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TECHNOLOGY ADVANCEMENT OF THE STATIC FEED WATER ELECTROLYSIS PROCESS

ANNUAL REPORT

by

F. C. Jensen and F. H. Schubert

January, 1977

Prepared Under Contract NAS2-8682

by

Life Systems, Inc.
Cleveland, OH 44122

for

AMES RESEARCH CENTER
National Aeronautics and Space Administration

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FOREWORD

The development work described herein was conducted by Life Systems, Inc. at Cleveland, Ohio, under Contract NAS2-8682, during the period of March, 1975, through November, 1976 All program activities are scheduled for completion by November, 1977. The Program Manager was Fred C Jensen. Support was provided as follows

Personnel	Area of Responsibility
Michael L Kruszynski	Program Testing
J David Powell	Electrical Design
Franz H Schubert	Electrochemical Design
John W. Shumar	Product Assurance
Daniel C Walter	Mechanical Design
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The Contract Technical Monitor was P. D. Quattrone, Chief, Environmental Control Research Branch, NASA Ames Research Center, Moffett Field, CA

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LIST OF ACRONYMS

C/M I	Control and Monitor Instrumentation
DM	Dehydrator Module
KOH	Potassium Hydroxide (SFWEM electrolyte)
LBS-B/ORS-4(A)	Laboratory Breadboard System of a Bosch-based Oxygen Reclamation System at the four-man level using air cooling
LBS-S/ORS-1(L)	Laboratory Breadboard of a Sabatier-based Oxygen Reclamation System at the one-man level using liquid cooling
LSS	Life Support Systems
OGS	Oxygen Generation Subsystem
SFWE	Static Feed Water Electrolysis
SFWEM	Static Feed Water Electrolysis Module
SFWES	Static Feed Water Electrolysis System
SSP	Space Station Prototype

SUMMARY

A research and development program is presently being conducted at Life Systems, Inc. to continue the development of a method to generate oxygen for crew metabolic consumption during extended manned space flights. The concept being pursued is that of static feed water electrolysis.

Spacecraft water is statically fed (no moving parts) to the electrolysis site where it is electrolyzed, yielding hydrogen and oxygen saturated at the temperature and pressure of the electrolyte in the water electrolysis cell These moist gases are then passed through an electrochemical Dehydrator Module to remove the water vapor The Dehydrator Module accomplishes this by electrolyzing the water vapor contained in both the incoming hydrogen and oxygen gas streams. This vapor is absorbed in the acid electrolyte due to its lower water vapor pressure (as a result of water consumption), and electrolyzed. The result is additional dry product gases

The present program, "Technology Advancement of The Static Water Electrolysis Process," accomplished the following.

1 Advanced the system technology by:

- improving components, such as the product gas pressure regulators and the coolant pump
- modifying instrumentation and control electronics
- performing aerosol studies
- performing a system design analysis

2 Advanced single cell and module level technology by providing new·

- high current density current collectors
- insulation plates with integral cooling passages
- advanced non-corrosive electrode substrates
- O-rings less susceptible to taking a permanent set

3. Verified this advancement via testing at the:

- single cell level
- six-cell module level (one-man metabolic oxygen)

Specific major results of the above work included.

- Completion of a 30-day electrode test using a Life Systems, Inc. - developed high performance catalyst During startup the

cell voltages were as low as 1.38V at current densities of 108 mA/cm^2 (100 ASF) and temperatures of 355K (180F). At the end of 30 days of testing the cell voltages were still only 1.42V at 108 mA/cm^2

- Determination that the Static Feed Water Electrolysis Module does not release an aerosol of the cell electrolyte into the product gas streams after a break-in period of 24 hours following a new electrolyte charge
- Completion of a detailed design analysis of an electrochemical Oxygen Generation Subsystem at a three-man level (4.19 kg/day (9 24 lb/day) of oxygen).(1) The results showed the following

THREE-MAN OGS DESIGN ANALYSIS SUMMARY

Crew Size	3
Total O_2 Generation Rate,(a) kg/day (lb/day)	4 20 (9 24)
Fixed Hardware Weight, kg (lb)	54 0 (119)
Total Equivalent Weight, kg (lb)	382 (841)
Overall Dimension, cm (in)	41.3 x 43 8 x 59.7 (16 25 x 17.25 x 23.50)
Total Volume, m^3 (ft^3)	0.108 (3.81)
Total Power Required, kW	1 09(b)

(a) Includes oxygen requirements for the Electrochemical Depolarized Carbon Dioxide Concentrator Subsystem

(b) Using power controller conversion efficiency of 85%.

INTRODUCTION

Technology and equipment are needed to sustain man in space for extended time periods An Oxygen Generation Subsystem (OGS) is required to generate breathable oxygen (O_2) onboard a spacecraft. Presently considered techniques accomplish this through the electrolysis of water with the byproduct hydrogen (H_2) used within the Air Revitalization System (ARS) of the spacecraft to recover O_2 from expired carbon dioxide (CO_2)(2,3)

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(1) Numbers in parentheses are references found at the end of this report.

Background

Past development efforts on water electrolysis systems and modules have included those that use the static water feed concept.(4-7) Systems using this concept have demonstrated an inherent simplicity and long operating life capability.(4-6) The Static Feed Water Electrolysis Subsystem (SFWES) has the most potential as the lowest power-consuming electrolysis system due to its use of an alkaline electrolyte.(7) Various approaches to SFWES designs by different developers and results of extensive test programs have identified key system improvements required Problems inherent in the design of a SFWES and of water electrolysis systems in general, have been eliminated as demonstrated by.

- elimination of water feed compartment degassing(5)
- elimination of the zero gravity condenser/separators which are characteristic of all other applicable water electrolysis subsystems(5)
- elimination of aerosols in the product gas stream(1)

A reliable, low equivalent weight OGS based on the static feed concept and including peripheral support hardware has been under development at Life Systems, Inc. (LSI) for the past several years. The currently developed SFWES has demonstrated a capability of operating with current densities of 54 to 1080 mA/cm^2 (50 to 1000 ASF), pressures from ambient to 4140 kN/m^2 (600 psia) and internal temperatures from 323 to 372K (120 to 210F). The requirement of past SFWESs to vent the feed water cavity has been solved A 90-day endurance run was completed successfully and two approaches to delivering dry product O_2 and H_2 gases to the spacecraft environment and other ARS subsystems were demonstrated.(5) One approach was gas expansion through a regulator, the second was an electrochemical Dehydrator Module (DM) in the product gas lines.

The objective of the present program is to continue to advance the technology of the SFWES with special emphasis on improving performance (lower cell voltages at higher current densities), customizing components inherently needed by the SFWES and reducing overall subsystem complexity in preparation for integration into a spacecraft's ARS.

Program Objectives

The general program objective is to advance the technology of the SFWES The detailed overall objectives of the program are to

1. Design a module that can reliably operate for 180 days with a lifetime of 2 5 years or more.
2. Advance the technology as far as possible without risking the overall system design on such an advanced concept that might prevent successful completion of the parametric and endurance test programs

3. Aim toward a flight-qualifiable configuration. The program is not viewed as an isolated end in itself, but as a step toward designing the optimum method for meeting the water electrolysis requirements of future space activities.

4. Emphasize "self-contained" aspects during testing so that operation will be as independent of laboratory instrumentation and complicated startup/shutdown procedures as possible.

5 Develop a module (O_2 and H_2 generator) with the best chance for integration into the ARS of a Space Station. The Regenerative Life Support Evaluation (RLSE) design specifications(8) will be used as a guide throughout the development as well as the results of NASA's Modular Space Station studies.(9) This is particularly useful in the areas of reliability, maintainability, safety and materials compatibility

6 Emphasize, where applicable, integration with the Electrochemical Depolarized CO_2 Concentrator (EDC) and other life support systems, from an interface and parts commonality viewpoint

Program Organization

The Technology Advancement of the Static Feed Water Electrolysis Process program objectives stated above are long-term goals. To pursue these goals the program has been divided into five tasks plus Documentation and Program Management. These five tasks are

1 Develop, fabricate and assemble OGS's based on the Static Feed Water Electrolysis (SFWE) concept, employing electrolytic dehumidification to eliminate zero gravity condenser/separators The development shall evolve from the current one-man metabolic level to one capable of meeting the H_2 and O_2 needs of the EDC, in addition to the metabolic requirements The subsystem shall be of a type incorporating flight qualifiable concepts and, during the course of the development, allow for incorporation of specific flight qualifiable hardware items.

2. Design, develop, fabricate, assemble, functionally checkout and calibrate Test Support Accessories (TSA) to be compatible with the test objectives and testing of the OGS and the supporting research and technology testing.

3. Establish, implement and maintain a mini-Product Assurance Program through all phases of contractual performance, including design, fabrication, purchasing, assembling, testing, packaging and shipping consistent with such a program in the early stages of development.

4. Perform a variety of single cell subsystem and integrated subsystem testing associated with the OGS. The testing to be accomplished

shall include checkout, shakedown, parametric, endurance as well as special types of testing

5 Complete essential and desirable supporting research and development effort to further expand the technology base associated with spacecraft OGSs

Report Organization

This Annual Report covers the work performed from the start of the program, March, 1975 through November, 1976 The following section presents the technical results grouped according to Process Descriptions, Subsystem Technology and Hardware Developments, Single Cell Developments and SFWE Single Cell and Static Feed Water Electrolysis Module (SFWEM) Testing. The section is followed by conclusions and recommendations based on the work performed

TECHNOLOGY ADVANCEMENT OF THE STATIC FEED WATER ELECTROLYSIS PROCESS

Process Descriptions

An OGS based on the SFWE principle incorporates basically two electrochemical modules with a source of water and a technique to control product gas and subsystem pressures. To serve as a basis for understanding an SFWE-based OGS, the following are described briefly below.

- Electrochemical process descriptions
- Oxygen Generation Subsystem concept description

Electrochemical Process Descriptions

Two different electrochemical processes occur within the OGS being developed

1. The production of H_2 and O_2 gas with some residual water vapor within the SFWEM
2. The electrochemical dehumidification of the product gases within the DM.

Static Feed Water Electrolysis Module The reactions occurring at the anode and cathode of the SFWE cell with an alkaline electrolyte are

Anode

$$2OH^- = H_2O + 1/2\ O_2 + 2e^- \qquad (1)$$

Cathode

$$2e^- + 2H_2O = H_2 + 2OH^- \qquad (2)$$

resulting in the overall net reaction of

$$\text{electrical energy} + H_2O = H_2 + 1/2\ O_2 + \text{heat} \qquad (3)$$

Schematically, these reactions are shown in Figure 1. The water to be electrolyzed is supplied statically via water vapor diffusion to the cathode side of the cell The additional water components $(x + y)(H_2O)$ indicated in the figure are not included in the electrochemical reaction. They represent the water required for humidification of the cathode and anode gases at the electrodes The amount of humidification (x and y) is determined by the pressure, temperature and local concentration of the aqueous electrolyte.

Since water is also generated at the anode but must be consumed at the cathode, concentration gradients exist between the two electrodes The magnitude of these gradients is a function of the current density and of the characteristics and configuration of the electrodes and cell matrix. For calculations of humidification requirements, the equivalent concentration of the electrolyte at the respective cell electrode must be used. This value differs from the initial charge concentration and from the anode to the cathode side.

Dehydrator Module The reactions occurring at the anode and cathode of the dehydrator cell with an acid electrolyte are·

Anode

$$H_2O = 1/2\ O_2 + 2\ H^+ + 2e^- \qquad (4)$$

Cathode

$$2H^+ + 2e^- = H_2 \qquad (5)$$

resulting in the overall net reaction of

$$\text{electrical energy} + H_2O = H_2 + 1/2\ O_2 + \text{heat} \qquad (6)$$

Schematically, these reactions are shown in Figure 2.

The water to be electrolyzed is supplied as water vapor contained in both the incoming H_2 and O_2 gas streams. This vapor is absorbed in the acid electrolyte due to the latter's lower vapor pressure (as a result of water consumption), and electrolyzed. The result is additional dry product gases. Electrolyte concentration gradients must again be considered when analyzing and designing DM hardware and performance.

Oxygen Generation Subsystem Concept Description

A conceptional schematic of the OGS using the SFWE concept is shown in Figure 3. The OGS consists of three main parts the combined SFWE and dehydrator modules, a water feed tank and a product gas pressure controller(s). Oxygen and H_2 are generated in the electrolysis module from water supplied by the water feed tank and dried in the DM. The pressure controller (1) maintains the absolute

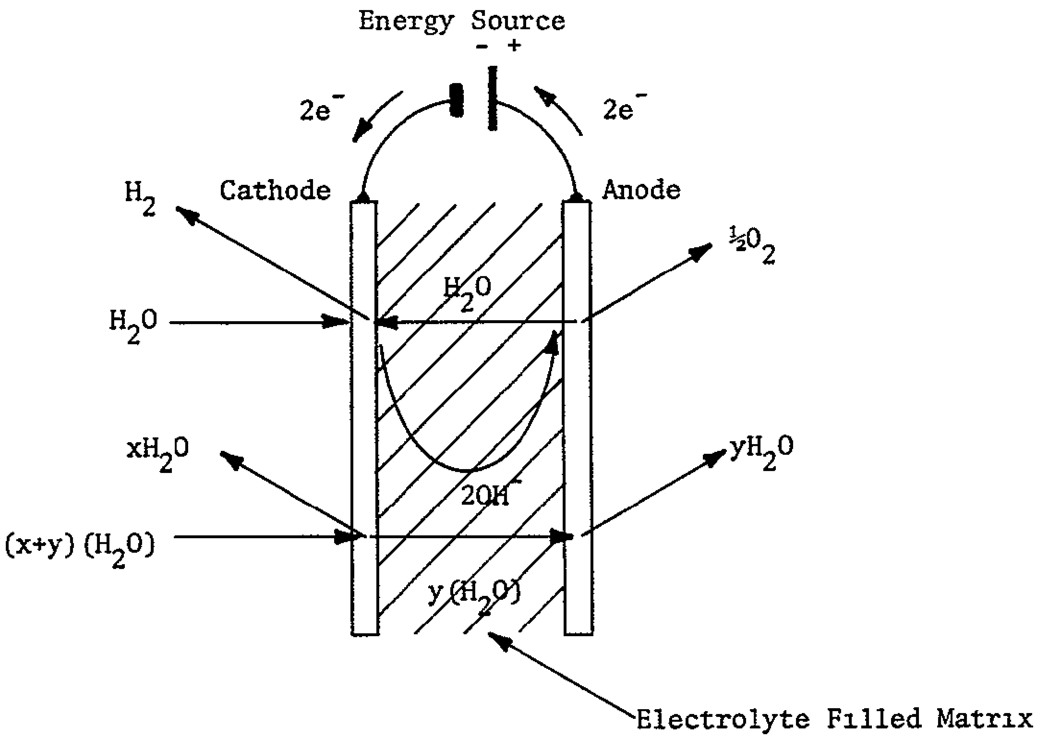


FIGURE 1 SFWE REACTIONS

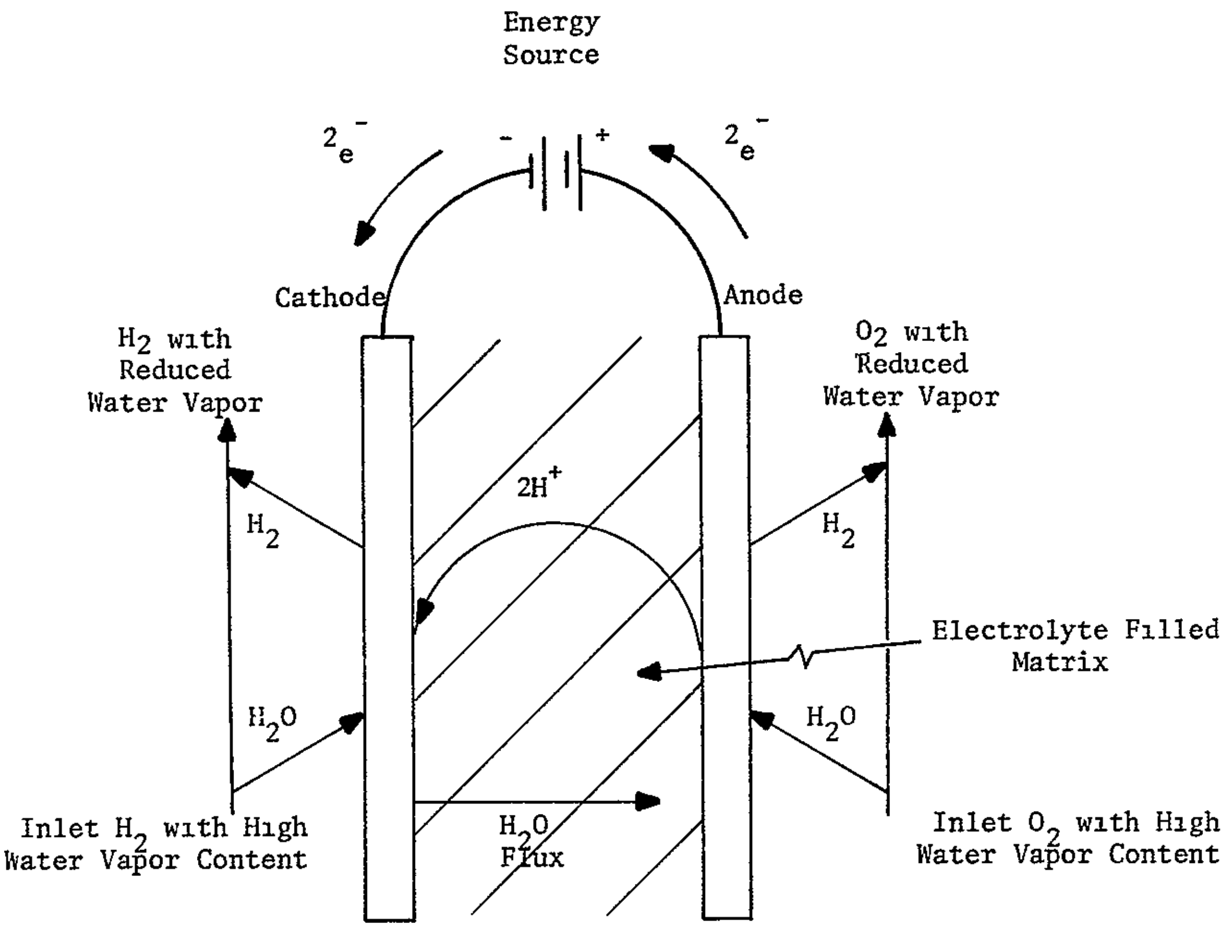


FIGURE 2 DEHYDRATOR MODULE REACTIONS

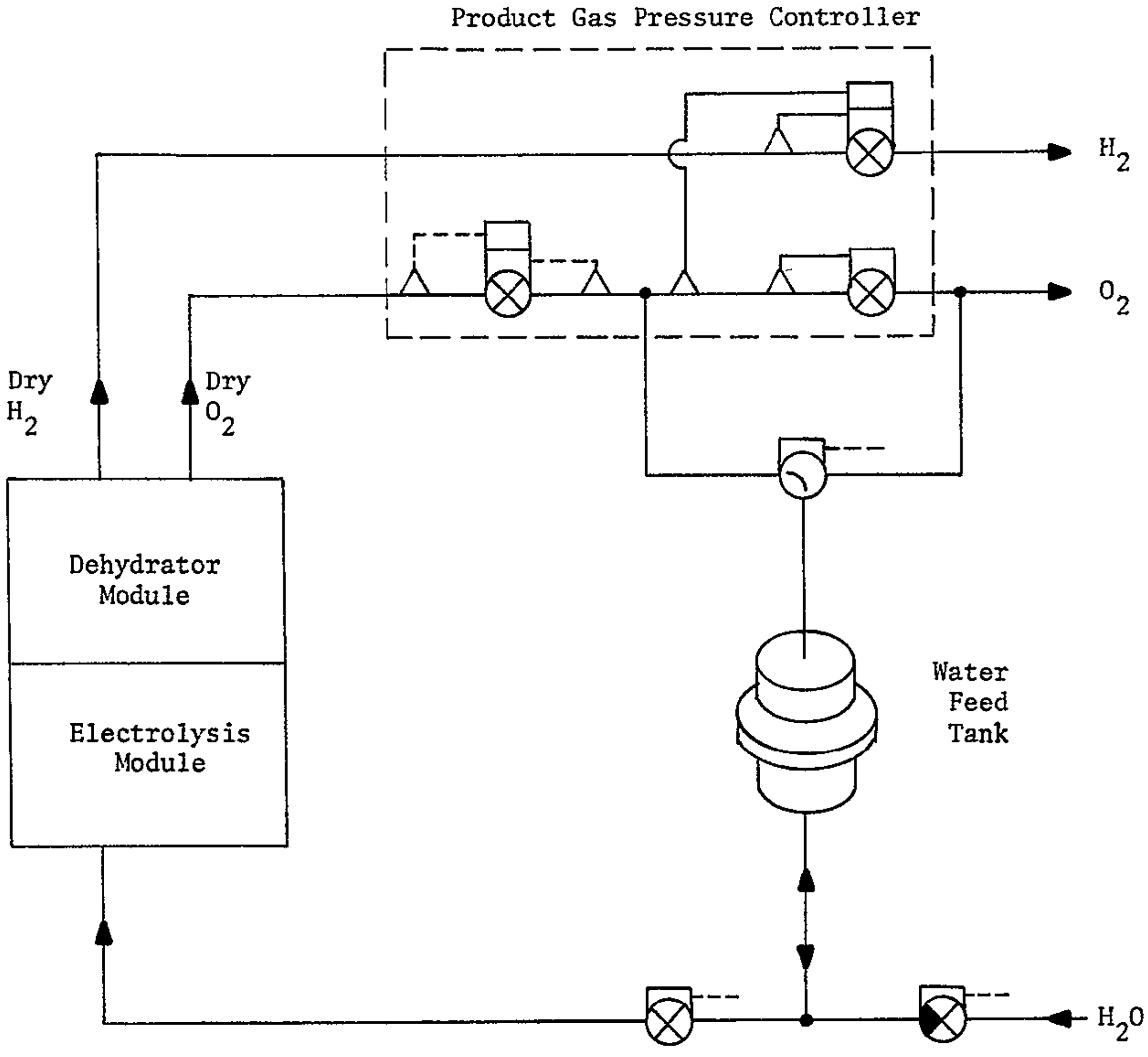


FIGURE 3 OXYGEN GENERATION SUBSYSTEM CONCEPT

pressure of the subsystem, (2) maintains the pressure differentials required to establish and maintain fluid locations within the cell and (3) controls pressurization and depressurization of the OGS during startups and shutdowns, respectively

Subsystem Technology and Hardware Developments

This part of the development effort concentrated on the subsystem improvements exclusive of the SFWEM and DM The activities included analyses and solutions to component and peripheral hardware problems and overall subsystems operation. Specifically, the following were examined·

- Overall subsystem engineering considerations
- Peripheral component improvements
- Control and sequence improvements
- OGS packaging considerations
- OGS reliability and maintainability considerations

Overall Subsystem Engineering Considerations

The subsystem's engineering considerations for the OGS were divided into the following activities

- OGS engineering specifications
- OGS schematic and component list
- OGS mass balance
- Product gas aerosol formation studies

OGS Engineering Specifications A set of engineering specifications were prepared to serve as a design goal for the subsystem A three-man level was selected The resulting specification is shown in Table 1.

In order to complete the specification, several assumptions were made·

1 A power penalty of 0.268 kg/W (0.591 lb/W) was used to allow evaluation on a total equivalent weight basis.

2. Similarly, a heat rejection penalty of 0.198 kg/W (0 436 lb/W) was used for rejection of waste heat to air.

3 A Respiratory Quotient (RQ) (defined as volumetric rate of CO_2 exhaled divided by the volumetric rate of O_2 inhaled) was defined at 0 84 This quotient is needed to derive the amount of O_2 needed by an EDC since the EDC consumes O_2 in its collection of CO_2.

4 The RLSE crew size of three was chosen.

5. The OGS was sized based on continuous operation. If solar cells were the power source, a cyclic operation of 58 minutes on and 36

TABLE 1 SUBSYSTEM DESIGN SPECIFICATIONS

Number of Crew (Continuous)	3
O_2 Production Rate	
Metabolic Consumption (3 Men), kg/d (Lb/Day)	2.50 (5.52)
EDC Consumption, kg/d (Lb/Day)	1.36 (3.00)
Cabin Leakage, kg/d (Lb/Day)	0.32 (0.72)
Total, kg/d (Lb/Day)	4.18 (9.24)
H_2 Production Rate, kg/d (Lb/Day)	0.52 (1.15)
Cabin Atmosphere	
Total Pressure kN/m^2 (Psia)	101 to 104 (14.7 to 15.2)
Temperature, K (F)	291 to 297 (65 to 75)
Dew Point Temperature, K (F)	281 to 287 (46 to 57)
O_2 Partial Pressure, kN/m^2 (Psia)	20.8 to 22.5 (3.04 to 3.28)
Diluent	Air Constituents
Cooling Air (Ambient)	
Total Pressure, kN/m^2 (Psia)	101 to 104 (14.7 to 15 2)
Temperature	Ambient
H_2O Supply	
Pressure, kN/m^2 (Psia)	206 (30)
Temperature, K (F)	277 to 295 (40 to 72)
Purity	Deionized
Electrical Power, V	
DC	28
AC	120 (60 Hz, Single Phase)
Purge Supply	
Type Gas	N_2
Pressure, kN/m^2 (Psia)	862 (125)
Packaging	Self-contained
Gravity, g	0 to 1
Allowable Downtime, h	8 to 48
Duty Cycle	Continuous(a)

(a) Potential near-earth orbit specifications also cite an on/off cyclic operating mode.

minutes off would require a 2.25 kg (4.96 lb) of O_2 per equivalent man-day generation rate as opposed to the 1.40 kg (3 08 lb) O_2 used

6. The size and weight of the existing cell frames were used in this analysis This results in a cell active area of 0 0093 m^2 (0.10 ft^2) which is not necessarily optimized for the O_2 generation rate chosen. The cell area optimization was not included in this analysis since it is a state-of-the-art comparison. Possible weight savings projected at this time based on cell weight are small when compared to total equivalent weight

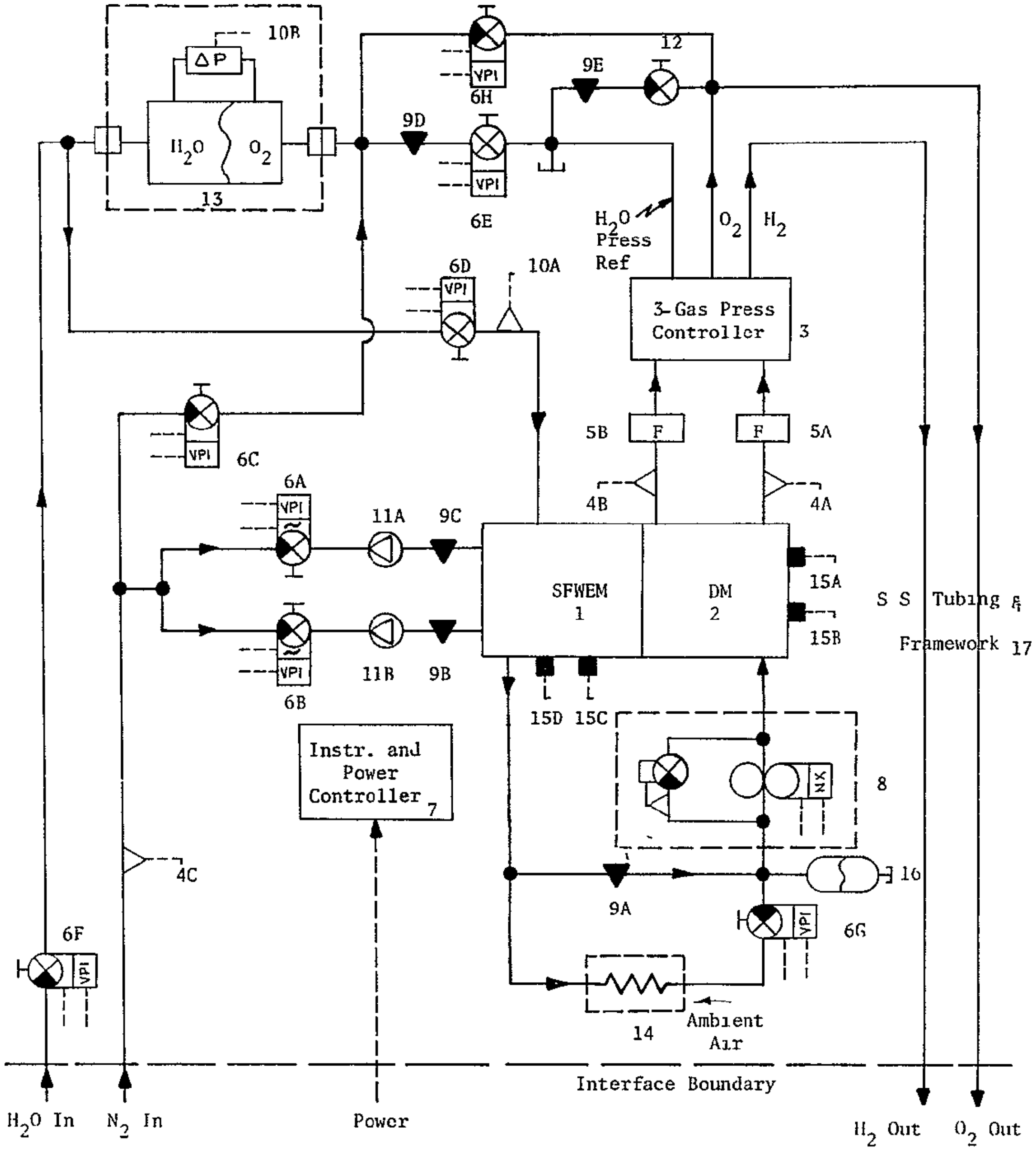
OGS Schematic and Component List The OGS schematic is shown in Figure 4. The corresponding components list with the weight, volume and power for each indicated component in the schematic is given in Table 2. Figure 4 also indicates the OGS interfaces with other elements of an ARS These are summarized in Table 3 The principal outputs of the OGS are O_2 for crew consumption and H_2 for the CO_2 collection (EDC) and CO_2 reduction processes

OGS Mass Balance Subsystem operating conditions and fluid flow quantities were defined and are presented in the mass balance described in Figure 5 and Table 4 All fluid flow rates in the table are given on a per man-day basis.

Product Gas Aerosol Formation Studies. The objective of this study was to determine whether or not potassium hydroxide (KOH) was lost from the SFWEM as an aerosol, and if so, in what quantity. Visible aerosol had been noticed in the past, following initial module startups. This had been assumed to be due to the "wet" conditions characteristic of a fresh electrolyte charge and low pressure operation. A break-in period of at least 24 hours of running after a fresh charge eliminated all visible aerosols. Additional testing was conducted to verify that elimination of visible aerosol also meant stoppage of all aerosoling.

First a technique to measure possible aerosoling was derived and used for all testing. Samples were taken by directing the SFWEM effluent into a test chamber containing quartz wool which trapped the aerosol particles on its absorbent fibrous surfaces. Samples were then removed from the system and analyzed The quartz wool was placed in a clean beaker and rinsed thoroughly with triply distilled water. This rinsed water was then placed in a volumetric flask and titrated with 0.1 normal hydrochloric acid (HCl) and 0.01 normal KOH

Four aerosol collection tests were run as shown in Table 5 The first test used a blank tube to calibrate the equipment. Test 2 was run at 108 mA/cm^2 (100 ASF), ambient pressure, and 355K (180F) during the time when aerosol was visibly present. A total of 0.0015 g of KOH was detected Test 3 was run after the module had been operated for 42 hours and no aerosol was visibly detectable The six-cell module at that time had been operated at 216 mA/cm^2 (200 ASF), ambient pressure, and 355K (180F). No KOH was detected. Another sample (Test 4) was obtained when the module had operated for 64 hours after starting and at the above conditions. Again, no KOH was observed or detectable by the analytical technique described.



Note See Table 2 for component number relationship

FIGURE 4 OXYGEN GENERATION SUBSYSTEM SCHEMATIC

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TABLE 2 THREE-MAN OXYGEN GENERATION SYSTEM (9 24 Lb O_2/Day)
COMPONENT LIST (1976 TECHNOLOGY)

OGS Part No.	Component	No. Req'd	Indiv. Wt., g	Total Wt., g	Indiv. Dimensions, cm	Total Volume, cm^3	Total Power, W
1	SFWEM	1	23,900	23,900	22.9 x 27.9 x 35.9	22,900	903
2	DM	1	6,590	6,590	22 9 x 27.9 x 13.2	8,430	12.5(a)
3	Three-Gas Pressure Controller	1	3,640	3,640	7.00 x 12.7 x 17 8	1,580	2
4	Pressure Transducer (Gas)	3	77	231	2.54 x 2.54 x 2.54	49	1
5	Product Gas Filter	2	155	310	3.80 dia x 6 35	144	-
6	Solenoid Valves(b)	8	318	2,540	5.08 x 3.81 x 8.89	1,380	-
7	Power Controller	1	9,320	9,320	11 1 x 27.0 x 31.8	9,530	159(c)
8	Coolant Pump	1	395	395	3.50 dia x 13.0	125	12
9	Flow Restrictor	5	18	90	2.00 dia x 3.17	50	-
10	Pressure Transducer (H_2O)	2	41	82	2.54 x 2.54 x 2.54	33	1
11	Check Valves	2	73	146	2.38 dia x 5.71	25	-
12	Hand Valve	1	59	59	1.58 dia x 4.19	8	-
13	Water Storage Tank	1	1,395	1,395	12.1 dia x 10.2	1,170	-
14	Heat Exchanger	1	55	55	1.58 dia x 7 62	15	-
15	Temperature Probes	4	27	108	0.31 dia x 7 62	2	2
16	Accumulator	1	177	177	6.35 x 6.35 x 6.35	256	-
17	Frame (Aluminum) Tubing and Fittings (Stainless Steel)	AR(d)	5,550	5,550	-	-	-

Total Volume, m^3 (Ft^3). 0.0457 (2.0)
Total Weight, kg (Lb) : 54.6 (120)
Total Power, kW : 1.09

(a) When the DM is operating, the SFWEM power consumption is reduced by an amount equal to the DM's gas production.

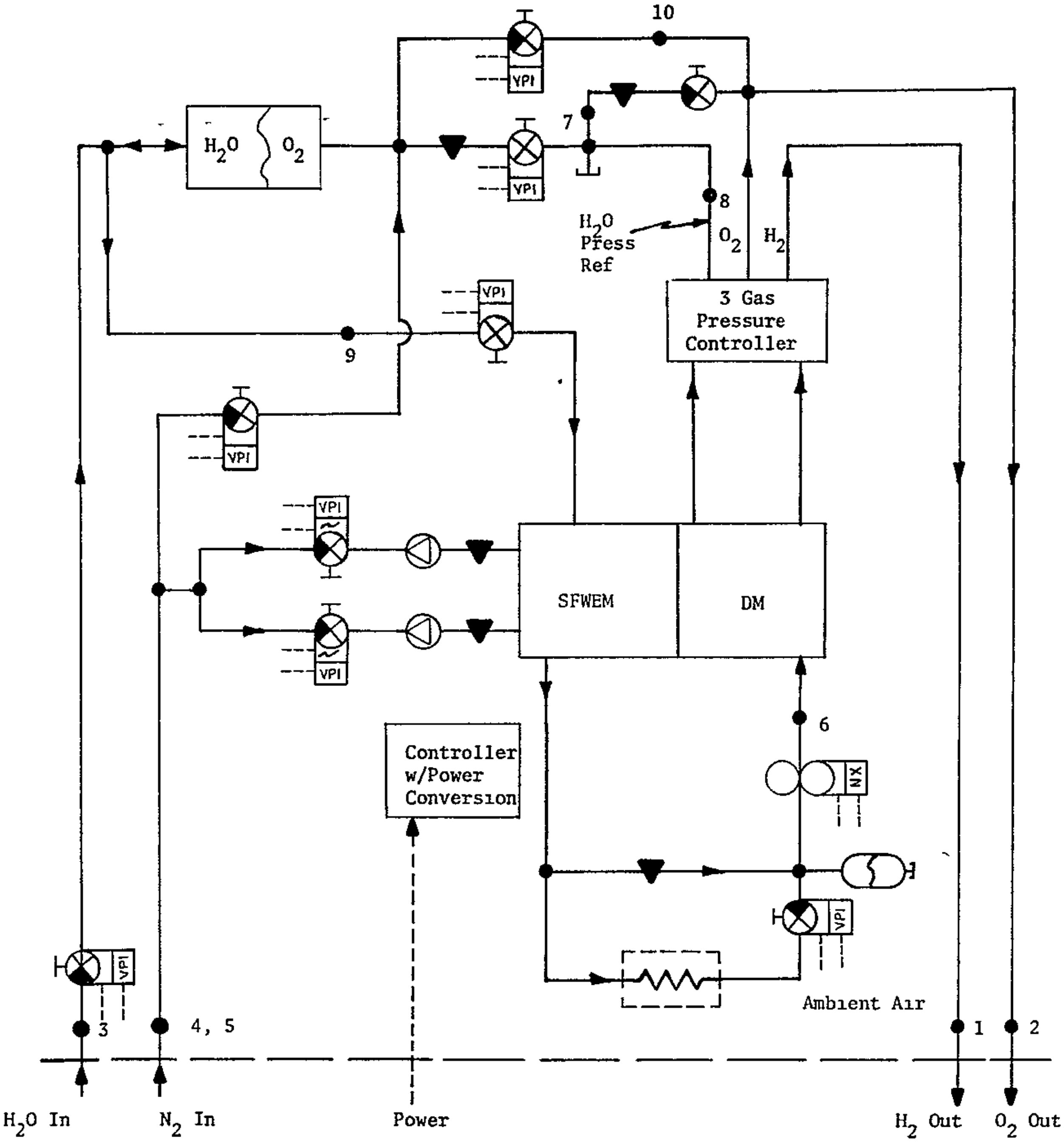
(b) With valve position indicator, manual override, latched when normally energized, no steady state power required, only actuation power.

(c) Assuming a state-of-the-art 85% conversion efficiency

(d) As Required.

TABLE 3 OGS INTERFACES

1. Water Feed
2. N_2 (Purge and Pressurization)
3. O_2 to Cabin
4. H_2 to EDC
5. Power
6. Heat Rejection to Ambient Air



Note See Table 4 for parameters of above indicated locations

FIGURE 5 OGS MASS BALANCES SCHEMATIC

TABLE 4 OGS MASS BALANCE(a)

Location	Fluid	Flow Rate, kg/man-day (lb/man-day)	Temperature, K (F)	Pressure, kN/m^2 (psia)
1	H_2 Gas	0.17 (0.38)	316 (110)	Ambient
2	O_2 Gas	1.40 (3.08)	316 (110)	Ambient
3	Deionized Water	1.57 (3.46)	Ambient	207 (30)
4	N_2 Purge Gas	(b)	Ambient	861 (125)
5	N_2 Gas (Press. Ref.)	Nil	Ambient	848 (123)
6	Coolant (H_2O)	<1360 (<3000) (c)	344 (160)	344 (50)
7	O_2 Gas (Depowered Tank Bleed)	None	Ambient	-
8	O_2 Gas (Tank Pressure Ref)	Nil	Ambient	848 (123)
9	Deionized Water	1.57 (3.46)	Ambient	848 (123)
10	O_2 Gas (Tank Bleed During Fill)	Nil	Ambient	Ambient

(a) Refer to Figure 5.

(b) Not continuous, flowing only during purge cycle, approximately 0.027 kg - N_2/min-man.

(c) Dependent on module and line heat loss to cabin air stream before the heat exchanger.

TABLE 5 AEROSOL TEST RESULTS

Test	Time After Start-up, Hr	Sample Description (Sample No, Collection Time, SFWEM Current Density)	Aerosol, g of KOH
1	-	Blank	--
2	4	#1, 3 hr 20 min @ 108 mA/cm^2	0.0015
3	42	#2, 2 hr, @ 216 mA/cm^2	0.0000(a)
4	64	#3, 5 hr, @ 216 mA/cm^2	0.0000(a)

(a) Values were within uncertainty limits of the analytical method and were considered zero.

Ambient pressure and relatively high current densities were chosen for the aerosol test because this was considered the worst case. Higher pressures tend to keep large gas bubbles from evolving from the electrode surfaces, carrying less electrolyte into the product gases. Higher current densities would generate more vigorous bubbling, therefore, more chance for aerosol formation.

In summary, the detailed, comprehensive tests with a one-man capacity module, showed that a 24-hour break-in period effectively eliminates all aerosoling.

Peripheral Component Improvements

Under this part of the program, LSI evaluated and improved selected OGS components. Specifically, the following components were included

- Pressure Regulators
- Module Coolant Pump

Pressure Regulators. The first OGS components studied were the pressure regulators used for product gas pressure level and differential pressure control. An off-the-shelf modified design was evaluated and a customized pressure control technique evaluation was initiated.

Off-the-Shelf Modified Design. A vendor search was conducted to determine if an off-the-shelf regulator type was available that could meet the following specifications

1. All wetted parts to be stainless steel or Teflon.

2 Pressure differential control capability to 3.4 kN/m^2 (0.5 psid) over a range of pressure from ambient to 2760 kN/m^2 (400 psia).

3 Control capability for both the low density H_2 and higher density O_2

One regulator's characteristics were sufficiently close to the desired specifications that a subcontract was awarded to the vendor to deliver the regulators according to the specifications. Three regulators were purchased and tested in a one-man capacity OGS (5)

During this testing the regulators demonstrated excessive pressure drifts and low reliability One regulator lost pressure control and caused damage to the module. Upon disassembly, the regulator was found to have been constructed contrary to the specifications. A detailed analysis of the failure and requirements was performed and design recommendations and specifications for a high reliability differential backpressure regulator suitable for water electrolysis operation was prepared and submitted to NASA

Figure 6 is a cross section of the regulator pictorially demonstrating the findings, recommendations and/or corrective actions implemented.

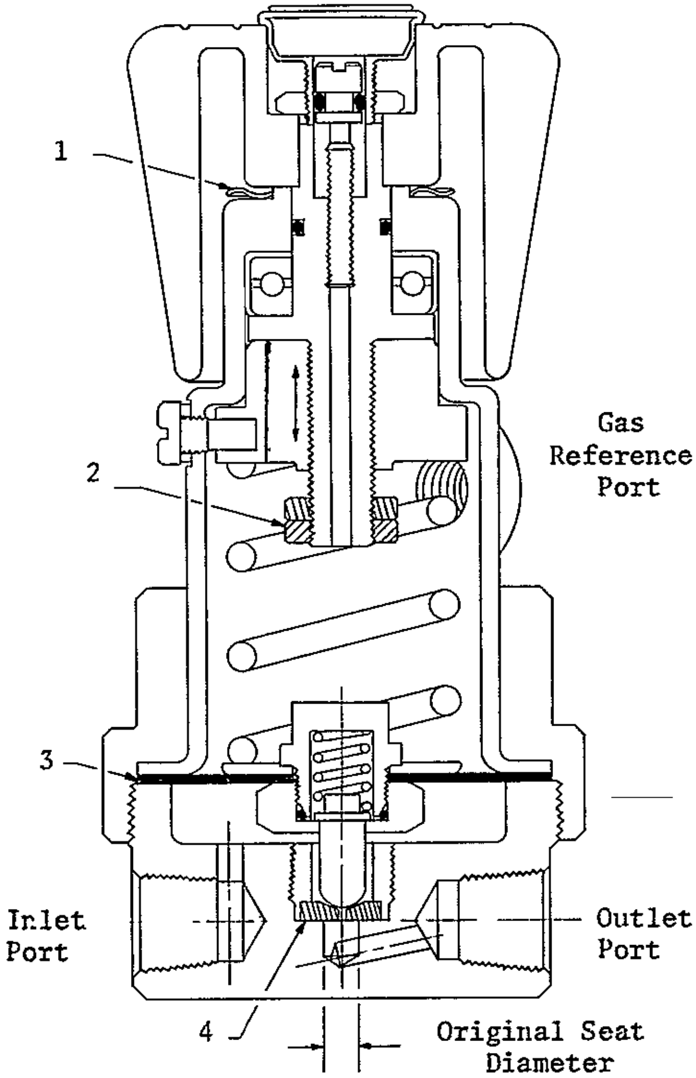


FIGURE 6 CROSS SECTION OF IMPROVED REGULATOR DESIGN

1 The wave spring washers were omitted by the manufacturer causing forward travel of the regulator handles when manual pressure was applied This forward travel caused the regulators to change flow and gas pressure when an operator grasped a regulator handle. Wave washers were designed, fabricated and installed.

2 A double lock nut was added to each threaded stem of the three regulators to prevent disengagement of the spring drive collar. It was this disengagement that caused one regulator to fail, damaging module parts

3 The rubber diaphragms were to be protected on the wetted side by Teflon membranes The membranes were incorrectly assembled at the factory, causing leaks and potential diaphragm deterioration. The membranes were relocated to the wetted sides No leaks were subsequently found

4. The Teflon seats had holes that were too large causing an excessive imbalance of gas forces on the diaphragm A Teflon insert with a substantially reduced hole was designed, constructed and inserted in the original regulator seat, greatly reducing the imbalanced forces

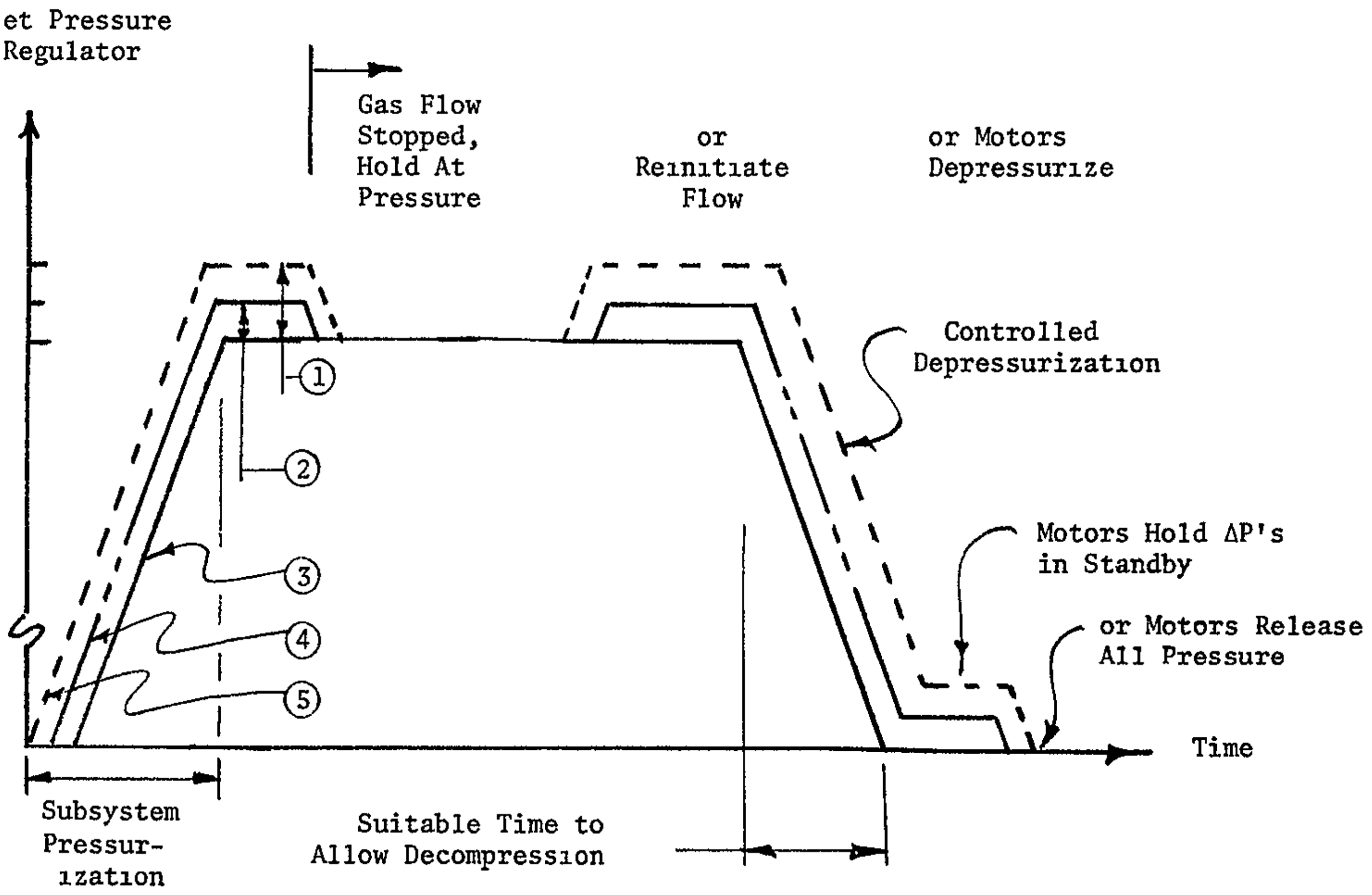
The LSI-modified regulators were then installed into the test system and successfully demonstrated the capability to provide proper product gas pressure control

Advanced Pressure Control Technique. When a water electrolysis cell containing an aqueous electrolyte solution in its matrices and water feed compartment is depressurized rapidly, as may occur following a shutdown, a phenomena known as decompression occurs This is similar to the deep-sea diver's "bends " Rapid decompression causes the gas disolved in the electrolyte to come out of solution and expand causing electrolyte shifts which may result in undesirable electrolyte/gas interface relocations These relocations are detrimental to efficient operation and decrease the pressure differential capability of the matrices.

To eliminate the adverse side effects of depressurization, LSI derived a technique using motor-controlled regulators which will allow for controlled depressurization as well as repressurization of the OGS. A projected, simulated pressure versus time schedule is shown in Figure 7.

Such a "Three-Gas Pressure Controller" has been designed and is presently being built as part of the program activities. The unit will be housed in a package 6 8 x 13 x 17.8 cm (2.7 x 5 x 7 in) complete with motor-driven controls, feedback position pots and pressure sensors. This unit will be able to control the three fluid pressures in the SFWE-type OGS Completion of fabrication, assembly and testing of the Three-Gas Pressure Controller is projected for the next annual reporting period.

OGS Coolant Pump Leakage. Periodic leakage was observed during the operation of the coolant pump used during previous testing of the SFWES. Upon disassembly



1. Oxygen to water pressure ΔP
2. Hydrogen to water pressure ΔP
3. Water pressure
4. Hydrogen pressure
5. Oxygen pressure

FIGURE 7 PRESSURE VERSUS TIME SCHEDULE FOR A THREE-GAS PRESSURE CONTROLLER of this pump, it was noted that the pump housing endplate was constructed of thin aluminum protected only by a Teflon washer. This endplate was changed to stainless steel, thereby eliminating a cause of corrosion and a structural weakness in the coolant pump. This pump is now undergoing testing in the OGS.

Control and Sequencing Improvements

The following control and sequencing problems were evaluated and improved

- Current control modifications
- OGS water tank fill sequence

Current Control Modifications The SFWEM test system electronic Control and Monitor Instrumentation (C/M I) was thoroughly bench-checked to determine the causes of occasional current drift observed during previous endurance testing (5) The following problems were identified

1. A compensating capacitor had begun to leak causing a gain change in the current control amplifier. This resulted in a slow downward drift of the current
2. An integrated circuit operational amplifier was found to be excessively temperature sensitive which resulted in current fluctuations
3. The current control potentiometer was found to have worn contacts resulting in erratic settings.
4. The leads carrying the high current from the ground support power supply to the power converter had to be shielded to reduce the 60 Hz noise coupling to low level control circuits.
5. The low level signal leads from the system transducers had to be shielded to reduce potential 60 Hz noise pickup

These problems were corrected and the C/M I package was than operated for 90 days using a simulated OGS complete with resistors to simulate controlled and monitored parameters Tables 6 and 7 list the controlled and monitored parameters, respectively, simulated for the checkout tests.

Following the testing, the C/M I was returned for operation in the test system with a high level of assurance that no system shutdowns would originate from the C/M I package

OGS Water Feed Tank Fill Sequence After studying the results of the 90-day endurance test,(5) and other tests run on the OGS, a slight SFWEM performance degradation was noted after each water fill sequence. To determine the cause, the three module outlet pressure levels (points 1, 2 and 3 in Figure 8) were monitored during a fill sequence using a chart recorder.

Figure 8 shows the observed pressure levels versus time while operating at 1089 kN/m^2 (158 psia). As can be seen in the figure, a 158 kN/m^2 (23 psi)

TABLE 6 PARAMETERS CONTROLLED IN THE OGS

1. WEM Current
2. DM Current/Voltage
3. Temperature (Modules)
4. H_2 to System ΔP
5. O_2 to System ΔP
6. System Pressure
7. Water Fill Sequence
8. Mode Transition Sequencing

TABLE 7 PARAMETERS MONITORED IN THE OGS

1. H_2 to System ΔP
2. O_2 to System ΔP
3. System Pressure
4. SFWE Individual Cell Voltages
5. DM Individual Cell Voltages
6. N_2 Purge Pressure Standby Level
7. SFWEM Temperature
8. DM Temperature

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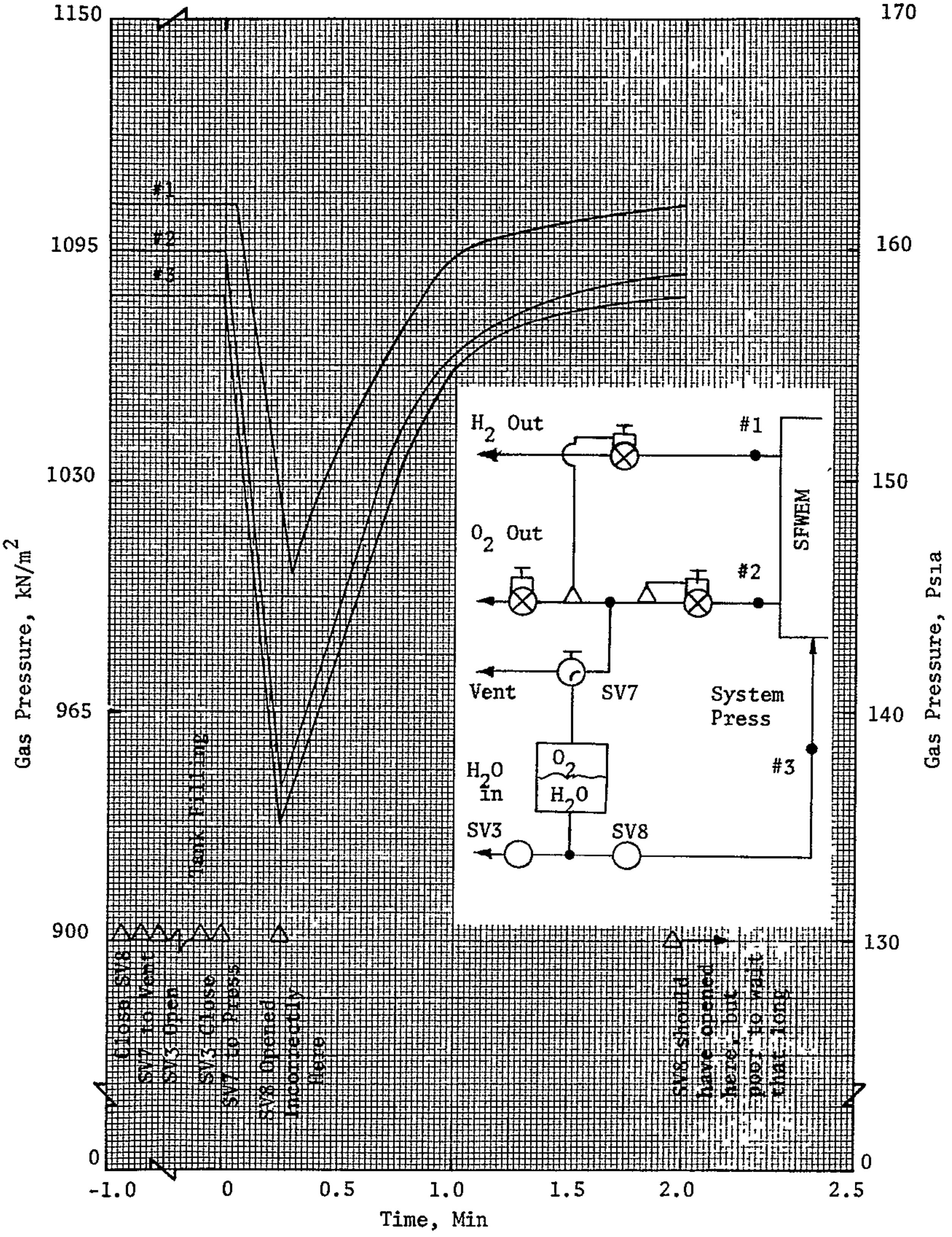


FIGURE 8 GAS PRESSURES SEEN BY SFWEM DURING A H_2O TANK FILL BEFORE DESIGN MODIFICATION

differential pressure spike was observed. This spike is in excess of the allowable differential for the water feed matrices. The large spike is caused by the sudden compression of trapped, ambient pressure gas in the plumbing and water tank following a refill. To eliminate the spike, a nitrogen (N_2) pressure source was added to allow for quick repressurization of the tank and plumbing to the overall system pressure level before exposing the module water feed cavities to the tank pressure To implement this change required additional plumbing and valving and an additional control sequence

OGS Packaging Considerations

In order to identify a typical packaging envelope of a SFWE-based OGS, a three-man, OGS layout was prepared and is presented in Figure 9.

Each component can be maintained from the front with the removal of no more than one other component The framework is welded aluminum. The electronics are mounted on the top. The heaviest components, the modules, are mounted on the bottom Note that the water feed tank is the lowest item to facilitate 1-g testing since, during shutdown, it is necessary to keep a slight negative pressure on the water feed matrix for containment of the fluid For a zero-g environment, the water tank location is independent of the module location As shown by Figure 9, the overall dimensions of the three-man subsystem are 41 3 x 43 8 x 59.7 cm (16.25 x 17.25 x 23.50 in) to result in a total volume of only 0.108 m^3 (3.81 ft^3). The components packaged were those listed in Table 2.

OGS Reliability and Maintainability Considerations

The following two Product Assurance considerations were included as part of the overall subsystem technology development effort

- Reliability
- Maintainability

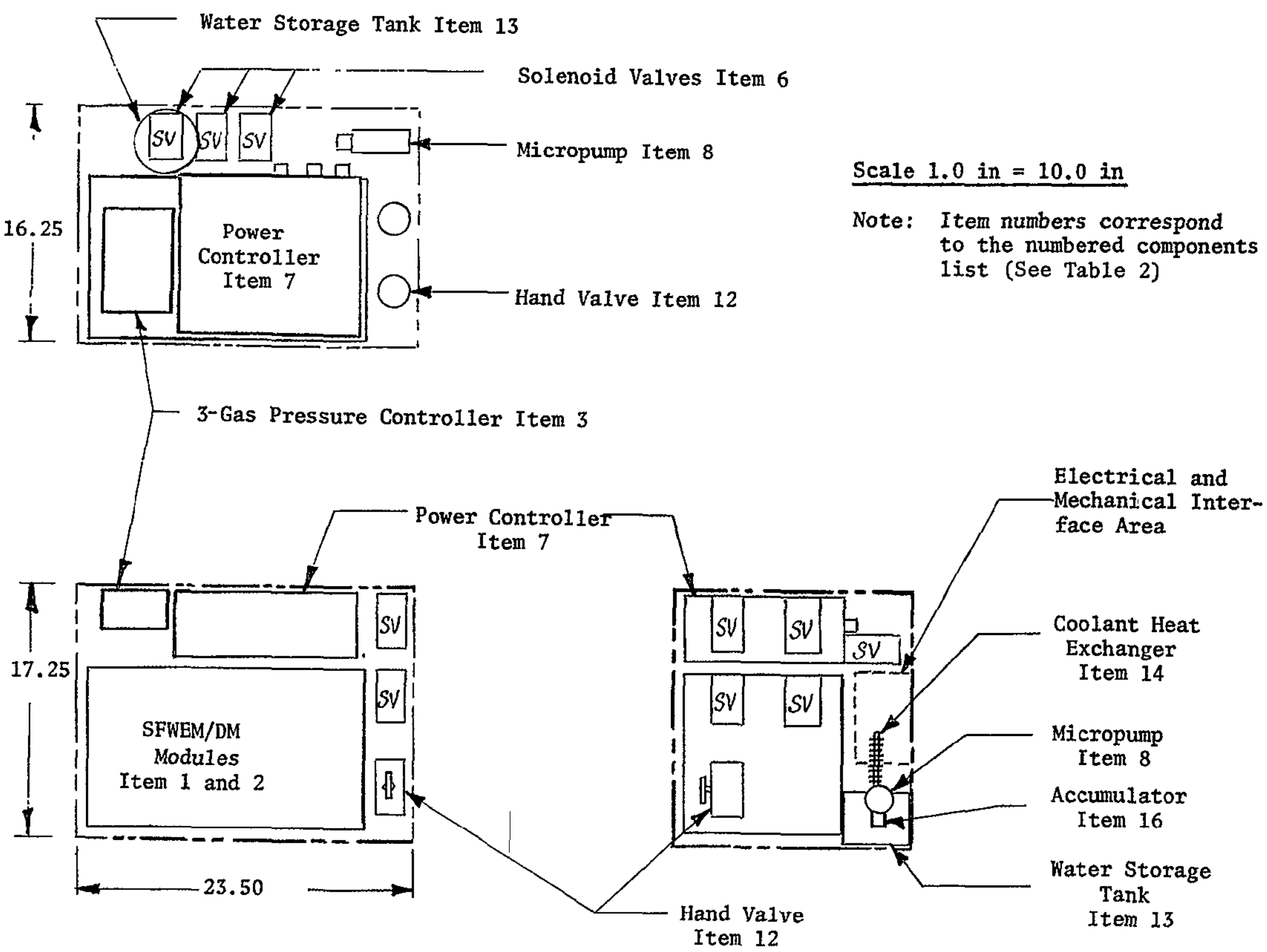
Reliability Based on the OGS schematic and component parts list presented previously, a reliability analysis was made with the results shown in Table 8. For a three-man system, a Mean-Time-Between-Failure (MTBF) of 15,806 hours is projected.

Maintainability. The maintainability considerations emphasized the aspects of module maintenance A water electrolysis module may be maintained in two ways

1. In situ maintenance of each cell in a cell stack

    a Each cell independent of its neighbors in a stack with its own endplates and insulation plates.
    b A series of cells sharing common endplates to form a submodule.

2 Maintenance of one entire module.



Scale 1.0 in = 10.0 in

Note: Item numbers correspond to the numbered components list (See Table 2)

FIGURE 9 THREE-MAN OGS LAYOUT

TABLE 8 THREE-MAN OGS RELIABILITY ANALYSIS

Item No	Component	No Req'd	λ Failure Rate x 10^{-6} Hrs^{-1}	$n\lambda t^{(a)}$	No of Spares	Weight Spares, kg	Total Volume Spares cm^3	Component/ Spares Reliability
1	SFWEM	1	4.83	0.0209	1	23.92	22936	0.99979
2	DM	1	1.40	0.0037	1	6.56	8484	0.99999
3	Three Gas Pressure Controller	1	6.80	0.0294	1	3.63	1576	0.99960
4	Pressure Transducer (gas)	3	3.31	0.0286	1	0.077	8	0.99960
5	Product Gas Filter	2	0.20	0.0017	1	0.156	72	0.99999
6	Solenoid Valve w/VPI and Manual Override (Latched when Normally Energized)	8	2.17	0.0656	2	0.636	344	0.99996
7	Power Controller	1	3.65	0.0158	1	9.31	9504	0.99987
8	Coolant Pump	1	10.89	0.0470	2	0.794	54	0.99998
9	Flow Restricter	5	0.27	0.0058	1	0.018	2	0.99998
10	Pressure Transducer (water)	2	3.30	0.0285	1	0.041	8	0.99960
11	Check Valves	2	0.56	0.0048	1	0.073	12	0.99998
12	Hand Valve	1	0.84	0.0036	1	0.059	8	0.99999
13	Water Storage Tank	1	0.05	0.0002	0	-	-	0.99980
14	Heat Exchanger	1	0.10	0.0004	0	-	-	0.99960
15	Temperature Probe	4	1.00	0.0173	1	0.016	0.57	0.99983
16	Accumulator	1	0.05	0.0002	0	-	-	0.99980

(a) Mission time 180 days = 4320 hours

- $\Sigma n\lambda t$ = 0.2733
- MTBF = 15,806 hours
- Spares Reliability = 0.9975

In situ cell maintenance was considered impractical for the SFWEM from a weight and volume penalty point of view Each cell in an independent type of construction would have to be designed to withstand the high pressure operation. Individual fluid fittings are bulky and would add to the complexity of the system, thereby, decreasing reliability. If a series of cells share common endplates, as in bipolar plate construction, one cell lost in the center of the electrolysis stack cannot be electrically removed from the system. The second option, maintenance of an entire module, is therefore projected as the most desirable.

The overall subsystem maintenance concept derived and proposed is as follows If a component failure does not endanger the immediate safety of the crew, no installed redundancy is required for that component This is possible since each component in the SFWES can be replaced in less than two hours and the capacity for O_2 of the cabin typically allows for downtimes in excess of 24 hours.

OGS Weight and Power Summary

Table 9 presents an overall weight and power summary of a three-man subsystem based on the SFWE state-of-the-art technology (1976) For comparison a projected weight and power summary is presented for 1980 technology

Single Cell Developments

Single cell development activities for both SFWEM and DM cells were performed These activities were divided into two areas·

- SFWE single cell technology and hardware improvements
- Dehydrator single cell technology and hardware improvements

SFWE Single Cell Technology and Hardware Improvements

The following SFWE single cell technology and hardware improvements were completed

- SFWE single cell cross sectional schematic
- Critical feed diameter analysis and implementation
- High current density nickel (Ni) current collectors
- Insulation plate with internal cooling
- Square cathodes
- Correction of cell frame warpage
- O-rings with reduced compression set

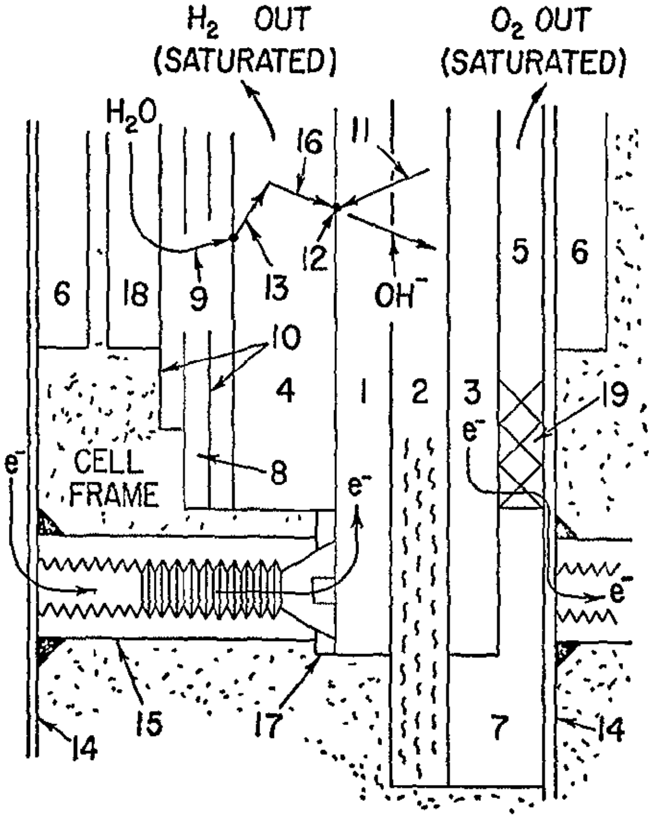
SFWE Single Cell Cross-Sectional Schematic The functional cell schematic was presented in Figure 1. A cross sectional schematic showing details of the cell hardware is shown in Figure 10. The metallic structural parts are fabricated from high tensile strength Ni. The cell housing is injection molded polysulfone. The matrices are LSI reconstituted asbestos and the electrodes

TABLE 9 THREE-MAN OGS WEIGHT SUMMARY[a]

Item	1976 Technology	1980 Technology
SFWEM	23.9 (52.7)	17.2 (37.8)
DM	6.6 (14.5)	1.1 (2.4)
Power Controller	9.3 (20.5)	7.4 (16.3)
Fixed Hardware Weight of Peripherals	14.4 (31.6)	10.7 (23.5)
Subtotal Fixed Hardware Weight, kg (Lb)	54.2 (119.3)	36.4 (80.0)
WES Heat Rejection Weight Penalty	7.5 (16.5)	0
WES Controller Heat Rejection Penalty	31.5 (69.3)[b]	6.2 (13.6)
WES Power Penalty	285.2 (627.4)[b]	249.7 (549.3)
DM Heat Rejection Weight Penalty	0.2 (0.41)	0
DM Controller Heat Rejection Penalty	0.3 (0.6)	0.05 (0.11)
DM Power Penalty	3.3 (7.3)	1.6 (3.62)
Subtotal Heat Rejection and Power Penalty Weight, kg (Lb)	328 (722)	258 (567)
Total Equivalent Weight, kg (Lb)	382 (841)	294 (647)

(a) For both metabolic and EDC O_2 requirements or 4.20 kg O_2/day (9.24 lb O_2/day)

(b) Includes 85% efficiency of present Power Controller



1. CATHODE
2. CELL MATRIX
3. ANODE
4. H_2 CAVITY
5. O_2 CAVITY
6. COOLANT
7. COMPRESSION FRAME
8. FEED MATRIX
9. H_2O DIFFUSION
10. PLASTIC SCREEN
11. H_2O BACKDIFFUSION
12. H_2O CONDENSATION
13. H_2O EVAPORATION
14. CURRENT COLLECTOR
15. CURRENT STUB
16. H_2O VAPOR DIFFUSION
17. CATHODE CURRENT COLLECTOR
18. H_2O FEED CAVITY
19. EXPANDED NICKEL

FIGURE 10 SFWEM CELL CROSS SECTION

are activated porous plaques. The electrical current flows through internal stubs connecting the bipolar current collecting fins, as indicated by items 14, 15 and 17 in Figure 10

Critical Feed Diameter Analysis and Implementation. The individual water feed passage diameter on the previously tested cell design was too large to prevent possible gas entrapment in the water feed manifolding. This entrapment could cause maldistribution or discontinuities in water feed under certain conditions. An earlier cell design used with the NASA Aircrew Oxygen Subsystem (NAOS)(10) electrolysis module had a 0 10 cm (0.040 in) diameter feed water passage. With the smaller diameter line, sporadic gas bubbles were pulled into the cell feed water compartment where a small number of bubbles would not be harmful as compared to remaining stationary in the water feed lines where water flow blockage could result.

To reduce the feed water passage diameter of the present cell design a small polysulfone insert was designed and fabricated and placed directly into the larger water feed passage. A modified cell was then operated with this insert in position. A clear quartz endplate was placed over the single cell and water feed operation was observed. During the testing, bubbles were intentionally fed into this line The observed results are shown in Figure 11. It was noted that when a single, small bubble entered the feed manifold, it seemed to stagnate at the junction of the cell water feed passage and the module water manifold. At no time, however, did a gas bubble totally block the water flow. Water feed would still occur through a small water film between the gas bubble and the passage walls.

When a large bubble or several small bubbles were introduced into the manifold, gas would be drawn downward through the water feed passage and would enter the cell water feed cavity as desired With the larger bubbles a certain amount of gas would still stagnate at the manifold/water feed passage junction

The results showed that the resizing of the critical diameter for the water feed passage was correct but that a similar change is required for the module manifold. The latter is being planned for completion under the remaining program activities.

High Current Density Nickel Current Collectors Following previously conducted testing, the Ni current collectors had been extensively analyzed.(5) The current flow in the collectors had been experimentally mapped. This mapping showed that the original current collector tab design resulted in preferential current flow to the nearest current collecting stub with resulting localized overheating at high current densities. Overheating had been verified on disassembly by discolored areas in the cell matrix around the current stub Overheating could result in asbestos matrix deterioration since fuel cell grade asbestos has shown long-term deterioration when operated at temperatures over 355K (180F).

A new current collector design was completed and is shown in Figure 12. The new design placed the current tab in the center of the leading edge of the collector. This resulted in a more even current distribution. Consequently, heating at higher current densities was greatly reduced.

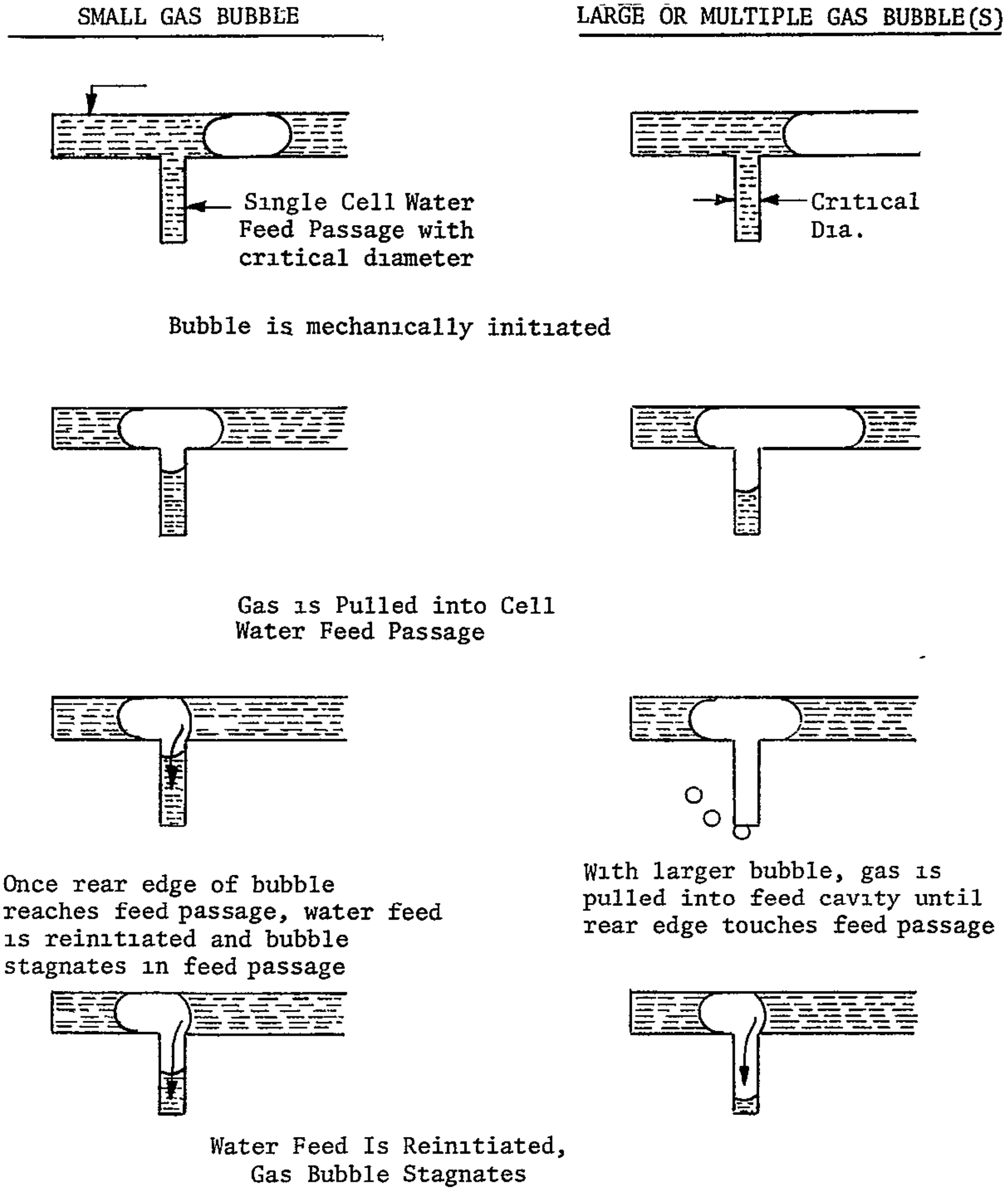
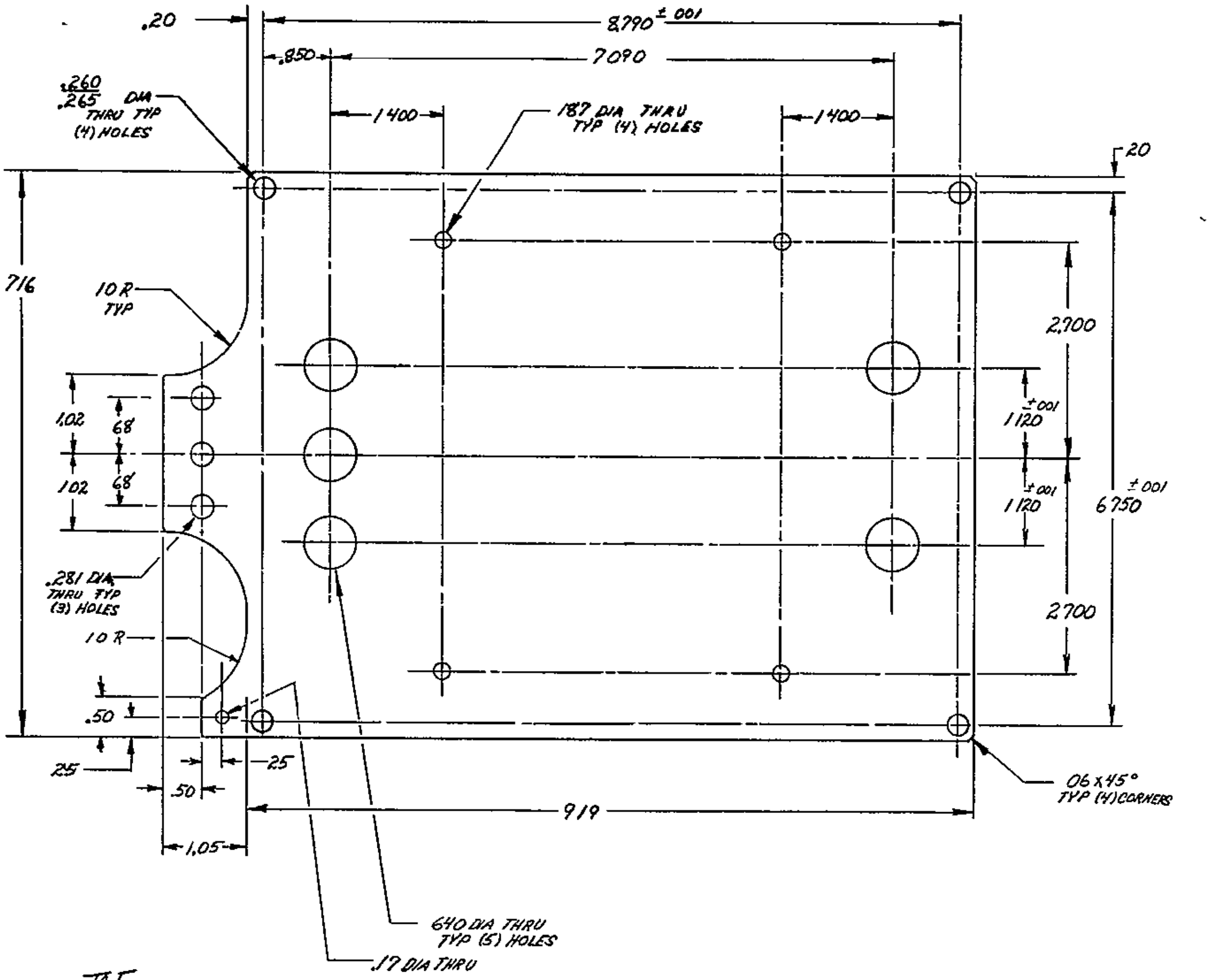


FIGURE 11 PICTORIAL RESULTS OF CRITICAL WATER FEED PASSAGE DIAMETER ANALYSIS



NOTE:
1) MATERIAL SPEC NICKEL 200, "A" NICKEL, OR ASTM B-162 NICKEL, MINIMUM CERTIFIED 0.2% YIELD STRENGTH TO BE 40,000 PSI
2) TRACIBILITY NOT REQUIRED
3) NO BURRS, BREAK SHARP EDGES
4) INSPECT PER OP-107

FIGURE 12 IMPROVED CURRENT COLLECTOR DESIGN

The original Ni current collectors, due to their low yield strength, deformed under high pressure into the low pressure coolant channels molded into the back of each cell. This caused internal leaks in the SFWEM The material specification was changed from a fully annealed Ni to hard Ni which was sufficient for 4140 kN/m^2 (600 psi) water electrolysis cell operation.

Insulation Plate with Internal Cooling. A new insulation plate with an integral liquid-cooling compartment was designed, fabricated and installed The cooling channel was added to provide a thermal environment for the top end cell similar to that of the other cells in a module. The new insulation plate design is shown in Figure 13 The cooling path was machined into the back of the plate requiring the addition of a large O-ring groove around the channel to contain the liquid coolant.

Square Cathodes The cathodes developed previously had the four corners cut off to facilitate mounting of the bipolar polar current collector connection screws (see Figure 10).(5)

The requirement for the removal of the cathode corners was eliminated by closer tolerancing of the screw mounting holes.

A new electrode configuration was designed and is shown in Figure 14.

Correction of Cell Frame Warpage The original SFWEM cells showed signs of warpage following injection molding and cooldown In order to use the cell frames individually each frame was annealed in a hot air oven.(5) Subsequent injection mold design improvements performed at LSI derived the use of cored out channels in thick areas of a cell frame. This provided more even cross sections and allowed the plastic to cool uniformly, resulting in flatter parts

A literature search suggested that additional warpage improvements are possible if the molding conditions are adjusted.(11) For polysulfone parts, high injection molding forces are required for every portion of projected area of the molded part. Based on the size of the SFWEM cell design, a 1.6 x 10^5 kg (180 ton) injection molding machine is needed. Previous frames were formed on a much smaller machine, resulting in low injection flow rates This allowed the plastic to cool prematurely and cause undue stresses, resulting cell frame warpage.

To produce the additional frames required under the program an alternate injection vendor with a larger machine was identified. Several modifications to the mold supports had to be incorporated to allow the use of the larger injection molding machine. Parts were successfully molded using the corrected molding technique and the frames could be used without the costly annealing process

O-Rings with Reduced Compression Set. The design of the SFWEM includes double O-ring sealing around all H_2 cavities for increased reliability. To keep the overall size of the cell to a minimum, O-rings had to be selected which were of non-standard size.

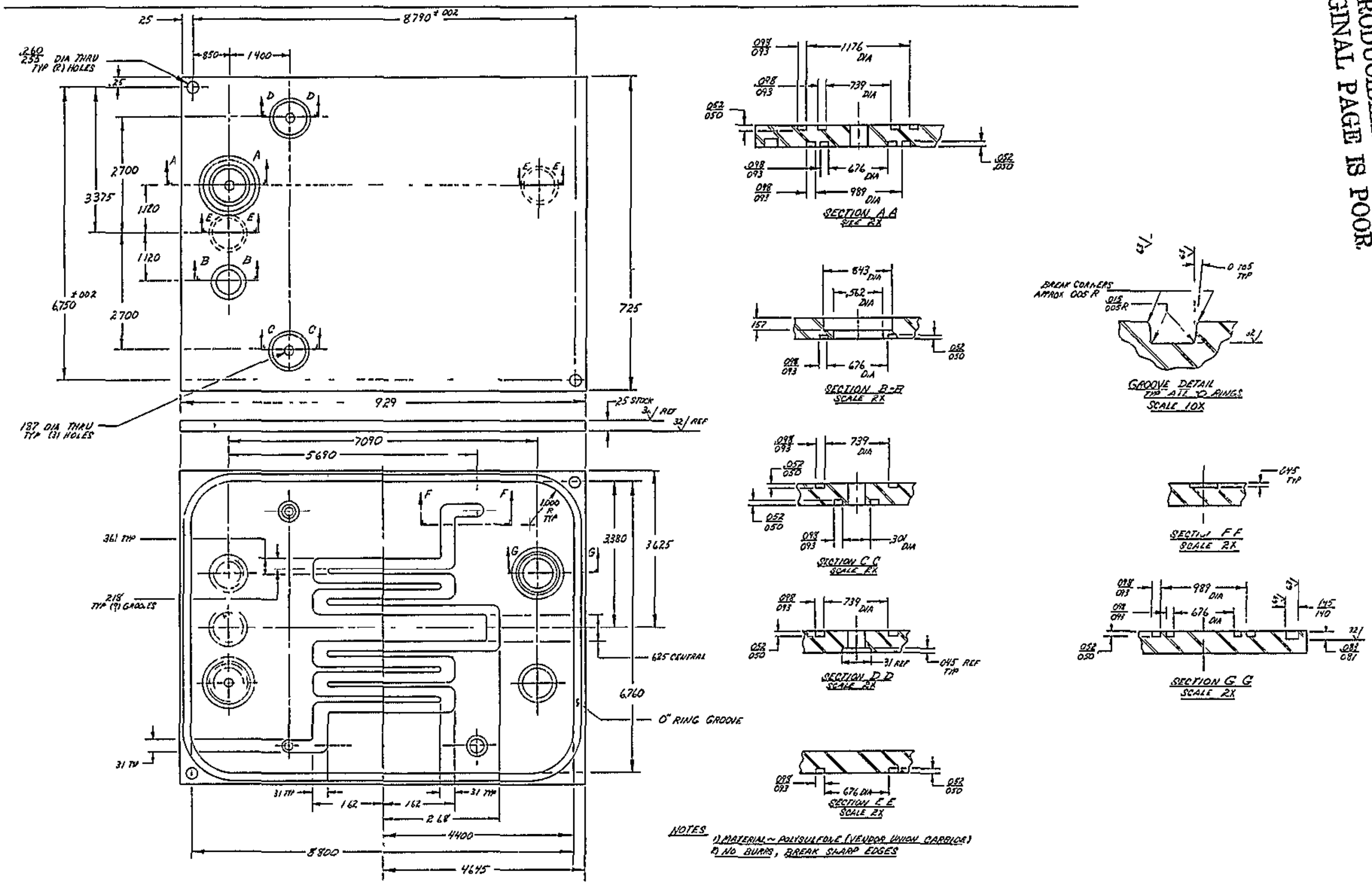
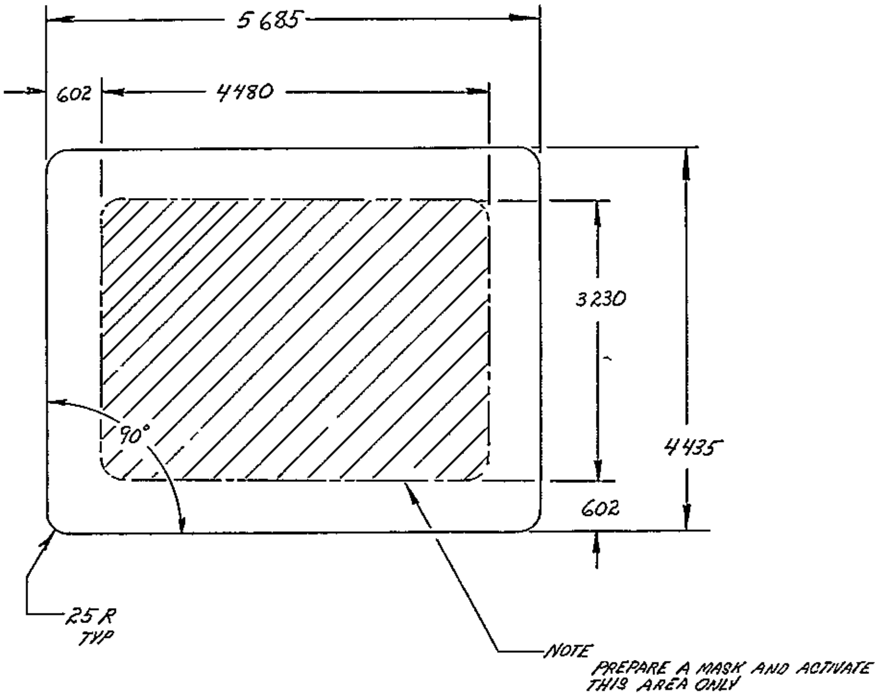


FIGURE 13 NEW INSULATION PLATE DESIGN



NOTE
PREPARE A MASK AND ACTIVATE
THIS AREA ONLY

FIGURE 14 NEW ELECTRODE DESIGN

Two vendors supplied the required O-ring sizes One vendor's O-ring took on a permanent compression set during extended testing and loss of seal resulted The other vendor's product was satisfactory but was unavailable in the precise size required

A special mold was designed and fabricated and the proven compound was used to manufacture new O-rings The new O-rings successfully sealed the cells and subsequent disassemblies showed minimal permanent set.

Dehydrator Single Cell Technology and Hardware Improvements

The dehydrator cell, as functionally shown in Figure 15, uses the same polysulfone cell housing design as the SFWE cell. The original design incorporated a relatively thick electrode for the O_2-evolving anode This electrode has been replaced with a higher performance but thinner electrode. The changes needed to accommodate the new electrode were incorporated into the design as shown in Figure 15.

A three-cell DM was assembled using the improved hardware. The DM is being stored for testing as part of the integrated SFWEM/DM endurance test scheduled for a later time under this program.

Program Testing

The overall program test requirements were divided into the following four activities

- SFWE single cell test stand construction
- SFWE single cell 30-day electrode test
- SFWE single cell 30-day high temperature test
- SFWEM/DM integrated 30-day endurance test

SFWE Single Cell Test Stand Construction

A low pressure test stand was designed and built to provide a test bed for single cell work. A schematic of this test stand is shown in Figure 16 The purpose of the test stand was to allow for comparative evaluations of high performance electrodes and high temperature compatible matrices. Neither evaluation requires high pressure operation. The low pressure approach also conserved program funds since high pressure equipment and the components required for pressure regulation increase construction costs

At low pressures (ambient) operation, gas will build up in the feed water cavity To remove this gas, the feed water cavity fluid was recycled and the gas separated in a water accumulator for subsequent removal.

SFWE Single Cell 30-Day Electrode Test

During the previous SFWEM development program a single cell test was performed evaluating an advanced electrode (anode) catalyst that had previously shown much promise in lowering OGS power consumption.(5) The original substrate material for this advanced catalyst, however, deteriorated.

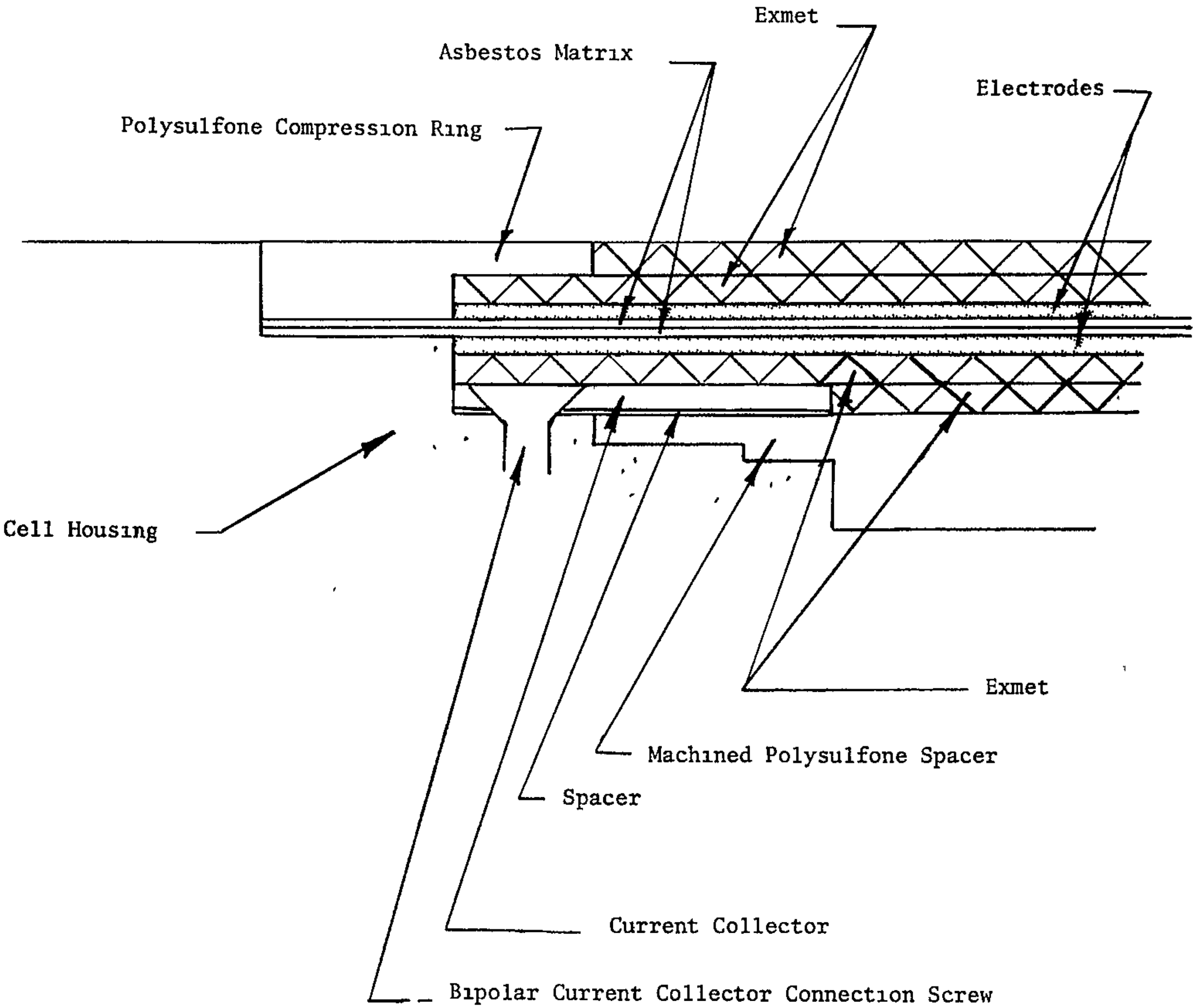


FIGURE 15 DEHUMIDIFIER CELL CONSTRUCTION AND STACKUP

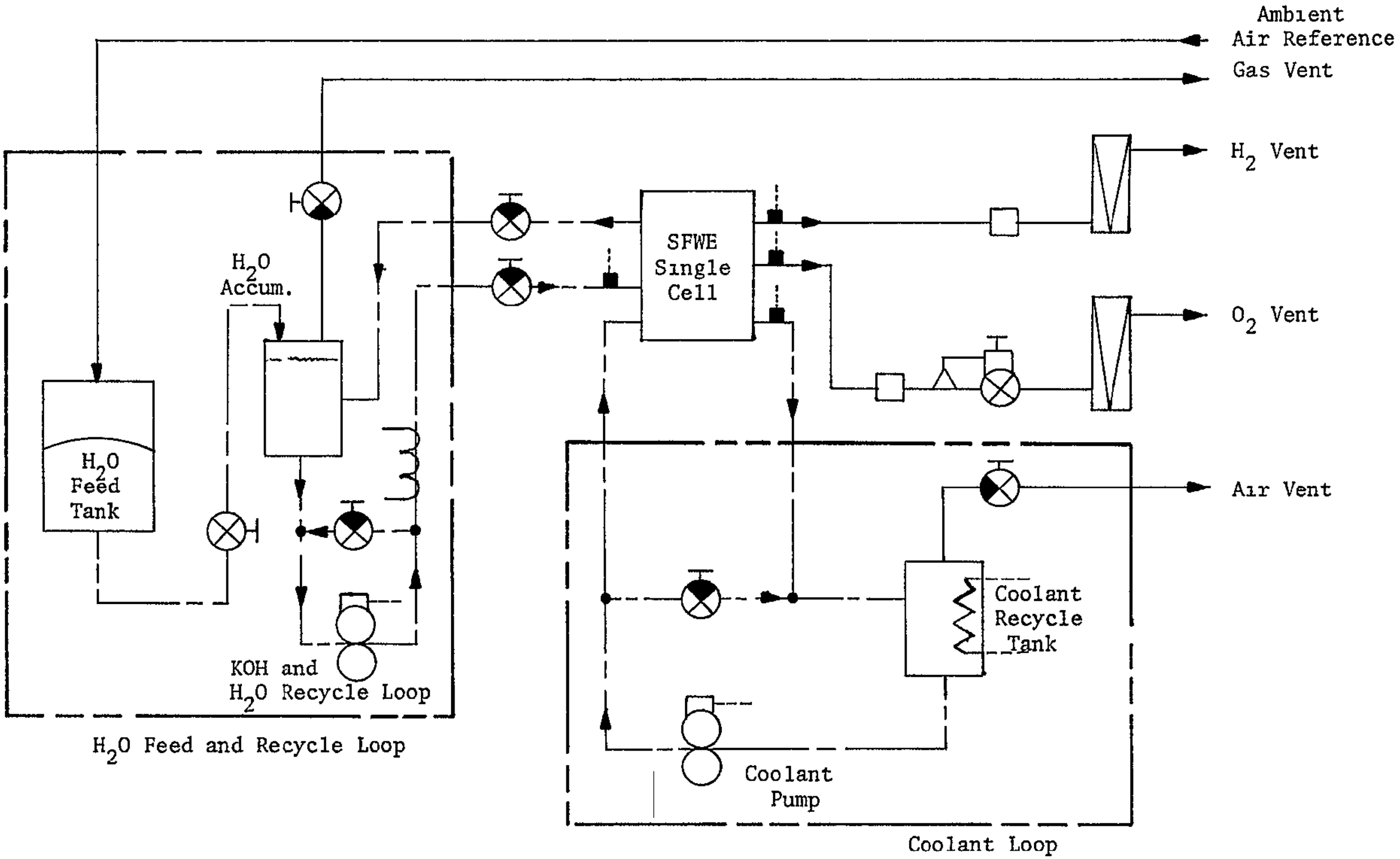


FIGURE 16 SINGLE CELL TEST STAND SCHEMATIC

As part of the present program, a potentially non-corrosive substrate for the catalyst was evaluated with a projected test goal of 30 days of operation. The new electrode was designated WAB-5. After approximately two days of running, as shown in Figure 17, the performance started to degrade rapidly. The test was therefore terminated.

A decision was made to continue the single cell test using an advanced anode (WAB-6) that had been developed under a company-funded activity.

Figure 18 shows cell voltage versus current density plots for the WAB-6 electrode at three different operating life times. Endurance test results for the 30 days of scheduled operation are shown in Figure 19. Table 10 lists the shutdown and causes for the 30-day test. Figure 20 and Table 11 show a comparison of this WAB-6 electrode performance with that of other electrodes previously developed by LSI(5,6,12,13) Excellent competitive cell voltage levels at elevated current densities were demonstrated with the WAB-6 electrode.

SFWE Single Cell 30-Day High Temperature Test

Water electrolysis performance has a strong dependence on temperature. As the temperature increases, the power required for the cell to produce the product H_2 and O_2 gases is reduced For actual hardware, this temperature dependence is generally on the order of 4.3 mV decrease per degree K rise in temperature over a range of 295 to 354K (72 to 178F)(12) To accomplish high temperature, low power SFWES operation requires that the baseline fuel cell grade asbestos matrix be replaced with a material that is compatible with KOH at the greater than 366K (200F) temperature.

A matrix constructed from potassium titinate (PKT) fibers was identified, tried, found acceptable and selected to conduct a 30-day high temperature (366K (200F)) single cell test. For best performance the cell was constructed using the new WAB-6 anode with other components being baseline.

Figure 21 shows current density spans performed with the high temperature cell at start-up and after 48 hours of operation. A comparison with the performance using baseline asbestos at 355K (180F) and using PKT fibers at 366K (200F) shows little advantage for the high temperature operation using the new matrix material. Also, in recent conversations with the supplier for PKT fibers, it was found that this product will no longer be produced. This means the material identified under the task will not fit the long-term availability needs. A search to identify suitable alternate sources and/or materials proved unsuccessful.

As a result, the need for the high temperature (greater than 366K (200F)) SFWES operation was reevaluated. Recent advances in LSI's electrode technology have shown that voltages below 1.5V and a current density of 161 mA/cm^2 (150 ASF) are possible while operating at temperatures of up to 355K (180F) and using fuel cell grade asbestos (see Figure 18). Cells operating at these low cell voltages produce very little waste heat, making high temperature operation (above 355K (180F)) and low cell voltages incompatible for a practical OGS This is due to the fact that the cells do not generate sufficient heat and,

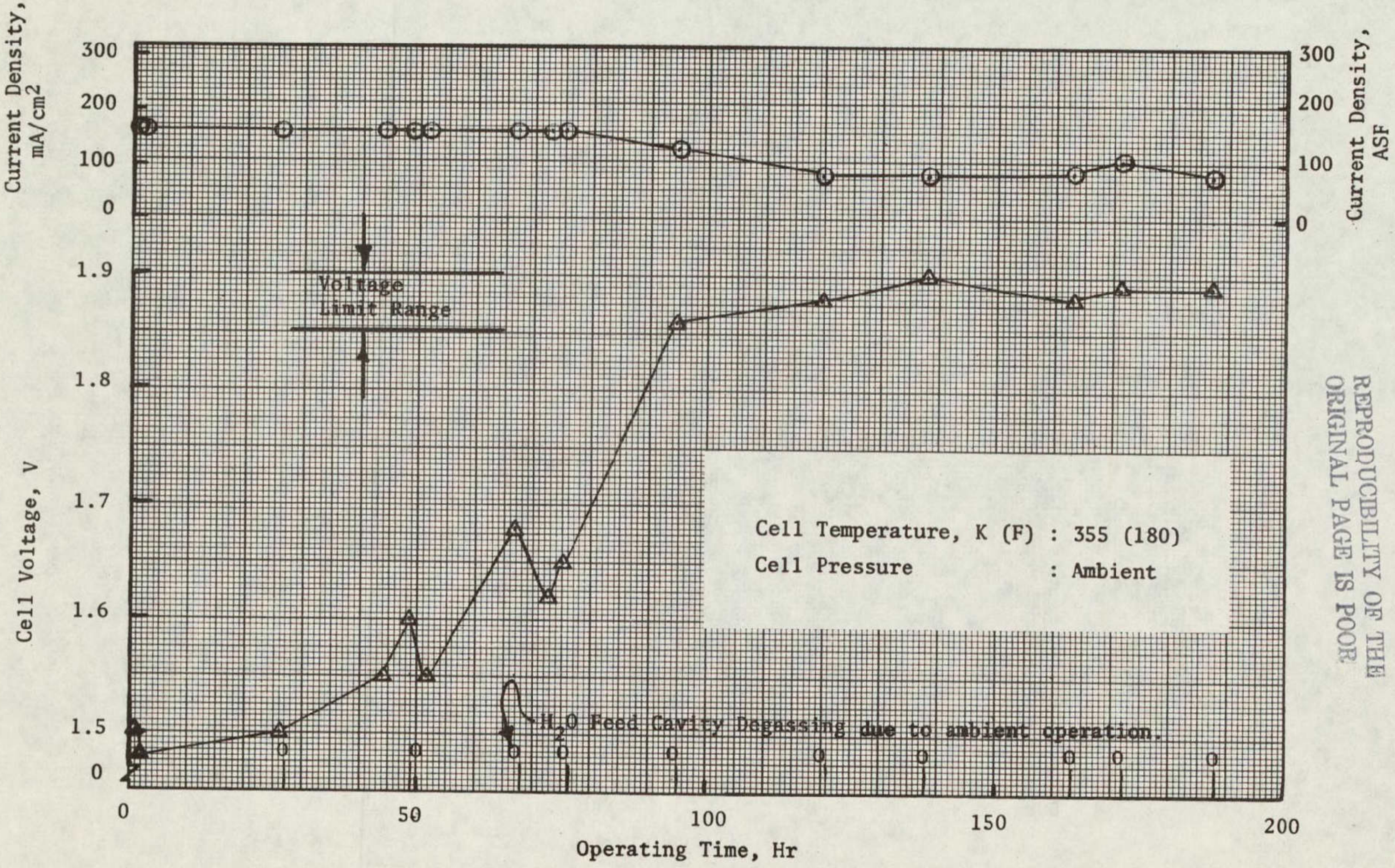


FIGURE 17 WAB-5 PERFORMANCE VERSUS TIME

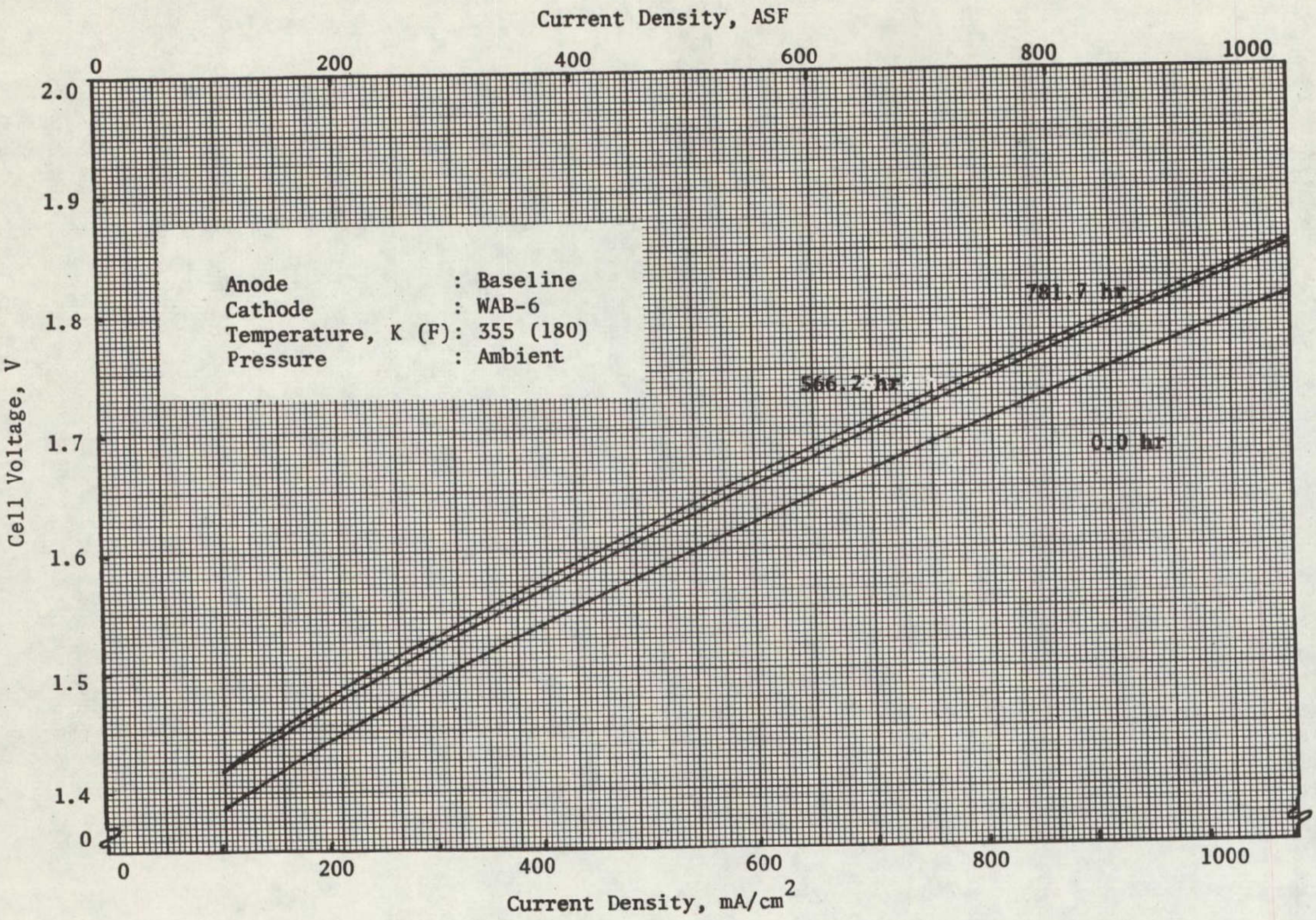


FIGURE 18 WAB-6 PERFORMANCE VERSUS CURRENT DENSITY

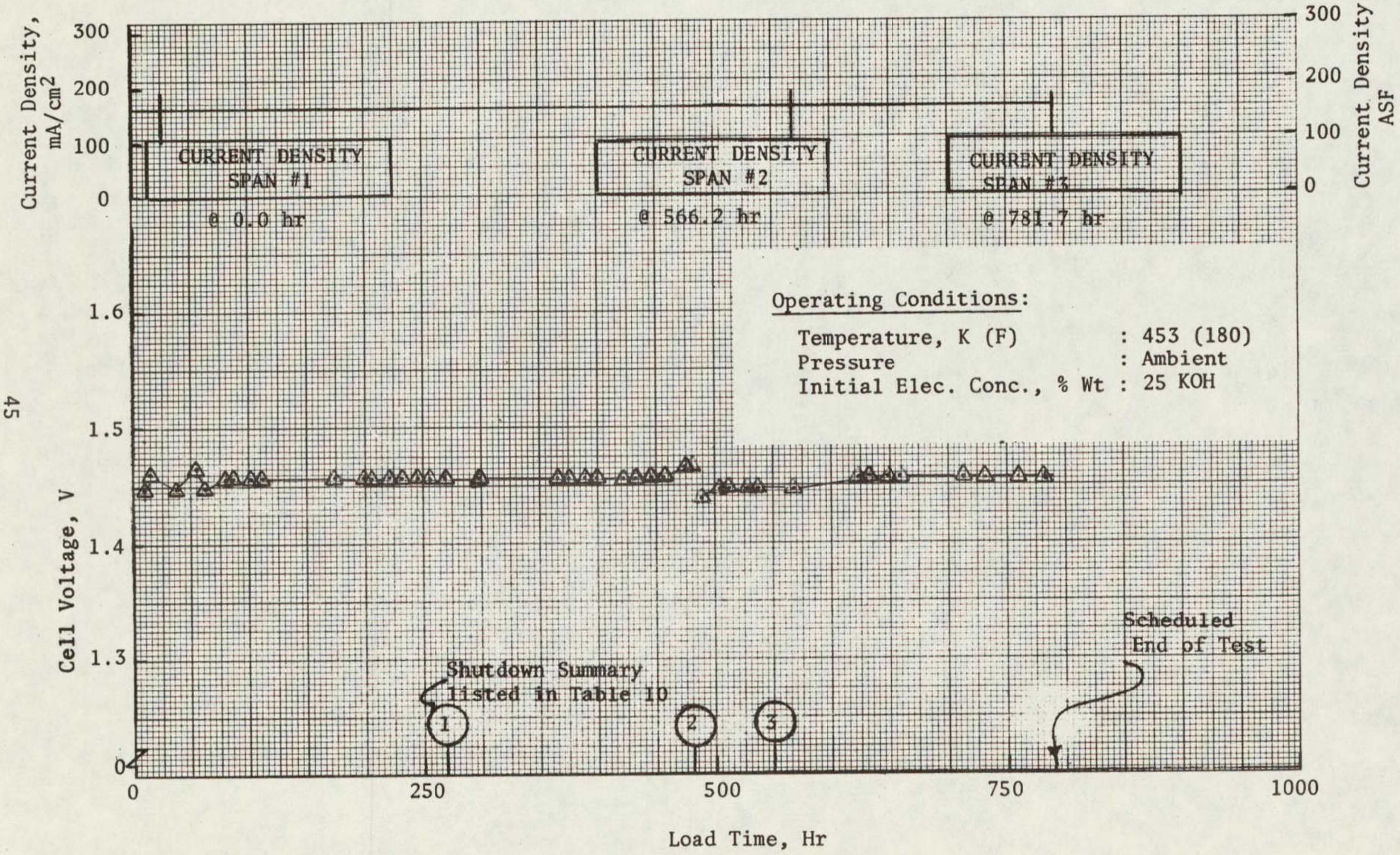


FIGURE 19 WAB-6 PERFORMANCE VERSUS TIME

TABLE 10 SHUTDOWN RECORD

Shutdown Number	Explanation	Downtime, Hr
1	TSA shutdown caused by failure of KOH recycle pump.	2
2	Building power failure.	14
3	TSA shutdown caused by failure of KOH recycle pump. Resulted in operation at 43 mA/cm^2 (40 ASF) during downtime.	4 to 10

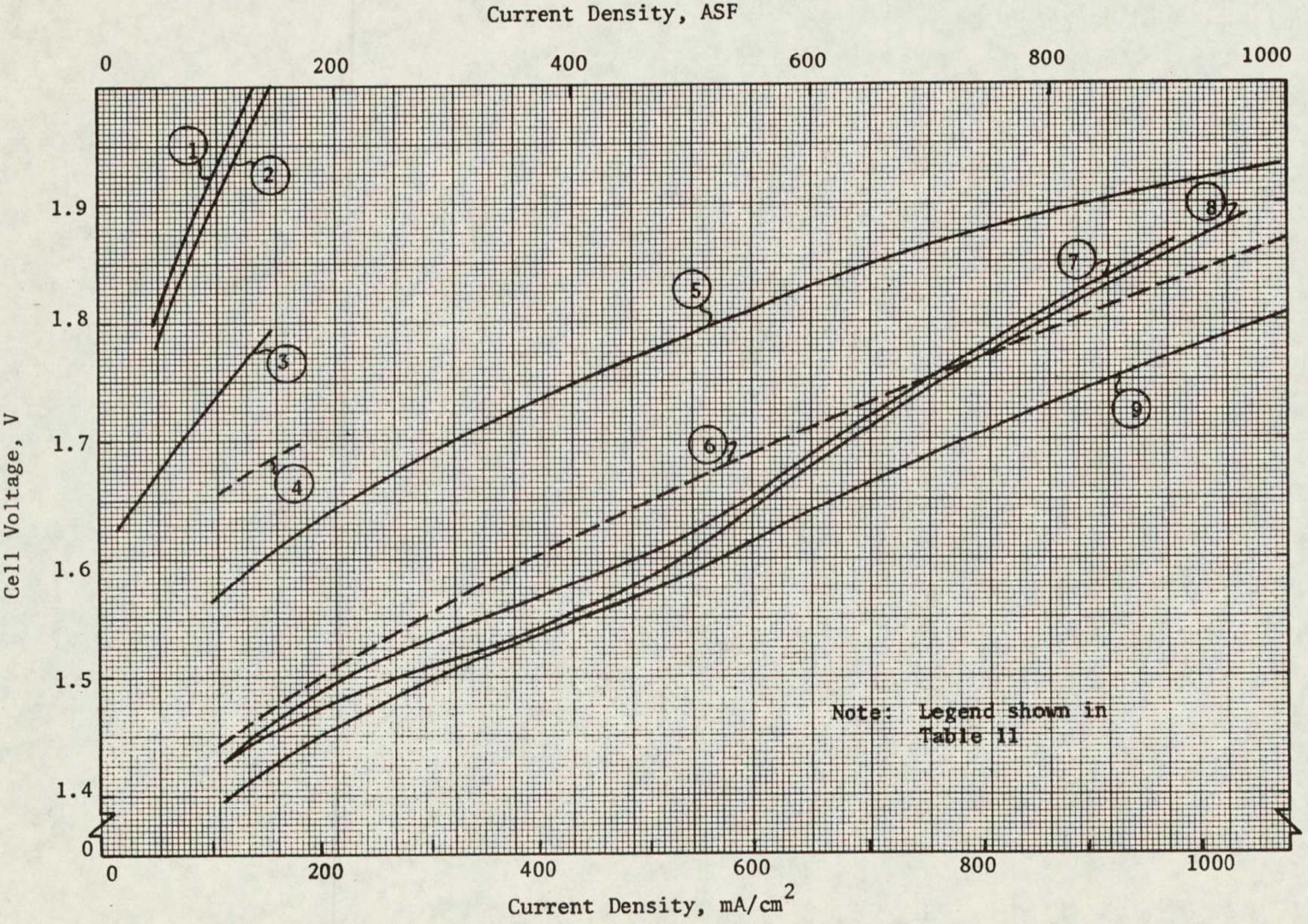


FIGURE 20 ELECTROLYSIS CELL VOLTAGE COMPARISONS

TABLE 11 ELECTROLYSIS CELL VOLTAGE COMPARISONS[a]

1. 1970 after 2500 hours at 353K (175F)
2. 1970 after 6671 hours at 353K (175F)
3. 1970 after 81 hours at 353.5K (177F)
4. 1974 after 2540 hours at 792 kN/m^2 (115 psig) and 341 to 344K (155 to 160F)
5. 1973 after 2 hours at 313K (104F)
6. Curve Number 5 normalized mathematically to 355K (180F)
7. 1976 (Electrode WAB-6) after 781.7 hours at 355K (180F) and ambient pressure
8. 1976 (Electrode WAB-6) after 566.2 hours at 355K (180F) and ambient pressure
9. 1976 (Electrode WAB-6) on startup at 355K (180F) and ambient pressure

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(a) Refer to Figure 20.

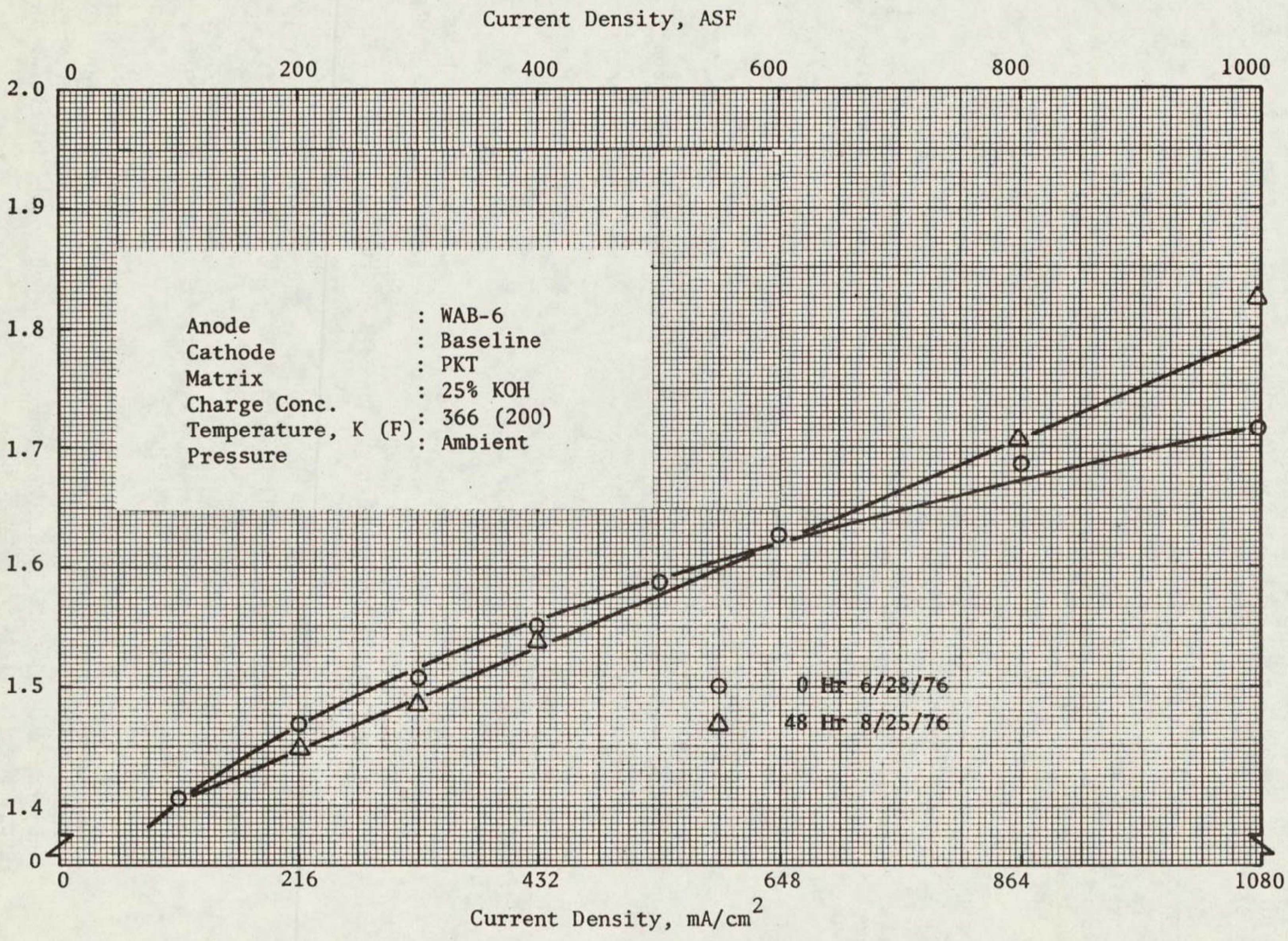

FIGURE 21 SINGLE CELL HIGH TEMPERATURE TEST RESULTS

therefore, an external heat source (e.g., waste heat from another subsystem) would have to be utilized. This complicates OGS/ARS integration. As a result it was recommended that high temperature operation be discontinued.

SFWEM/DM Integrated 30-Day Endurance Test

The existing one-man test system(5) was modified and refurbished to allow operation with a 3-cell DM. The modifications included additions of plumbing, hand valves, DM support brackets and DM power and voltage leads. The modified stand was checked out and is ready for the integrated testing scheduled as part of the remaining program test activities.

CONCLUSIONS

Five conclusions were drawn based on the activities completed to date:

1. Comparing present technology with projected 1980 technology, a three-man OGS (4.19 kg O_2/day (9.24 lb O_2/day)) is at the following development stage:

	1976	1980
Fixed Hardware Weight, kg (lb)	54 (119)	36 (80)
Total Heat Rejection and Power Penalty, kg (lb)	328 (723)	258 (568)
Total Equivalent Weight, kg (lb)	382 (841)	294 (647)
Estimated Volume, m^3 (ft^3)	0.108 (3.81)	0.085 (3.00)
Total Power, kW	1.09	0.93

2. The alkaline electrolyte-based SFWES has the potential for one of the lowest power-consuming electrolysis-based OGSs. A new electrode, WAB-6, has been developed by LSI for use in alkaline electrolytes. At the end of 30 days of testing the cell voltage was only 1.42V at 108 mA/cm^2 and a temperature of 355K (180F).

3. High temperature operation (greater than 355K (180F)) of electrolysis cells has been demonstrated, although the practicality of using waste heat that is required to maintain these temperatures is in question. The external heat requirement is due to recent advances in electrode technology, where cells operate at very low cell voltages and produce very little waste heat.

4. The SFWEM does not release an aerosol of the cell electrolyte into the product gas streams after a minimum module break-in period of 24 hours. This removes the possibility of depletion of the electrolyte or contamination of downstream components such as the DM and/or pressure regulators, with KOH.

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