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TEST OF GEMINI FUEL BATTERY SECTION TO MANNED ORBITING LABORATORY MISSION POWER REQUIREMENTS

L. J. Nuttall

L. R. Stevens, Jr.

Direct Energy Conversion Operation

General Electric Company

Technical Report AFAPL-TR-65-77

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prepared for

Air Force Aero Propulsion Laboratory

Research and Technology Division

Air Force Systems Command

Wright-Patterson Air Force Base, Ohio

under

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Best Available Copy

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FOREWORD

This report was prepared by the Direct Energy Conversion Operation of the General Electric Company, Lynn, Massachusetts, under USAF Contract No. AF 33 (615)-2500. The contract was initiated under Budget Program Sequence Number 5 (63 817303 62405214). The work was administered under the direction of the Air Force Aero Propulsion Laboratory, Research and Technology Division, Air Force Systems Command with Lt. L. S. Harootyan, Jr/APIP-2 as the project engineer.

This report covers work conducted from February 1965 through May 1965.

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ABSTRACT

It was requested that the General Electric Company furnish a complete Gemini fuel cell battery with canister and all associated auxiliary equipment and all personnel and facilities required to accomplish a 1000-hour operational test under conditions which simulate the mission power requirements of the Air Force's Manned Orbiting Laboratory (MOL).

The objective of this program was to test a Gemini fuel cell battery and to obtain and evaluate data on its performance throughout the continuous operational test.

A Gemini fuel cell battery, consisting of three individual 32-cell modules, was tested in accordance with a test plan approved by the Air Force Aero Propulsion Laboratory.

The Gemini production fuel cell battery successfully met all requirements of the test plan for the 1000 hour period. Complete MOL power requirements were successfully met for 810 hours (34 days) following which the peak powers were reduced in accordance with the test plan to maintain a 25 volt output.

The test confirmed that Gemini production hardware is capable of satisfying the 30-day MOL mission requirements and provides the growth capability to serve missions up to and beyond 1000 hours duration.

SECTION I

INTRODUCTION

During the development and verification of the Gemini fuel cell battery, life testing was completed on six battery sections as well as 35 individual 32-cell modules. Analysis of this data has provided a determination of the capabilities (and limitations) of this equipment and an understanding of the effect of system parameters, load profiles, temperatures, and handling and operating procedures on its life and reliability. On the basis of this information it was concluded that the Gemini fuel cell battery could meet the 30-day mission requirements of the Air Force Manned Orbiting Laboratory (MOL) program. To verify this conclusion an operational test was scheduled on a standard production section.

The detailed profile for the test program was specified by the Air Force Aero Propulsion Laboratory, with appropriate inputs from Space Systems Division (SSD) and the Aerospace Corporation. This profile was based on the "MOL Electrical Power Subsystem Study" completed by the General Electric Company in October, 1964. This study was one of four (4) electric power subsystem studies conducted by three contractors under the direction of SSD.

One recommendation of the General Electric study was that eight Gemini battery sections be used to provide the full spacecraft power requirements for 30 days at a level of reliability suitable for the Manned Orbiting Laboratory Mission. Five of the eight sections would be required to carry the full MOL electrical load with three being held in operating redundancy.

The Air Force specified that the power level for this test would initially simulate a system with only seven sections operating, it being assumed that one section might be rendered inoperative prior to launch.

It was further assumed that an additional section would be lost after 180 hours and still another at the 360-hour mark, leaving five sections to complete the remainder of the mission. This together with the load increase to allow for parasitic losses, implied a higher power requirement on the section tested than that corresponding to the study recommendation.

The significance of the test program lies in the fact that the fuel battery section comprised of three fuel cell modules operated successfully beyond the 30-day test criteria under maximum system temperature conditions and to the specified MOL load profile. This confirmed the ability of the Gemini fuel cell battery design to meet the requirements of the MOL mission.

SECTION II

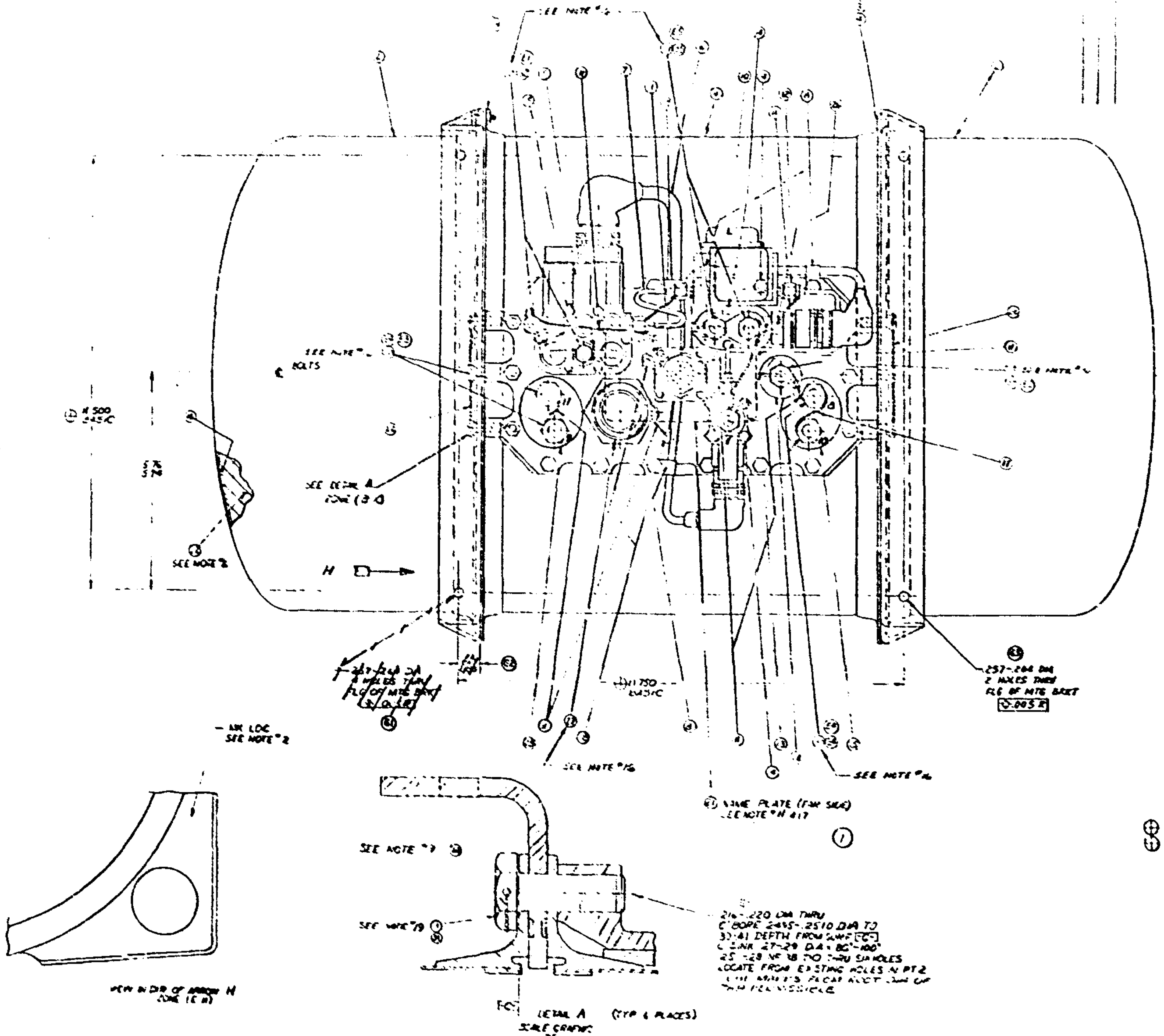
DESCRIPTION OF TEST UNIT

The fuel battery section used for the MOL mission test was a standard production unit drawing no. 723E147, manufactured for the Gemini program during August 1964. It was the eighth section manufactured to this design, of which approximately thirty have been produced to date.

The section shown in Figure 1, consists of three separate modules, similar to that shown in Figure 2, packaged in a pressure tight casing, together with appropriate reactant and coolant ducts and manifolds, a water separator for each module, electrical power and instrumentation wiring. An accessory pad is mounted on the outside of the casing which contains the gas inlet and outlet fittings, purge and shut-off valves, and electrical power connector. Since the system design proposed for MOL does not require a separate water shut-off valve for each section, the solenoid valve used for this purpose in the Gemini design was not included on the test unit.

Structurally, the casing is a titanium pressure vessel consisting of a central cylinder, two end covers, mounting brackets and plastic angle rails. Location and shape of the mounting brackets is, of course, adapted to the available structure and envelope within the vehicle. Within the casing, the modules are mounted on fiberglass-impregnated epoxy rails by bolts which pass through the module end-plates. These rails are, in turn, bolted to the mounting rings sandwiched between the two flanges on the section casing.

The hydrogen manifolds on each module within a section are parallel fed with a hydrogen shut-off and check valve in the feed line to each module. Oxygen is fed into the section casing so that the entire free volume of the tank contains oxygen at a pressure



23 THE FOLLOWING TORQUE VALUES SHALL BE USED FOR ANY CONNECTIONS MADE TO THE FOLLOWING FITTINGS:

FITTING NO		FITTING NO		FITTING NO	
1	32-40	5	40-45	10	40-45
2	30-40	7	60-65	11	60-80
3	40-45	8	60-80		
4	40-45	9	60-80		

22 PRIOR TO USE, CLEAN PT 34 / [P5RS440] PLUS A FINAL RINSE WITH ISOPROPYL ALCOHOL [D5857] FILTERED THROUGH A 5 MICRON FILTER. AFTER RINSE, THE ALCOHOL SHALL MEET REQUIREMENT OF TABLE I OF [P5?6N387]

5 PERFORM H_2 SIDE FLOW TEST AND O_2 SIDE FLOW TEST / [P5?6N378] EXCEPT THAT TEST SHALL BE PERFORMED AFTER FOAMING

21 INSTALLATION CONTROL / [723E128]

20 ELECTRICAL & FLUID CONNECTIONS / [723E127]

19 BEFORE ASSEMBLING PT 19 TO SECT, COAT WITH BOLT LUBRICANT - G.E. SPEC D4(?)

18 AFTER ASSY, INSPECT DIMENSIONALLY / [[illegible]]

17 NAME PLATE PT 41 TO BE STAMPED / [[illegible]] AS APPLICABLE.

16 REMOVE PT 27,28,29,30,32,33,34 & 35 AT INSTALLATION

15 ALL PORTS MUST BE SUITABLY PROTECTED WHEN REMOVED FROM CLEAN ROOM

14 NO SELF LOCKING BOLTS OR NUTS SHOULD BE REUSED

13 COLOR CODE IDENT AS FOLLOWS:

CONN NO	COLOR & MARKING	
1 H_2 IN	YEL W/BLK LTR	"IN"
2 H_2 PURGE	YEL W/BLK LTR	"PURGE"
3 O_2 IN	GRN W/BLK LTR	"IN"
4 O_2 PURGE	GRN W/BLK LTR	"OUT"
5 PROD H_2O BLEED	WHT W/BLU LTR	"WATER BLEED"
7 PROD H_2O OUT	WHT W/BLU LTR	"WATER OUT"
8 COOL #1 IN	BLU W/WHT LTR	"COOLANT IN NO 1"
9 COOL #1 OUT	BLU W/WHT LTR	"COOLANT OUT NO 1"
10 COOL #2 IN	BLU W/WHT LTR	"COOLANT IN NO 2"
11 COOL #2 OUT	BLU W/WHT LTR	"COOLANT OUT NO 2"

12 TEST / [P5?6N?8?]

11 TO ATTACH [illegible] & [illegible], REMOVE PROTECTIVE BACKING & WITHOUT TOUCHING ADHESIVE, PLACE [illegible] AT LOCATION SHOWN. USE BRAYER ROLLER [illegible] WITH ONLY ENOUGH FORCE TO SMOOTH ON

10 ASSEM ALL PARTS IN CLEAN ROOM / [[illegible]] EXCEPT PT 17 & 31

9 SAF TIE / [[illegible]] DOUBLE TWIST METHOD

8 AFTER APPLYING TORQUE VALUES / NOTE 7 STRIPE PT 3, 14, 15, 16, 19, & 26

7 TORQUE RANGE — FASTENER SEATED

PT 3	32-40 IN LBS
PT 14, 15, 16, 26	10-12 IN LBS
PT 19	80-100 IN LBS
PT 2, 12 (NUTS)	45-50 IN LBS

6 FOAM REQ / [[illegible]]

4 AFTER FOAMING [illegible] VALVE ASSY, ATTACH PT 2, SUBSTITUTING A SCR NUT IN PLACE OF PT 4, OMIT PT 23 & PERFORM DRILLING & TAPPING OPERATIONS, TAKING APPROPRIATE STEPS TO AVOID ANY CONTAMINATION OF SECTION

3 SCR THREAD / [[illegible]] THREAD SURF

2 MK / [[illegible]] BY [illegible], IDENT NO, SER NO & ASSY DATE (MONTH & YEAR) AT MK LOC SHOWN

1 INTERPRETATION OF DWG / [[illegible]]

ASSEMBLY DWG SEE SEP PTS LIST

SECTION, FUEL CELL BATTERY

723E147

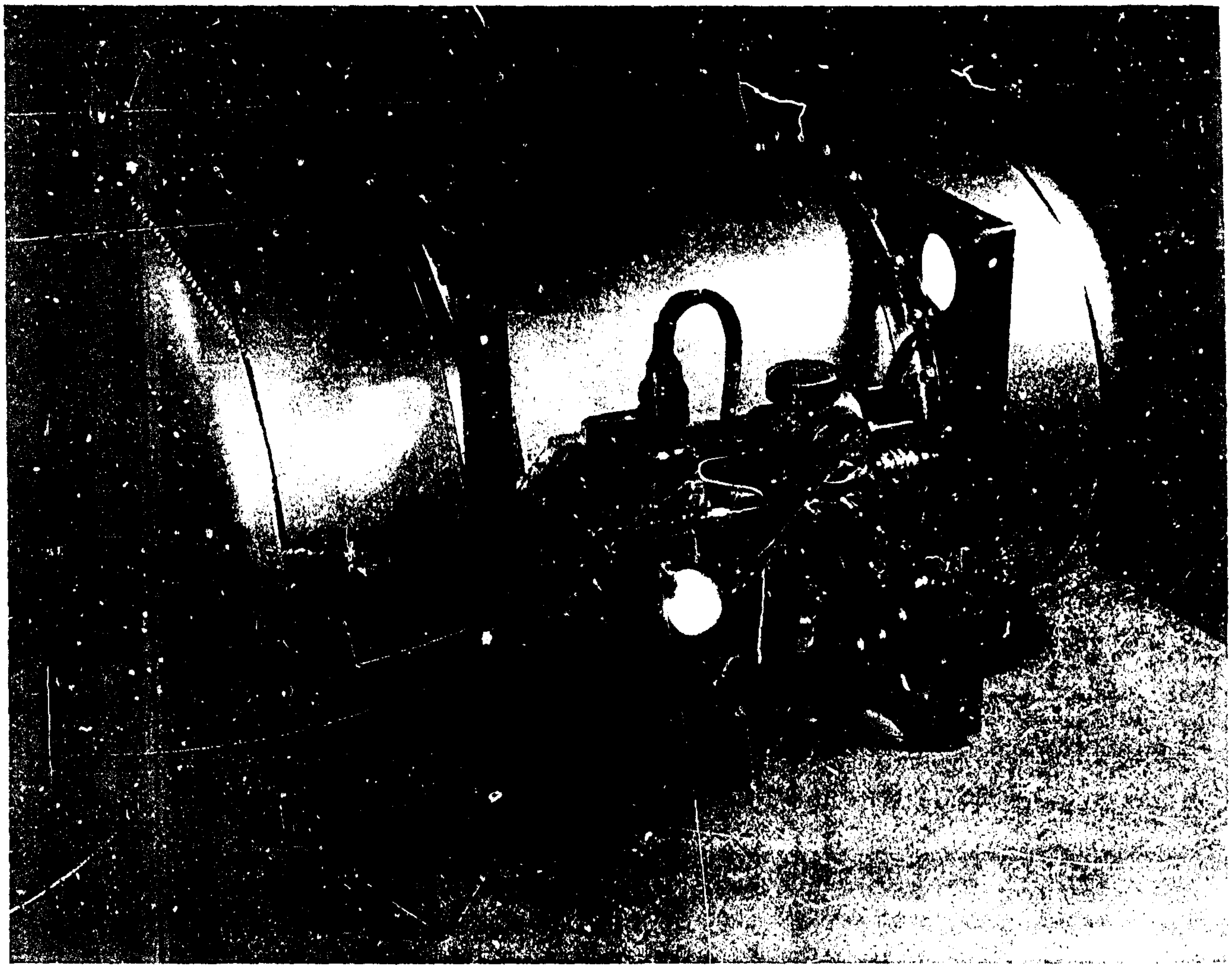


Figure 1 Gemini Fuel Cell Battery Section

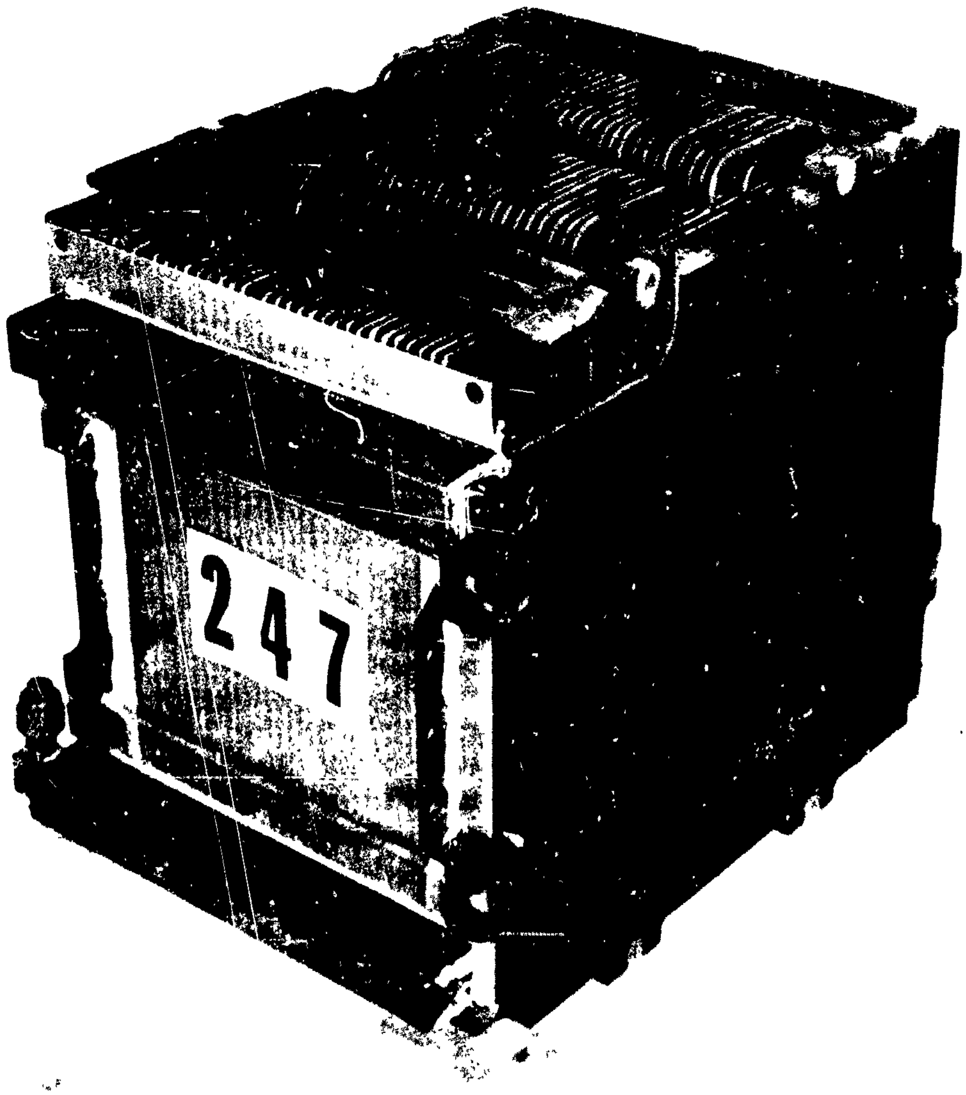


Figure 2 Gemini Fuel Cell Module

of approximately 1-1/2 atmospheres. The coolant is provided to the modules by two separate and isolated lines. Any malfunction in one coolant loop will not affect the cooling function of the other.

All hydrogen, oxygen, coolant, electrical and water storage pressure line connections at the section tank are fastened to standard bulkhead fittings on the accessory pad.

After the modules are completely assembled within the container, all void spaces are filled with unicellular foam. Thin plastic covers are placed over the top and bottom of each module to manifold oxygen to the cells and to keep the foam material from getting into areas around the coolant manifolds and oxygen-water separator.

Each of the three modules in the section is comprised of 32 fuel cell assemblies stacked in series between end plates as shown in Figure 2. The hydrogen feed tubes for each of the cells are connected to a common manifold, as are the coolant inlet and outlet tubes and the hydrogen purge tubes. The electrical power leads are connected to terminal current collector plates sandwiched between each of the two end plates and their adjacent fuel cells.

As applied to the MOL system, the maximum rated output of each module would be 10.4 amps at 25 volts. This compares with a maximum rated output of 15 amps at 23.3 volts in the Gemini installation.

SECTION III

TEST PLAN

The test was conducted in accordance with the approved Test Plan of the Air Force Aero Propulsion Laboratory. Major provisions of the Test Plan concerned the exact load profile to be run and the coolant temperature and flow rate in order to duplicate the most stringent conditions which might be expected in the MOL spacecraft.

The load profile for the test was established on the basis of an assumed peak spacecraft load requirement of 3.6 KW, which would occur for an approximate total of four hours during each eighteen-hour period, and a normal continuous load of 1.6 KW. To these loads was then added the parasitic power requirements of the fuel battery - in this case conservatively estimated as 180 watts.

The complete fuel battery system proposed for the MOL consists of eight three-module sections, five of which can readily carry the above loads. Although previous test experience indicates that any modules which do fail during a 30-day mission would most likely do so toward the end of the mission, in order to impose worst-case conditions on this particular section, it was assumed that the first of the three redundant sections would fail during launch, the second at 180 hours and the third at 360 hours. On the basis of these assumptions, the specific load profile to which the test was run is shown in Table 1.

The Test Plan specified that the MOL profile should be held without deviation to the 720-hour (30 days) point and as long as possible beyond 720 hours at a voltage of 25V or above. The maximum load was to be reduced thereafter as required to maintain the 25V level. In the event of a module failure, the load was to be reduced by the ratio of the number of active modules to the total number (three). The test was to be terminated and the Section considered to have failed when and/or if it was unable to produce at least 200 watts continuous power output.

TABLE I

Simulated MOL Mission Profile

18-Hour Cycle	0-180 Hours		180-360 Hours		360-1000 Hours	
	Module	Section	Module	Section	Module	Section
2 hrs.	180W	539W	210W	630W	252W	756W
1 hr.	94	282	110	330	132	396
2 hrs.	180	539	210	630	252	756
1 hr.	94	282	110	330	132	396
12 hrs.	85	254	99	297	119	356

The three modules within the section were to be cooled in series with water flowing at the rate of 400 lb/hr. This flow was to be equally divided between the two coolant loops in the section. Coolant inlet temperature was to be held to 74 ± 3°F in order that the outlet temperature should not exceed a nominal value of 80°F at maximum load when the zero redundancy case was being simulated. The 74°F also corresponded to the inlet temperature of the last of five active series-cooled sections at maximum load after all redundancy had been lost. It therefore duplicated the most stringent cooling condition. Figure 3 is a photo of the fuel battery Section 9 test set-up. Figures 4, 5 and 6 are functional schematics representing the individual test set-ups used for the Gas Supply System, Coolant Supply System and the Power System, respectively.

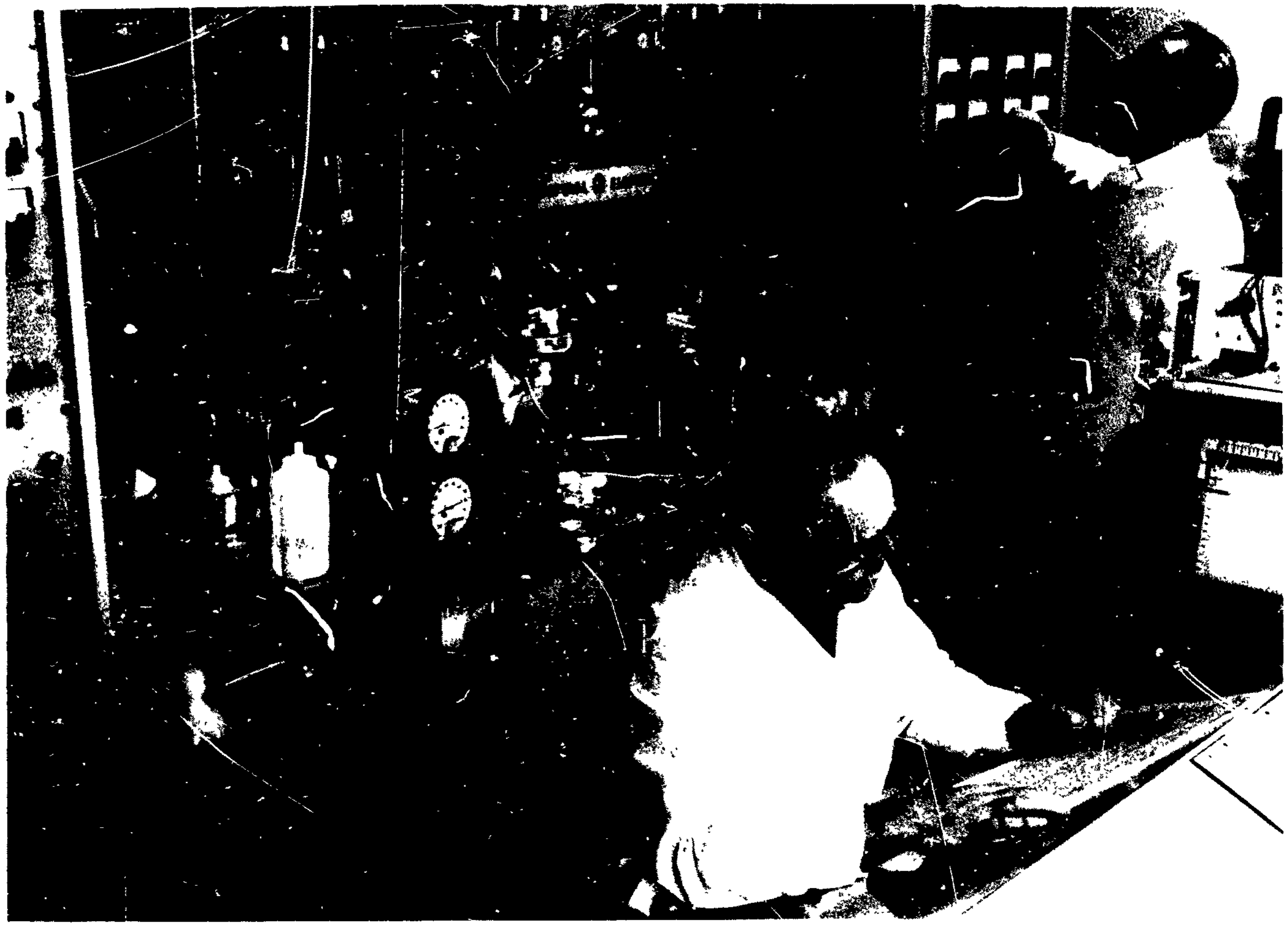


Figure 3 Fuel Cell Battery Section No. 9 Test Set-Up

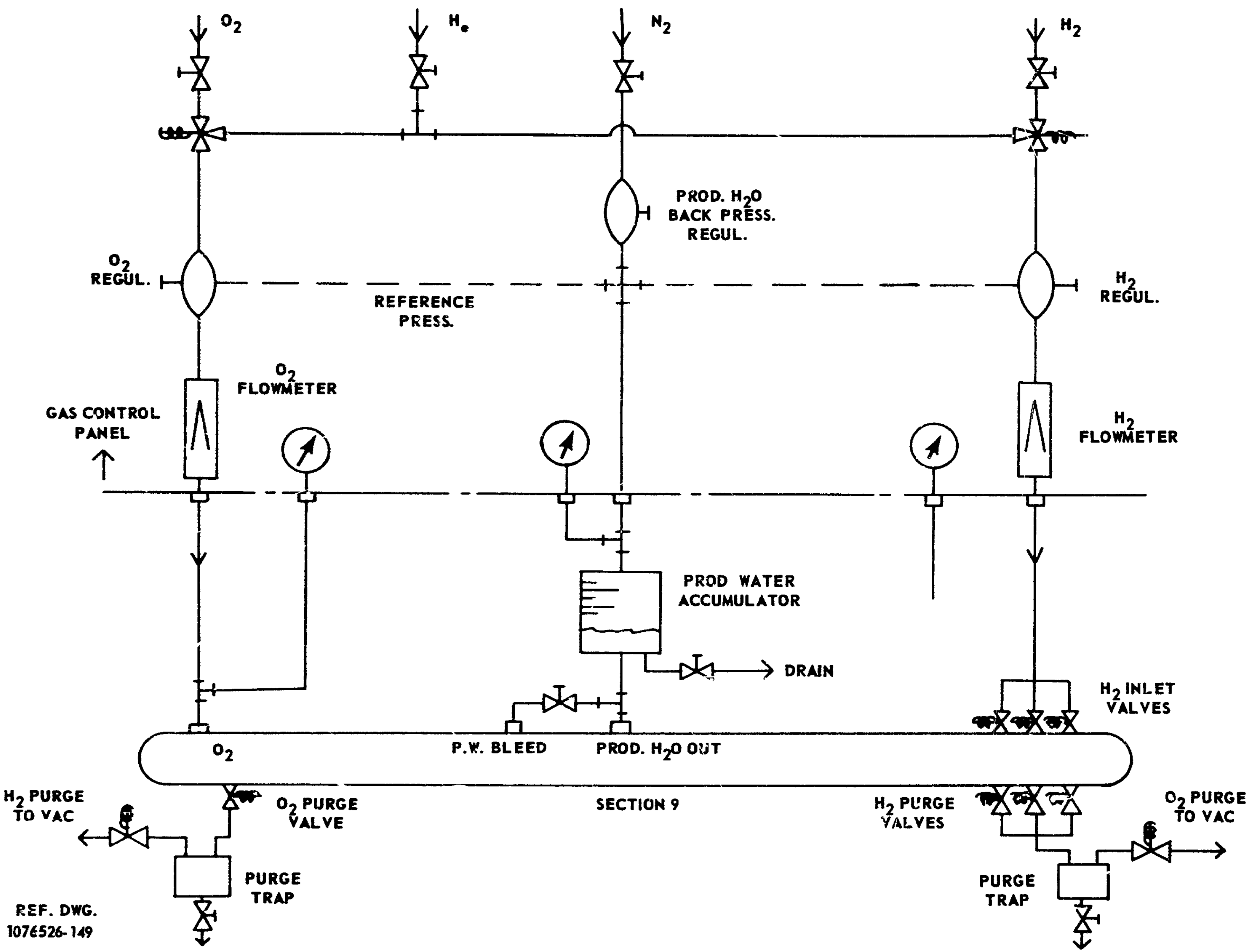


Figure 4 Functional Schematic of Gas Supply System Test Set-Up (Section No. 9)

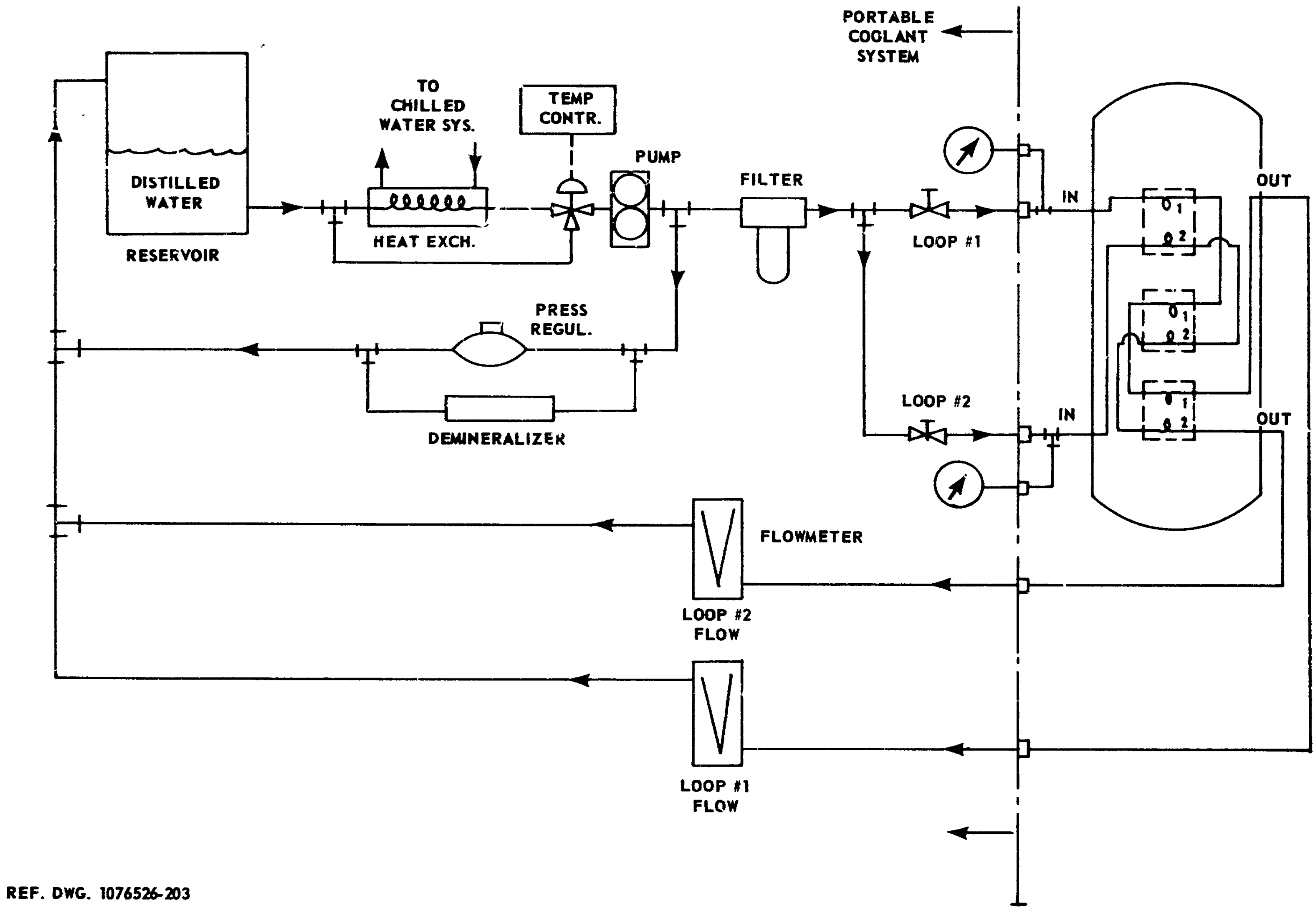


Figure 5 Functional Schematic of Coolant Supply System Test Set-Up (Section No. 9)

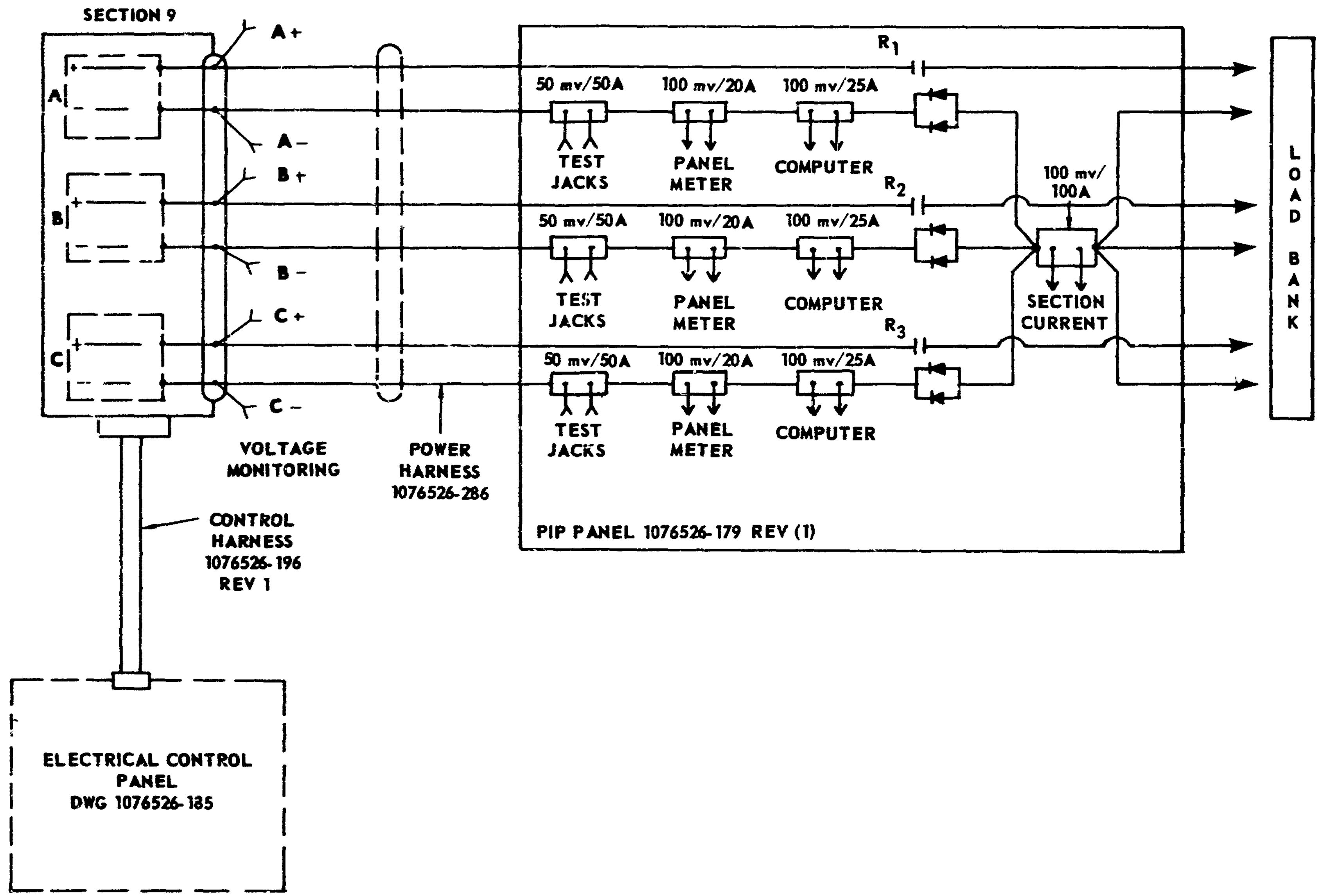


Figure 6 Functional Schematic of Power System Test Set-Up (Section No. 9)

SECTION IV

PRE-TEST HISTORY

The manufacture of the section which was tested reached completion in August of 1964. From that time until the test, a period of about eight months, the unit was stored on inert gas at normal room temperatures.

Normal operating procedures for the Gemini Fuel Cell Battery call for two separate activations. The first time the hydrogen and oxygen reactants are introduced into the fuel cell, electrical performance is usually below the normal operational level, due to the presence of inert gases which become adsorbed on the electrodes during manufacturing processes and storage. Brief operation of the fuel cell at this point, followed by a discharge and a second activation serves to flush these inert gases from the electrodes and enable attainment of design performance levels after second activation.

At the completion of the manufacturing cycle, both the hydrogen and oxygen cavities are helium gas filled and there is no electrical potential across the cell. The activation procedure consists of purging out all the helium and replacing it with the hydrogen and oxygen reactants, at which time the cell begins to generate an electrical potential. By applying a load across the terminals, a performance check is then made, immediately followed by a discharge procedure. This consists of flushing the reactants out with helium and electrically discharging the cell by placing a resistor across the terminals.

Second activation is a repeat of the initial procedure. When completed, the performance level should be up to design criteria. As soon as the performance level is confirmed, the fuel cell battery is ready to be placed on the line for normal mission operation.

Following preparation of the test stand as well as the section to be tested, initial activation was accomplished at 11:30 hours on 23 March 1965. At this time average module open circuit voltage was 32.44V. In accordance with the normal activation procedures previously discussed the section was then discharged and subsequently charged a second time. In the process, the open circuit voltage was raised to 34.90V. Both of these values fall within the normal band for the acceptance test performance of production units for the first and second activations respectively. The initial polarization curve at the start of the test is defined by the following points:

Bus Current	Module Current			Average Module Voltage
	A	B	C	
3.05 amps	1.04	1.01	1.03 amps	31.30 volts
7.75	2.60	2.55	2.63	29.70
12.03	4.00	3.97	4.11	28.75
18.06	5.98	5.98	6.18	27.89
24.01	7.93	7.93	8.25	27.21

Referring to Figure 7, it is apparent that these points lie at the bottom of the band, which represents polarization data on current Gemini production sections, indicating that the fuel cell battery section to be tested was typical of Gemini hardware.

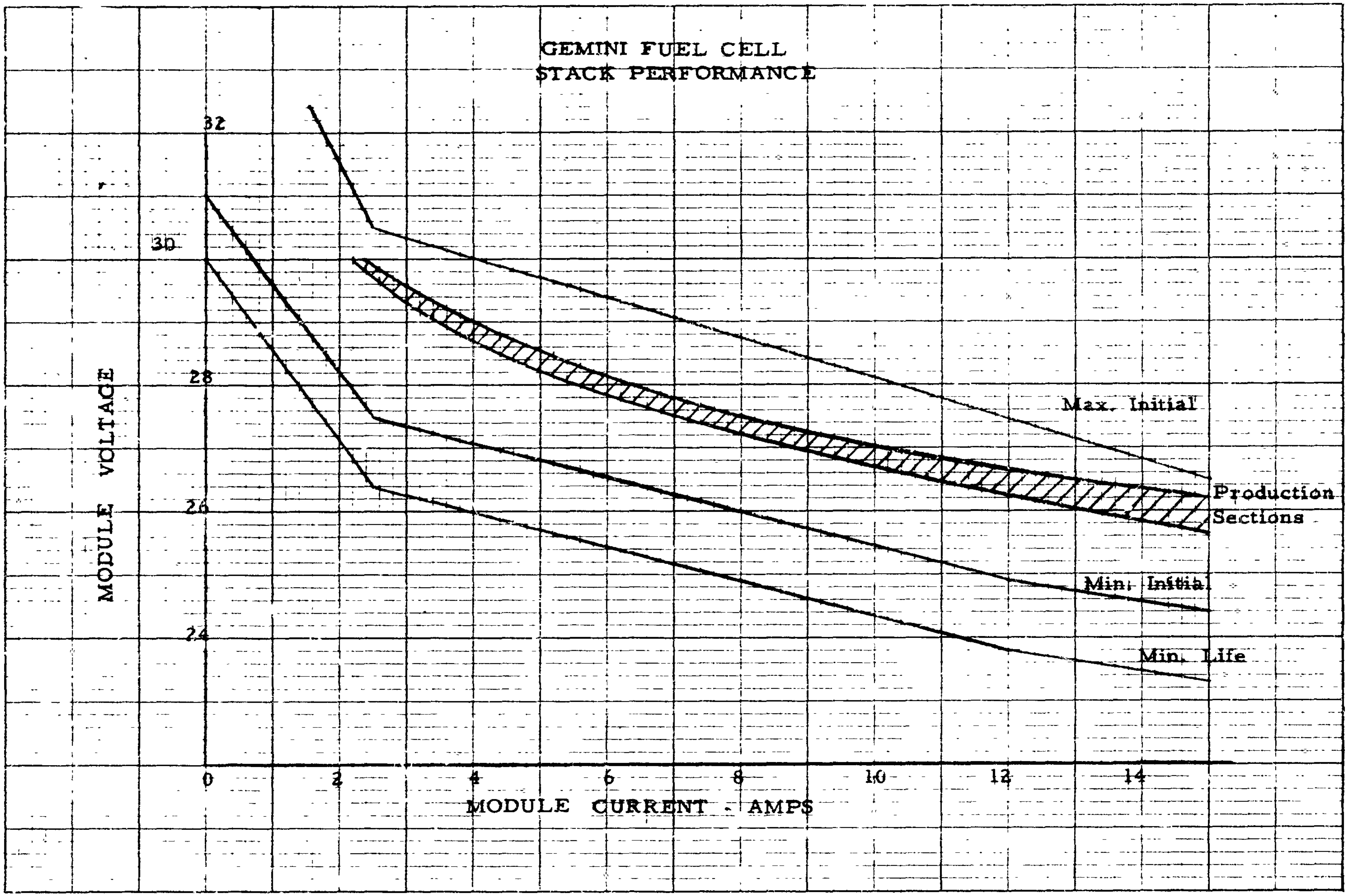

GEMINI FUEL CELL
STACK PERFORMANCE
MODULE VOLTAGE
32
30
28
26
24
0
2
4
6
8
10
12
14
MODULE CURRENT - AMPS
Max. Initial
Production
Sections
Min. Initial
Min. Life

Figure 7

SECTION V

TEST CHRONOLOGY

Following the second activation and completion of the polarization run shown in Section IV of this report, the first of the planned 56 eighteen-hour cycles of the MOL mission test was initiated on 24 March 1965 under the surveillance of the Air Force Project Officer, Lt. L. S. Harootyan. A chronological record of the overall section performance throughout the entire test is shown on Figure 8.

The first 10 cycles were run to the equivalent seven-section load conditions without incident. Beginning with the eleventh cycle, the load profile was raised to that equivalent to the six-section system. Once again, the next 10 planned cycles were completed without incident and the load profile raised to the equivalent five-section level for the 21st cycle. This load level was continued through the completion of the 30-day mission and was, in fact, maintained for nearly 34 days (cycle 45) before a slow performance degradation of the B module necessitated a reduction in the peak loads. The deterioration of module B performance was first noticed during the 37th cycle, at which point a brief open circuit check was made in accordance with standard Gemini procedures. The check was made during the low power portion of the cycle, and total section power was maintained by increasing the output of modules A and C.

Following cycle 45, operation was continued at reduced peak powers until approximately 918 hours into the mission, at which time the A module deteriorated in performance and had to be shut down and removed from the bus. The last complete cycle before the failure of module A was cycle 51.

At 11:10 A.M. on 2 May 1965, the degradation of module B dropped its performance below an acceptable level at 936 hours and it, also, was shut down and removed from the bus. Since the test plan required that a minimum continuous power capability of 200

DWG. NO. B

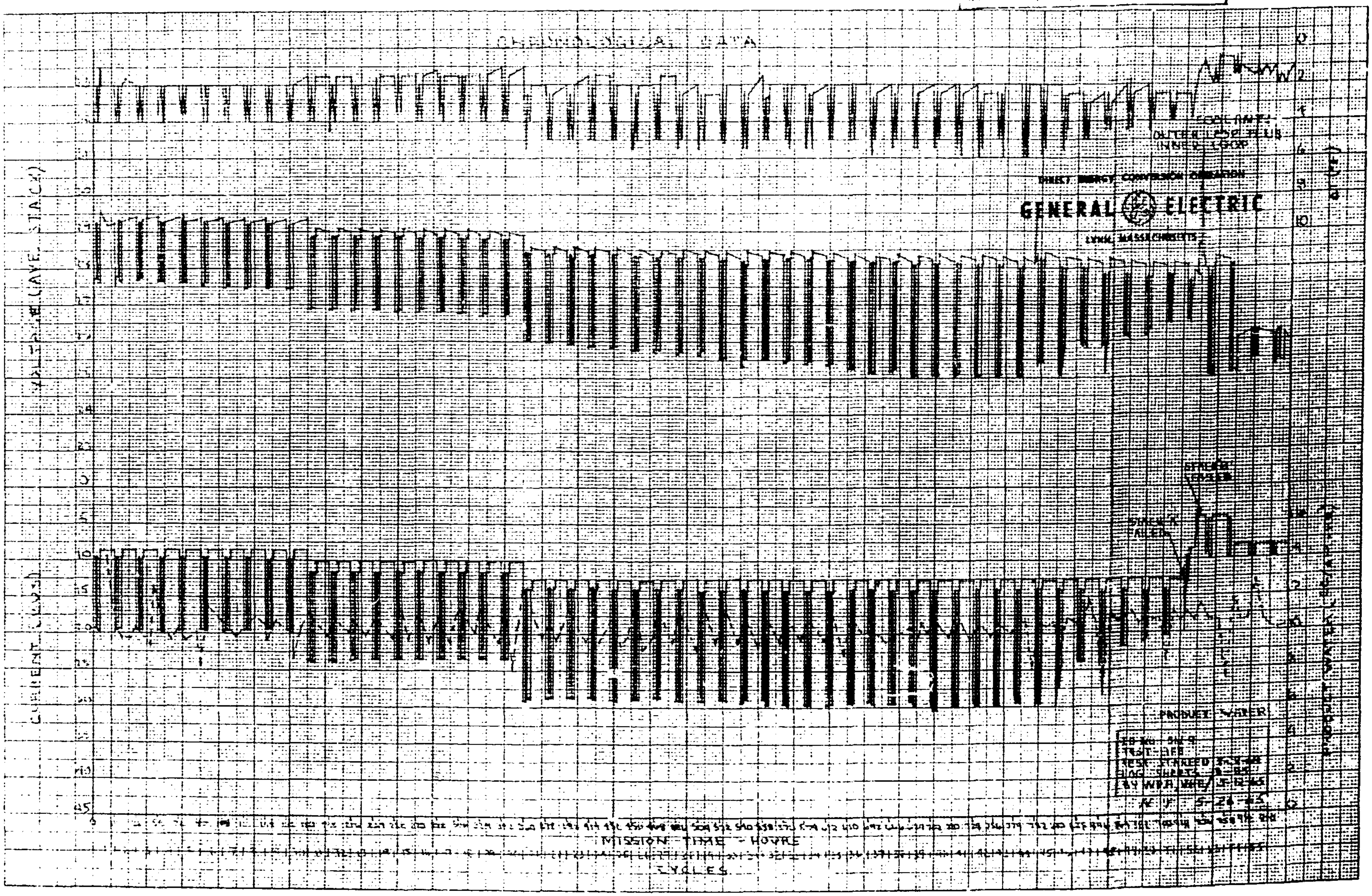


Figure 8

watts be demonstrated through the 1000-hour test period, the minimum power level of the C module was maintained at 215 watts, while the peak power levels were run to the maximum mission level of 252 watts.

Representative performance readings for each of the three modules during the various load regimes are shown on Table II.

Throughout the 30-day test the section operation conformed to procedures compatible with the spacecraft installation. The only discrepancy to occur from normal planned procedures, concerned the hydrogen purge cycle due to a partial clogging of the purge valve. During cycle 18 a reduction in the hydrogen purge flow rate was first noted, attributable to a partial clogging of the valve, possibly by soluble polystyrene sulfonate leached out of the ion-exchange membrane material. As a result, the duration of the purge cycle, normally 11 seconds for hydrogen and 2 minutes for oxygen, was increased to compensate for the reduced flow, as dictated by the flow restriction for each stack in order to maintain the required volume of the standard purge.

After 816 hours (34 days) it became necessary to by-pass the hydrogen purge valve because of erratic operation caused by the valve sticking. Provisions for such a by-pass can be made in the spacecraft system design if necessary. The possibility of changing the valve clearances is under review.

TABLE II

REPRESENTATIVE PERFORMANCE READINGS

Cycle #	Test Hours	Power Watts	Bus Current (Amps)	Module Current (Amps)			Average Module Voltage (Volts)
				A	B	C	
1	18	539	18.54	6.29	6.43	6.92	27.60
		282	9.73	2.89	3.15	3.73	29.10
		254	8.71	2.75	2.89	3.11	29.32
10	180	539	19.48	6.22	6.64	6.72	27.48
		282	9.69	3.09	3.27	3.39	29.16
		254	8.63	2.71	2.90	3.05	29.34
11	198	630	23.79	7.68	8.10	8.10	26.92
		330	11.53	3.68	3.90	3.99	28.83
		297	10.32	3.28	3.47	3.61	29.00
20	360	630	23.38	7.73	7.92	7.80	26.77
		330	11.49	3.75	3.86	3.92	28.72
		297	10.28	3.31	3.44	3.55	28.90
21	378	756	28.92	9.66	9.86	9.50	26.08
		396	13.86	4.59	4.67	4.65	28.36
		356	12.51	4.04	4.22	4.28	28.48
40	720	756	30.46	11.20	9.12	10.25	25.09
		396	14.00	5.03	4.22	4.79	28.06
		356	12.66	4.50	3.79	4.40	28.20
45	810	756	29.61	10.29	10.04	9.37	25.41
		356	12.70	4.42	4.10	4.22	28.28
51	919	542	20.48	6.97	5.65	7.93	26.46
		356	12.83	4.35	3.77	4.75	28.18
52	937	349	13.15	-	5.53	7.66	26.58
		237	8.66	-	2.72	5.90	27.25
56	1000	253	10.04	-	-	10.04	25.37
			8.39	-	-	8.39	26.20

SECTION VI

DISCUSSION OF RESULTS

A characteristic of the Gemini fuel cell design with the presently used ion-exchange membrane material is that it exhibits a gradual increase in internal resistance over the duration of the mission with a resultant decrease in performance. Thus the life of a typical unit is normally determined by the length of time it can maintain the capability of generating the rated current output at, or above, the minimum system voltage. The rate at which this performance degradation occurs, and hence the life that can be expected from this design, is directly related to temperature of the membrane which, in turn, is a function of coolant temperature and flow rate and the loads at which the module is operated. The ratings and coolant conditions proposed for the application of the Gemini fuel battery to the MOL power system were based on an analysis of life test data from the Gemini program extrapolated to a 30-day minimum life requirement. The objective of this test, then, was to check the validity of this extrapolation and establish the capability of this design to meet the MOL mission requirements under suitable system operating conditions as mutually established by the General Electric Company and the Air Force. The test results as viewed in relation to this objective are discussed below:

Mission Power Capability:

The actual power levels versus time at which the fuel battery section operated throughout the test is shown in Figure 9. From this curve, it can be seen that a maximum scheduled load profile for the complete section was maintained for 810 hours. At this point, performance degradation of module B necessitated a reduction in the level of the peak load portion of the duty cycle, as shown. As mentioned previously, however, the maximum load profile was established on the basis of having failed more than one-third of the modules in the complete fuel battery system. If it is assumed that the three

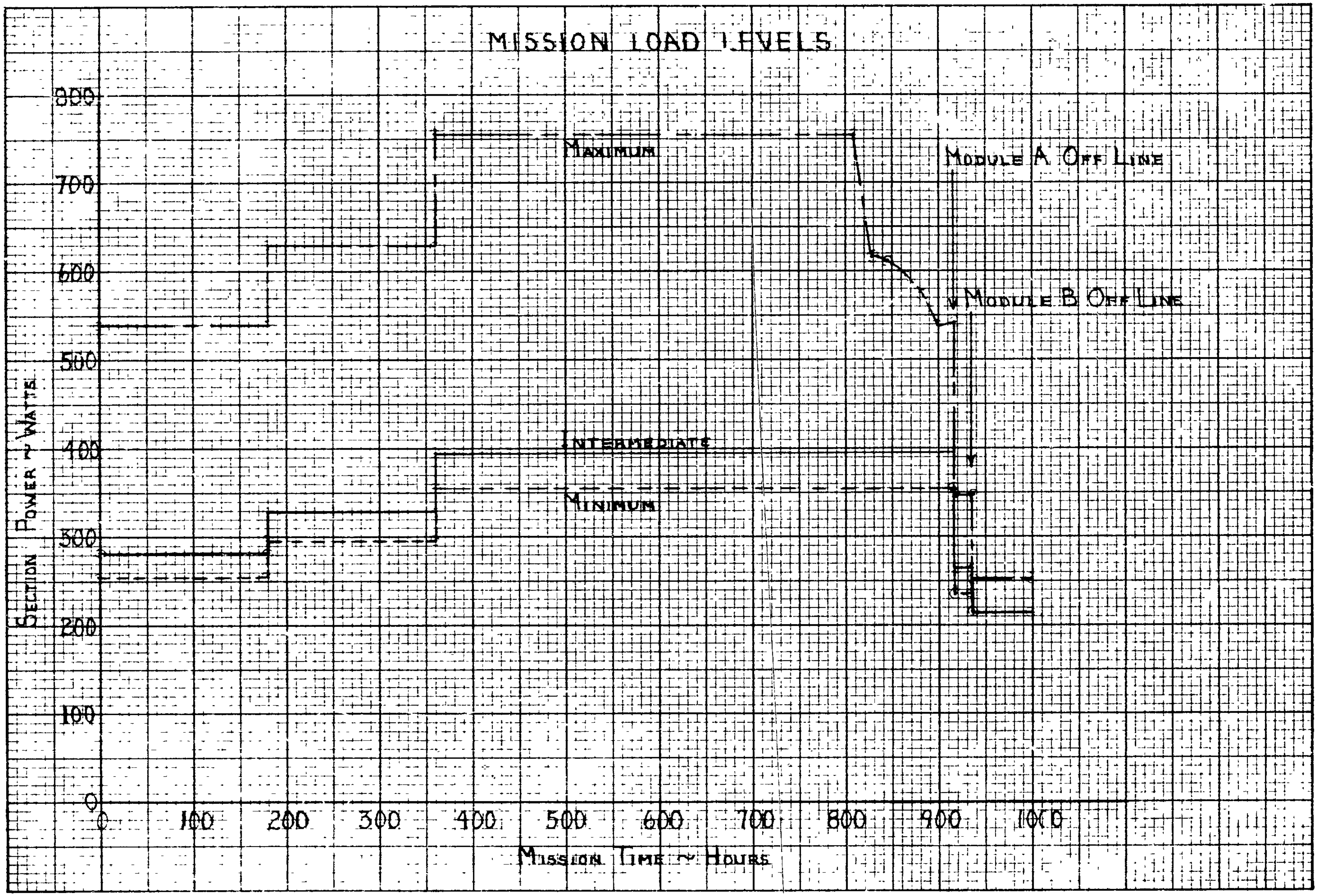

MISSION LOAD LEVELS
MAXIMUM
INTERMEDIATE
MINIMUM
MODULE A OFF LINE
MODULE B OFF LINE
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
SECTION POWER ~ WATTS
MISSION TIME ~ HOURS

Figure 9

modules used for this test are representative samples, therefore, it can be interpreted that the full mission power requirements could be met as long as the section power capability exceeded the equivalent maximum rated output of two of the three modules - or 504 watts. This power capability was maintained for 918 hours, until the point at which module A was shut down.

In order to assure adequate power for life support, a minimum continuous capability of at least 200 watts was specified for the section at the completion of the 1000-hour test. Following the failure of modules A and B, module C maintained a continuous output of 215 watts and peaks of 252 watts (the maximum rating for an individual module) for the remainder of the 1000-hour period. The last four hours were run at the peak power condition to demonstrate this full capability at the completion of the test.

Load Sharing:

The complete power system in the MOL vehicle will include a multiplicity of fuel cell modules operating electrically in parallel on a common bus. The capability of maintaining stable operation under all operation conditions throughout the mission is, therefore, an important factor in the capability of the Gemini fuel battery design to meet MOL requirements.

Figure 10 shows the overall performance characteristics of the section at various times during the mission, which represents the sum of the outputs from the three modules. The individual module performance at these times is shown on Figure 11. It can be seen from this figure that most of the performance loss indicated on the section performance curve was attributable to module B - which contributed a progressively lower percentage of the total current as time went on. During all this time, however, it did contribute useful power to the bus and was operating satisfactorily in parallel with the other two modules.

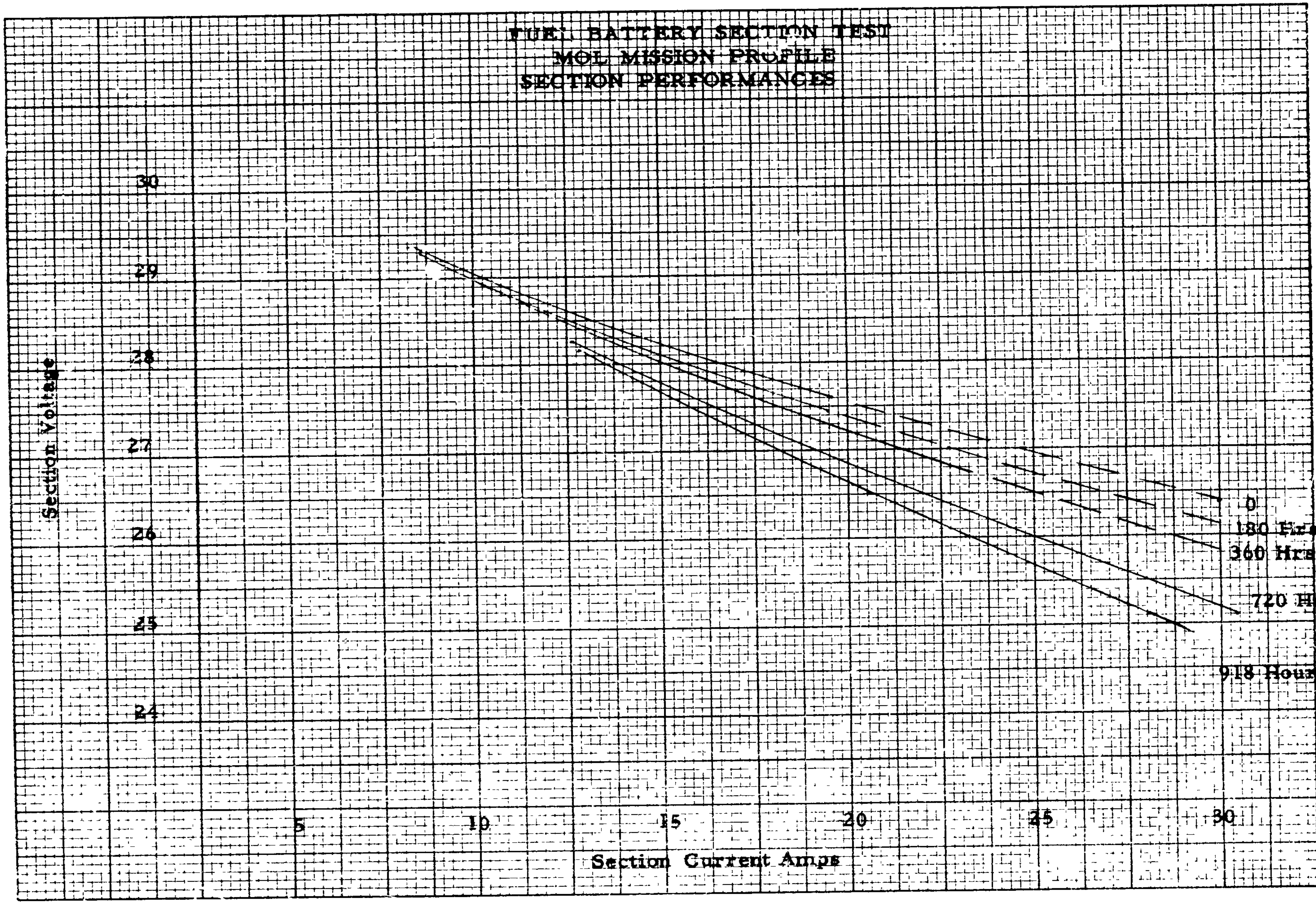
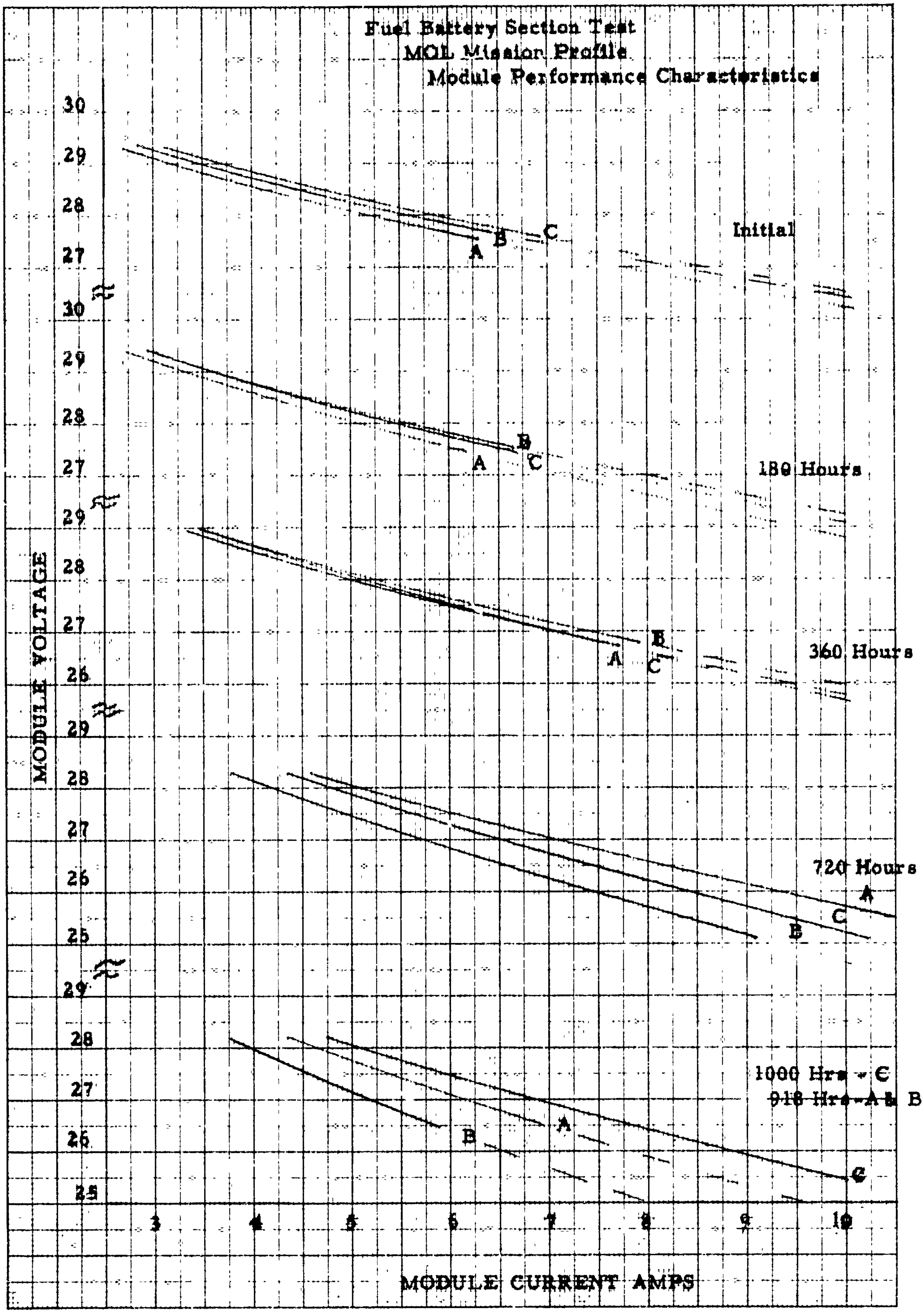

FUEL BATTERY SECTION TEST
MOL MISSION PROFILE
SECTION PERFORMANCES
Section Voltage
30
29
28
27
26
25
24
Section Current Amps
5
10
15
20
25
30
0
180 Hrs.
360 Hrs.
720 Hrs.
918 Hours

Figure 10



Fuel Battery Section Test
MOL Mission Profile
Module Performance Characteristics
Initial
180 Hours
360 Hours
720 Hours
1000 Hrs - C
918 Hrs - A & B
A
B
C
MODULE VOLTAGE
MODULE CURRENT AMPS

Figure 11

During the early part of the mission, load sharing between the three modules was very good - within ± 5%. At the 30-day point, this had increased to approximately ± 12%, and at the time of module A failure, was about 13.5%. Thus, even though there may be non-uniformity in module performance during a mission, each module can be expected to operate satisfactorily in parallel with better-or-worse performing modules, providing useful power to the bus up to the point of complete power loss.

Transient Response:

During the conduct of the test, a Sanborn recorder was used to obtain traces of typical transient voltage and current characteristics. These are shown in Figures 12 and 13, which depict both the bus parameters and those of the individual modules.

For both a step load increase and load removal, it will be noted that the power response is virtually instantaneous, with a slight overshot (or undershoot) of current. Of significance, however, is the fact that there is no overshoot of voltage which would affect regulation limits. The total time to reach steady-state conditions is approximately 1.5 seconds.

Product Water:

Product water samples were taken each day throughout the test and analyzed for pH value and conductance. Characteristic results are shown in Table III. The pH values varied from a high of 3.4 at the end of the test to a low of 2.6 at the eight-day point. The conductance, which provides an indication of the quantity of dissolved solids, increased from 391.8 micromhos/cubic inch at the beginning of the test to 923.3 after eight days. It then decreased to 189.4 at the completion of the test - following approximately the decrease and subsequent improvement in the pH values.

SECTION - RESPONSE TO STEP LOAD INCREASE
(14.0 amps to 29.0 amps, Total Load) 4/15/65

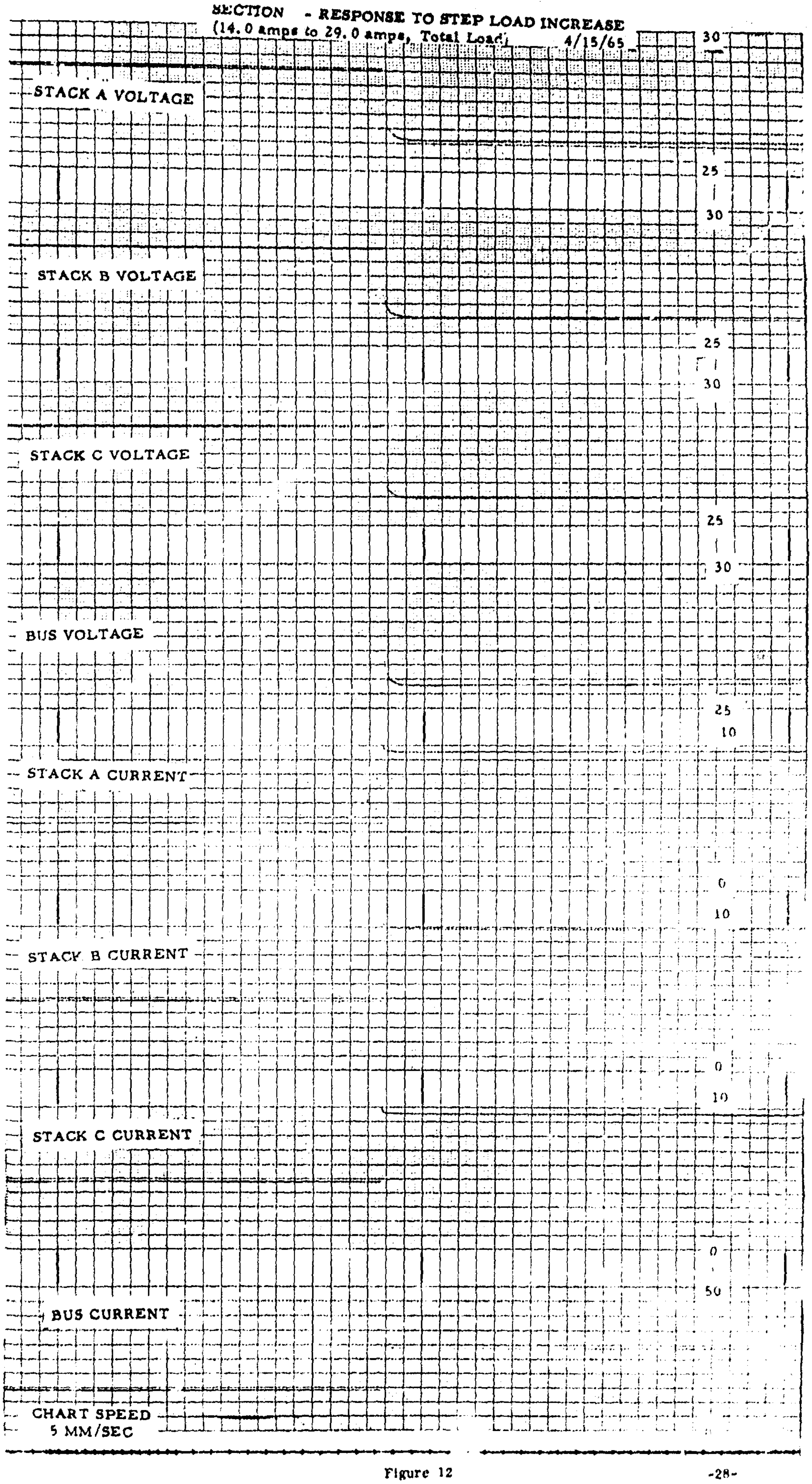


Figure 12

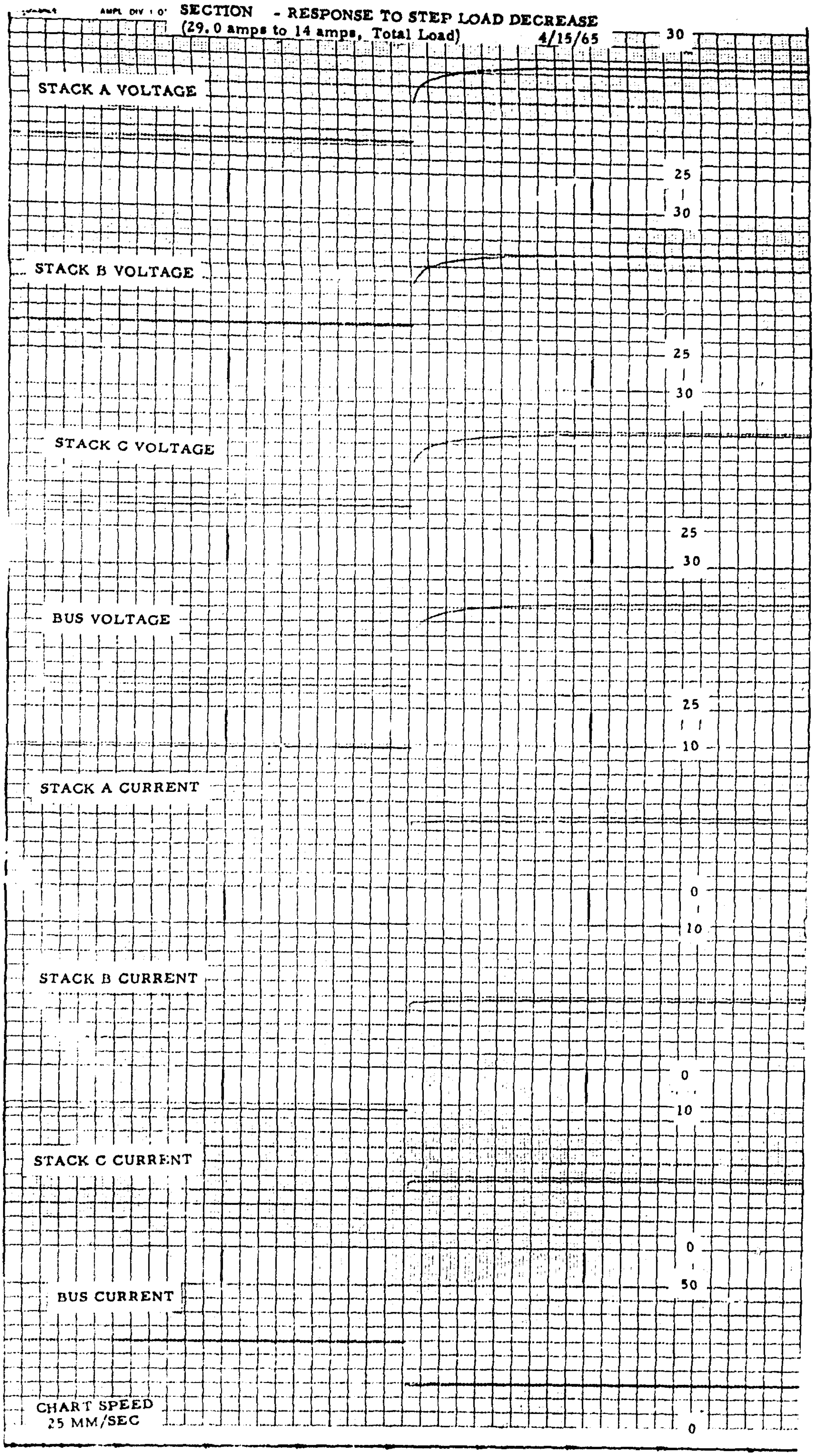

SECTION - RESPONSE TO STEP LOAD DECREASE
(29.0 amps to 14 amps, Total Load) 4/15/65
30
STACK A VOLTAGE
25
30
STACK B VOLTAGE
25
30
STACK C VOLTAGE
25
30
BUS VOLTAGE
25
10
STACK A CURRENT
0
10
STACK B CURRENT
0
10
STACK C CURRENT
0
50
BUS CURRENT
CHART SPEED
25 MM/SEC
0

Figure 13

TABLE III

PRODUCT WATER CHARACTERISTICS

Date	Approximate Mission Hours	pH	Specific Conductance (Micro mhos/cu. in.)	Appearance
3/26/65	16	3.0	391.8	clear
3/30/65	139	3.0	424.6	clear
4/3/65	237	3.0	463.0	clear
4/7/65	330	3.0	474.5	clear
4/11/65	427	2.8	549.8	clear
4/15/65	523	2.7 +	777.0	clear
4/19/65	619	2.8	636.1	clear
4/23/65	714	2.6	923.3	very pale yellow
4/27/65	810	2.9 -	508.2	clear
5/1/65	906	3.0	418.8	clear
5/5/65	1000	3.4	189.4	clear

SECTION VII

CONCLUSIONS

The salient conclusions reached as a result of this test are the following:

1. The section tested maintained the MOL power profile in all respects at a voltage above 25V for 810 hours.

2. The section demonstrated a capability of meeting at least 2/3 of the peak power requirements up to 918 hours.

3. A single module in the section carried its share of the section load above 25V for 1000 hours.

4. At the end of 1000 hours of mission time the remaining module was capable of producing 253 watts at a voltage of 25.37V.

5. After failure of individual modules, the remaining modules are able to continue extended operation independently.

6. Satisfactory load sharing and stable parallel operation can be maintained even with non-uniform performance characteristics.

7. The Gemini fuel cell design will respond instantaneously to step load changes with no effect on load sharing between modules.

8. Characteristic results indicated pH values varying from a high of 3.4 at the end of test to a low of 2.6 at the eight-day point. Conductance values increased from 391.8 micromhos/cubic inch at the beginning of the test to 923.3 micromhos/cubic inch after eight days. It then decreased to 189.4 micromhos/cubic inch at the completion of test - following approximately the decrease and subsequent improvement in the pH values.

9. As a result of the above conclusions, the Gemini fuel battery design appears suitable for the MOL mission.

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11 SUPPLEMENTARY NOTES --	12 SPONSORING MILITARY ACTIVITY Air Force Aero Propulsion Laboratory Research and Technology Division AFSC, Wright-Patterson AFB

13 ABSTRACT It was requested that the General Electric Company furnish a complete Gemini fuel cell battery with canister and all associated auxiliary equipment and all personnel and facilities required to accomplish a 1000-hour operational test under conditions which simulate the mission power requirements of the Air Force's Manned Orbiting Laboratory (MOL). The objective of this program was to test a Gemini Fuel cell battery and to obtain and evaluate data on its performance throughout the continuous operational test. A Gemini fuel cell battery, consisting of three individual 32-cell modules, was tested in accordance with a test plan approved by the Air Force Aero Propulsion Laboratory. The Gemini production fuel cell battery successfully met all requirements of the test plan for the 1000 hour period. Complete MOL power requirements were successfully met for 810 hours (34 days) following which the peak powers were reduced in accordance with the test plan to maintain a 25 volt output. The test confirmed that Gemini production hardware is capable of satisfying the 30-day MOL mission requirements and provides the growth capability to serve missions up to and beyond 1000 hours duration.

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