185/205 °F
KOH INLET/EXIT CONC 35.5/28.6 %
3 INLET : 3 EXIT PORTS
MANIFOLD SIZE = 1.875 by .844 with .375 RADIUS IN CORNERS
.030 FIELD DEPTH
CELL PRESSURE DROP AT PURGE FLOW (26.37 PPH)
CELL PRESSURE DROP AT 1.5 x PURGE FLOW
DESIGN POINT
EQUIVALENT SQUARE PORT WIDTH INCHES
.020
.030
.040
.050
.020
INLET PORT KOH BUBBLE PRESSURE VERSUS PORT DEPTH
.020
.030
.030
TOTAL CELL PRESSURE DROP VERSUS PORT DEPTH
1.5 x CDR PURGE FLOW
CDR PURGE FLOW
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.020
.030
.040
.050
.060
.070
PORT DEPTH, INCHES
PRESSURE, in H2O

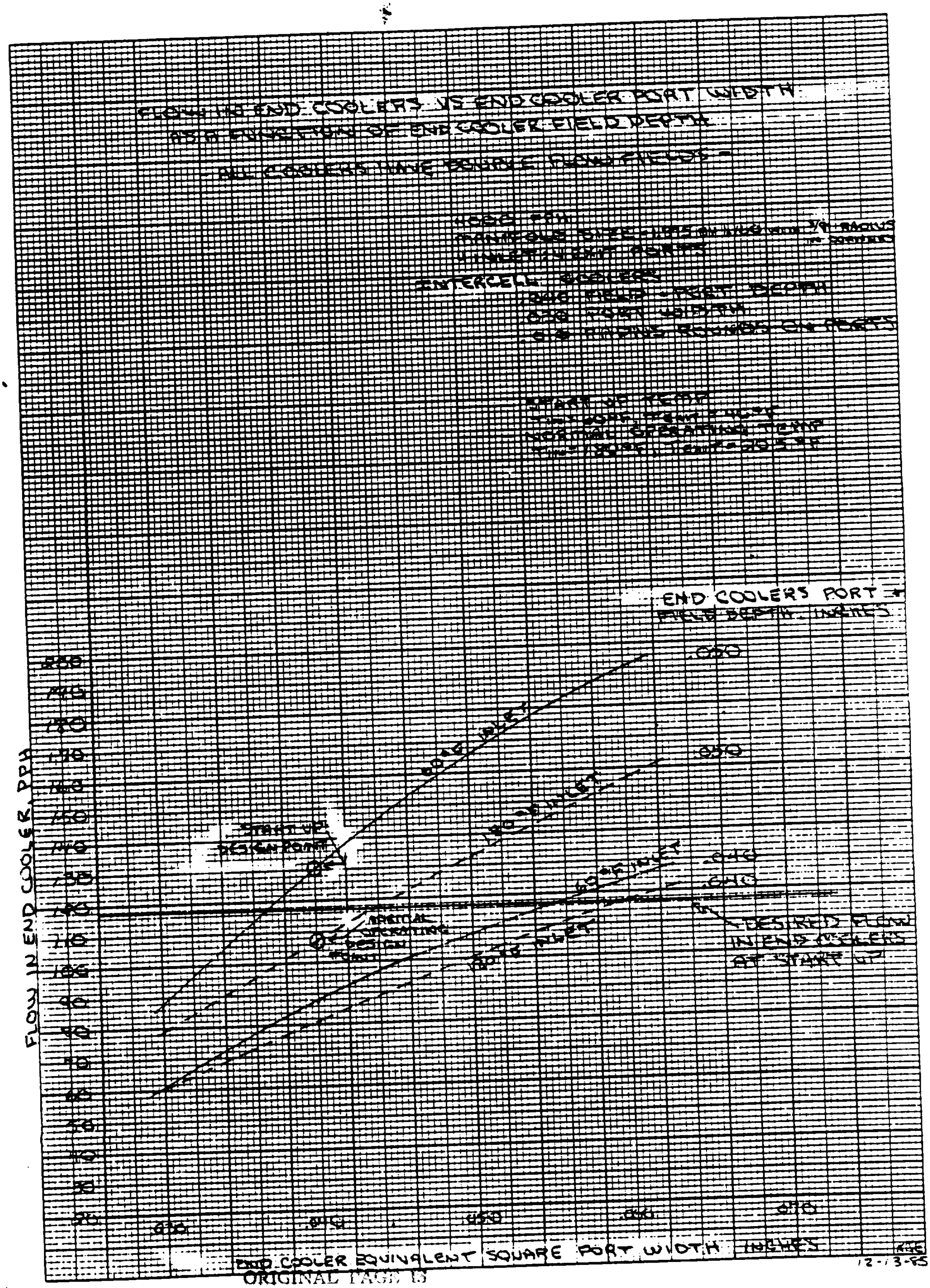
EFFECT OF MANIFOLD SIZE AND COOLANT FLOW ON FLOW MALDISTRIBUTION




COOLANT PRESSURE DROP VS INTERCELL COOLER'S PORT WIDTH
4000 PPH
3/5 ΔP ALLOCATION
DESIGN POINT
AT 4000 PPH
.040 FIELD AND PORT DEPTH FOR
INTERCELL COOLERS
PRESSURE DROP - PSI
INTERCELL COOLER'S EQUIVALENT SQUARE PORT WIDTH, INCHES
.020
.030
.040
.050
.060

POWER SECTION END CELL HEAT LOSS

- ASSUMPTIONS
  - NO ELECTRICAL HEATERS ON END CELLS
  - END CELL HEAT SUPPLIED BY COOLER ON STACK ENDS
- SPECIAL COOLER PLATE DESIGN
  - INCREASED COOLANT FIELD DEPTH - 10 MILS
  - INCREASED COOLANT PORT DIMENSIONS - 10 MILS
  - CALCULATED COOLANT PRESSURE - 0.5 PSI (ALLOCATED 1.5 PSI)
  - POWER PLANT STARTUP ANALYSIS REQUIRED
- COOLER DESIGN VERIFIED BY DESIGN ANALYSIS


FLOW IN END COOLERS VS END COOLER PORT WIDTH
AS A FUNCTION OF END COOLER FIELD DEPTH
ALL COOLERS HAVE DOUBLE FLOW FIELDS -
INTERCELL COOLERS
NORMAL OPERATING TEMP
END COOLERS PORT + FIELD DEPTH, INCHES
.050
START UP DESIGN POINT
DESIRED FLOW IN END COOLERS AT START UP
FLOW IN END COOLER, PPH
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
.030
.040
.050
.060
.070
END COOLER EQUIVALENT SQUARE PORT WIDTH, INCHES
12-13-85

REMAINING CELL STACK DESIGN TASKS

- IDENTIFY MAXIMUM POWER CAPABILITY OF THE 1.0 FT^2 POWER SECTION
- REVIEW COMPATIBILITY OF MATERIALS IN THE CELL STACK ASSEMBLY WITH OXYGEN
  REFERENCE: NASA PUBLICATION 1113

TECHNOLOGY DEVELOPMENT STATUS

TECHNOLOGY DEVELOPMENT STATUS

SUMMARY

- ORDERS FOR MATERIAL AND CELL COMPONENTS REQUIRED FOR BOTH NASA PROGRAMS HAS BEEN PLACED.
    - GOLD-PLATED PERFORATED NICKEL FOIL ELECTRODE SUBSTRATES
    - CATHODE CATALYST
    - STACK NON-REPEATING PARTS
- CELL COMPONENT FABRICATION TRIALS INITIATED
- ENDURANCE TESTING OF THE NASA-LEWIS SIX-CELL 1.0 FT^2 PILOT STACK PLANNED TO BEGIN - SEPTEMBER 1986
- NASA-JSC 15-CELL 1.0 FT^2 TECHNOLOGY READY MODULE PERFORMANCE CHECKOUT TEST PLANNED FOR FEBRUARY 1987
- IDENTIFIED REMAINING DEVELOPMENT TASKS

CELL ELECTRODE ASSEMBLY

SEALS

- STATUS
  - CELL EDGE SEAL
    - SUBSCALE (4" X 4") ONE-PIECE EDGE SEAL ASSEMBLY TRIAL COMPLETED.
    - EDGE SEAL CONCEPT CROSSPRESSURE GOAL $>$ 20 PSID ATTAINED
  - FRAME SEALS
    - PARKER SEAL SCHEDULED TO MOLD STANDARD GASK-O-SEAL IN PPS PLATE
    - FABRICATION TRIALS AT PARKER FOR IMPROVED CONTOUR SEALS ON HOLD
    - DOWTY LTD. CONTINUES TO DEVELOP PRINTED SEALS
      - SCREEN PRINTED EPR SEALS DEVELOPED FROM BUTYL RUBBER EXPERIENCE
      - SCREEN PRINTED EPR SEALS 4-MILS HIGH-ADVANCED CELL DESIGN REQUIRES 8-MIL HIGH SEALS
      - DOWTY CONTINUES TO DEVELOP SEALS AT NO COST TO IFC
  - CONCERNS - 1.0 FT^2 CELL ASSEMBLY
    - MANUFACTURING TOLERANCES - REACTANT CROSS LEAKAGE
    - CELL ASSEMBLY THERMAL GROWTH

CELL ELECTRODE ASSEMBLY

CATHODE

- STATUS
  - GOLD-PLATED PERFORATED Ni-FOIL ELECTRODE SUBSTRATES
    - SUBSTRATES AVAILABLE FOR NASA-LEWIS 6-CELL STACK
    - SUBSTRATES FOR NASA-JSC PROGRAM ORDERED
  - Au Pt CATALYST
    - CATALYST AVAILABLE FOR NASA-LEWIS 6-CELL STACK
    - CATALYST FOR NASA-JSC PROGRAM ORDERED
  - ELECTRODES
    - MANUFACTURING TRIALS ON ONE - 1.0 FT^2 ELECTRODE COMPLETED
    - HALF-CELL PERFORMANCE OF TRIAL SAMPLE EXCEEDS ORBITER SPECIFICATION
    - SHOP READY TO FABRICATE ELECTRODES
    - ELECTRODES FOR NASA-LEWIS 6-CELL STACK COMPLETED
  - CONCERNS
    - NONE

CELL ELECTRODE ASSEMBLY

ANODE

- STATUS
  - Au-PLATED Ni-FOIL ELECTRODE SUBSTRATES
    - SUBSTRATES AVAILABLE FOR NASA-LEWIS 6-CELL STACK
    - SUBSTRATES FOR NASA-JSC PROGRAM ORDERED
  - SUPPORTED Pt-on-CARBON CATALYST - AVAILABLE
- PLAN
  - ELECTRODES FOR NASA-LEWIS TO BE CATALYZED EARLY IN JUNE
- CONCERNS
  - ELECTROLYTE FILL METHOD

CELL ELECTRODE ASSEMBLY

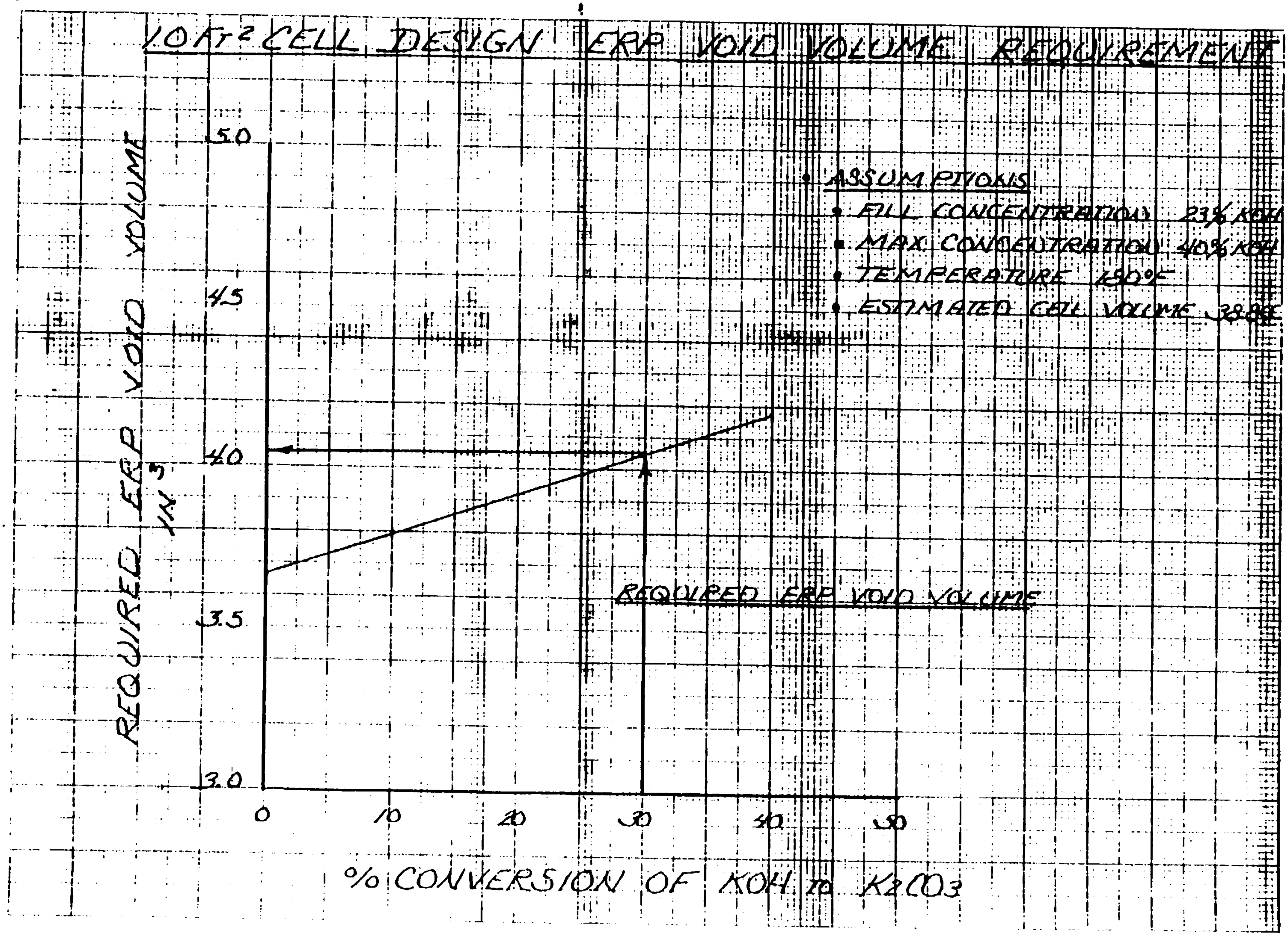
BUTYL BONDED POTASSIUM TITANATE MATRIX

- STATUS
  - POTASSIUM TITANATE AND BUTYL RUBBER MATERIAL FOR BOTH PROGRAMS AVAILABLE
  - PRELIMINARY 1.0 FT^2 FABRICATION TRIALS COMPLETED - CROSS PRESSURE GOAL $>$ 20 PSID ATTAINED
- PLAN
  - MATRICES FOR NASA-JSC AND NASA-LEWIS PROGRAMS TO BE FABRICATED IN LATE JUNE
- CONCERNS
  - CONSISTENT CROSS PRESSURE CAPABILITY
  - HANDLEABILITY

CELL ELECTRODE ASSEMBLY

CARBON ELECTROLYTE RESERVOIR PLATE (ERP)

- STATUS
  - FINE-PORE ($\sim$10 MICRONS) CARBON ERP BLANKS FOR BOTH PROGRAMS AVAILABLE
  - MACHINING TRIALS SUCCESSFULLY COMPLETED
  - PLACED ORDER FOR MACHINING CARBON ERP'S FOR BOTH PROGRAMS IN SHOP
- CONCERNS
  - NONE



1.0 FT² CELL DESIGN ERP VOID VOLUME REQUIREMENT
REQUIRED ERP VOID VOLUME IN³
5.0
4.5
4.0
3.5
3.0
0
10
20
30
40
50
% CONVERSION OF KOH TO K2CO3
• ASSUMPTIONS
• FILL CONCENTRATION 23% KOH
• MAX CONCENTRATION 40% KOH
• TEMPERATURE 180°F
• ESTIMATED CELL VOLUME
REQUIRED ERP VOID VOLUME

POLYPHENYLENE SULFIDE (PPS) CELL AND COOLER PLATES

- STATUS
  - FIFTY MOLDED PPS BLANKS FOR BOTH PROGRAMS AVAILABLE (25 BLANKS AT TWO MOLD TEMPERATURES)
  - VENDOR MACHINING TRIALS IN PROGRESS
  - REQUEST FOR QUOTATION ISSUED TO THREE MACHINING VENDORS - QUOTES OVERDUE
  - SILVER PLATING OF PPS (4 IN X 4 IN) BLANKS SUCCESSFULLY COMPLETED

- PLANS
  - MOLDED EDGE SEAL TRIALS (0.5 FT^2 CELL)

- CONCERNS
  - PLATE DISTORTION FROM MOLDING AND MANUFACTURING OPERATIONS
    - EFFECTS OF THERMAL CYCLING
    - EFFECTS OF SEAL MOLDING
  - PLATED PLATE ELECTRICAL CONDUCTIVITY
  - MANUFACTURED COST

RIG NON-REPEAT HARDWARE STATUS

- DRAWINGS FOR RIG NON-REPEAT PARTS COMPLETED
- ORDER ISSUED FOR NON-REPEAT PARTS FOR BOTH PROGRAMS
    - LOAD COLLECTOR PLATES
    - INSULATOR PLATES
    - END PLATES
- DESIGN ANALYSIS REVIEWING TIEROD REQUIREMENTS FOR 6-CELL AND 15-CELL MODULE
- CONCERNS
    - NONE

REMAINING DEVELOPMENT TASKS

- CONDUCT CELL COMPONENT FABRICATION TRIALS
- MANUFACTURE AND ASSEMBLE 1.0 FT^2 CELL ELECTRODE ASSEMBLY
- IDENTIFY AND CONSTRUCT MODULE TEST STAND FIXTURES
- ASSEMBLE MULTI-CELL 1.0 FT^2 MODULES
- CONDUCT MODULE PERFORMANCE EVALUATION TEST

CRITICAL ISSUES AND RISK ASSESSMENT

	ASSESSMENT
• POLYPHENYLENE SULFIDE CELL AND COOLER PLATE MANUFACTURING AND COST	H
• ELECTRICAL CONDUCTION OF PLATED POLYPHENYLENE SULFIDE PLATES	M
• CELL ELECTRODE ASSEMBLY EDGE SEAL	M
• CONSISTENT POTASSIUM TITANATE MATRIX CROSSPRESSURE CAPABILITY	L

ADDITIONAL PROGRAMS NEEDED

SUPPLEMENTARY TASKS

- COMPLETE POWER SECTION DETAIL DESIGN
    - LIGHTWEIGHT CURRENT TAKEOFF PLATES
    - LIGHTWEIGHT END PLATES
    - LIGHTWEIGHT INSULATOR PLATES
    - END CELL COOLER DRAWINGS
- IDENTIFY IMPACT OF INCREASED SYSTEM PRESSURE (120 PSIA) ON SPECIFIC WEIGHT
- EVALUATE EDGE SEAL APPROACHES WITH THE POTENTIAL FOR "ZERO" REACTANT LEAKAGE TO AMBIENT
- CONDUCT A PRODUCTION DEVELOPMENT PROGRAM
    - DEVELOP CELL COMPONENT AND CELL ASSEMBLY PRODUCTION CAPABILITY
    - DEVELOP A PRODUCTION POWER SECTION
- ASSEMBLE AND TEST FULL SIZE (200 CELLS) POWER SECTION
- DEFINE AN ADVANCED TECHNOLOGY ALKALINE FUEL CELL POWER PLANT SYSTEM
- IDENTIFY ALKALINE FUEL CELL POWER PLANToPTIMUMoRBITAL REPLACEMENT UNITS (ORU)
- IDENTIFY COMPONENT SECTION REQUIREMENTS
- DEVELOP COMPONENT SECTION (ACCESSORY SECTION)
- PROCURE, ASSEMBLE AND CHECKOUT TEST COMPONENT SECTION
- ASSEMBLE POWER PLANT
- CONDUCT A SYSTEM DEMONSTRATION TEST OF THE ADVANCED TECHNOLOGY ALKALINE FUEL CELL POWER PLANT