APPENDIX

FINAL REPORT
CAPILLARY MATRIX AND FUEL CELL DEVELOPMENT STUDY

Contract NAS9-10443

ALLIS-CHALMERS

ADVANCED ELECTROCHEMICAL PRODUCTS DIVISION • GREENDALE, WISCONSIN 53129

CR-108759

APPENDIX

TO

CONTRACT NAS 9-10443

FINAL REPORT

FOR

CAPILLARY MATRIX AND FUEL CELL

DEVELOPMENT STUDY

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Document No. 80045-165
September 17, 1970

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2.2 HYDROGEN VENTING

The outlet port of the hydrogen relief valve and purge valve is connected to a "hydrogen dump line" which is vented to the outside of the building.

2.3 PURGING

Each test bench has the capability of manual or automatic purging. A regulating valve, which is adjusted to pre-set the required ampere-equivalent purge flows, is located downstream of both the hydrogen and oxygen purge valve. Traps are installed in both purge lines to monitor the amount of liquid that is expelled from the reactant cavities during a purge.

2.4 INERTING

Helium is supplied to each test bench up to 100 psig and may be regulated to supply all cavities at pressures up to 30 psig. The gas is filtered through a 15 micron filter.

2.5 PRODUCT WATER

2.5.1 Vacuum

The laboratory vacuum supply is used to apply vacuum to the water removal cavity. A manual vacuum regulator located at each test bench permits manual adjustment of the vacuum supply level from 0 to 28 inches of mercury vacuum. The water cavity pressure is maintained within required tolerance by a special circuit which is used in conjunction with an absolute pressure mercury manometer (U-tube). The manometer is used for readout of water cavity pressure as well as control. The water cavity pressure controller is such a unique feature of the semi-automatic test bench design that further discussion of operation is warranted.

Refer to Figure 1 for reference. The water cavity pressure controller consists of a closed end manometer and associated circuitry depicted in Figure 1. Three nichrome wires are enclosed in one leg of the manometer. Wire No. 1 is always in contact with

APPENDIX A

SMALL STACK TEST BENCH DESCRIPTION

1.0 GENERAL DESCRIPTION

The NASA small module test benches consist of items depicted on electrical schematic 49602873 and pneumatic schematic 49602872. The test benches used to test small modules in accordance with Contract NAS9-10443.

A total of nine test benches used to test small modules and to monitor necessary performance evaluation parameters; i.e., voltage, temperature, etc. The test benches involved are numbers 220-1, 2, and 3; 230-1, 2, and 3; and 240-1, 2, and 3. The aforementioned test benches have been used on a previous NASA program and have currently been modified per updated design requirements. Modifications of the test benches incorporate the "cold plate" temperature control method for stabilizing cell temperature. Each test bench has the capability for semi-automatic operation which eliminates the need for 24 hour test operator surveillance. An automatic shutdown for any test bench will result if the value of any one of five parameters exceeds or falls below predetermined set limits. The five parameters are cell voltage, cell temperature, hydrogen reactant pressure, oxygen reactant pressure, and water cavity pressure. Provisions have been made to retain the cause of shutdown; i.e., low cell voltage, etc.

2.0 PNEUMATIC AND ELECTRICAL FEATURES

2.1 REACTANT CONTROL

Reactants are accepted by the test benches at a nominal pressure of 75 psig. Reactant pressures are reduced from an inlet level of 75 psig to 22 $\pm$ 0.2 psig which is required by the small module. Manual pressure regulators are used to regulate the reactant inlet pressures to the desired level. The reactant pressures are also balanced to within 1.0 psid maximum from 1 to 100 ampere equivalent flow.

Reactant gases, utilized by the small modules, are filtered through 15 micron filters. Either reactants can be manually isolated from the cell by means of manual valves and/or electrical solenoid valves.

the mercury. The remaining two wires (No. 2 and 3) are normally slightly above the mercury column. All three wires terminate outside of the manometer through a rubber stopper which fits snugly in one end of the manometer. The vertical distance (d) between wires no. 2 and 3 conform to the required control tolerance of the water cavity pressure; e.g., $\pm$ 5 mm of mercury. If the water cavity pressure decreases below desired setpoint, the column of mercury in the right leg of the manometer will rise until it makes contact with wire no. 3. At that point the external circuit is completed by the mercury and the relay R1 is energized. Relay R2 is energized subsequent to the energization of relay R1. The contacts of relay R2 close and energizes a normally closed solenoid valve. The solenoid valve allows air to be bled into the vacuum line, thus increasing the water cavity pressure. As the water cavity pressure increases, the mercury column in the right hand leg of manometer moves downward. The solenoid valve continues to stay open as long as the mercury is in contact with wire no. 2. The mercury column continues to move downward until discontinuity exists between the mercury and wire no. 2, at which time the solenoid valve is de-energized. The vertical distance between wire no. 2 and 3 is critical in determining the tolerance of control for the water cavity pressure. The water cavity pressure controller will be set to maintain the water cavity pressure to within $\pm$ 3 millimeters of mercury of setpoint.

2.5.2 Product Water Condensation

Individual 250 milliliters graduates are provided for each test bench for collecting and measuring the product water during daily operation (first shift only). Since the cells are to run continuously, a 4000 milliliter flask is provided for each test bench to collect the product water during the 16 hours of non-surveillance operation. The vacuum supply to the flask or graduate may be individually shut off at the product water collectors.

2.5.3 Thermal Control

Each test bench has the capability of supplying water coolant to a pair of "cold plates" each of which are located on the top and bottom end plate of the cell. A temperature controller is setup to open a solenoid valve which allows coolant to circulate through the cold plate when the cell temperature exceeds a predetermined upper limit. A thermocouple located on a cell plate is used as the temperature sensor for the temperature controller.

The aforementioned cold plate consists of a copper plate (5.5" x 7.5" x 3/32") with a 1/4" O.D. copper coil which is silver soldered onto one face of the plate. The copper coil is sinusoidal in shape and symetrically traverses the longer side of the plate. Each cold plate has five screw holes which allow it to be securely attached to each stainless steel end plate of the cells.

Four strip heaters are located on the flat edge of the end plates of the module (a pair of heaters on each end plate). Each strip heater is rated for 150 watts. It is possible to adjust the total power to the heaters from 0 to 600 watts by manipulating a variable rheostat located at each test bench. The module, along with heaters, is mounted inside of a thermally insulated cubicle which is located behind each test bench.

2.5.4 Reactant Purge Network

The reactant purge valves may be manually opened or automatically opened, by actuating the purge switch to the "manual" position. When the purge switch is actuated to the "auto" position, the purge valves will be energized to open at a time pre-set by an interval timer. The interval timer can be adjusted from one to sixty minutes in one minute increments. In conjunction with the interval timer, a duration timer is used to set the time during which the purge valve stays open. The duration timer can be adjusted from 0 to 15 seconds (0.2 second increment). Thus, each test bench has the maximum capability of purging a small module for 15 seconds every hour. A light illuminates on each bench panel when either the oxygen or hydrogen purge valve is energized.

2.5.5 Water Cavity Control Valve

The water cavity valve is normally energized to stay open while the small module is on load. The valve is energized to stay open by actuating the water cavity valve switch to the "manual position". A light illuminates when the water cavity valve is energized to open.

2.5.6 Load Circuit

Each test bench has the capability of monitoring up to four sections. During setup, the small module is placed in a thermally insulated cubicle. Load cables and cell voltage readout wires are connected to certain tabs located on the cell plates. The load cables and readout wires are brought out through the oven interface and terminate at specified points within the test bench. A variable carbon pile resistor is used to vary loads from 1 up to 100 amperes. For one section (one cell pair) either the complete section or each single cell within the section can be monitored for current.

2.5.7 Instrumentation

Each test bench panel contains a selector switch which selects the instrumentation points to be read out on the DVM. Signals available for monitoring on the DVM are as follows:

(a) Total Module Voltage

(b) Module Current

(c) Individual section voltages up to a maximum of four sections

The aforementioned signals are monitored on two DVM's which are centrally located in reference to the nine test benches. The signals can be monitored separately for each test bench but only for one bench at a time. One DVM monitors current only, the other monitors cell voltages. The voltage leads emanating from the module for voltage readout are protected by 1/8 ampere fuses. The following are the instrumentation requirements of the bench:

Function	Type	Range	Accuracy
H_2 Supply Pressure	Gauge	0 - 60 psig	2% mid-half of scale; 3% other
O_2 Supply Pressure	Gauge	0 - 60 psig	2% mid-half of scale; 3% other
H_2 Regulated Pressure	Gauge	0 - 30 psig	2% mid-half of scale; 3% other
O_2 Regulated Pressure	Gauge	0 - 30 psig	2% mid-half of scale; 3% other

Function	Type	Range	Accuracy
H_2 Reactant Flow	Rotameter	400 amp @ 38 psia	$\pm$ 2% Full Scale
O_2 Reactant Flow	Rotameter	400 amp @ 38 psia	$\pm$ 2% Full Scale
Temperature Control	Temperature Controller	0 - 400°F	1% at 200°F
Voltage and Current Readout	DVM	0 - 100 millivolts 0 - 10 volts	$\pm$ 0.1% of reading
Temperature Measurement	Thermo-couple Bridge	-100 to 400°F	0.3% of reading
Coolant Flow (water)	Rotameter	0 - 300 cc/minute	$\pm$ 2% Full Scale
On Load Time	Elapsed Timer	0 - 99999.9 hours	
Vacuum Leak Indicator	Rotameter	Not Applicable	Indicator

A 12 point temperature recorder will be provided to continuously record small module temperature for each bench. Thermocouples will be iron/constantan.

3.0 AUTOMATIC SHUTDOWN

Each test bench has the capability of automatically shuting down a small module in the event the reactant pressure, cell temperature, cell voltage, or water cavity pressure exceeds or falls below pre-set limits. The automatic shutdown mode consists of the following steps:

1. Any one of the aforementioned parameters exceeds or falls below pre-set limits.
2. Reactant valves are automatically de-energized, thus, isolating the reactant supply from the module.

3. Oxygen is burned off in the cell and replaced with nitrogen or air. Hydrogen is continually supplied at 2 psig to the hydrogen reactant cavity until most, if not all, of the oxygen gas is consumed in the cell.

4. The cell sits with a 2 psi differential between the hydrogen and oxygen reactant cavities ($H_2 > O_2$). The cell remains in this mode until it is restarted.

The sensors that are used to detect out-of-limit conditions are as follows:

Parameter	Sensor	Range	High and Low Limits*
O_2 Reactant Pressure	Pressure Switch	0.5 to 80 psig	19 to 25 psig
H_2 Reactant Pressure	Pressure Switch	0.5 to 80 psig	19 to 25 psig
H_2O Cavity Pressure	Vacuum Switch	0.8 to 29.34" Hg vacuum	To be set depending on KOH concentration
Cell Temperature	Double Setpoint Meter Relay	0 - 300°F	± 3°F of setpoint
Cell Voltage	Single Setpoint Meter Relay	0 - 5 VDC	To be set depending on size of module

*NOTE: The limits depicted above are tentative and are subject to change.

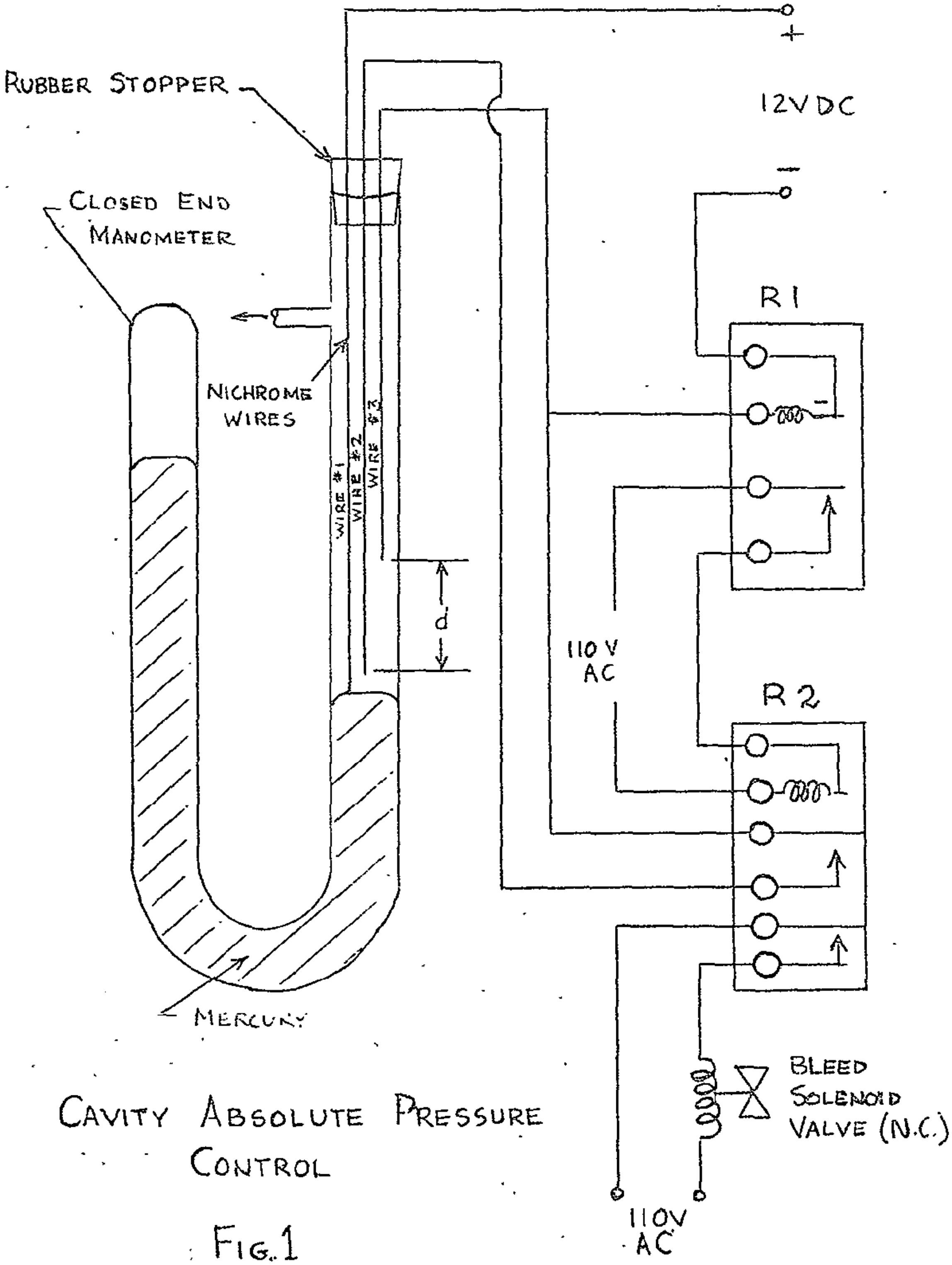
Each of the aforementioned sensors are equipped with electrical contacts which can be wired externally to relays. When any of the fuel cell parameters are out of limits, a main relay is de-energized. The contacts of the main relay open and de-energizes the hydrogen and oxygen reactant inlet solenoid valves. The reactants are isolated from the cell. Since the cell is still connected across the load, the reactants remaining in the cell cavities will continue to be consumed. When the reactant cavity pressure decreases to a value below 2 psi, the hydrogen cavity will be automatically supplied with hydrogen at 2 psi (NOTE: hydrogen reactant inlet solenoid valve is by-passed at this point). The reactants are burned off until most of the oxygen gas is consumed and a 2 psi differential exists between the hydrogen and oxygen cavities.

Each test bench has the capability of retaining the cause for shutdown. There are five lights located on a special panel above each test bench which when illuminated depicts the cause for shutdown. Once an alarm light is illuminated, it will remain illuminated until the alarm system is reset. Therefore, if the test bench is automatically shutdown during the 16 hour non-surveillance period, the following morning the operator can determine which parameter went out of limits. It should be emphasized that an illuminated alarm light indicates that a parameter is out-of-limits, but does not specifically depict whether the parameter has exceeded its upper limit or decreased below its lower limit. It is left up to the test engineer to determine which limit was surpassed.

4.0 SPECIAL INSTRUMENTATION

Internal resistance measurements of the stacks are made with a modified Keithly milliohmeter model 503. The IR measurement technique involves furnishing a known alternating (40 cps) test current to a sample and then measuring the resultant voltage drop.

The voltage is measured by a synchronous ac voltmeter sensitive only to the test current frequency. The test current is a square wave derived from a transistor inverter. The modification to the milliohmeter consists of two 16,500 mfd, 50 Vdc capacitors in series with the current and voltage lines between the milliohmeter and the fuel cell.



CAVITY ABSOLUTE PRESSURE CONTROL

FIG. 1

APPENDIX B

SYSTEM SPECIFICATION

(SECTION 3 - TECHNICAL REQUIREMENTS)

This document was prepared for the National Aeronautice and Space Administration (NASA) to serve as a guide in defining advanced fuel cell system requirements.

The primary application for future fuel cells is the "Shuttle" vehicle proposed by NASA. Requirement descriptions and other information were obtained from NASA and various aerospace contractors participating in the development of the "Shuttle" vehicle concept. This information was consolidated and evaluated in terms of the fuel cell.

This document represents the system requirements as would be reflected in the 3.0 section of a typical End Item Specification. This includes system functional, interface, and environmental requirements. In many interface and environmental areas, specific numbers could not be obtained since the particulars of the vehicle are not established. These are noted as "To Be Determined" (TBD).

1.0 SCOPE

This document was prepared for the National Aeronautice and Space Administration (NASA) to serve as a guide in defining advanced fuel cell system requirements.

The primary application for future fuel cells is the "Shuttle" vehicle proposed by NASA. Requirement descriptions and other information were obtained from NASA and various aerospace contractors participating in the development of the "Shuttle" vehicle concept. This information was consolidated and evaluated in terms of the fuel cell.

2.0 APPLICABLE DOCUMENTS

TBD

3.0 TECHNICAL REQUIREMENTS

3.1 PERFORMANCE

3.1.1 Functional Characteristics

The Fuel Cell Power System shall provide direct current (dc) to the Vehicle Bus at a nominal voltage of 28 volts dc (Vdc). It shall also provide potable water to a storage system in the vehicle. The FCPS shall provide instrumentation and override capability in all critical areas where on-orbit functional improvements or corrections can be made. Reactants and heat transport fluids will be supplied by the vehicle to the FCPS for the purpose of chemical energy conversion and thermal control, respectively. The FCPS shall be capable of providing power as specified in 3.1.1.1.2 and 3.1.1.1.3, on demand.

3.1.1.1 Primary Performance Characteristics

3.1.1.1.1 FCPS Terminal Voltage - The voltage at the power connector interface shall be 28V ± 5% over the range of power as stated in Paragraph 3.1.1.1.1.2.

3.1.1.1.2 FCPS Regulated Power Output - The FCPS shall deliver electrical power within voltage regulation over the range of 0 to 5 kW.

3.1.1.1.2.1 FCPS Rated Power - The maximum sustained power at which thermal equilibrium and voltage regulation are maintained with a maximum coolant inlet temperature as stated in Paragraph 3.2.4, shall be no less than 5 kW.

3.1.1.1.2.2 Average Power - The power which can be sustained for the life of the fuel cell,as stated in Paragraph 3.1.2.3.2, while retaining the capability to demonstrate the rated power of Paragraph 3.1.1.1.2.1 at the end of life, shall be no less than 2.5 kW.

3.1.1.1.3 FCPS Overload Power Capacity - The FCPS shall be capable of delivering electrical power up to 10 kW.

3.1.1.1.3.1 Transient Power - The FCPS shall be capable of supplying electrical power up to and including 11 kW during step change demands of TBD ms or less.

3.1.1.1.4 Power/Life Relationship - The total energy production capability of the FCPS while operating under any combination of power conditions as defined in Paragraphs 3.1.1.1.2 and/or 3.1.1.1.3 for any life up to and including that stated in paragraph 3.1.2.3.2 shall be no less than 12,500 kW-hr.

3.1.1.1.4.1 Power Time Profile - The FCPS shall meet the requirements of paragraphs 3.1.1.1.2 and 3.1.1.1.3 as applicable when operating within the power-time profile shown in Figure 3-1.

3.1.1.1.5 Parallel Operation - The FCPS shall be capable of meeting all the requirements specified herein when operating in parallel with any other power source.

3.1.1.1.6 Reactants

3.1.1.1.6.1 Hydrogen Consumption - Maximum hydrogen (H_2) consumption rate of the FCPS, when operating within the power requirements of 3.1.1.1.2 shall be equivalent to or less than that given by the curve of Figure 3-2.

3.1.1.1.6.2 Hydrogen Purity - The FCPS shall perform as specified herein when supplied at the FCPS interface with hydrogen gas meeting MSFC-SPEC-356 containing impurities not to exceed the following:

Helium and other inerts	39 parts per million (ppm)
Water	3 ppm
Hydrocarbons (methane equivalent)	6 ppm
Oxygen	1 ppm
Carbon Monoxide plus Carbon Dioxide, Total	1 ppm
Total Impurity	50 ppm
Total Hydrogen Purity	99.995%

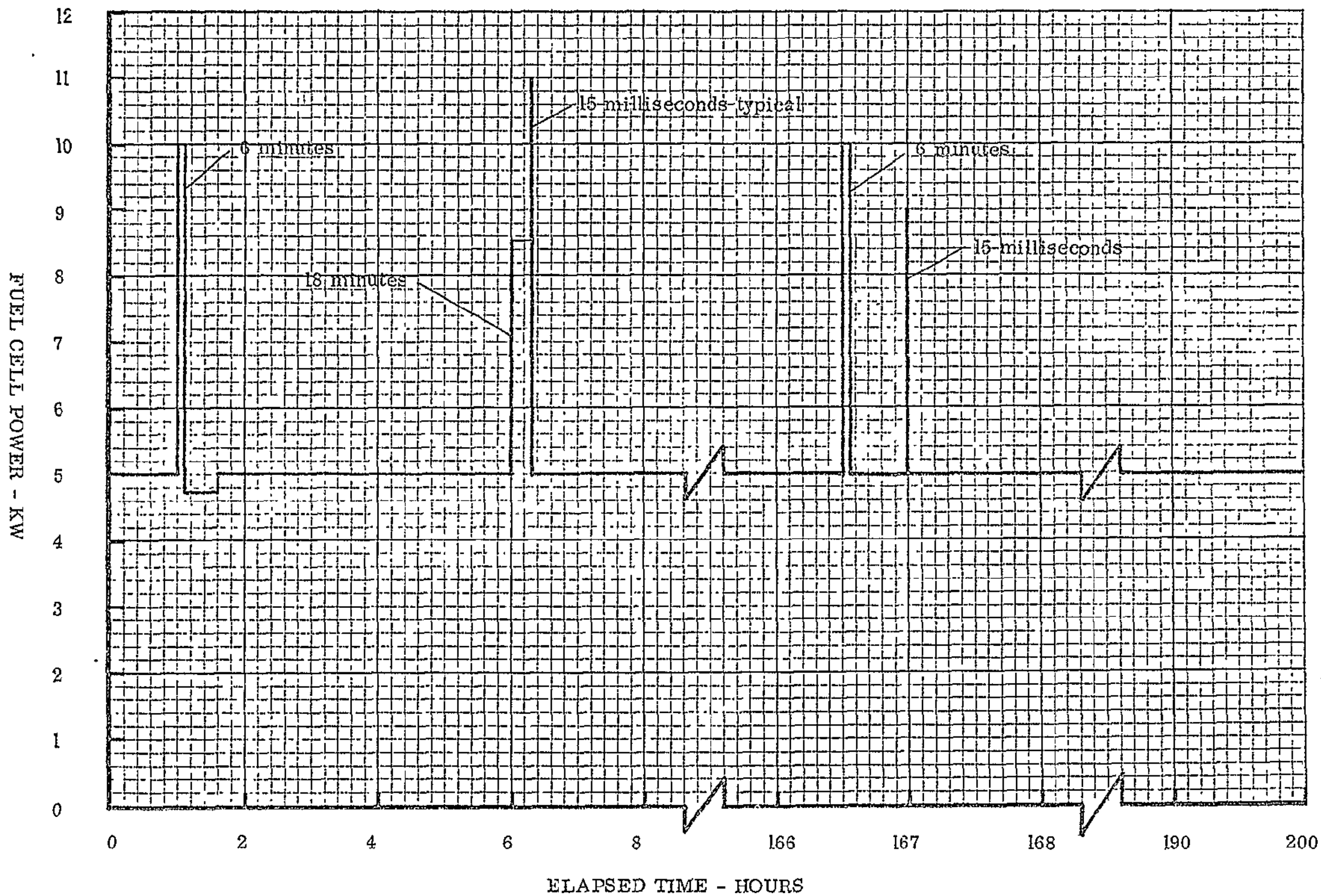


Figure 3-1 Power Profile

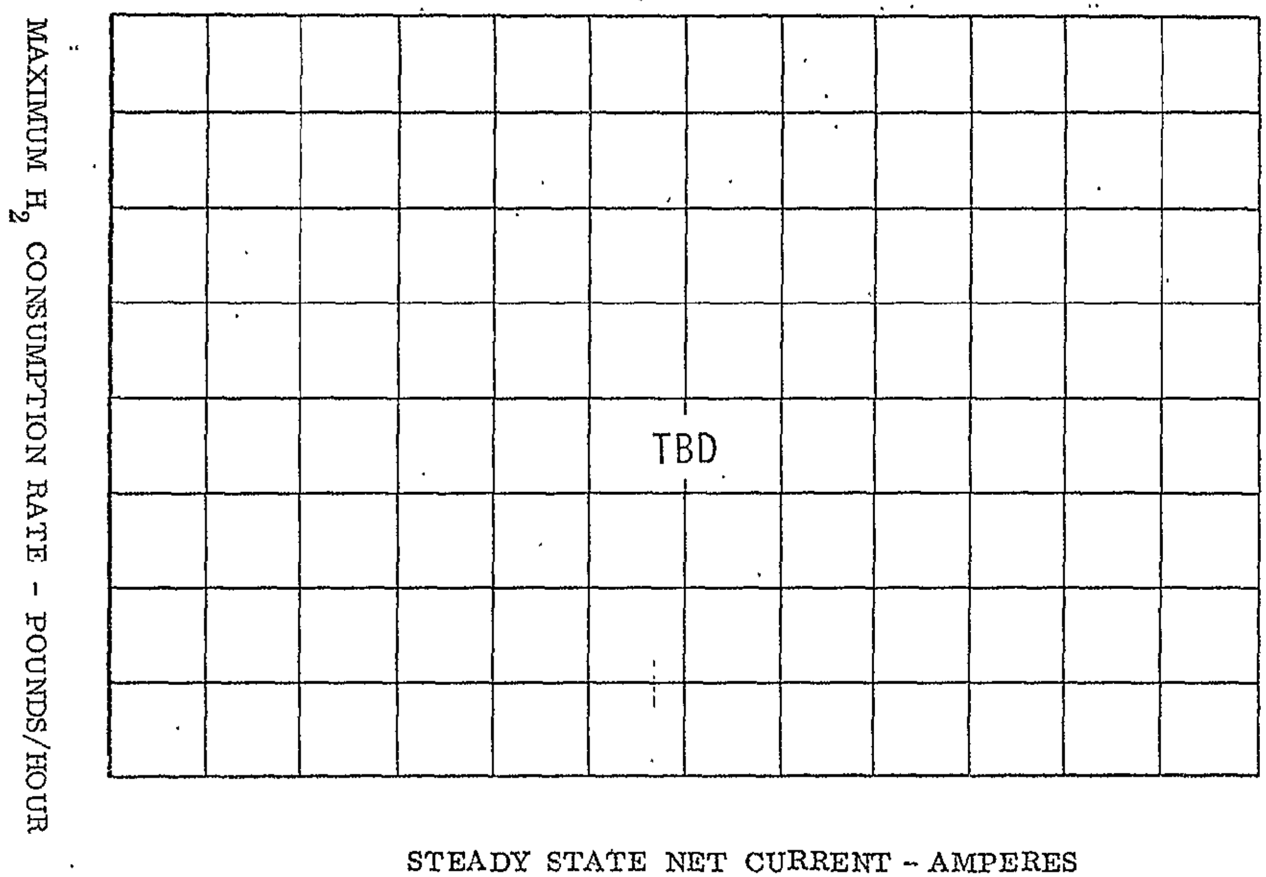


Figure 3-2. Maximum Allowable Total Hydrogen Consumption

3.1.1.1.6.3 Oxygen Consumption - Maximum oxygen (O_2) consumption rate of the FCPS, when operating within the power requirements of 3.1.1.1.2 shall be equivalent to or less than that given by the curve of Figure 3-3.

3.1.1.1.6.4 Oxygen Purity - The FCPS shall perform as specified herein when supplied at the FCPS interface with oxygen gas meeting MSC-SPEC-399, Grade A, containing impurities not to exceed the following:

Helium and other inerts	80 ppm
Nitrous Oxide	1 ppm
Hydrocarbons (methane equivalent)	15 ppm
Water	3 ppm
Carbon Monoxide plus Carbon Dioxide, Total	1 ppm
Total Impurity	100 ppm
Total Oxygen Purity	99.99%

3.1.1.1.7 Startup and Shutdown

3.1.1.1.7.1 Startup - The FCPS shall provide, within 15 minutes, power as specified in 3.1.1.1.2 within the environments of 3.1.2.4.3, 3.1.2.4.4, and 3.1.2.4.5 when provided with reactants, coolant, electrical switching functions, vacuum service, and electrical load.

3.1.1.1.7.2 Shutdown - The FCPS shall be capable of shutdown consisting of:

- Complete electrical shutdown (zero gross power)
- Complete reactant supply isolation of hydrogen and oxygen

The FCPS shall be capable of meeting the requirements of 3.1.1.1 following each cycle of startup and shutdown for a minimum of 200 cycles.

3.1.1.1.7.3 Standby - The FCPS, when supplying zero net electrical power under the environments specified in 3.1.2.4.3, 3.1.2.4.4, or 3.1.2.4.5, shall be capable (within

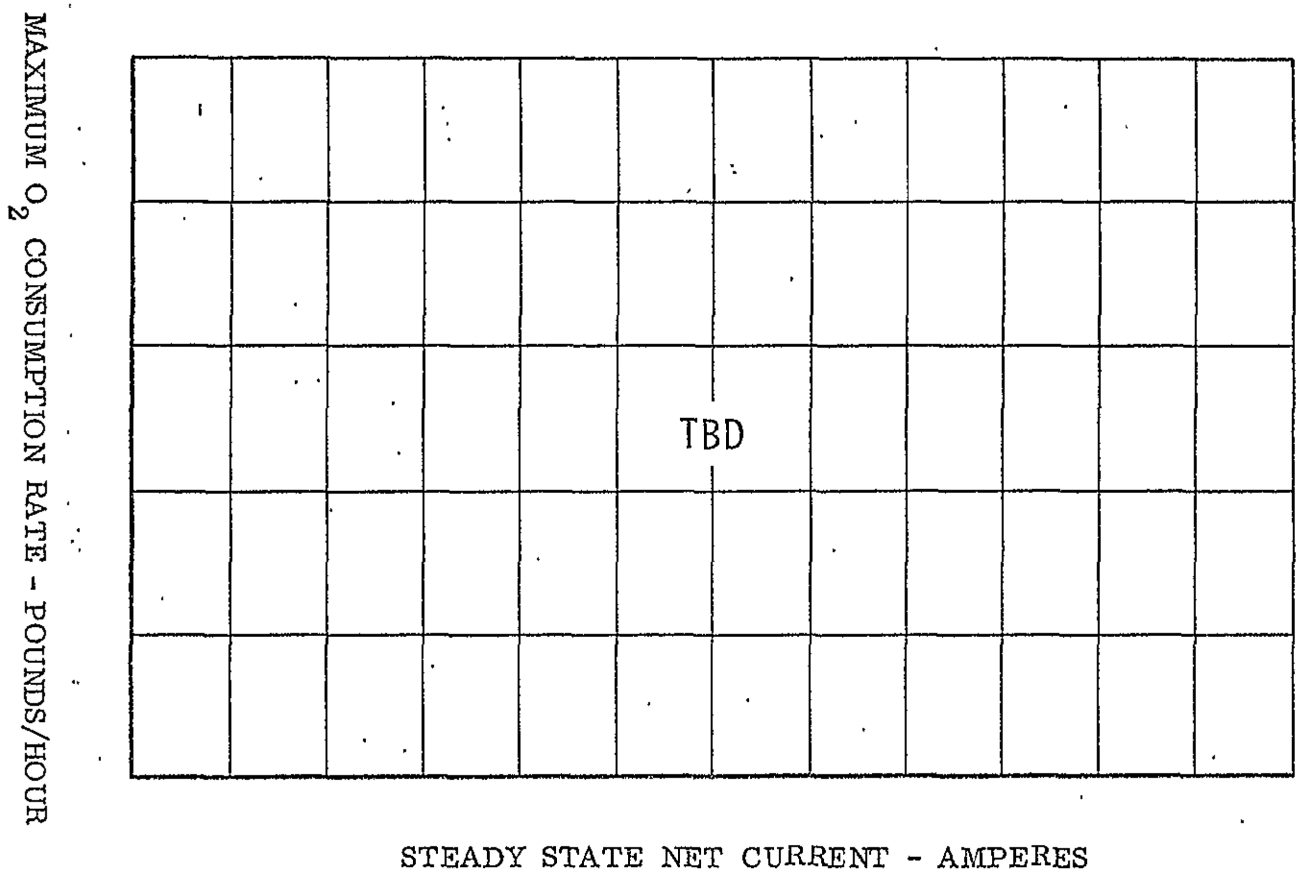


Figure 3-3. Maximum Allowable Total Oxygen Consumption

15 minutes) of meeting the requirements as specified in 3.1.1.1.

3.1.1.1.8 Controls - The FCPS shall include integral self-regulation and control for reactants, temperature, and product water removal. Provisions shall be included to permit interface with a vehicle computer which will accomplish FCPS startup, checkout, performance monitoring, fault detection, isolation, and shutdown.

3.1.1.1.9 Water Production - The FCPS water production rate shall be proportional to the FCPS current production.

3.1.1.1.10 Powerplant Heat Rejection

3.1.1.1.10.1 Heat Rejection to Thermal Control Loop - The FCPS heat rejection to the interfacing coolant loop shall be within the bands specified in Figure 3-4.

3.1.1.1.10.2. Heat Rejection to Environment - The maximum heat loss from the FCPS to the vehicle environment specified in 3.1.2.4.5 shall be in accordance with Figure 3-5.

3.1.1.2 Secondary Performance Characteristics

3.1.1.2.1 Auxiliary Power Devices - All FCPS auxiliary loads supplied from the vehicle bus shall be designed to provide specified performance when supplied with steady-state voltages from 24 through 32 Vdc. All auxiliary power devices also shall withstand without damage (1) continuous overvoltages from 32 through 34 Vdc, (2) continuous undervoltages from 20 through 24 Vdc, and (3) any transient voltage between 0 and 24 volts for durations up to 30 milliseconds. The operation of the FCPS shall not adversely be affected as a result of any of the above conditions. The FCPS shall perform as specified herein upon return to steady-state voltage limits.

3.1.1.2.2 Instrumentation - The FCPS shall provide signals at the FCPS electrical interface for monitoring FCPS performance. All signals shall have singel-ended, two-wire outputs unless otherwise noted. The parameters to be monitored are included in Table 3-1.

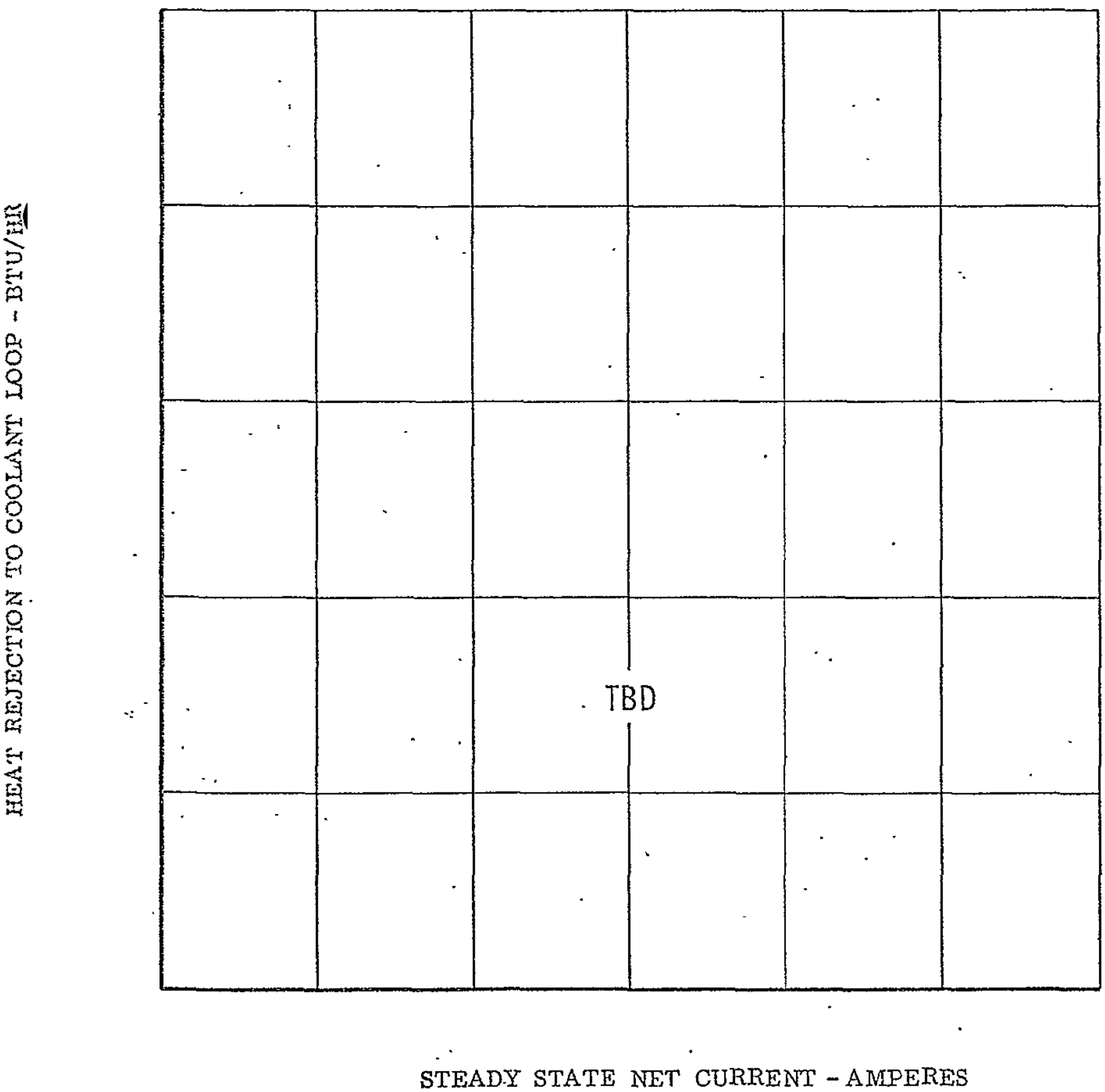


Figure 3-4. Heat Rejection to Coolant Loop

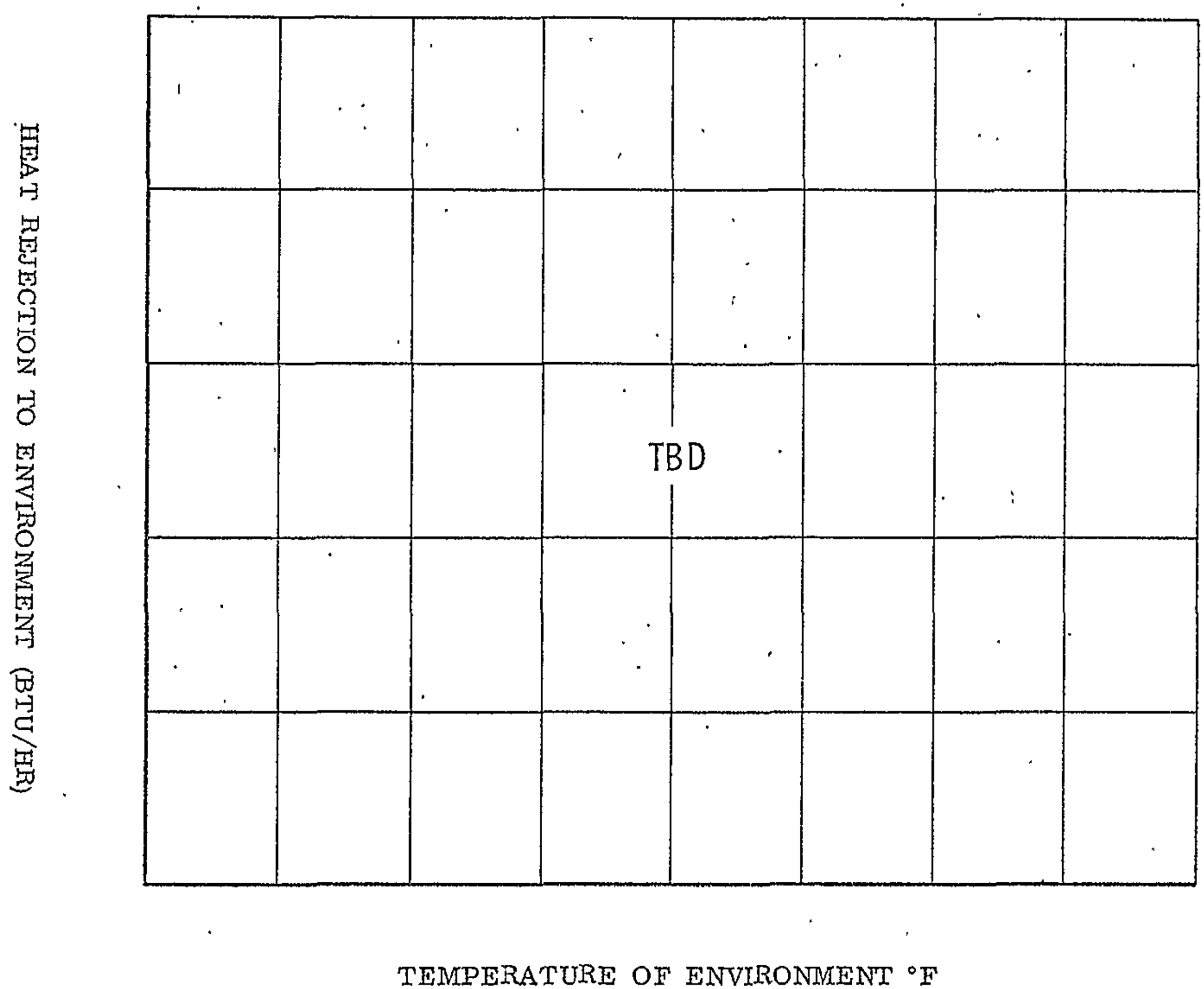


Figure 3-5. Allowable Heat Rejection To Environment

TABLE 3-1

INSTRUMENTATION REQUIREMENTS

Parameter	Parameter Range	Signal Range
Stack Temperature	130 to 230°F	0 to 5 vdc
Reactant Pressure (High) Reactant Pressure (Low) Water Cavity Pressure	>66 psia <28 psia 2.6 - 9.0 psia	4.5 - 5.5 vdc 2.0 - 3.0 vdc 0 to 5 vdc
Volts - Terminal at Stack(s)	0 to 36 vdc	0 to 36 vdc
Current - Stack(s)	0 to 210 amp	0 to 5 vdc
Purge Valve Position	Valve closed Valve open	Contacts open Contacts closed
Vent Valve Position	Valve closed Valve open	Contacts open Contacts closed
Other Parameters	TBD	TBD

3.1.1.2.3 Reverse Current - The FCPS, as a load, shall not be damaged by repetitive but random occurrences of reverse currents within the non-operating region(s) shown in Figure 3-6 and shall not cause or contribute to reverse currents outside of the non-operating region.

3.1.1.2.4 Product Water Conditioning

3.1.1.2.4.1 De-ionization - The product water shall be treated to control the product water pH within the range of 6.0 to 8.0.

3.1.1.2.4.2 Potability - The FCPS shall provide, at the interface, product water which is suitable for astronaut consumption as defined in MSC-PF-SPEC-1 (conductivity through particle size per test point 3, ionic species through sterility per test point 4).

3.1.1.2.4.3 Product Water Delivery - The FCPS shall supply product water to the Vehicle against a maximum steady-state system back pressure of 30 psia and a minimum of 0 psia.

3.1.2 <u>Operability</u>

3.1.2.1 Reliability - While operating within the requirements of this specification, The FCPS shall have a reliability of TBD or greater for a mission of 200 hours.

3.1.2.2 Maintainability - The FCPS shall be composed of modular plug-in Line Replaceable Units (LRU) that can be removed and replaced.

3.1.2.2.1 Ramp Maintenance - The ramp maintenance shall be accomplished in an average time of TBD hours. This time shall include the time to isolate the fault, remove and replace the faulty items(s), and retest to verify proper operation after repair.

3.1.2.2.2 Shop Maintenance - Shop maintenance shall be accomplished on any of the LRU's within an average time of TBD hours with no repairs exceeding a maximum of TBD hours. This time shall include the time to isolate the fault, remove and replace the

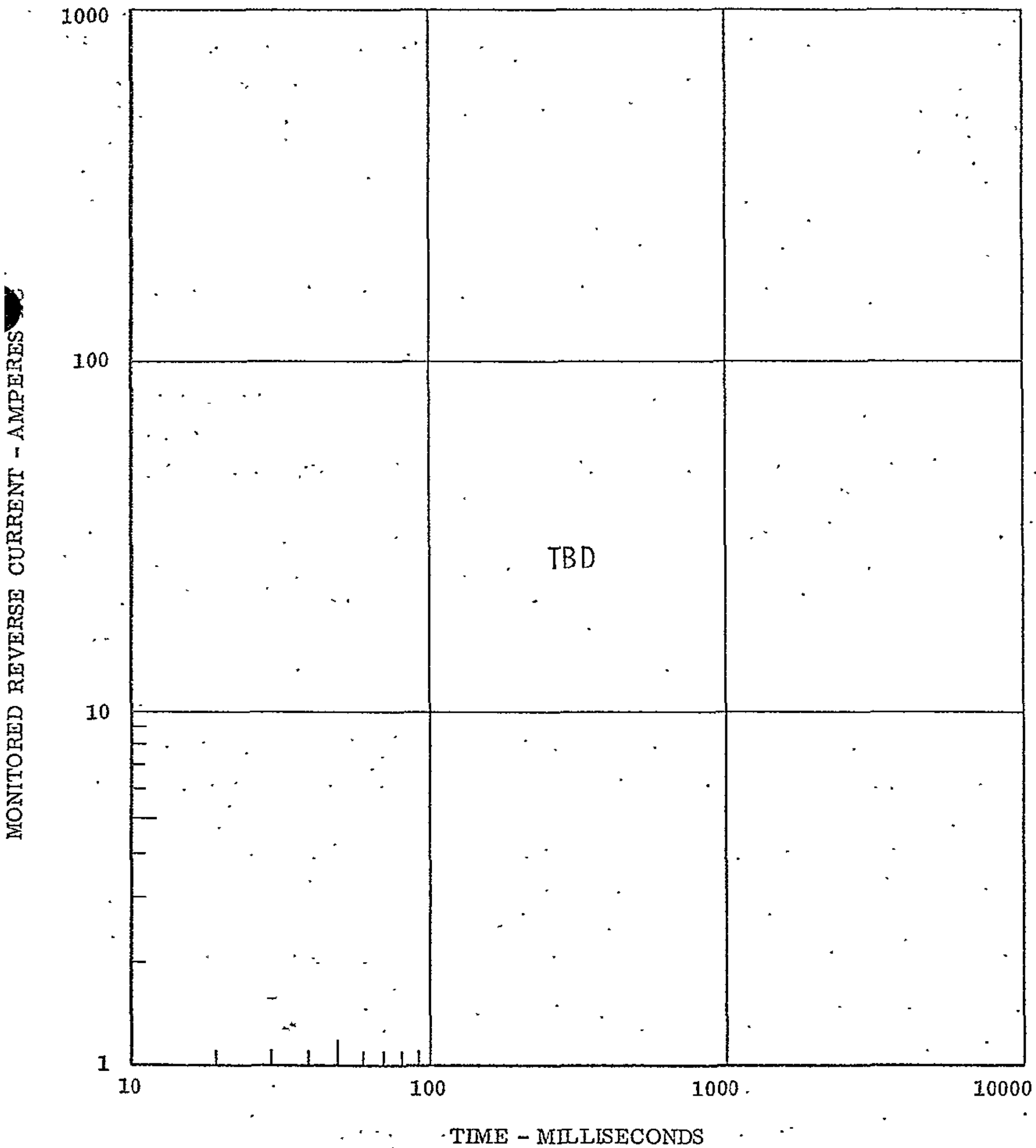


Figure 3-6. Reverse Current Characteristics

faulty item(s), and retest to verify proper operation after repair. Test equipment requirements shall be of such a nature that minimum training and skills are required by the maintenance personnel.

3.1.2.2.3 Preventive Maintenance - Preventive maintenance actions shall be kept to a minimum. Items identified for preventive maintenance shall be scheduled for action well in advance of expected end-of-life with an interval of no less than 200 hours.

3.1.2.2.4 Fault Detection and Isolation - Sufficient signals shall be monitored within the FCPS to provide the on-board computer with information necessary to monitor system health, identify fault occurrence, and take corrective action.

3.1.2.3 Useful Life - The FCPS shall have a minimum useful life of 45,000 hours under the environments specified in 3.1.2.4.. Useful life is comprised of storage life and operating life.

3.1.2.3.1 Storage Life - The FCPS or any part thereof shall have a storage life of 40,000 hours after which it shall be capable of supplying the power as specified in 3.1.1.1.2 and 3.1.1.1.3 minimum operating life as specified in 3.1.2.3.2. Preventive maintenance maybe accomplished during the storage life.

3.1.2.3.2 Operating Life - The FCPS shall be capable of supplying power as specified in 3.1.1.1.2 and 3.1.1.1.3 for a minimum of 5,000 hours cumulative. Operating life shall be considered to be the sum of all period of time during which reactants are applied to the FCPS.

3.1.2.4 Environment

3.1.2.4.1 Shipping, Handling and Storage - The FCPS may be exposed while non-operational to the following environments. During these exposures the FCPS shall suitably be protected to prevent exposure to the environments which are beyond the normal operational design limits. The FCPS shall be capable of operating within the performance requirements of this specification following shipping, handling, or storage under any combination of the following conditions:

a. Temperature - A minimum of minus 40°F and a maximum of plus 160°F.

b. Humidity - Relative humidities up to 100 percent including condensation in the form of water or frost.

c. Altitude - Altitudes to 50,000 feet during air shipment in unpressurized aircraft.

d. Transportation Shock - The FCPS shall be packaged to reduce the shocks induced by transporation and handling, to a level below that for which the FCPS was designed. The shock encountered by the packaged FCPS is given in Table 3-2. Severe shocks may be experienced during loading or unloading from a transport vehicle as indicated in Table 3-3. On-site assembly, loading, and transporation shock levels encountered by the unpackaged or packaged FCP shall be maintained at less than those experienced during transportation by common carrier.

e. Transportation Vibration - The FCPS shall be packaged to attenuate the transportation vibration to a level below that for which the FCPS was designed. During transportation by common carrier, the packaged FCPS may experience vibration amplitudes equivalent to those shown in Figure 3-7 subject to the weight-frequency dependence shown in Figure 3-8.

3.1.2.4.2 Installation and Checkout - When installed, protected and checked out in conformance with customer-approved Allis-Chalmers procedures, the FCPS shall suffer no performance degration beyond the range of electrical and mechanical performance criteria specified herein from exposure to the following environments:

a. Temperatures and humidities equal to or less severe than those imposed on the FCPS during prelaunch, launch and ascent, and on-orbit.

b. Pressure and Atmosphere - Normal exposure to air at 15 psia

SHOCK ENVIRONMENT

GROSS WEIGHT SHIPPING CONFIGURATION	MODE OF TRANSPORTATION			
	Rail	Truck	Cargo Aircraft	Cargo Vessel
0 to 250 lb	65 (max)	10	8	1.5
250 to 500 lb	45 (max)	8	6	1.5
500 to 1,000 lb	35 (max)	7	6	1.5
Above 1,000 lb	20 (max)	6	5	1.5
Duration(milliseconds)	10 to 50	8 to 40	0.8 to 40	0 to 40

Table 3-2. Shock Levels in G Experienced During Transportation

GROSS WEIGHT NOT EXCEEDING	DIMENSIONS ON ANY EDGE OR DIAMETER NOT EXCEEDING	FREE-FALL CORNERWISE DROP TEST (HEIGHT OF DROP)	EDGEWISE ROTATIONAL DROP TEST (HEIGHT OF DROP)	CORNERWISE ROTATIONAL DROP TEST (HEIGHT OF DROP)	INCLINE IMPACT TEST (IMPACT VELOCITY IN MPH)
Pounds	Inches	Inches	Inches	Inches	
50	36	22			
51 - 100	48	16			
101 - 150	60	14			
151 - 200	60	12			
201 - 600	72		27	27	5
601 - 3000	No Limit		18	18	5
No Limit	No Limit		9	9	5

NOTE: Height of drops shall satisfy both gross weight and dimensions. A container weighing between 51 and 100 pounds, having a diameter between 48 and 60 inches (or a maximum edge dimension between 48 and 60 inches) shall be free-fall dropped 14 inches.

Table 3-3. Handling Shock Levels

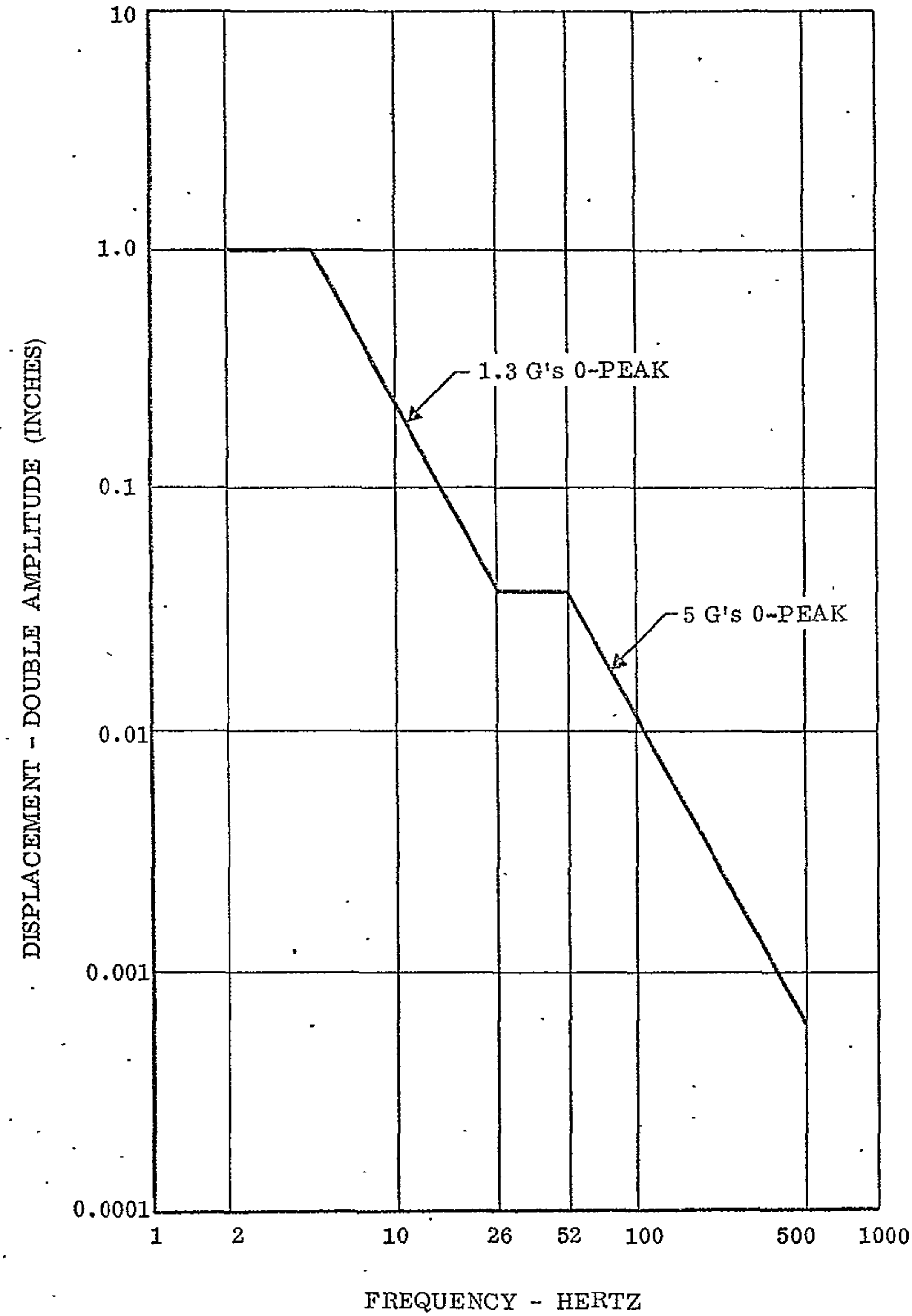


Figure 3-7. Sinusoidal Vibration Levels, Equipment Transported By Common Carrier

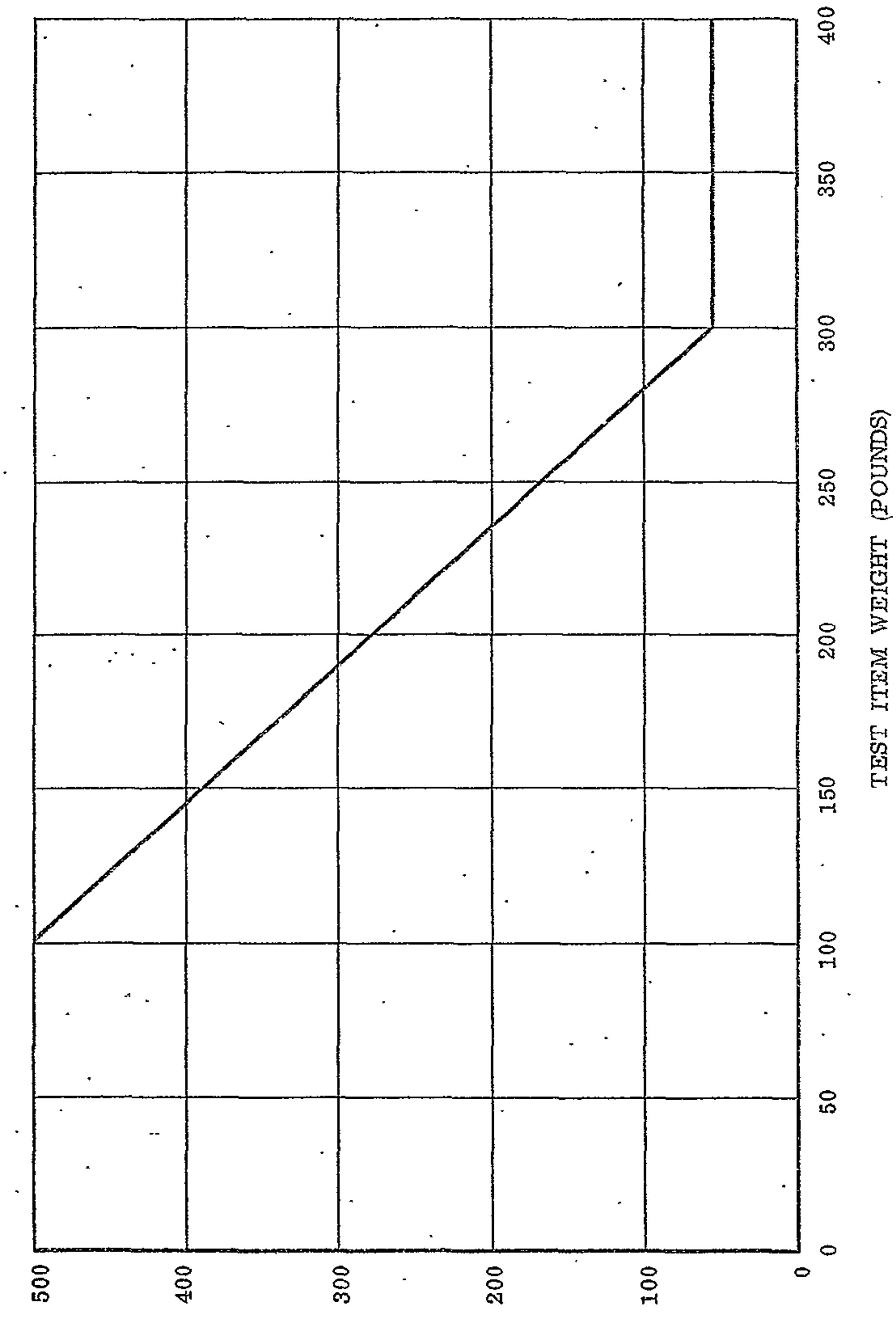


Figure 3-8. Maximum Vibration Frequency for Equipment Transported by Common Carrier

3.1.2.4.3 Prelaunch - The FCPS shall be capable of operating within the performance requirement of this specification during or after exposure to the following environments:

a. Temperature - Surrounding air temperatures from a minimum of plus 40°F to a maximum of plus 140°F.

b. Humidity - Relative humidity up to 100 percent.

c. Explosive Atmosphere - Hydrocarbons (fuel in air) of one to six percent by weight and hydrogen gas of one to four percent in the air by weight.

d. Salt Fog - Exposure equivalent to 1 percent by weight salt spray for 24 hours at 90 degrees ± 5°F.

3.1.2.4.4 Launch, Ascent, and Descent - The FCPS shall be capable of operating within the performance requirements of this specification during or after exposure to the following environments:

a. Pressure - Ambient atmospheric to 2×10^{-8} torr minimum space vacuum.

b. Atmosphere - Air or space vacuum.

c. Temperature - Plus 40°F minimum to plus 140°F maximum.

d. Humidity - A normal dewpoint of plus 60°F with a minimum of plus 80°F.

e. Acoustic Field - The maximum acoustic spectra is shown in Figure 3-9.

f. Vibration - The vibration level input at the FCP attach points, in all three axes, shall be as shown in Figure 3-10, Curve "A".

g. Acceleration - Exposure to maximum acceleration of TBD g's in the longitudinal axis and maximum lateral acceleration of TBD g's.

h. Sinusoidal Vibration - The FCPS shall be designed to withstand the following logarithmic swept sinusoid applied in its longitudinal axis.

5 to 8 Hz	TBD g's peak
8 to 10 Hz	TBD inches double amplitude
10 to 100 Hz	TBD g's peak

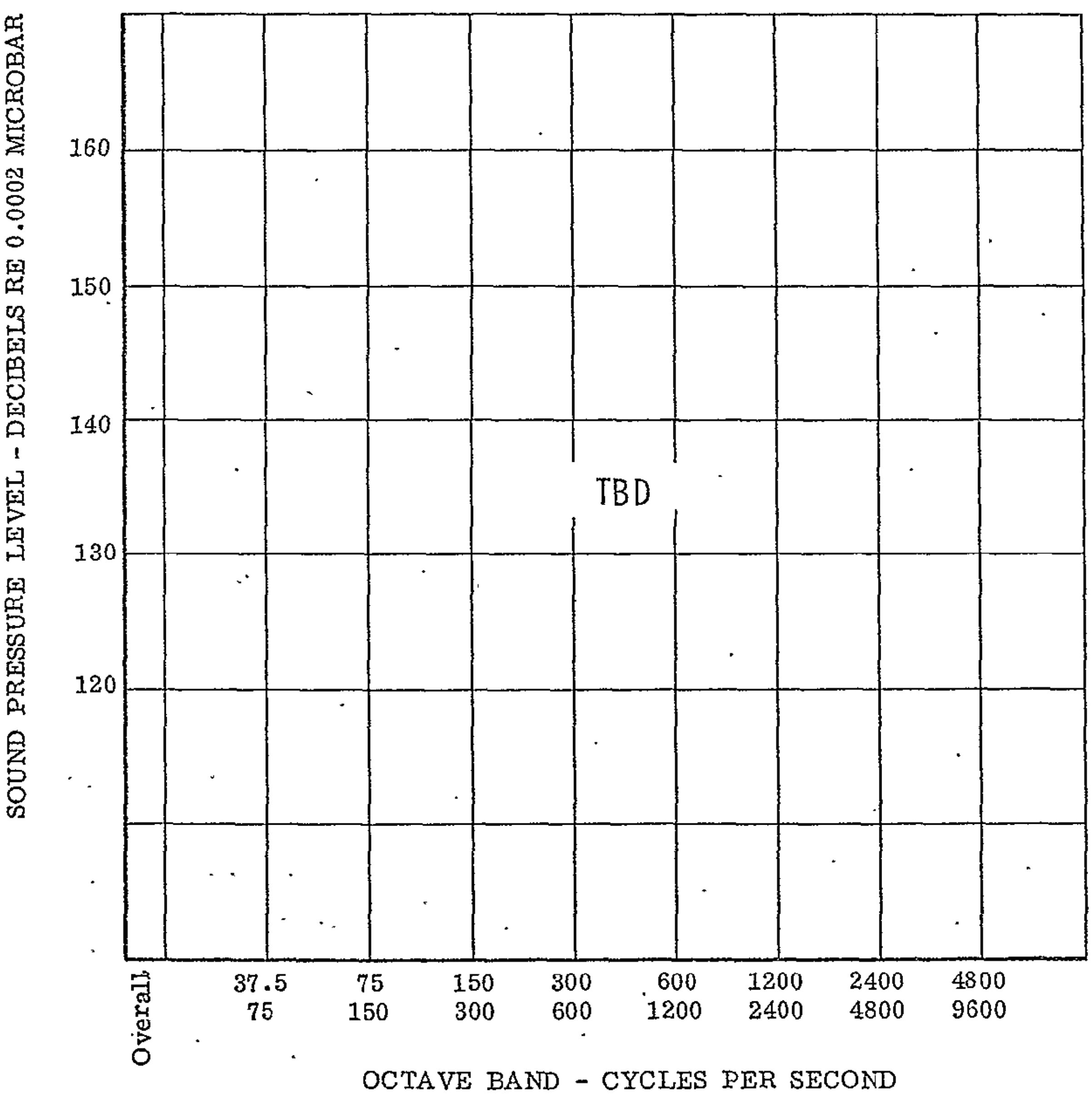


Figure 3-9. Octave Band Sound Pressure Levels Envelope of Maximum Launch and Ascent Levels

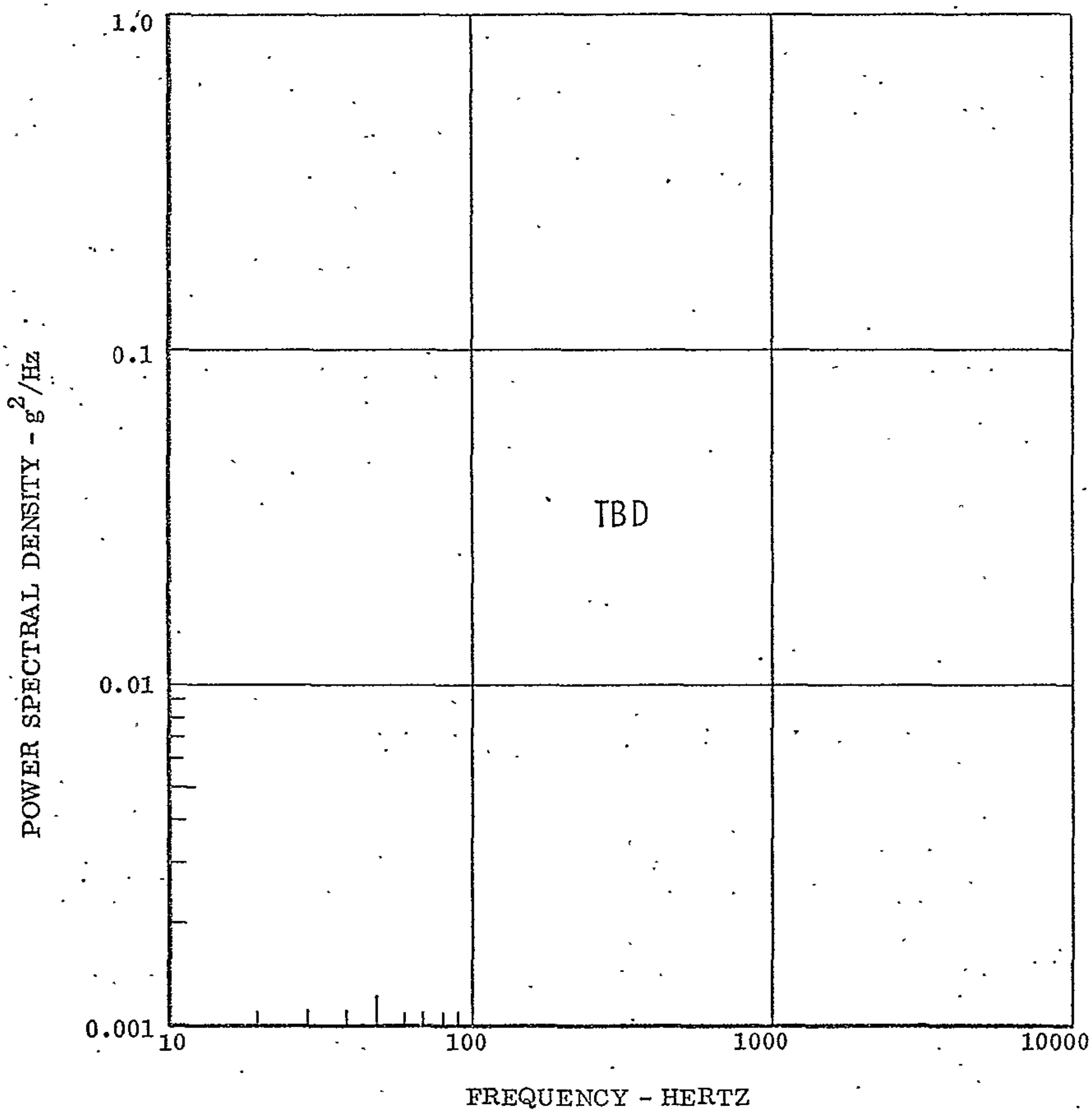


Figure 3-10. Fuel Cell Random Vibration Levels

3.1.2.4.5 On-Orbit - The FCPS shall be capable of operating within the performance requirement of this specification during or as a result of exposure to the following environments:

a. Pressure - A nominal static ambient pressure varying from 1×10^{-5} torr to 4×10^{-7} torr, and a minimum static pressure of 2×10^{-8} torr.

b. Temperature - Surrounding wall temperature of 40° to 140°F.

3.1.2.5 Transportability - Transportation handling provisions shall be provided in accordance with MIL-S-8512, Paragraph 3.3.4, Handling Provisions. Packaging, handling and shipping methods shall be provided to ensure the FCPS is not damaged by the environments in 3.1.2.4.2.

3.1.2.6 Human Factors. Human factors shall be a design consideration utilizing MIL-STD-1472 as a guide.

3.1.2.7 Safety - The FCPS shall be designed for inherent ground and flight safety through the selection of appropriate design features and proven qualified components, materials, processes, and operating principles. Identified Class III and Class IV hazards (Paragraph 3.2.6.2.1 System Failure Hazard of MIL-S-3813) shall be reduced or eliminated through design optimization.

a. Safety devices shall be provided to protect personnel from the effects of potentially hazardous equipment and materials, voltages, pressures, temperatures, irradation, gasses, acoustic noise, and explosive or toxic substances in excess of human tolerance limits.

b. Where safety is a consideration, the center of gravity, total weight, and lifting points of the FCPS, and the FCPS shipping container shall be properly marked.

c. The FCPS shall have adequate safeguards to prevent hazardous conditions and inadvertent operation; and, normal operations, components replacement, the act of replacing components, malfunctions, or failures shall not disable other equipment, personnel, or the flight vehicle.

d. The design and construction of the FCPS shall be such that ground or flight personnel required to handle, maintain or operate the equipment will not be subject to injury. Sharp edges and corners, burrs, and protuberances are not permitted. Hardware shall be designed to prevent personnel contact with high temperature surfaces and hazardous electrical points.

e. FCPS hardware shall be designed to meet the requirements of KMI 1710.1 Attachment A and AFETRM 127.1.

f. The various components of Flight Hardware shall be hermetically sealed or of explosion-proof construction.

3.2 INTERFACE REQUIREMENTS

The FCPS shall have the following interfaces:

a. Mechanical

b. Support Structure

c. Electrical (as shown in Table 3-1)

d. Fluid (as shown in Table 3-4)
   1) Reactant supply inputs (TBD)
   2) Coolant input and output (1 each)
   3) By-product water output (2)
   4) Vent lines (TBD)

3.2.1 Mechanical Interface

Fluid connectors shall be mounted to withstand an axial load of TBD pounds and a lateral load of TBD pounds. Electrical connectors shall be mounted to withstand an axial load of TBD pounds and a lateral load of TBD pounds.

Designation	Fitting No.	Function	Fitting Designation

TBD

Table 3-4. FCP Fluid Interface

3.2.2 Support Structure Interface

The FCPS support structure shall be as defined in Figure 3-11.

3.2.3 Electrical Interface

The electrical interfaces between the FCPS and all other associated vehicle subsystems and equipment shall conform to the following:

a. Bonding - Bonding shall comply with the requirements of MIL-B-5087.

b. Environmentally resistant electrical connectors shall be crimp contact, bayonet couplings meeting the performance requirements of MIL-C-26482 except all aluminum parts shall be finished in accordance with MIL-C-5541 Class III or equivalent. Hermetically sealed electrical connectors shall be bayonet couplings meeting the performance requirements of MIL-C-26482.

   Steel parts shall have a suitable conductive finish. Stainless steel parts shall be passivated. Neither cadmium nor zinc platings shall be used.

   Power output connectors shall be insertable crimp contact, screw thread coupling, environmentally resistant connectros meeting the performance requirements of MIL-C-5015 except all aluminum parts shall be finished in accordance with MIL-C-5541 Class III or equivalent.

c. Auxiliary Parasitic Power Circuits - (1) Each individually functioning auxiliary parasitic power device within the FCPS shall be designed to isolate itself from its power input in case of internal short circuit. (2) Auxiliary parasitic power devices which function together as a unit to perform a particular design function shall be integrated in such a way as to isolate themselves as a unit from their power input in the event that any portion of the unit fails by internally shorting. (3) All signal inputs and outputs of auxiliary power devices shall be designed so that the device is not damaged if any of the inputs or outputs are short circuited to ground. A short circuited input or output shall not affect other inputs or outputs except where an output requires the short circuited input as a funcational

TBD

Figure 3-11. FCPS Support Structure Interface condition. (4) The monitoring and test points shall incorporate isolation devices so that a fault or short circuit in a monitoring or test circuit shall not damage or adversely affect the operation of the prime or using circuit. Sufficient test points shall be provided to permit identification of failure within the FCPS.

3.2.4 Fluid Interface

a. Coolant - The FCPS shall reject heat to a liquid water/glycol coolant supplied to the interface. The water/glycol coolant used in the FCPS shall be a solution of ethylene glycol 6201/2 percent by weight), nominally. Mixture tolerance shall be no more than plus or minus 3/4 percent. The composition and purity of the glycol shall be in accordance with Specification 49153022 Type III inhibited. The characteristics of the coolant at the inlet of the FCA shall be as follows.

1. Coolant Temperature

	Minimum	Maximum
Inlet	40°F	120°F
Outlet	40°F	180°F

2. Coolant Pressure

	Minimum	Maximum
Inlet	50 psia	75 psia
Outlet	25 psia	75 psia

3. Coolant Flow Rate

60/40 EGW

All FCPS materials, which contact the coolant, shall be compatible with the other materials in the entire coolant circuit. The FCPS shall not cause a total coolant pressure drop of more than 25 pounds per square inch differential (psid).

The coolant interfaces shall be such that, with the FCPS heat loads of Figure 3-4, the coolant temperatures above will not be exceeded.

b. Reactants - The steady-state reactant gas inlet temperatures and pressures at the FCPS interface shall be as shown below.

		Minimum	Maximum
1.	Temperature		
	Inlet	-220°F	+140°F
	Oxygen	-120°F	+140°F
2.	Pressure		
	Hydrogen	200 psia	400 psia
	Oxygen	800 psia	1000 psia

3.3 DESIGN AND CONSTRUCTION

3.3.1 Mechanical Requirements

3.3.1.1 Subassemblies and Modules - Wherever practical, the FCPS design shall incorporate subassemblies and modules that have been proven on other space projects giving due consideration to state-of-the-art, cost, schedules, and reliability requirements.

3.3.1.2 Vibration Isolators - Vibration isolators shall not be allowed at the structural interface between the vehicle and the FCPS mounting base. The electrical, fluid, and gas line interfaces shall be static.

3.3.1.3 Lubrication - The FCPS shall not require maintenance lubrication.

3.3.1.4 Leakage Rate - The leakage rate from each fluid circuit shall be TBD.

3.3.1.4 Proof Pressure - Proof pressure applied at each fluid interface shall be at least 1.5 times the maximum operating pressure of the circuit. Components, such as regulators having bellows or other sensitive subassemblies, may be proof tested to 1.5

times their maximum operating pressure prior to final assembly. The proof pressure of all lines and fittings shall be at least 2.0 times the maximum operating pressure. The maximum localized stress at proof pressure shall be less than the guaranteed minimum yield strength of the material.

3.3.1.6 Burst Pressure - The burst pressure of all components within all the fluid systems within the FCPS shall not be less than 2.0 times the maximum operating pressure at the maximum operating temperature of the circuit involved. The burst pressure of all lines and fittings within the FCPS shall not be less than 4.0 times the maximum operating pressure.

3.3.1.7 Structural Factor of Safety - A safety factor of 1.50 shall be used as the standard value in structural design of flight hardware to determine ultimate loads. Ultimate loads are limit loads multiplied by the safety factor. The basic values for material allowable design stresses are as defined by MIL-HDBK-5. Limit loads are defined as the maximum calculated load that will be experienced by the hardware under conditions specified herein.

3.3.1.8 Weight - The total weight of the flight configured FCPS, including all parasitic power devices and mounting provisions, shall not exceed TBD pounds.

3.3.2 Electrical Requirements

Electrical wiring within the FCPS shall conform to MIL-W-81381 and MIL-W-8160.

3.3.2.1 Flammability of Wiring Insulation, Materials, and Accessories - Insulation used in wiring anywhere within pressurized compartments of manned spacecraft shall not be capable of sustaining combustion after removal of the source of ignition or following melting of the electrical conductor by high currents such as those resulting from short circuits or circuit breaker failures. Insulation on other conductors which may be in contact with it. This requirement does not apply to wiring which is completely isolated from the compartment atmosphere by potting, bundle ties, bundle chafe guards, heat shrinkable tubing, protective covering, solder sleeves, cable clamps and bundle identification tags that are in contact with electrical wire bundles, shall meet these flammability requirements (see paragraph 5.1.9.2.5).

3.3.2.2 Toxicity of Wiring Insulation, Materials, and Accessories - Wiring insulation used in Flight Hardware shall be a material which, when operating at its maximum temperature during a nominal mission or when exposed to temperatures up to the melting point of a single wire shall not generate toxic fumes in such concentration as to impair astronaut functioning or safety. Materials and accessoreis associated with wiring, such as pottings, bundle ties, bundle chafe guards, heat shrinkable tubing, protective covering, cable clamps, bundle identification tags and identification marks shall meet this requirement.

3.3.2.3 Electrical Connectors - All electrical plugs and receptacles used in FCPS hardware shall be keyed and polarized or otherwise configured to prevent incorrect connection with other accessible plugs or receptacles.

a. Electrical circuits for FCPS hardware shall not be routed through adjacent pins of an electrical connector if a short circuit between them would constitute a single point failure as defined in Paragraph 3.3.5.

b. Cable connections of FCPS hardware shall be designed so that pin and socket connectors are properly used to prevent power from shorting to ground. They also shall be designed to protect personnel both when connected and disconnected and, through the use of dead facing, explosion-proof connectors or similar means, during the operations of connection and disconnection.

3.3.2.4 Materials Detrimental to Electrical Connectors - Materials containing or coated with substances which are detrimental to metals used in electrical connectors shall not be used in FCPS hardware adjacent to exposed electrical contact surfaces. Specifically included in this category are materials containing or coated with sulfides or free sulfur.

3.3.2.5 Electrical and Electronic Piece Parts Closure - Electrical and electronic piece parts with all-welded closure construction shall be used in flight hardware wherever practical in preference to piece parts with other types of closure construction.

3.3.2.6 Protection of Electrical and Electronic Devices - Electrical and electronic devices used in FCPS hardware shall incorporate protection against reverse polarity or other improper electrical inputs during qualification, acceptance, and other tests if such inputs could damage the devices in a way that would not be immediately and unmistakably apparent. If it is impractical to incorporate adequate protection as a part of the device, protection shall be provided externally by ground-based equipment at the interface between the device and the ground test equipment.

3.3.2.7 Corona Suppression - Electrical and electronic systems and components of FCPS hardware shall be designed so that proper functioning will not be impaired by corona discharge under any of the required operating conditions.

a. Where adverse corona effects are avoided by pressurizing or evacuating a components, the seals used shall be capable of maintaining the required internal pressure throughout the useful life of the hardware.

b. Where adverse corona effects are avoided in unsealed components by restricting operation to space-vacuum conditions, the ability of the equipment to reach the required vacuum in the planned time shall be demonstrated.

3.2.2.8 Moisture Protection of Electrical and Electronic Devices - Electrical connectors, wiring junctions, and all electrical and electronic devices used in flight hardware shall be hermetically sealed or otherwise positively protected against moisture.

3.3.2.9 Redundant Electrical Circuits - Redundant electrical circuits in flight hardware shall not be routed through the same connector.

3.3.2.10 Temperature Control - If electrical temperature control of FCPS hardware is required, power requirements shall be minimized.

3.3.2.11 Wire Splicing - Splicing of wires in FCPS hardware shall be avoided. If splices are required, the requirements of Paragraph TBD shall apply.

3.3.2.12 Wire Bundle and Harness Protection - All wire bundles and harnesses of FCPS hardware shall be designed to withstand anticipated handling including disconnection and reconnection and operating deformations without damage to the wires, insulation, or electrical connections. Wire smaller than 22 gauge shall not be used in wire bundles. Routing and installation of all wire bundles and harnesses shall be specified on the drawings. Special precautions shall be taken to prevent damage as a result of extreme temperature conditions, chafing, or any other conditions that may result in damage.

3.3.3 Fluid Requirements

3.3.3.1 Flow Restriction Requirements - Where pressurized gas lines of FCPS hardware could fail in such a way that the total gas supply dumped directly into a compartment would be greater than relief valve venting could handle without overpressurization of the compartment, flow restrictions shall be incorporated at the pressure source to restrict the mass flow to a level that can be handled by the relief valve or venting.

3.3.3.2 Fluid Line Installation - Routing and installation of all fluid lines for flight hardware, including pressure-sensor lines, shall be specified on the drawings. Special precautions shall be taken to prevent the installation of such lines where they would be exposed to extreme temperature conditions. A design analysis shall be made for each such line installation to show that the temperature extremes to which the line will be subjected are within limits acceptable for the fluid involved.

3.3.3.3 Service Points -

a. Service points for fluid systems of FCPS hardware shall be designed with positive protection by location, connector size or type, to prevent connection to incorrect fluid service lines.

b. Fluid systems of flight hardware shall be designed so that service points (including those for filling, draining, purging, or bleeding) can be located external to pressurized spacecraft compartments. Fluid systems which are portable and do not require servicing after being installed in a spacecraft compartment are excluded from these requirements.

c. Service and test points for fluid systems of flight hardware shall be designed to prevent leakage in flight. Capping immediately after servicing or test is permitted. The method and material used for capping shall be compatible with the applicable system and the expected environment.

3.3.3.4 Protection for Fluid System Tubing, Fittings, and Components -

a. All ends of tubing, fittings, and components used in fluid systems of FCPS hardware shall be protected against damage and entry of contaminants in each step of the manufacturing process and assembly. Design drawings and process specifications shall designate the method of complying with the requirement. Equivalent protection shall be provided for tubing, fittings, and components when the fluid system is open to effect repair or replacement. All protective devices shall be designed so that it is impossible to complete hardware assembly or installation with the protective devices in place.

b. Tubing assemblies, fittings, or components of FCPS hardware shall be protected during storage and shipment as specified in 3.3.3.4a above and shall be sealed in clean, transparent, moisture-proof bags with sufficient protective strength. All assemblies shall be cleaned and dried before packaging, and sealing shall be done in an air-conditioned environment with 50% or lower, relative humidity and 75°F or lower, temperature.

c. Positive measures shall be taken to prevent incorrect installation of fluid line components which function is dependent on direction of flow.

(1) Where feasible, the design of these fluid line components shall incorporate end fittings or connections whose dimensions or configuration will not permit incorrect installation.

(2) The direction of fluid flow shall be clearly indicated with permanent markings on the exterior of the component and the parts and lines to be mated with it.

(3) Where feasible, flow checks shall be made after each installation or change.

3.3.3.5 Joining of Stainless Steel Tubing and Fittings - Stainless steal tubing and fittings for flight hardware shall be joined by brazing or welding where mechanical disconnects are required for replacement or servicing or where components would be adversely affected by brazing or welding.

3.3.3.6 Stress Corrosion - Fluid system components of FCPS hardware shall be designed so that no failures will occur due to stress corrosion resulting from exposure to specified natural and induced environments or from the fluids used in or on the system or components of the system during fabrication, cleaning, flushing, inspecting, testing, or operating.

3.3.3.7 Use of Titanium or Titanium Alloys - Titanium or titanium alloys shall not be used in FCPS hardware where exposed to gaseous oxygen exceeding two atmospheres of absolute pressure or where exposed to liquid oxygen.

3.3.3.8 Moisture Separation in Zero-G Environment - The design of water separators for use in gas streams in flight hardware shall consider the fact that free moisture under zero gravity conditions may be attracted to and adhere to the surface of the tube or duct rather than to float freely throughout the stream.

3.3.3.9 System Venting - Each pressure system of FCPS hardware equipment shall have relief capability to assure that the pressure in the system remains below the yield point of the weakest component in the system. When practical, the relieved fluid shall be ducted into the lower pressure (sump) side of the system. The design of venting systems for operation in zero gravity conditions shall consider that fluid entering the system may be a liquid, vapor, gas, or combination of these states.

3.3.4 Debris Protection

Flight hardware shall be designed so that malfunctions or inadvertent operation cannot be caused by exposure to conducting or non-conducting debris or foreign material floating in a gravity-free state.

a. Electrical circuitry shall be designed and fabricated to prevent unwanted current paths being produced by such debris.

b. Critical mechanical items shall be provided with debris-proof covers or containers while critical electrical items shall be provided with suitable containers, potting, or conformal coatings.

c. Filters, strainers, or traps shall be provided in all moving-fluid systems to trap residual debris in a manner which will eliminate it as a threat to critical mechanical or electrical components. In installations where in flow reversal may occur, filters or strainers shall be installed on both sides of critical components.

3.3.5 Single-Point Failures

FCPS hardware shall be designed so that no single-point failure will affect astronaut or ground personnel safety, cause loss of a flight vehicle/module, prevent or compromise accomplishment of a primary FCPS performance requirement, or cause a launch to be rescheduled.

3.3.6 Redundancy

3.3.6.1 Separation of Redundant Paths - Redundant paths in FCPS hardware (such as fluid lines, electrical wiring, and connectors) shall be located to insure that an event which damages one will not damage the other.

3.3.6.2 Redundant Paths - Verification of Operation - The design of FCPS hardware systems incorporating redundancies shall include a means of verifying satisfactory operation of each redundant path at any time the system requires testing.

3.3.7 Selection of Specifications

Unless otherwise specified, specification and standards for materials, parts, and processes shall be selected in the order of preference as follows:

- NASA Specifications and Standards
- Federal Specifications and Standards
- Military Specifications and Standards (MIL, JAN, or MS)
- Other Governmental Specifications and Standards
- Specifications and Standards released by nationally recognized associations, committees, and technical societies

3.3.8 Materials, Parts, and Processes

All materials, parts, and processes shall be compatible with the performance and environmental criteria for the FCPS as delineated in this specification. Manufacturing processes and associated materials used on off-the-shelf hardware previously developed on other Government projects shall be acceptable provided the hardware meets all other requirements of this specification. Non-metallic materials which outgas corrosive vapors shall not be used on the FCPS.

3.3.8.1 Cleanliness - The FCPS shall be designed, manufactured, assembled, and handled in a manner to insure the highest practical level of cleanliness. Suitable precautions shall be taken to insure freedom from debris within the FCPS; inaccessible areas where debris and foreign material can become lodged, trapped, or hidden shall be avoided. Protective covers shall be provided to prevent entrance of debris into inaccessible areas, or access panels shall be provided for removal of debris from these areas. Where appropriate, these protective covers may be designed for ground operations only and may be removed for flight.

3.3.8.2 Welding and Brazing - Resistance welding (sport and seam) shall be in accordance with MIL-W-6858. Fusion welding of steel and corrosion resistant steels shall be in accordance with MIL-W-8611. Fusion welding of aluminum shall be in accordance with MIL-W-8604. Brazing shall be in accordance with MIL-B-7883.

3.3.8.3 Soldering - NHB 5300.4(3A) shall apply for soldering of all electrical connections in FCPS hardware,and solder connections shall be designed to meet the Quality Assurance.Requirements.

3.3.8.4 Strategic Materials - Attention shall be given to the prevention of unnecessary use of strategic and critical materials as specified in 3.3.

3.3.8.5 Finishes - Neither zinc nor cadmium finishes shall be used in parts exposed to space vacuum. All steel fastener parts threaded into magnesium shall be tin plated per MIL-T-10727.

3.3.8.6 Restriction on Use of Transistors and Capacitors - Point-contact, grown junction, or alloy junction transistors and tantalum-wet-slug capacitors shall not be used in flight hardware.

3.3.8.7 Etching of Wire Insulation for Potting - When etching of wire insulation is required in FCPS hardware to provide satisfactory bonding to potting materials, the open end of the wire shall not be exposed to the etchant. The preferred process is to form the wire into a "U" shape, immersing only the bent portion in the etchant with the open ends above the etchant level. The unetched end of the wire shall not be cut off prior to neutralization of the etchant. Electrical wire or cable insulated or coated with polytetrafluoroethylene or fluorinated ethylene propylene shall be etched prior to potting to assure mechanical bond strength and environmental seal. Potting shall be accomplished within three weeks after etching.

3.3.8.8 Adhesive Bonding - Adhesive bonding in FCPS hardware shall be in accordance with MIL-A-9067.

3.3.8.9 Restriction on Use of Mercury - Mercury in liquid or vapor from shall not be used in FCPS hardware or in equipment used in conjunction with FCPS hardware (i.e., manometers, lights, thermometers, etc.) if a substitute of equivalent performance exists or an alternate design or method can be used. Where no satisfactory substitute exists or an alternate design or method cannot be used, the justification for the use of mercury, the protection provided to prevent its release and a plan for decontamination in the event of its release shall be submitted for approval.

3.3.8.10 Ultrasonic Cleaning - Ultrasonic vibration shall not be used as a method for cleaning electronic assemblies of FCPS hardware.

3.3.9 Standard and Commercial Parts

Parts selected for this application shall be of known reliable design and performance capability. These parts shall be standard NASA, AN, MS, or JAN parts where practical. Where standard parts from these categories are not available, non-standard parts will be subjected to requirements for qualification, screening, burn-in, radiographic inspection, or other testing as required to guarantee part reliability.

3.3.10 Moisture and Fungus Resistance

Non-nutrient materials which resist damage from moisture and fungus shall be used. Protective coatings which are worn off or otherwise lost during the normal course of operation, inspection maintenance, or periodic testing shall not be acceptable as a moisture and fungus preventative. Use of materials which are nutrients for fungus is not prohibited in hermetically-sealed assemblies and in other accepted and qualified uses such as paper capacitors and treated transformers. If it is necessary to use fungus nutrient materials in other than such qualified application, these materials shall be treated with aprocess which will render the resulting exposed surface fungus resistant.

3.3.11 Corrosion Prevention

Metals used in FCPS hardware shall be corrosion-resistant type or suitably treated to resist corrosive conditions likely to meet in manufacture, assembly, testing, servicing, storage, or normal service use. Protective coatings shall not crack, chip, peel, or scale with age when subjected to the environmental extremes specified. Unless suitably protected against electrolytic corrosion, dissimilar metals, as defined in MS 33586, shall not be used in direct physical contact. Any protection used shall offer a low impedance path to radio frequency currents. FCPS hardware shall be designed so that no failures will occur due to stress corrosion resulting from exposure to specified natural and induced environments or from fluids used in or on the system or components of the system during fabrication, cleaning, flushing, inspecting, testing, or operating.

3.3.12 Interchangeability and Replaceability

Items of FCPS hardware with the same part numbers shall be physically and functionally interchangeable.

3.3.13 Workmanship

Workmanship on FCPS hardware shall be in accordance with the best practice for high quality equipment within the state-of-the-art.

3.3.14 Electromagnetic Interference

The FCPS shall be designed to meet the electromagnetic interference requirements of MIL-I-26600 (as amended by MSC-ASPO-EMI-10) except as modified and extended as follows:

3.3.14.1 Short Duration Interference - Paragraph 3.1.2 of the referenced specification shall not apply.

3.3.14.2 Shield Discontinuities - In Paragraph 3.2.3.2 of the referenced specification delete "3 inches" and substitute "1-1/2 inches".

3.3.14.3 Audio Frequency Shield Gaps - All audio frequency shields shall be terminated as close to their terminating connectors as physically possible and in no case shall be stripped back further than 3.0 inches from the connector.

3.3.14.4 Enclosure Design - Electronic assembly enclosures shall be designed to provide a minimum of 60 decibel (db) attentuation for electromagnetic waves from 30 Hz up to and including 10,000 MHz.

3.3.14.5 Grounding - All returns requiring ground shall be routed through intermediate connectors, equipment, and cables for ultimate connection to vehicle single-point ground and shall be isolated from grounded conductors, chassis, and structures.

3.3.14.6 Circuit Returns - Circuit returns shall not be shielded separately or carried outside the shield used for the corresponding "hot" conductor. Leads carrying audio frequency currents shall be tightly twisted with their returns in accordance with the wire twisting table of document MSC-13M6004.

3.3.14.7 Power Returns - Power returns shall be twisted with the "hot sides" to reduce the magnetic field coupling. The power leads and returns shall pass through adjacent connector pins to reduce capacitive coupling to other circuits. Power lines and signal lines shall be bundled separately. Power lines shall cross all other lines at right angles to minimize mutual coupling.

3.3.14.8 Interference Control Components - All suppression filters shall conform to the requirements of MIL-F-15733 and shall be tested in conformance with MIL-STD-220, at a rated current. All interference control components shall conform to the environmental requirements for the equipment in which they are assembled and shall be hermetically sealed.

3.3.14.9 Transient Suppression - Relays and other inductive sources of voltage transients shall be provided with bifilar windings, or shall be diode or resistance-capacitance suppressed, preferably within the confines of the devices, so that transient voltage in excess of 50 volts above or 30 volts below the nominal bus voltage, with a time width of more than 10 microseconds, shall not be conducted through any interconnecting wire.

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3.3.14.10 Electrical Power Systems - A minimum direct current (dc) isolation of one megohm shall exist between load equipment cases and all primary input power leads. Where two wires are connected in a parallel to form one phase of a three-phase power supply, a total of six wires shall be used and twisted to form a cable.

3.3.4.14.11 Primary Power Distribution - The neutral and phase wires are to be twisted together (per wire twisting table of document MSC-13M6004) for their entire length.

3.3.14.12 Secondary Power Distribution - The secondary distribution neutral wires shall be twisted with their respective phase wires (per wire twisting table of document MSC-13-M6004) for their entire length. Where equipment is to be served by 208/120 volt three-phase power, the neutral and phase wires shall be twisted for their entire length.

3.3.14.13 AC Power - Alternating current (ac) power leads shall be separately bundled from all other circuit leads.

3.3.14.14 Signal Characteristics - The following signal charactertistics and requirements must be established to determine the bundling and wiring of the signals. The following information shall be supplied to NASA by the contractor: (1) Minimum and maximum voltage levels of each signal, (2) Functions of signals, (3) Source or load impedance, (4) Type of signal (digital, analog, event, power), (5) Frequency, (6) Rise and fall time, (7) Current, and (8) Grounding requirements.

3.3.14.15 Wiring Implementation - Routing, bundling, and treatment of wire shall be designed to the wiring requirements of document MSC-13M6004. When returns of a given type must be combined because of lack of space or connector contacts, the contractor shall advise NASA of such combination prior to implementation.

3.3.15 Identification and Marking

a. The FCPS shall be marked for identification in accordance with MIL-STD-130.

Conspicuous markings or labels shall be affixed to the hardware to warn ground support personnel and astronauts of the presence of hazardous conditions. Materials shall comply with the requirements of Paragraph 5.1.9.2. Nameplates shall contain, as a minimum, the following:

(1) Nomenclature

(2) Stock Number

(3) Serial Number

(4) Part Number

(5) Contract Number

(6) Manufacturer

(7) Government Ownership Symbol

b. Hardware or equipment which is not suitable for use in flight, and which could be accidentally substituted for Flight Hardware or Backup Hardware shall be red striped with material compatible red paint to prevent such substitution. In the event the hardware is too small to be easily striped, or if test results would be affected by striping, a conspicuous red tag marked "NOT FOR FLIGHT USE" shall be attached.

c. Wires and Cables - Wires and cables for the FCPS shall not be identified by hot stamping directly onto primary or secondary (shield) insulation.

d. Serialization - Each FCPS shall have a different serial number. Gaps in serial number sequence are permissible, but the serial number order must conform to the order of production. Instrumentation Data Items and all replaceable subassemblies shall be serialized or otherwise marked to provide individual identification.

APPENDIX C

PERFORMANCE REQUIREMENTS

AND

COMPONENT DESCRIPTIONS

INSTRUMENTATION AND CONTROL SUBSYSTEM (ICS)

A. FUNCTIONAL REQUIREMENTS

1.1 Function

The ICS performs the functions of data management, vehicle data interface, and control of the FCPS purge valves and steam vent valve. This subsystem performs the functions of 1.1 through 1.1.2.5 of the functional network as shown on Figure C-1.

1.1.1 Instrumentation

Instrumentation functions include transducer excitation, acquisition and conditioning of data signals, and the subsystem thermal interface.

1.1.1.1 Transducer Excitation

Regulated excitation power shall be supplied to the following transducers:

- Hydrogen pressure sensor (2)
- Oxygen pressure sensor (2)
- Stack Temperature sensor (2)
- Water cavity pressure sensor (2)

1.1.1.2 Parameter Sensing

The ICS shall serve as the collection point for outputs from the transducer (sensors) listed below:

- Hydrogen pressure sensor (2), 0 - 70 psia
- Oxygen pressure sensor (2), 0 - 70 psia
- Stack temperature sensor (2), 130 - 230°F

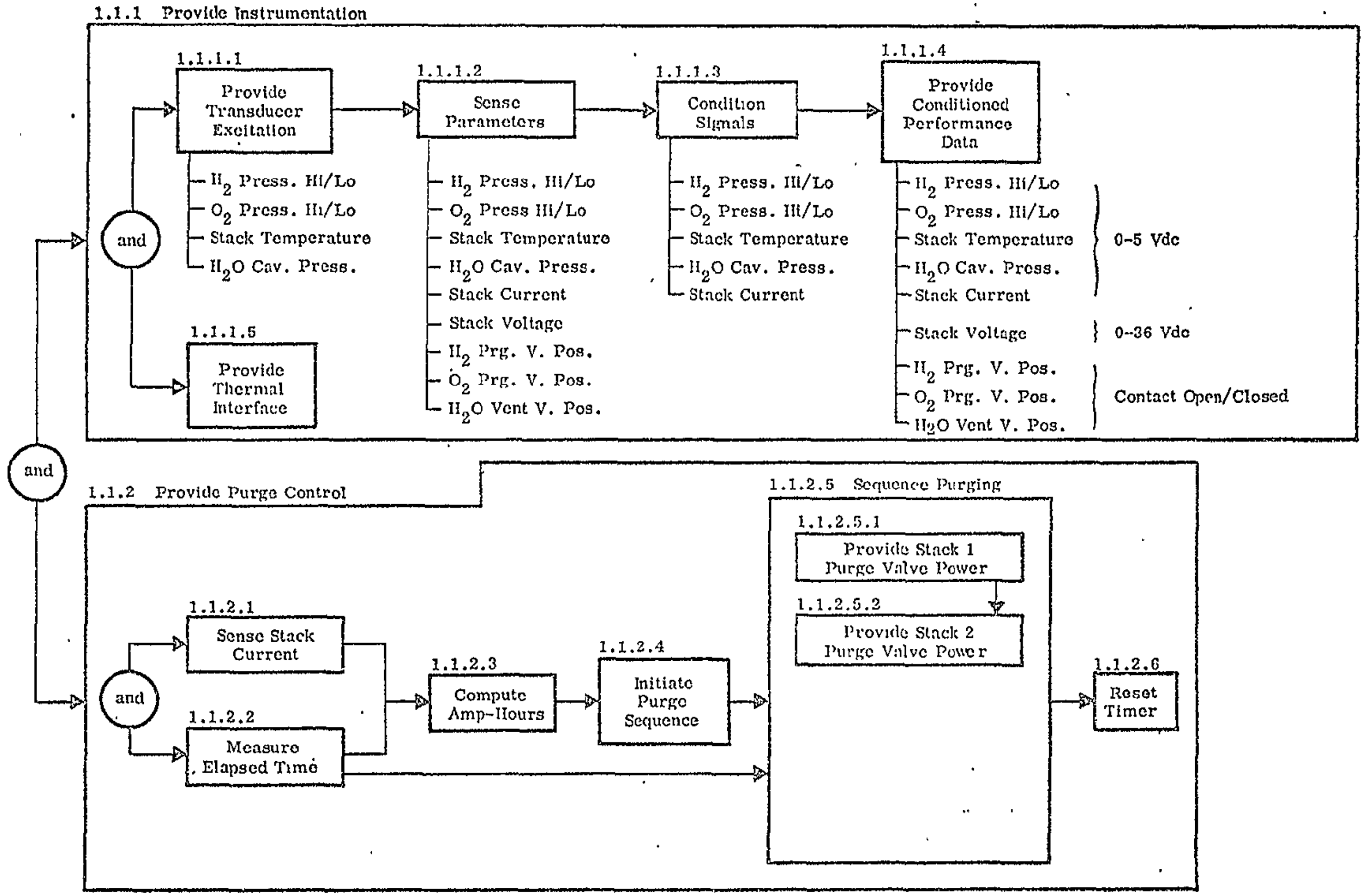

Figure C-1. Power Generation Network - Provide Instrumentation and Control

(c) <u>0 to 5 volts dc</u>

Stack temperature
Water cavity pressure
Stack current

(d) <u>0 to 36 volts dc</u>

Stack voltage

(e) <u>Contact open/closed</u>

Hydrogen purge valve position
Oxygen purge valve position

1.1.2 Purge Control

Control logic and valve driver elements are included in this function.

1.1.2.1 <u>Stack Current Sensing</u>

The purge controller shall sense the outputs of four stack-mounted current sensors (Function 1.3.2.4). Signal conditioning shall be provided as required to interface the current signals with the amp-hour counter described in Paragraph 1.1.2.3 below.

1.1.2.2 <u>Elapsed Time Measurement</u>

The purge controller shall provide for measurement of elapsed time within an accuracy of ± 1%. Timer output shall be conditioned as required for input to the amp-hour counter described in Paragraph 1.1.2.3.

1.1 2.3 <u>Amp-Hour Counter</u>

Utilizing the outputs of Functions 1.1.2.1 and 1.1.2.2, total cumulative ampere-hours produced by the stack subsystem shall be computed within an accuracy of ± 5%.

1.1.2.4 Purge Initiation

At intervals of 256 system amp-hours, the purge controller shall initiate a purge sequence.

1.1.2.5 Purge Sequencing

Upon receiving a purge command, the purge sequencer shall apply power to the purge valves (Functions 1.5.1.1 and 1.5.1.2) in conformance with the following requirements:

- Purging order: Stack 1, Stack 2
- Purge duration per stack: 6 ± 1.0 seconds
- Interval between stack purges: 0.5 ± 0.45 second

(Hydrogen and oxygen to be purged simultaneously for each stack)

1.1.2.6 Timer Reset

At the completion of each purge sequence, the timer shall reset to a "zero amp-hours, Stack 1 ready" configuration.

B. SCHEMATIC ARRANGEMENT

Figure C-2 is a schematic diagram of the ICS. The shaded portions of the figure indicate vehicle functions.

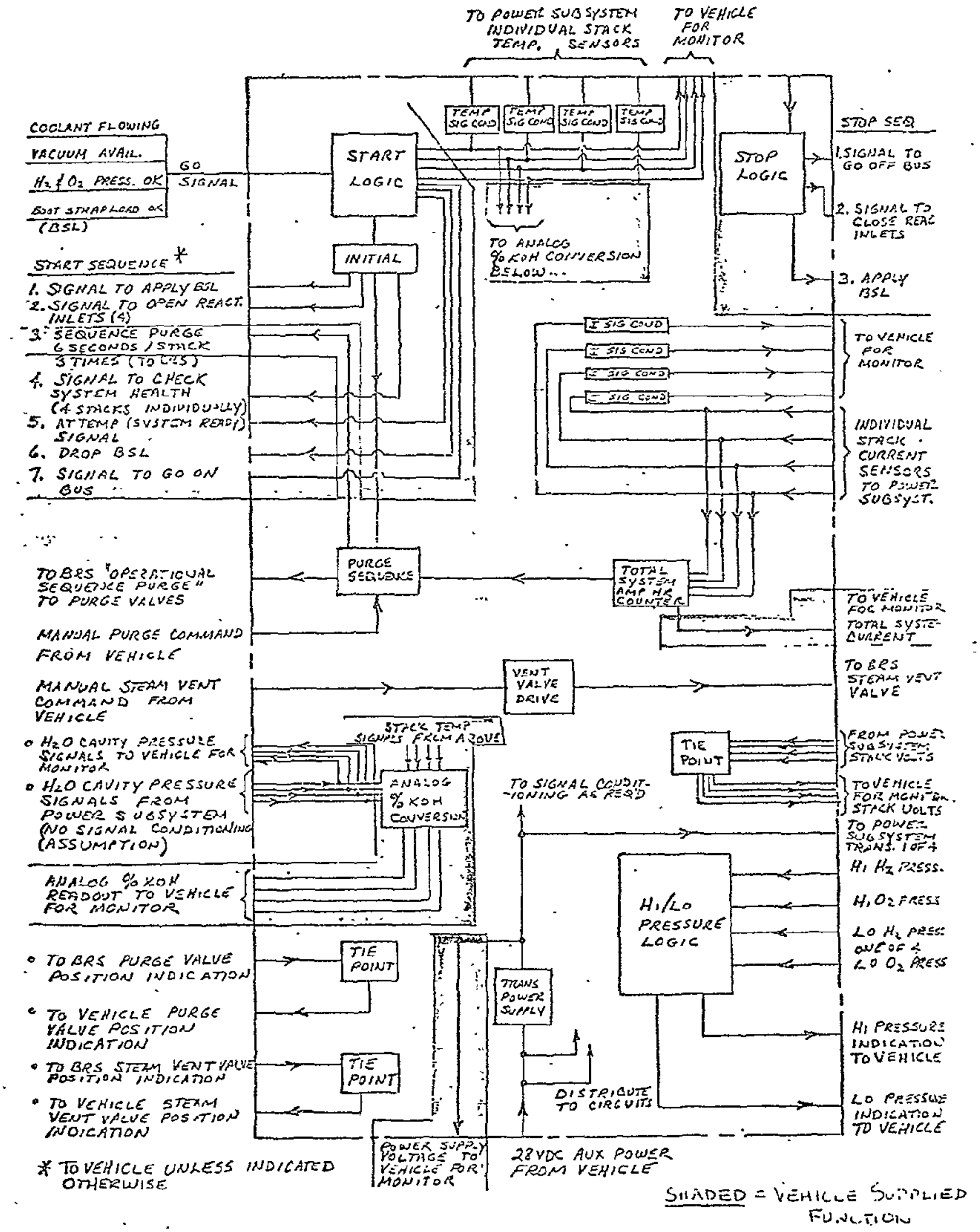

Figure C-2. Schematic-Instrumentation and Controls Subsystem (ICS)

- Water cavity pressure sensor (2), 0 - 10 psia
- Stack current sensor (2), 0 - 210 amp
- Stack voltage leads (2), 0 - 36 volts
- Hydrogen purge valve position sensor (2), closed/open
- Oxygen purge valve position sensor (2), closed/open

(All sensors are treated functionally as a part of the subsystem they serve rather than as a part of the ICS; cabling from the ICS to and from all sensors is part of the ICS.)

1.1.1.3 Signal Conditioning

Outputs from the following sensors shall be conditioned to a 0 - 5 volt range as required:

- Hydrogen pressure sensor
- Oxygen pressure sensor
- Stack temperature sensor
- Water cavity pressure sensor
- Stack current sensor

1.1.1.4 Conditioned Data Output

The ICS shall provide data outputs to the vehicle for the following parameters:

(a) 2.0 to 3.0 volts dc

Hydrogen pressure low
Oxygen pressure low

(b) 4.5 to 5.5 volts dc

Hydrogen pressure high
Oxygen pressure high

REACTANT CONTROL SUBSYSTEM (RCS)

A. FUNCTIONAL REQUIREMENTS

1.2 Function

The RCS performs all functions necessary for supplying reactants to the stack subsystem on demand. This subsystem performs the functions of 1.2 through 1.2.2.2 of the functional network shown in Figure C-3.

1.2.1 Reactant Conditioning

This function provides for conditioning of the incoming reactants.

1.2.1.1 Thermal Interface

The RCS shall provide a thermal interface to permit heat exchange between the reactant gases and the TCS reactant preheaters (Function 1.4.1.1.3). Performance characteristics at the interface are:

	Inlet		Outlet	
	Min.	Max.	Min.	Max.
Coolant temperature, °F	40	136	40	+180
Coolant flow, lb/hr*	755	910	755	910
Hydrogen temperature, °F	-220	+140	0	+180
Hydrogen flow, lb/hr	0	1.82	0	1.82
Oxygen temperature, °F	-120	+140	0	+180
Oxygen flow, lb/hr	0	13.75	0	13.75

1.2.1.2 Reactant Filters

Replaceable filters shall be provided in each reactant inlet line as near the vehicle interface as practicable. Filter performance requirements are as follows:

* Based on 62.5% Ethylene Glycol/Water Coolant

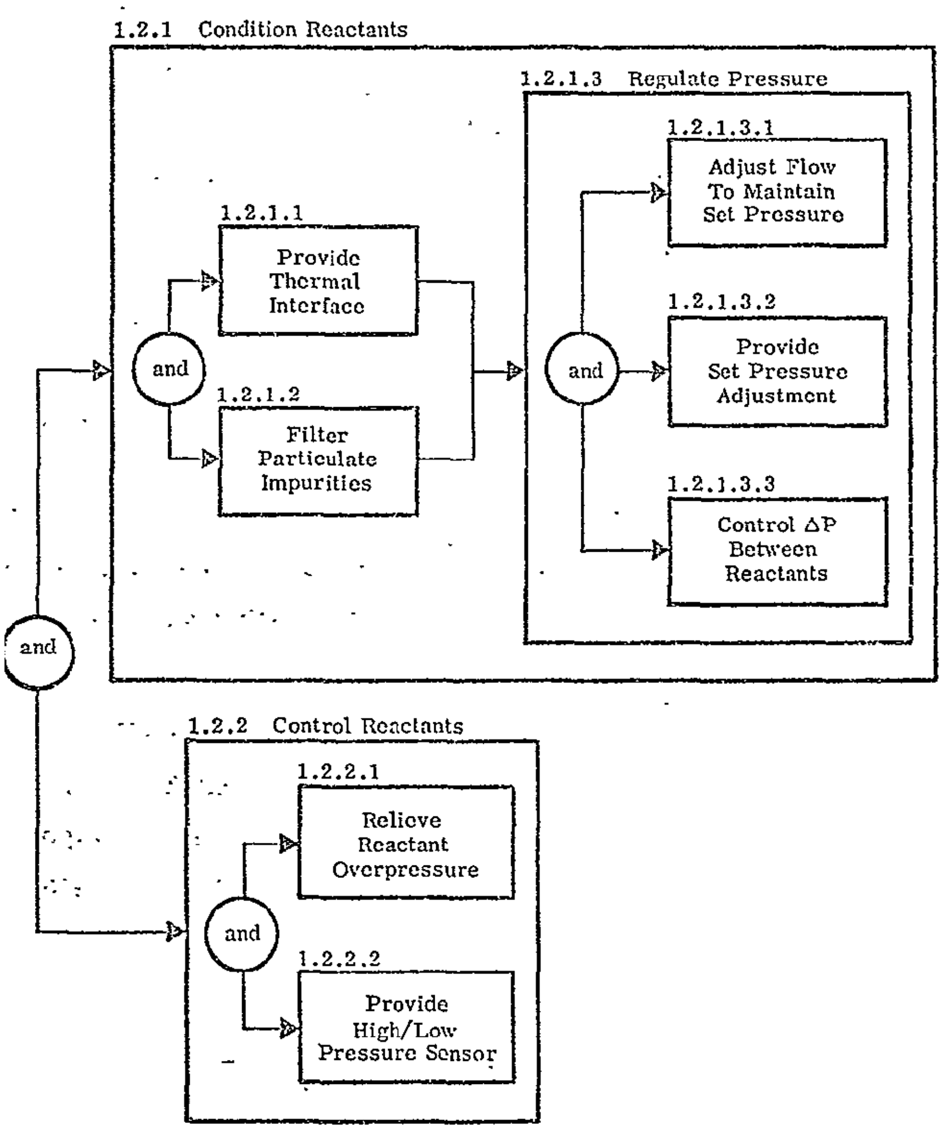

Figure C-3. Power Generation Network - Supply Reactants

Nominal rating	15μ
Absolute rating	10μ
Design life (replacement interval)	1000 hours

1.2.1.3 Pressure Regulation

The reactant pressures and pressure differentials shall be controlled over the demand flow range required by the stack subsystems.

1.2.1.3.1 Regulation at Set Pressure

The pressure regulator shall automatically adjust reactant flow to the Stack Subsystem (Function 1.3.1.3) to maintain the selected reactant feed pressure. Performance requirements are:

	Inlet		Outlet	
	Min.	Max.	Min.	Max.
Hydrogen:				
Pressure, psia	200	400	30±0.5	55±0.5
Temperature, °F	0	180	0	180
Flow, lb/hr	0	1.82	0	1.82
Oxygen:				
Pressure, psia	800	1000	30±0.5	55±0.5
Temperature, °F	0	180	0	180
Flow, lb/hr	0	13.75	0	13.75

1.2.1.3.2 Pressure Set Adjustment – Each pressure regulator shall include provisions for selection of operating pressure, in increments of 5 psi, over the range from 30 psia to 55 psia. Pressure tolerance of ± 0.5 psia maximum shall be maintained at all setpoints within the specified pressure range.

1.2.1.3.3 Delta-P Control - Each pressure regulator shall include provisions for maintaining the delta-P between reactant channels within a tolerance of ± 2.0 psi maximum over the following performance range:

	Inlet		Outlet	
	Min.	Max.	Min.	Max.
Hydrogen:				
Pressure, psia	200	400	0	67
Temperature, °F	0	180	0	180
Flow, lb/hr	0	1.82	0	1.82
Oxygen:				
Pressure, psia	800	1000	0	67
Temperature, °F	0	180	0	180
Flow, lb/hr	A-10	13.75	0	18.75

1.2.2 Reactant Control

This function incorporates safety features for protection against adverse conditions in the RCS.

1.2.2.1 Overpressure Relief

The RCS shall include provisions for relieving excessive regulator outlet pressure in the event of open failure of either channel in each pressure regulator. Performance requirements for each relief valve are:

	Inlet		Outlet	
	Min.	Max.	Min.	Max.
Hydrogen:				
Pressure, psia	0	67	Vacuum	14.7
Temperature, °F	0	180	0	180
Flow, lb/hr	0	1.82	0	1.82

	Inlet		Outlet	
	Min.	Max.	Min.	Max.
Oxygen:				
Pressure, psia	0	67	Vacuum	14.7
Temperature, °F	0	180	0	180
Flow, lb/hr	0	13.75	0	13.75

The relief valve shall reseat at $66 \begin{smallmatrix} +1 \\ -0 \end{smallmatrix}$ psia.

1.2.2.2 Pressure Sensing

The RCS shall include a pressure sensor in each output of each pressure regulator. The pressure sensor shall produce discrete outputs to the ICS (Function 1.1.1.2) for each of the following conditions:

Pressure $<$ 28 psia; "low" output

28 $>$ Pressure $<$ 66 psia; "normal" output

Pressure $>$ 66 psia; "high" output

Excitation power for the pressure sensors will be provided by the ICS (Function 1.1.1.1.).

B. SCHEMATIC ARRANGEMENT

Components in the subsystem are as shown below:

	Number Required	Function Performed	Interfacing Functions
Thermal Interface	2	1.2.1.1	1.4.1.1.3
Filter	2	1.2.1.2	--
Dual Channel Regulator	1	1.2.1.3	1.3.1.3
Pressure Sensor	2	1.2.2.2	1.1.1.1, 1.1.1.2
Relief Valve	2	1.2.2.1	--

STACK SUBSYSTEM (SS)

A. FUNCTIONAL REQUIREMENTS

1.3 Function

The Stack Subsystem (SS) converts reactant energy to electrical power, provides by-product removal interfaces, and sensors for instrumentation and controls. This subsystem performs the functions of 1.3 through 1.3.2.6 of the functional network shown in Figure C-4.

1.3.1 Hydrogen/Oxygen Reaction

The subsystem must provide for the controlled electrochemical reaction of hydrogen and oxygen at maximum practicable efficiency and minimum practicable time-degradation of performance. Overall performance requirements are represented by the voltage-power envelope in Figure C-5. The curves within the given envelope are typical performance curves which meet the envelope requirements. The stack temperatures, reactant pressures, and electrolyte concentrations on the figure constitute the allowable limits under which the individual stacks shall operate under controlled conditions.

1.3.1.1 Reaction Sites

The subsystem shall provide reaction sites to support hydrogen-oxygen combination. Qualitative functional requirements applicable to the reaction sites (electrodes) are:

- Mechanical stability (minimum breakup and migration)
- Chemical stability (corrosion resistance)
- High catalytic activity throughout design life

In 5,000 hours of operation at an average current density of 115 ASF, performance drop resulting from electrode degradation shall not exceed 25 millivolts per cell section, measured at a current density of 275 ASF.

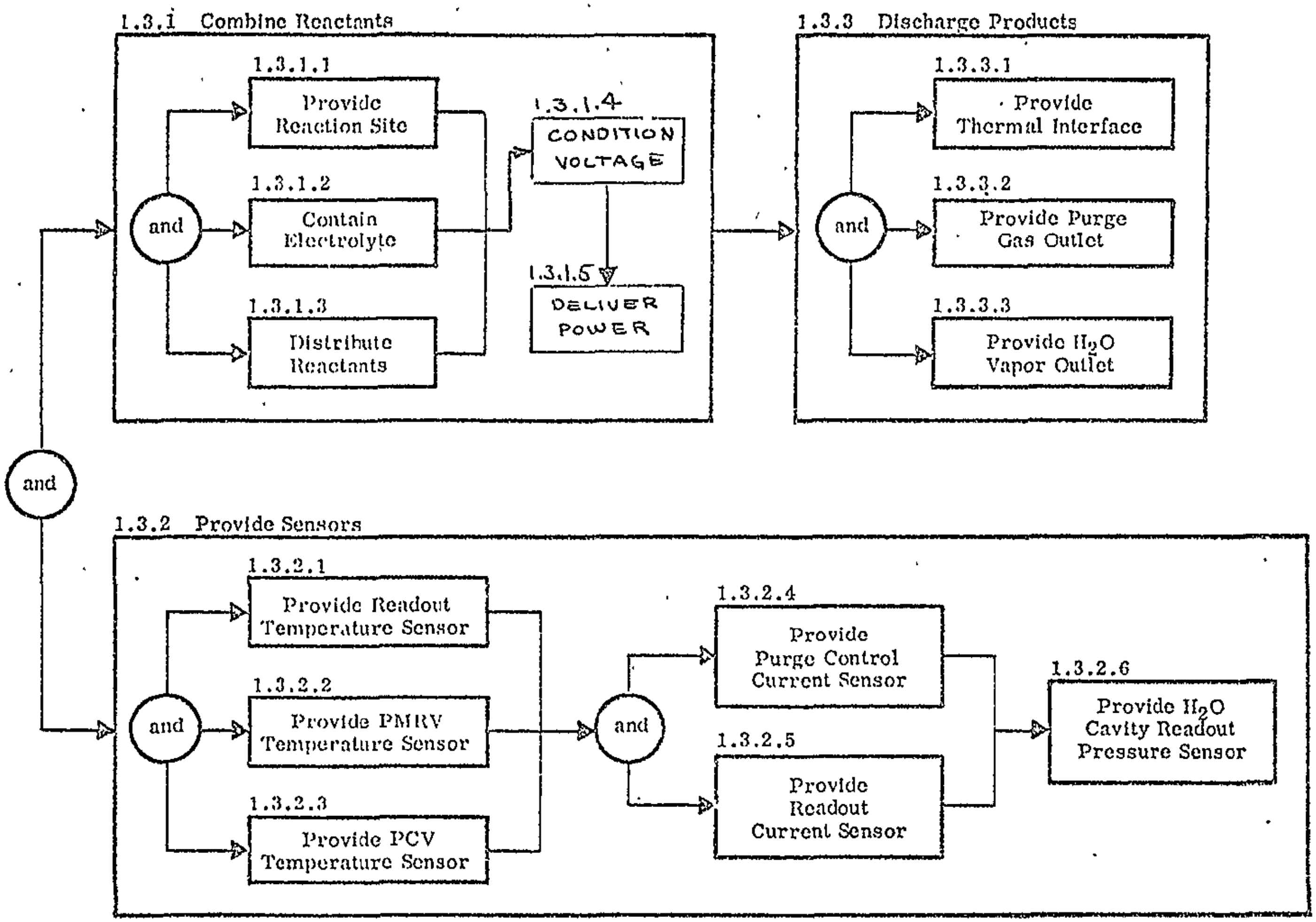

Figure C-4. Power Generation Network-Convert Reactant Energy

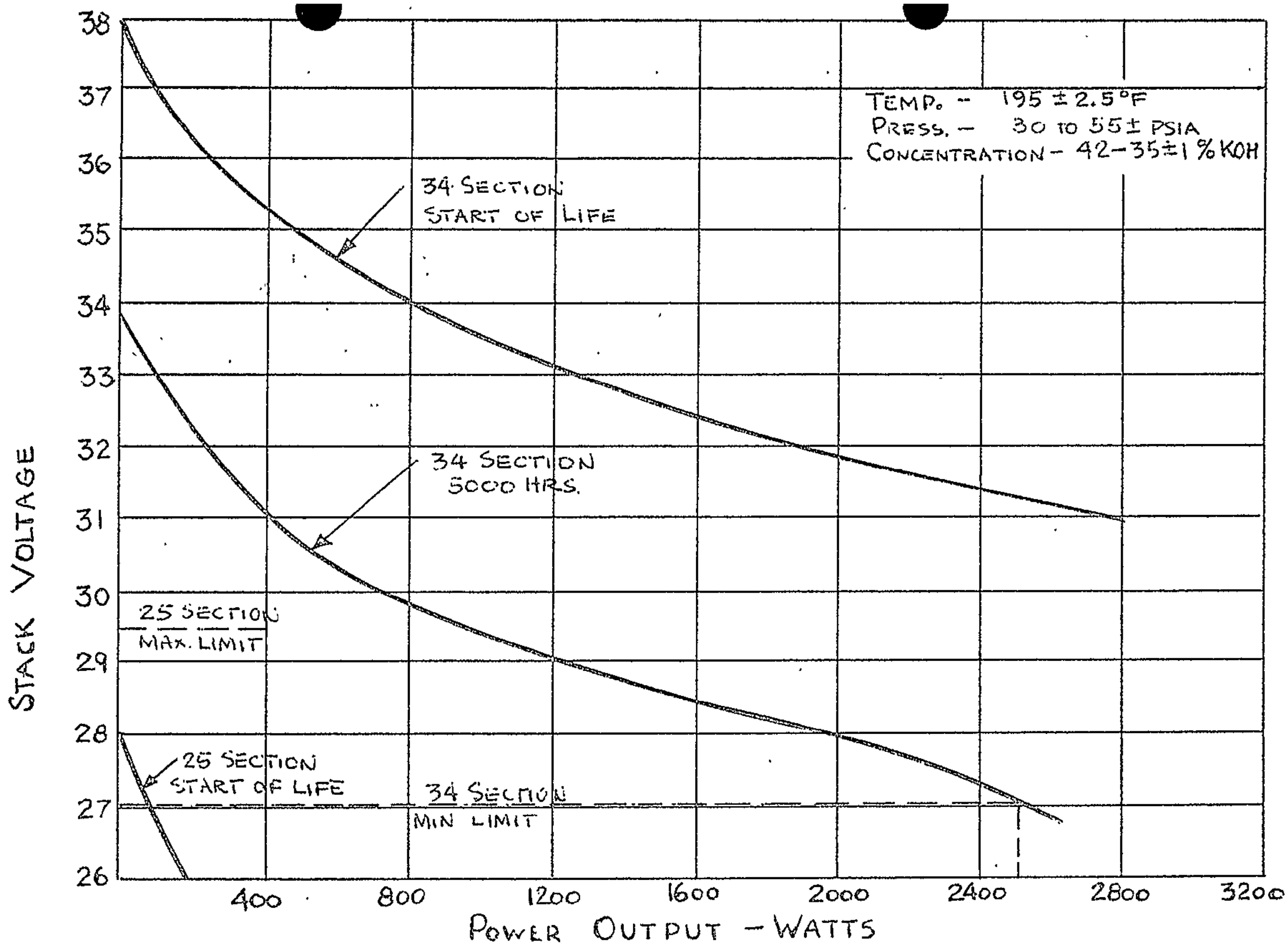

Figure C-5. Performance Requirements for One Stack

1.3.1.2 Electrolyte Containment

The subsystem shall provide means for positive containment of electrolyte within the cell reaction sites. Functional requirements for the electrolyte containment are:

- High breakthrough strength (resistance of 67 psi ΔP)
- Chemical stability (minimum reaction with KOH)
- High ratio of electrolyte volume to matrix volume (minimum IR drop)
- Uniform distribution of electrolyte between cells

Additional provisions shall be incorporated as required to prevent electrolyte creepage out of the cell stack.

In 5,000 hours of operation at an average current density of 115 ASF, performance drop resulting from electrolyte depletion (due to chemical reactions as well as bulk loss from the stack) shall not exceed 25 millivolts per cell section, measured at a current density of 275 ASF.

1.3.1.3 Reactant Distribution

The subsystem shall provide for distribution of reactants from the RCS (Function 1.2.1.3.1) to the cell reaction sites. The following qualitative requirements apply:

- Minimum cell-to-cell variation
- Maximum flow uniformity across cell area
- Minimum flow-induced electrolyte concentration gradients

In 5,000 hours of operation at an average current density of 115 ASF, performance drop resulting from concentration gradients shall not exceed 25 millivolts per cell section, measured at a current density of 275 ASF.

Reactant characteristics at the inlet to each stack are as follows:

	Hydrogen		Oxygen	
	Min.	Max.	Min.	Max.
Pressure, psia (normal)	30 ± 0.5	55 ± 0.5	30 ± 0.5	55 + 0.5
Pressure, psia (regulator failed)	0	67	0	H_2 ± 2.0
Temperature, °F	0	180	0	180
Flow, lb/hr	0	1.82	0	13.75
Purity, %	99.99	99.995	99.99	99.995
Particle Size	--	15μ	--	15μ

1.3.1.4 Power Delivery

The subsystem shall provide for delivery of output power to the vehicle. IR drop in current collectors, cell interconnects, bus bars, and interfacing connectors shall be held to a minimum. Each stack shall provide stack voltage taps for interfacing with the ICS (Function 1.1.1.2) and a single-cell voltage connector for non-mission use (no vehicle interface).

The output of each stack shall be conditioned by the power conditioner to provide power within the voltage limits shown in Figure C-5. Each stack shall provide appropriate power taps to allow operation with the power conditioner.

1.3.2 Sensors

The subsystem shall provide the sensors described below for monitoring and control functions to be performed by the supporting subsystems.

1.3.2.1 Readout Temperature Sensor (One Per Stack)

Parameter:	Stack temperature
Measured Range:	130 to 230°F
Excitation:	From ICS Function 1:1.1.1
Output:	To ICS Function 1.1.1.2 (Instrumentation)

1.3.2.2 PMRV Temperature Sensor (One Per Stack)

Parameter:	Stack Temperature
Measured Range:	180 to 220°F
Excitation:	None
Output:	To BRS Function 1.5.3.1 (PMRV)

1.3.2.3 PCV Temperature Sensor (One Per Stack)

Parameter:	Stack Temperature
Measured Range:	192.5 to 197.5°F
Excitation:	None
Output:	To TCS Function 1.4.2.3 (PCV)

1.3.2.4 Purge Control Current Sensor (One Per Stack)

Parameter:	Stack Current
Measured Range:	0 to 210 amperes
Excitation:	Stack current (SS Function 1.3.1.4)
Output:	To BRS Function 1.1.2.1 (Purge Control)

1.3.2.5 Readout Current Sensor (One Per Stack)

Parameter:	Stack Current
Measured Range:	0 to 210 amperes
Excitation:	Stack current (SS Function 1.3.1.4)
Output:	To ICS Function 1.1.1.2 (instrumentation)

1.3.2.6 Water Cavity Pressure Readout Sensor (One Per Stack)

Parameter:	Water Cavity Pressure
Measured Range:	0 to 10 psia
Excitation:	From ICS Function 1.1.1.1
Output:	To ICS Function 1.1.1.2 (Instrumentation)

1.3.3 Discharge of Reaction Products

The Stack Subsystem shall provide interfaces for removal of by-products of the hydrogen-oxygen reaction by the supporting subsystems.

1.3.3.1 Thermal Interface

The SS shall provide a thermal interface for transfer of waste heat to the TCS (Function 1.4.2.1). Performance characteristics at the interface are as follows for each stack:

	Inlet		Outlet	
	Min.	Max.	Min.	Max.
Coolant temperature, °F	40	136	40	180
Coolant flow, lb/hr*	188	227	180	227
Heat transfer, Btu/hr	–	–	0	3700

* Based on 62.5% Ethylene-Glycol/Water Coolant

1.3.3.2 Purge Gas Outlet

The SS shall provide for reactant outlets to permit removal of accumulated inerts by purging. Reactant cavities in each stack will be purged as follows:

	Inlet		Outlet	
	Min.	Max.	Min.	Max.
Purge interval, amp-hr	60	90	60	90
Purge duration, sec	5	7	5	7
Purge flow, lb/hr	–	5.8	–	5.8

The fluid interfaces for this function are BRS Functions 1.5.1.1 (Hydrogen Purge Valve) and 1.5.2.1 (Oxygen Purge Valve).

1.3.3.3 Water Vapor Outlet

The SS shall provide an interface for removal of product water. This functional requirement presupposes transport of the product water from the cell anodes and extraction from the hydrogen cavities in the form of vapor. Water removal rates will be controlled by the PMRV (BRS Function 1.5.3.3) as follows for each stack:

	Stack Temperature, °F			
	180		220	
	Min.	Max.	Min.	Max.
Water cavity pressure, psia (for 35 ± 1% KOH)	3.61	3.93	8.50	9.18
Water cavity pressure, psia (for 42 ± 1% KOH)	2.68	3.00	6.46	7.14
Steam flow rate, lb/hr	0	3.33	0	3.33

Four KOH concentration settings will be provided by the PMRV: 35.0 ± 1%, 37.3 ± 1%, 37.3 ± 1%, 39.6 ± 1%, and 42.0 ± 1%. The PMRV will remain closed at stack temperatures below 180°F and will remain open at stack temperatures above 220°F.

B. SCHEMATIC ARRANGEMENT

The major components in the Subsystem are listed below.

Component	Number Required	Functions Performed	Interfacing Functions
Fuel Cell Stack	2	1.3.1.1, 1.3.1.2, 1.3.1.3 1.3.1.4	1.2.1.3.1
Electrical Connectors	6	1.3.1.4, 1.3.1.5	1.1.1.2 and Vehicle Power Distribution
Power Conditioner	1	1.3.1.4	Vehicle Power Distribution, 1.3.1.5
Readout Temperature Sensor	2	1.3.2.1	1.1.1.1, 1.1.1.2
PMRV Temperature Sensor	2	1.3.2.2	1.5.3.1

B. SCHEMATIC ARRANGEMENT (continued)

Component	Number Required	Functions Performed	Interfacing Functions
PCV Temperature Sensor	2	1.3.2.3	1.4.2.3
Purge Control Current Sensor	2	1.3.2.4	1.1.2.1
Readout Current Sensor	2	1.3.2.5	1.1.1.2
Readout Cavity Pressure Sensor	2	1.3.2.6	1.1.1.1, 1.1.1.2
Thermal Interface	4	1.3.3.1	1.4.2.1
Purge Gas Outlet	2	1.3.3.2	1.5.1.1, 1.5.2.1
Water Vapor Outlet	2	1.3.3.3	1.5.3

THERMAL CONTROL SUBSYSTEM (TCS)

A. FUNCTIONAL REQUIREMENTS

1.4 Function

The TCS performs the function of waste heat removal from the FCPS. This subsystem performs the functions of 1.4 thru 1.4.2.4 of the functional network shown in Figure C-6.

1.4.1 Equipment Temperature Control

Heat removal from items other than the stack subsystem is included in this function. Reactant preheating is also included.

1.4.1.1 Equipment Heat Sinks

Heat sinks shall be provided for heat exchange between thermally sensitive equipment and the TCS.

1.4.1.1.1 Condenser Heat Sink - The condenser heat sink shall remove waste heat from the condenser thermal interface (Function 2.1). Performance requirements are:

	Inlet		Outlet	
	Min	Max	Min	Max
Heat Removal, Btu/h	-	-	0	5,000
Coolant Pressure, psia	50	75	40	75
Coolant Temperature, °F	40	120	40	136
Coolant Flow, lb/h*	410	490	410	490

1.4.1.1.2 Electronics Heat Sink - The electronics heat sink shall remove waste heat from the Instrumentation and Control Subsystem (ICS) thermal interface (Function 1.1.1.5). Performance requirements are:

*Based on 62.5% Ethylene Glycol/Water Coolant

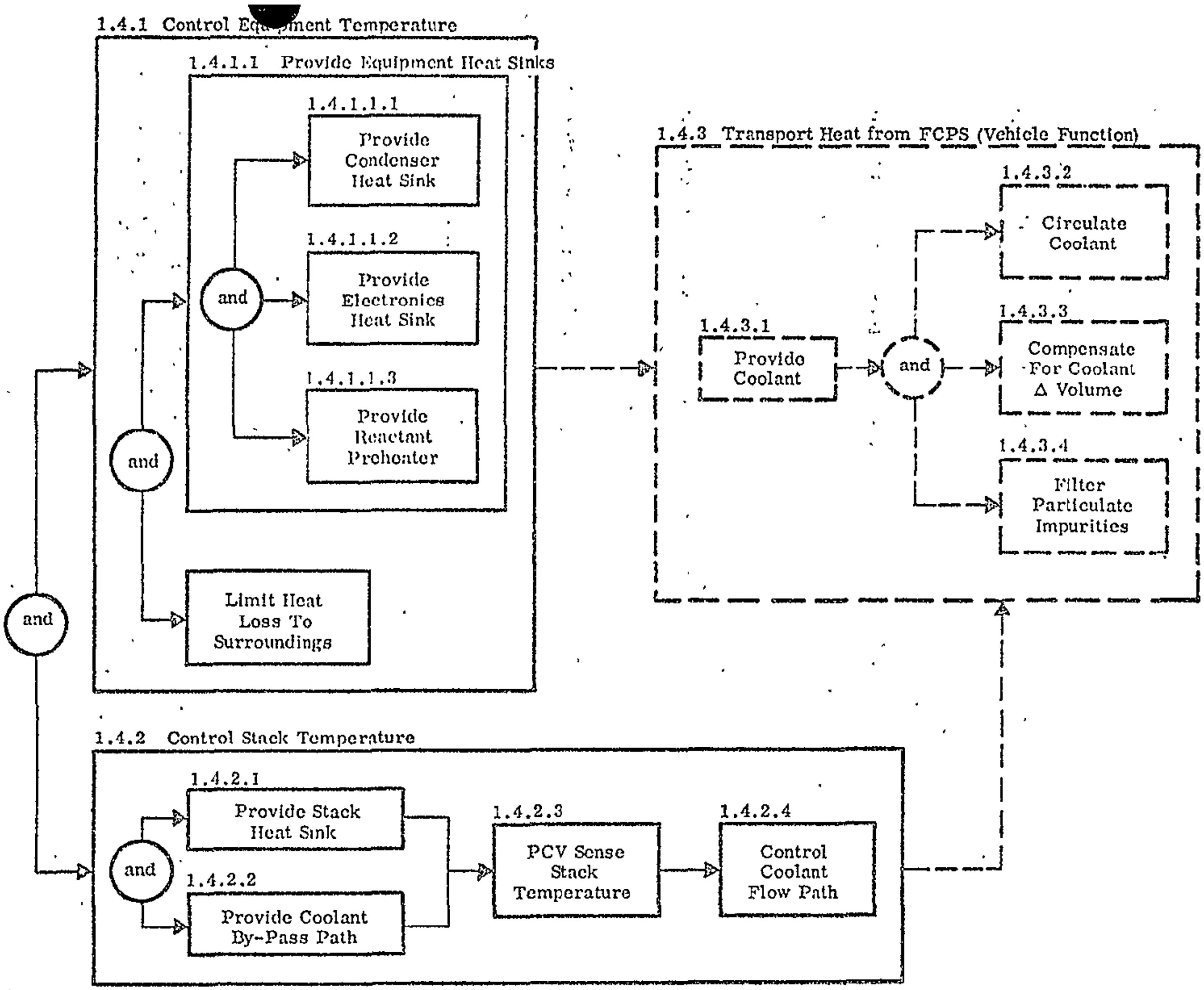

Figure C-6. Power Generation Network - Remove Waste Heat

	Inlet		Outlet	
	Min	Max	Min	Max
Heat Removal, Btu/h	-	-	0	1200
Coolant Pressure, psia	40	75	25	75
Coolant Temperature, °F	40	136	40	160
Coolant Flow, lb/h*	65	80	65	80

1.4.1.1.3 Reactant Preheaters - The reactant preheater shall provide for heat exchange between the TCS and the reactant thermal interface (Function 1.2.1.1). Performance requirements are:

	Inlet		Outlet	
	Min	Max	Min	Max
Coolant Pressure, psia	40	75	25	75
Coolant Temperature, °F	40	136	40	180
Coolant Flow, lb/h	755	910	755	910
Hydrogen Temperature, °F	-220	+140	0	+180
Hydrogen Flow, lb/h	0	1.82	0	1.82
Oxygen Temperature, °F	-120	+140	0	+180
Oxygen Flow, lb/h	0	13.75	0	13.75

NOTE: The reactant preheaters are centerlined as structurally and thermally integral with the stack cold plates (Function 1.4.2.1).

1.4.1.2 Insulation

Insulation shall be provided to limit heat loss from the FCPS to the system's surroundings. Performance requirments are TBD.

1.4.2 Stack Temperature Control

This functional includes heat removal from the fuel cell stack subsystem.

*Based on 62.5% Ethylene Glycol/Water Coolant

1.4.2.1 Stack Heat Sinks

Heat sinks shall be provided to remove waste heat from the stack thermal interface (Function 1.3.3.1). Performance requirements are:

	Inlet		Outlet	
	Min	Max	Min	Max
Heat Removal, Btu/h	–	–	0	7400
Coolant Pressure, psia	40	75	25	75
Coolant Temperature, °F	40	136	40	180
Coolant Flow, lb/h*				

1.4.2.2 Coolant Bypass

A by-pass path shall be provided to enable by-pass of the stack heat sinks by the coolant. Characteristics of the by-passing coolant are as presented in Function 1.4.2.1 except that no stack heat removal is required in the by-pass loop.

1.4.2.3 Stack Temperature Sensing

The stack temperature must be sensed by the proportional coolant valve (PCV), using a stack-mounted sensor (Function 1.3.2.3). The range of stack temperatures to be sensed over the required PCV control range is 192.5°F minimum to 197.5°F maximum.

1.4.2.4 Coolant Flow Path Control

The flow split between the stack heat sink and the by-pass loop shall be controlled by a proportional coolant valve (PCV) in response to the stimuli received from the stack PCV temperature sensor. Performance requirements are:

	Stack Temperature	
	192.5°F	197.5°F
Coolant Flow through Heat Sink	0%	100%
Coolant Flow through By-Pass	100%	0%
Coolant Characteristics (same as Function 1.4.2.1)		

*Based on 62.5% Ethylene Glycol/Water Coolant

B. SCHEMATIC ARRANGEMENT

Components comprising the subsystem are listed below:

	Number Required	Function Performed	Interfacing Functions
Condenser Coolant Manifold	1	Inlet Coolant Distribution	Coolant inlet from Vehicle
Condenser Heat Sink	2	1.4.1.1.1	2.1
Stack Coolant Manifold	1	Stack Coolant Distribution	-
Electronics Heat Sink	1	1.4.1.1.2	1.1.1.5
Proportional Coolant Valve	4	1.4.2.4	1.3.2.3
Coolant By-Pass Loop	4	1.4.2.2	-
Stack Heat Sink	8	1.4.2.1	1.3.3.1
Reactant Preheater	8	1.4.1.1.3	1.2.1.1
Coolant Return Manifold	1	Outlet Coolant Collection	Coolant outlet to Vehicle

BY-PRODUCT REMOVAL SUBSYSTEM (BRS)

A. FUNCTIONAL REQUIREMENTS

1.5 Function

The function of the BRS is controlled removal of by-product media from the fuel cell stacks. Control of KOH concentration is an integral part of this function. This subsystem performs the functions of 1.5 thru 1.5.3.4 of the functional network shown in Figure C-7.

1.5.1 Hydrogen Purge

This function provides for flow control and sensing of hydrogen purge gas flow.

1.5.1.1 Hydrogen Purge Valve

Upon command from the Purge Controller (Function 1.1.2.5), the hydrogen purge valve shall permit flow from its associated fuel cell stack (Function 1.3.3.2). Performance requirements for each purge valve are:

	Inlet		Outlet	
	Min	Max	Min	Max
Pressure, psia	30 ± 0.5*	67	28.5	67
Temperature, °F	0	220	0	220
Flow, lb/h	0	0.73	0	0.73

Number of cycles: 3500

*Less pressure drop through RCS and stack

1.5.1.2 Hydrogen Purge Valve Position Sensor

The hydrogen purge valve shall incorporate a sensor with two discrete outputs to indicate whether the valve is open or closed. The sensor outputs will be interfaced with the ICS (Function 1.1.1.2).

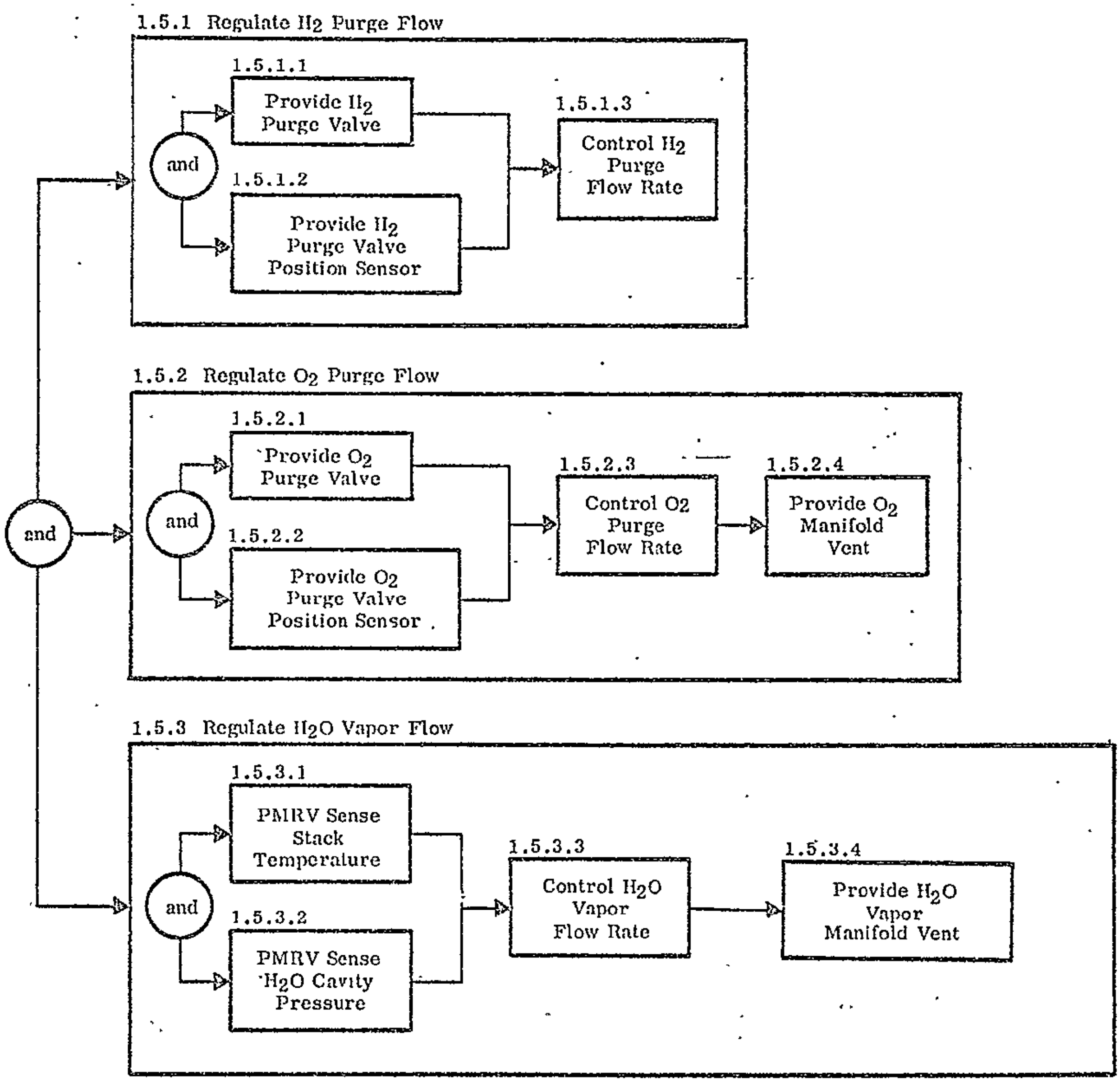

Figure C-7. Power Generation Network - Remove By-Products

1.5.1.3 Hydrogen Purge Rate Control

Control of the hydrogen purge gas flow rate shall be provided by a flow restrictor downstream of the purge valve. Gas properties for each restrictor are:

	Inlet		Outlet	
	Min	Max	Min	Max
Pressure, psia	28.5	67	15.2	35.5
Temperature, °F	0	220	0	220
Flow, lb/h	0	0.73	0	0.73

1.5.2 Oxygen Purge

This function provides for flow control and sensing of oxygen purge gas flow.

1.5.2.1 Oxygen Purge Valve

Upon command from the purge controller (Function 1.1.2.5), the oxygen purge valve shall permit flow from its associated fuel cell stack (Function 1.3.3.2). Oxygen purge gas characteristics are:

	Inlet		Outlet	
	Min	Max	Min	Max
Pressure, psia	30 ± 0.5*	67	28.5	67
Temperature, °F	0	220	0	220
Flow, lb/h	0	5.8	0	5.8

1.5.2.2 Oxygen Purge Valve Position Sensor

The oxygen purge valve shall incorporate a sensor with two discrete outputs to indicate whether the valve is open or closed. The sensor outputs will be interfaced with the ICS (Function 1.1.1.2).

1.5.2.3 Oxygen Purge Rate Control

Control of the oxygen purge gas flow rate shall be provided by a flow restrictor downstream of the purge valve. Gas properties for each restrictor are:

	Inlet		Outlet	
	Min	Max	Min	Max
Pressure, psia	28.5	67	15.2	35.5
Temperature, °F	0	220	0	220
Flow, lb/h	0	5.8	0	5.8

Number of cycles: 3500

*Less pressure drop through RCS and Stack

1.5.3 Water Vapor Removal

This function provides for regulation of the rate of removal of product water vapor from the fuel cell stacks (Function 1.3.3.3). The water removal rate must maintain the pressure in the stack moisture removal cavity within a tolerance corresponding to ± 1% control of the KOH concentration in the moisture cavity matrix. Compensation for stack temperature is required.

1.5.3.1 Stack Temperature Sensing

The stack temperature must be sensed by the PMRV, using a stack-mounted temperature sensor (Function 1.3.2.2). The range of stack temperatures to be sensed over the required PMRV control range in 180°F minimum to 220°F maximum.

1.5.3.2 Water Cavity Pressure Sensing

The moisture removal cavity pressure must be sensed directly by the PMRV in the stack water vapor outlet line (Function 1.3.3.3). The range of pressures constituting the PMRV control band is from 2.7 psia minimum to 9.2 psia maximum.

1.5.3.3 Water Vapor Flow Rate Control

The rate of removal of product water vapor from each fuel cell stack shall be controlled by a proportional moisture removal valve (PMRV). Utilizing the temperature and pressure stimuli received from Functions 1.5.3.1 and 1.5.3.2, the PMRV shall automatically regulate steam flow to maintain water cavity pressures in accordance with the following requirements.

	Stack Temperature, °F	
	180	220
Water vapor pressure for 35 ± 1% KOH, psia	3.77 ± 0.16	8.84 ± 0.34
Water vapor pressure for 42 ± 1% KOH, psia	2.84 ± 0.16	6.80 ± 0.34
Maximum individual stack water flow, lb/h	3.33	
Maximum system water flow, lb/h	10.0	

The PMRV shall remain closed at stack temperatures below 180°F and shall remain open at stack temperatures above 220°F.

The PMRV shall provide four control band settings for specific KOH concentrations as follows:

35 ± 1.0%
37.3 ± 1.0%
39.6 ± 1.0%
42.0 ± 1.0%

1.5.3.4 Water Vapor Manifold Vent

To assure that water removal capability is not compromised by flow blockage in the interfacing water delivery subsystem, a vent valve shall be provided in the water removal manifold to permit steam venting.

B. SCHEMATIC ARRANGEMENT

The components are as follows:

	Number Required	Function Performed	
Hydrogen purge valve	2	1.5.1.1	1.1.2.5, 1.3.3.2
Hydrogen purge valve position sensor	2	1.5.1.2	1.1.1.2
Hydrogen purge restrictor	2	1.5.1.3	–
Hydrogen purge manifold		Outlet gas collection	Vehicle hydrogen vent
Oxygen purge valve	2	1.5.2.1	1.1.2.5, 1.3.3.2
Oxygen purge valve position sensor	2	1.5.2.2	1.1.1.2
Oxygen purge restrictor	2	1.5.2.3	–
Oxygen purge manifold	1	Outlet gas collection	2.6
Proportional MRV	2	1.5.3.1, 1.5.3.2, 1.5.3.3	1.3.2.2, 1.3.3.3
Steam manifold	1	Outlet steam collection	2.2
Steam vent valve	1	1.5.3.4	Vehicle water vent

WATER DELIVERY SUBSYSTEM (WDS)

A. FUNCTIONAL REQUIREMENTS

2.0 Function

The WDS receives steam from the By-Product Removal Subsystem (BRS) and performs the condensation and conditioning functions necessary to deliver potable liquid water to the vehicle. This subsystem performs the functions of 2.0 thru 2.7 of the functional network shown in Figure C-8.

2.1 Thermal Interface

The WDS shall provide a thermal interface for transfer of heat from the condensers to the TCS (Function 1.4.1.1.1). Performance characteristics at the interface are as follows:

	Inlet		Outlet	
	Min	Max	Min	Max
Coolant temperature, °F	40	120	40	136
Coolant flow, lb/h	410	490	410	490
Heat Transfer, Btu/h	-	-	0	5000

2.2 Water Condensation

The WDS shall provide for condensation of the steam received from the BRS (Function 1.6.3.3). Performance requirements are:

	Inlet		Outlet	
	Min	Max	Min	Max
Heat removal, Btu/h	-	-	0	5000
Coolant temperature, °F	40	120	40	136
	(Vapor)		(Liquid)	
Water Pressure, psia	2.83[1]	9.18[1]	0.125[2]	2.74[2]
Water temperature, °F	180	220	40	138
Water flow, lb/h	0	10.0	0	10.0

[1]Less PMRV pressure drop

[2]Less condenser matrix pressure drop

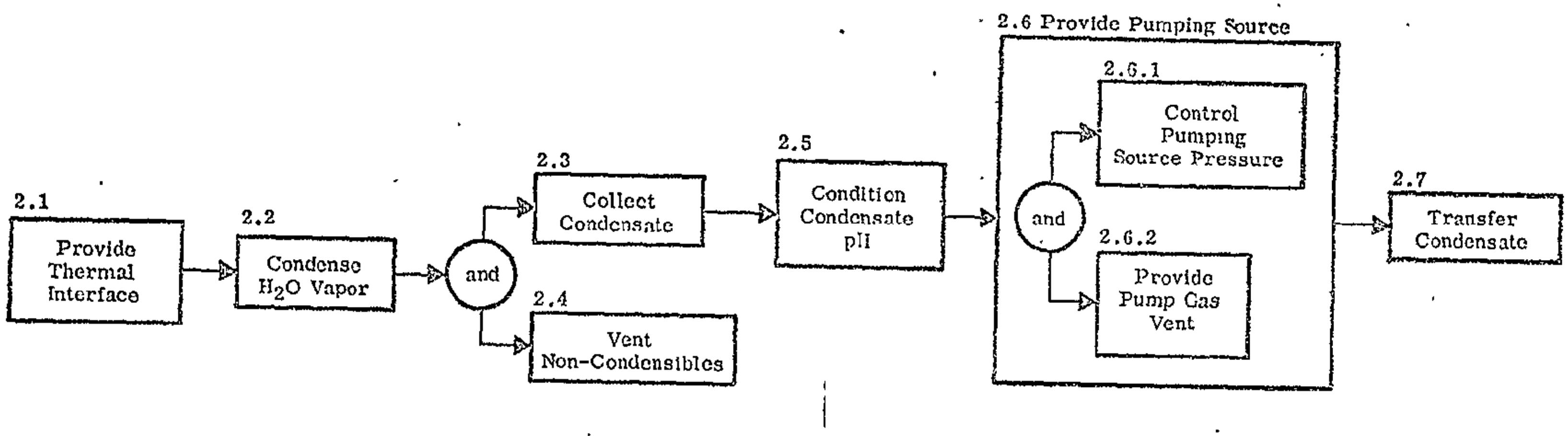

Figure C-8. Water Delivery Network-Deliver Potable Water

2.3 Condensate Collection

The condensate formed in the condenser must be collected and transported by static means (pressure differential) to the pH conditioning functional element (Function 2.5).

2.4 Non-Condensible Vent

The steam side of the condenser shall include provisions for periodic vent of non-condensibles accumulating in the condenser. Pressure/flow characteristics of the vent regulator are:

Up to 10 lb/h at 4.0 psia
Zero flow at 3.95 psia

2.5 Condensate pH Conditioning

The WDS shall provide for pH adjustment of the FCPS condensate prior to delivery to the vehicle. Performance requirements are:

	Inlet		Outlet	
	Min	Max	Min	Max
Condensate, pH	8	13	6	8
Water flow, lb/h	0	10	0	10
Total water processed, lb	0	2000	0	2000

2.6 Water Pumping Source

A gaseous pumping source shall be provided for transfer of FCPS condensate to the vehicle. Reactant oxygen shall be used for this purpose. Characteristics of the pumping oxygen at the WDS are:

	Inlet		Outlet	
	Min	Max	Min	Max
Pressure, psia	30 ± 0.5	55 ± 0.5	0	15
Temperature, °F	0	180	0	180
Flow, lb/h	TBD	TBD	TBD	TBD
Flow duration, seconds	15	28	TBD	TBD

2.7 Condensate Transfer

Condensate transfer to the vehicle shall be accomplished by oxygen-driven mechanical pumping. Performance requirements are:

	Inlet		Outlet	
	Min	Max	Min	Max
Pressure, psia	0.125[1]	2.74[1]	0	30 (static)
Temperature, °F	40	138	40	140
Flow, lb/h	0	5	0	170

Water capacity (lb)

Operating cycles: 3500

[1] Less deionized pressure drop

B. SCHEMATIC ARRANGMENT

The components in the subsystem are as follows:

	Number Required	Function Performed	
Thermal interface	1	2.1	1.4.1.1.1
Condenser	1	2.2, 2.3	1.5.3.3
Vent regulator	1	2.4	Vehicle water vent
Deionizer	1	2.5	-
Water pump	1	2.7	Vehicle water supply
Oxygen supply	1	2.6	1.5.2.3