



CUSTOMER TRAINING

APOLLO J-MISSION
ELECTRICAL POWER SYSTEM
AND
CAUTION AND WARNING SYSTEM
SYSTEM DESCRIPTION

1 OCTOBER 1971

FOR TRAINING PURPOSES ONLY

SPACE DIVISION
NORTH AMERICAN ROCKWELL CORPORATION

This J-Mission training handout is one of the listed documents.
The information in these handouts is designed for all personnel assigned
to the Apollo Program.

- 2.1 Guidance and Control System
- 2.2 Guidance and Navigation System
- 2.3 Stabilization and Control System
- 2.4 Service Propulsion System
- 2.5 Reaction Control System
- 2.6 Electrical Power System
- 2.7 Environmental Control System
- 2.8 Telecommunications System
- 2.9 Sequential Systems
- 2.10 Caution and Warning System
- 2.11 Scientific Instrument Module Experiments
- 2.12 Crew Personal Equipment
- 2.13 Docking and Transfer

Questions relative to the contents of these handouts should be
directed to:

Customer Training Group
D/073-120
Mail Code FB87
Ext 2021

SECTION 2

SUBSECTION 2.6

ELECTRICAL POWER SYSTEM (J-Missions)

2.6.1 INTRODUCTION

The electrical power subsystem (EPS) consists of the equipment and reactants required to supply the electrical energy sources, power generation and controls, power conversion and conditioning, and power distribution to the electrical buses (figure 2.6-1). Electrical power distribution and conditioning equipment beyond the buses is not considered a part of this subsystem. Power is supplied to fulfill all command and service module (CSM) requirements, as well as to the lunar module (LM) for operation of heater circuits after transposition and docking.

The EPS can be functionally divided into four major categories:

- Energy storage: Cryogenics storage, entry and postlanding batteries, pyrotechnic batteries.
- Power generation: Fuel cell power plants.
- Power conversion: Solid state inverters, battery charger.
- Power distribution: D-C and a-c power buses, d-c and a-c sensing circuits, controls and displays.

In general, the system operates in three modes: peak, average, and minimum mission loads. Peak loads occur during performance of major delta V maneuvers, including boost. These are of relatively short duration with d-c power being supplied by three fuel cell power plants supplemented by two of three entry batteries. A-C power is supplied by two of three inverters.

The second mode is that part of the mission when power demands vary about the average. During these periods d-c power is supplied by three fuel cell power plants and a-c power by one or two inverters.

During drifting flight when power requirements are at a minimum level, d-c power is supplied by three fuel cell power plants. A-C power is supplied by two inverters, but can be safely provided by a single inverter. In all cases, operation of one or two inverters is dependent on the total cryogen available. Two-inverter operation results in a slight increase of cryogenic usage because of a small reduction in inverter efficiency due to the lesser loads on each inverter. However, two inverter operation precludes complete loss of ac in the event of an inverter failure.

2.6.2 FUNCTIONAL DESCRIPTION

2.6.2.1 Energy Storage

The primary source of energy is the cryogenic storage system that provides fuel (H_2) and oxidizer (O_2) to the power generating system and O_2 to the environmental control system (ECS). Hydrogen and oxygen tanks, with the associated controls and plumbing, are located in the service module. Storage of reactants is accomplished under controlled cryogenic temperatures and pressures; automatic and manual pressure control is provided. Automatic heating of the reactants for repressurization is dependent on energy demand by the power generating and/or environmental control subsystems. Manual control can be used when required. A contingency isolation feature is provided to isolate an O_2 tank for ECS use in the event of a failure which could deplete all the oxygen tanks.

A secondary source of energy storage is provided by five silver oxide-zinc batteries located in the CM and one battery located in the SM. Three rechargeable entry and postlanding batteries in the CM supply sequencer logic power at all times, supplemental d-c power for peak loads, all operating power required for entry and postlanding, and can be connected to power either or both pyro circuits. Two pyro batteries in the CM provide energy for activation of pyro devices throughout all phases of a mission. The SM battery is interchanged on the main buses with fuel cell 2, and can supply power for an emergency return in the event of a failure resulting in an inability to operate any of the fuel cells.

2.6.2.2 Power Generation

Three Bacon-type fuel cell power plants, generating power through electrochemical reaction of H_2 and O_2 , supply primary d-c power to spacecraft systems until CSM separation. Each power plant is capable of normally supplying from 400 to 1420 watts at 31 to 27 vdc (at fuel cell terminals) to the power distribution system. During normal operation all three power plants generate power, but two are adequate to complete the mission. Should two of the three malfunction, one power plant will insure successful mission termination; however, spacecraft loads must be reduced to operate within the limits of a single power plant.

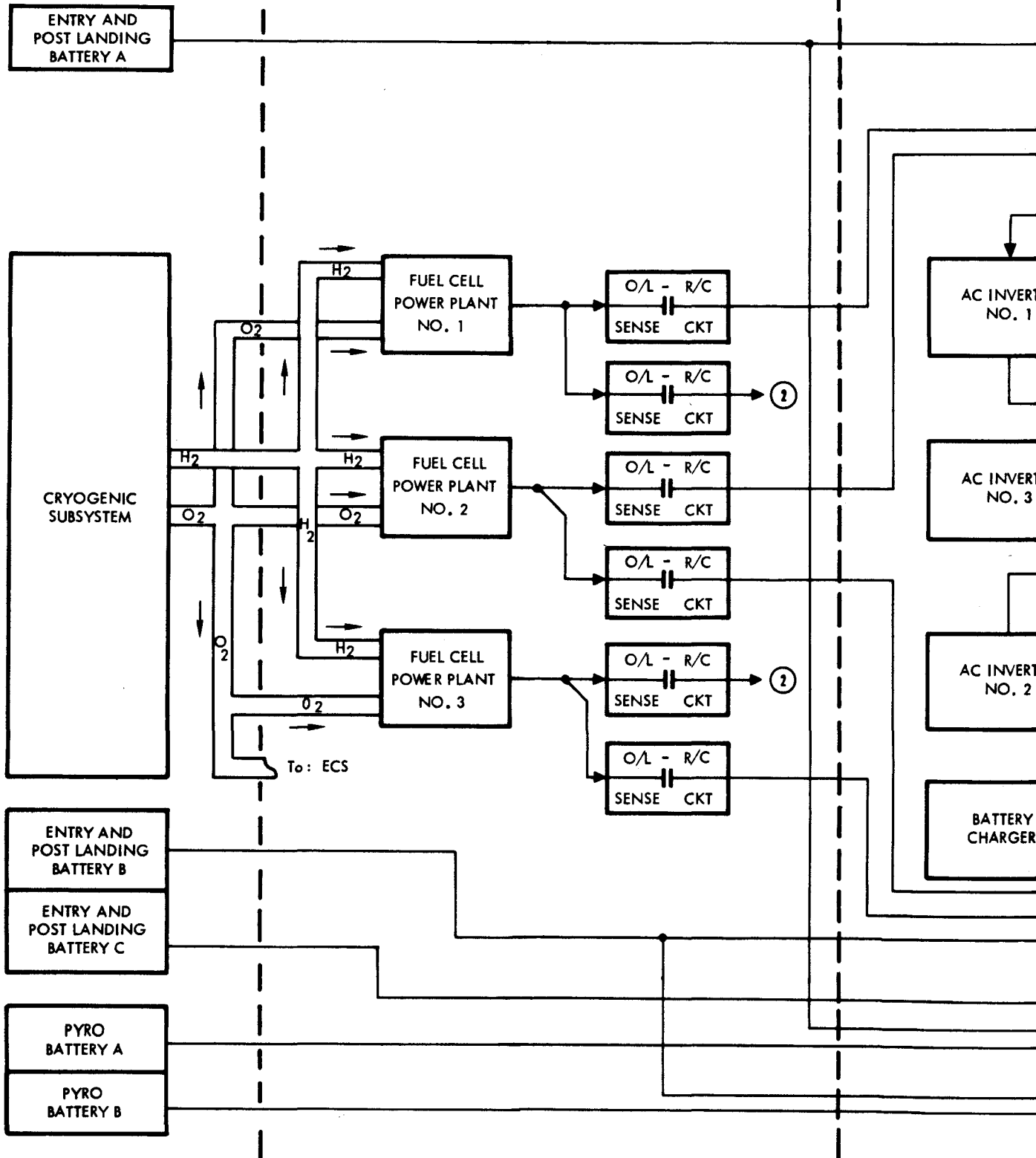
Normal fuel cell connection to the distribution system is fuel cell 1 and 2 to main d-c bus A, and fuel cell 3 to main d-c bus B. Manual switch control is provided for power plant connection to the distribution system, and manual and/or automatic control for power plant isolation in case of a malfunction.

During the CSM separation maneuver, the power plants supply power through the SM buses to two SM jettison controllers. The controllers sustain SM RCS retrofire during CSM separation and fire the SM positive roll RCS engines 2 seconds after separation to stabilize the SM during entry. Roll engine firing is terminated after 2 seconds and retrofire is terminated after 25 seconds. The power plants and SM buses are isolated from the umbilical by a SM deadface circuit. The controllers are connected to the SM buses when the CM/SM SEP switch (MDC-2) is activated; separation occurs 100 milliseconds after switch activation.

ENERGY STORAGE

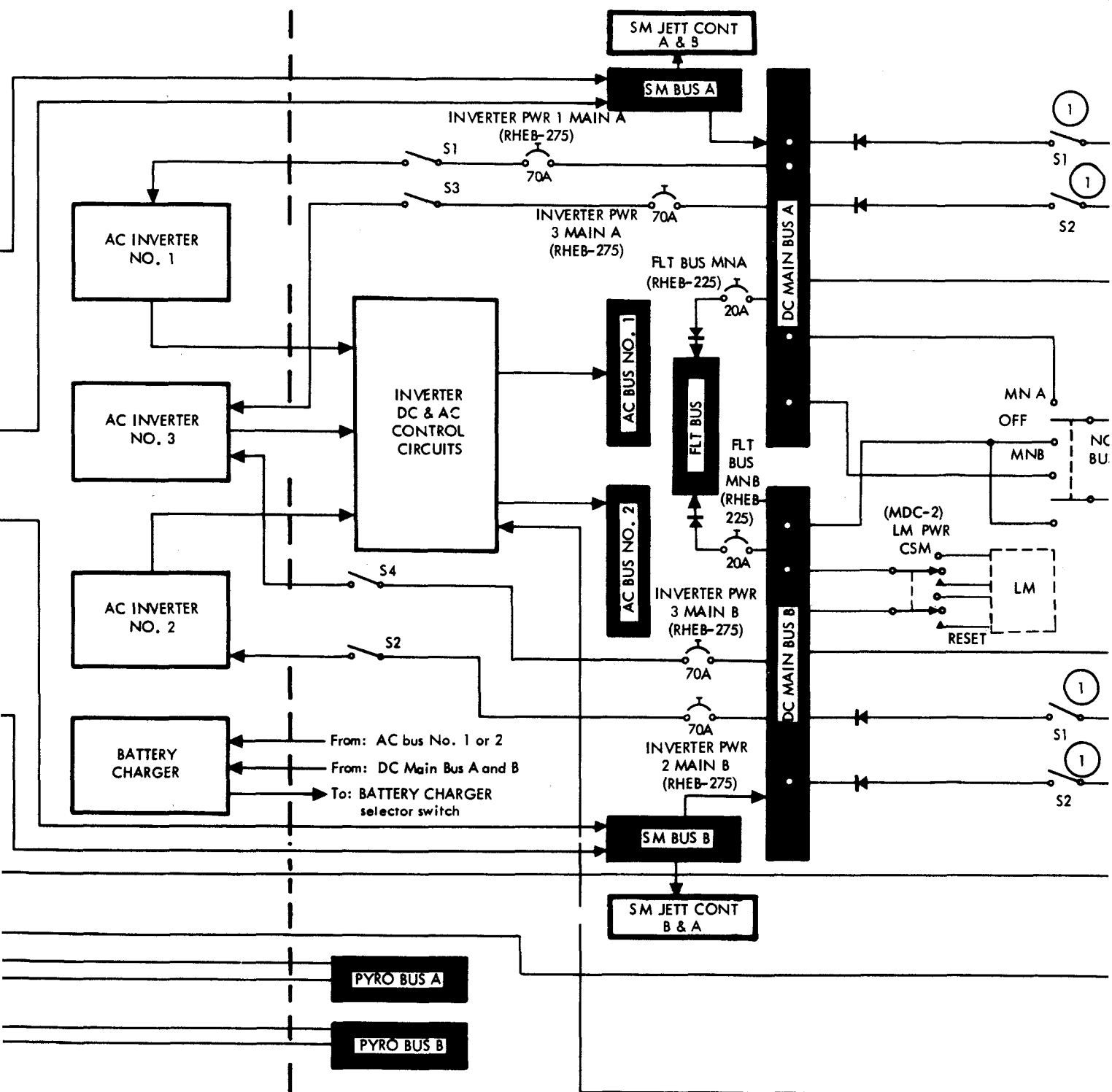
POWER GENERATION

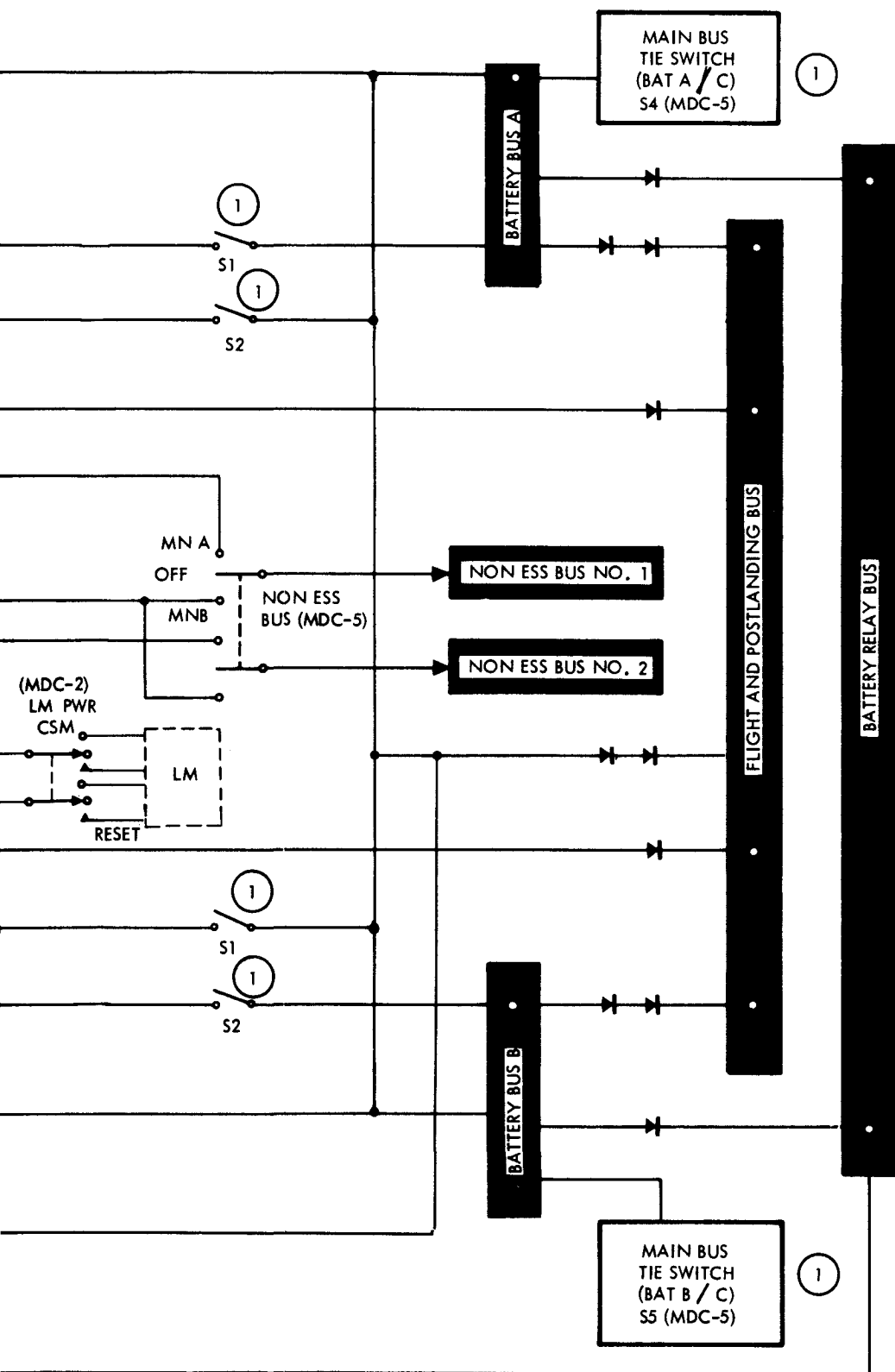
POWER CONVE



POWER CONVERSION

POWER DISTRIBUTION





NOTES:

- ① Motor switches S1 and S2 close when main bus tie switches S4 and S5 are set to Bat A/C and Bat B/C.
- ② FC1 can be connected to SM bus B & FC 3 to SM bus A
- ③ DC bus control circuit breakers are illustrated in battery charger and CM DC bus control circuits schematic

SM-2A-1175P

Figure 2.6-1. Electrical Power Subsystem Block Diagram

2.6.2.3

Power Conversion

Primary d-c power is converted into ac by solid state static inverters that provide 115/200-volt 400-Hz 3-phase a-c power up to 1250 volt-amperes each. A-C power is connected by motor switch controls to two a-c buses for distribution to the a-c loads. One inverter has the capability of supplying all spacecraft primary a-c power, and can power both buses while the two remaining inverters act as redundant sources. However, throughout the flight, each bus is powered by a separate inverter. Provisions are made for inverter isolation in the event of malfunctions. Inverter outputs cannot be phase-synchronized; therefore, interlocked motorized switching circuits are incorporated to prevent simultaneous connection of two inverters to the same bus.

A second conversion unit, the battery charger, assures keeping the three entry and postlanding batteries in a fully charged state. It is a solid state device utilizing dc from the fuel cells and ac from an inverter to develop charging voltage.

2.6.2.4

Power Distribution

Distribution of d-c power is accomplished via two redundant d-c buses in the service module which are connected to two redundant buses in the command module through a SM deadface, the CSM umbilical, and a CM deadface. Additional buses provided are a flight bus for servicing in-flight telecommunications equipment; two battery buses for distributing power to sequencers, gimbal motor controls, and servicing the battery relay bus for power distribution switching; a flight and postlanding bus for servicing some communications equipment and the postlanding loads; an experiments bus for servicing in-flight experiments; and an instrumentation bus for servicing certain CSM measurements.

Three phase ac is distributed via two redundant a-c buses, providing bus selection through switches in most of the a-c operated component circuits.

Power to the lunar module is provided through two umbilicals which are manually connected after completion of transposition and docking. An average of 81 watts dc is provided to continuous heaters in the abort sensor assembly (ASA), and cycling heaters in the landing radar, rendezvous radar, S-band antenna and inertial measurement unit (IMU). Power consumption with all heaters operating simultaneously is approximately 309 watts. LM flood-lighting is also powered through the umbilical for use during manned lunar module operation while docked with the CSM. The umbilicals provide a limited capability for supplying LM power to the CSM during contingencies.

A d-c sensing circuit monitors voltage on each main d-c bus and an a-c sensing circuit monitors voltage on each a-c bus. The d-c sensors provide an indication of an undervoltage by illuminating a warning light. The a-c sensors illuminate a warning light when high- or low-voltage limits are exceeded, and in addition, activate an automatic disconnect of the inverter from the a-c bus during an overvoltage condition. A-C overload conditions are displayed by illumination of an overload warning light and are accompanied by the voltage light. Additional sensors monitor fuel cell or auxiliary battery overload and reverse current conditions, providing an automatic disconnect, together with visual indications of the disconnect whenever either condition is exceeded.

Switches, meters, lights, and talkback indicators are provided for controlling and monitoring all functions of the EPS.

2.6.3 MAJOR COMPONENT/SUBSYSTEM DESCRIPTION

The subsequent paragraphs describe the cryogenic storage subsystem and each of the various EPS components.

2.6.3.1 Cryogenic Storage

The cryogenic storage subsystem supplies hydrogen and oxygen to the EPS fuel cells and oxygen to the ECS and for initial LM pressurizations. The J-Mission subsystem is illustrated in figures 2.6-2 and 2.6-3.

Each of the tanks is of sufficient size to provide a safe return from the furthest point of the mission on the fluid remaining in any one hydrogen and any one oxygen tank. Physical data of each tank and the overall subsystem are as follows:

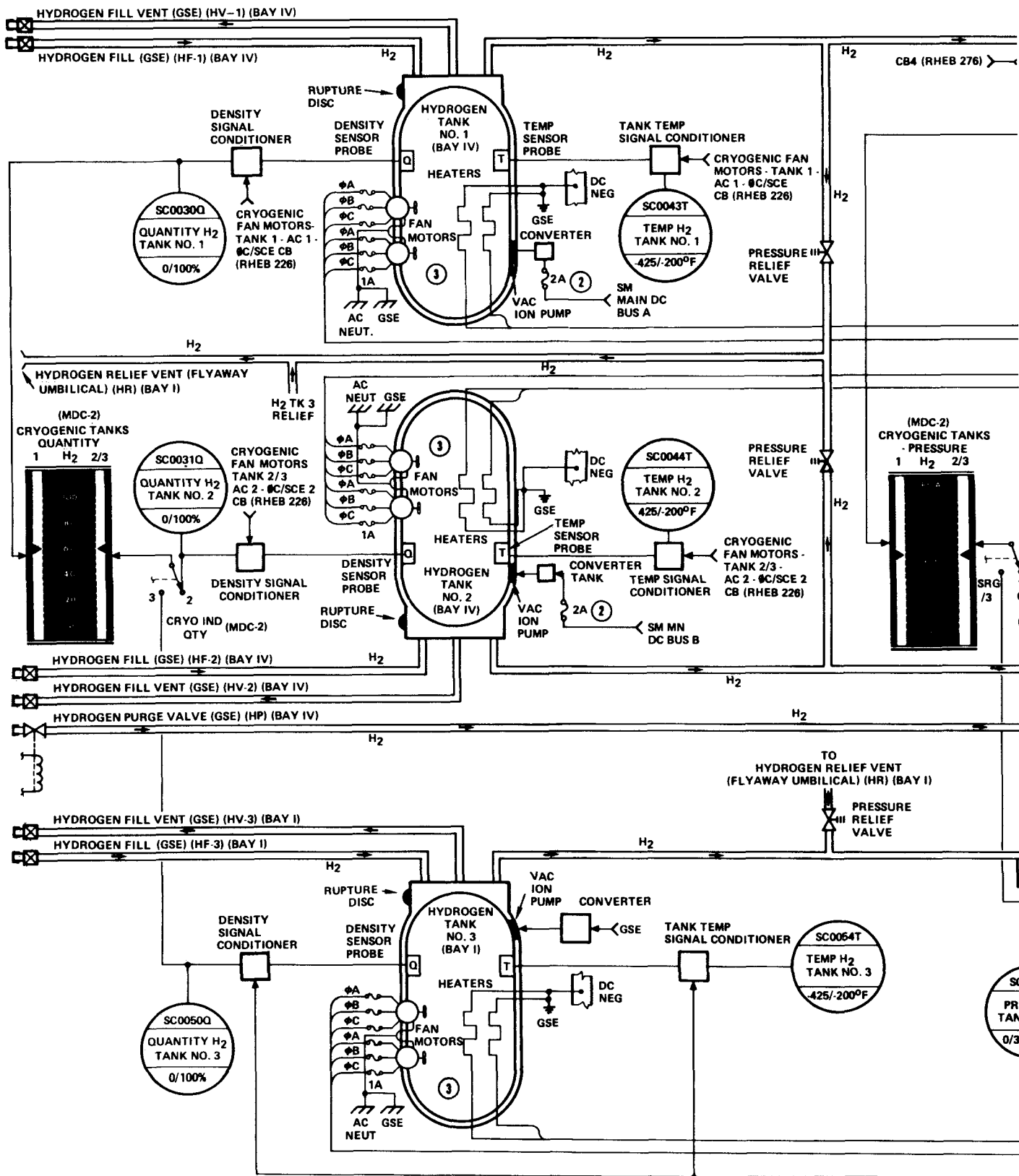
Weight of Usable Fluid (lb/tank)	Design Storage Pressure (psia)	Minimum Allowable Operating Pressure (psia)	Approximate Flow Rate at Min dq/dm (+145°F environment) (lb/hr/tank)	Approximate Quantities at Minimum Heater & Fan Cycling (per tank) (min dq/dm)
O ₂ 320 (min)	900 _± 35	150 (ECS) 865 (EVA)	0.69	45 to 25%
H ₂ 28 (min)	245 (+15, -20)	100	0.076	53 to 33%

Initial pressurization from fill to operating pressures is accomplished by GSE. After attaining operating pressures, the cryogenic fluids are in a single-phase condition, therefore completely homogeneous. This avoids sloshing which could cause sudden pressure fluctuations, possible damage to internal components, and prevents positive mass quantity gauging. The single-phase expulsion process continues at nearly constant pressure and increasing temperature above the 2-phase region. Relief valves provide overpressure relief, check valves provide tank isolation, and individual fuel cell shut-off valves provide for isolation of malfunctioning power plants. Filters extract particles from the flowing fluid to protect the ECS and EPS components. The pressure and temperature transducers indicate the thermodynamic state of the fluid, while a capacitive probe indicates quantity of fluid remaining in the tanks.

Monitoring of pressure, quantity and certain temperatures is available in the CM, while all items measured in flight are telemetered to the MSFN.

2.6.3.1.1 Hydrogen Storage

Two tanks in bay IV and one tank in bay I of the SM provide a minimum of 84 pounds of usable hydrogen for the mission, which includes launch pad usage. Tanks 1 and 2 contain two parallel heaters which are used to maintain design pressure of 245 (+15, -20) psia. Tank 3 heater circuits are not connected to any spacecraft power source and will only be powered from



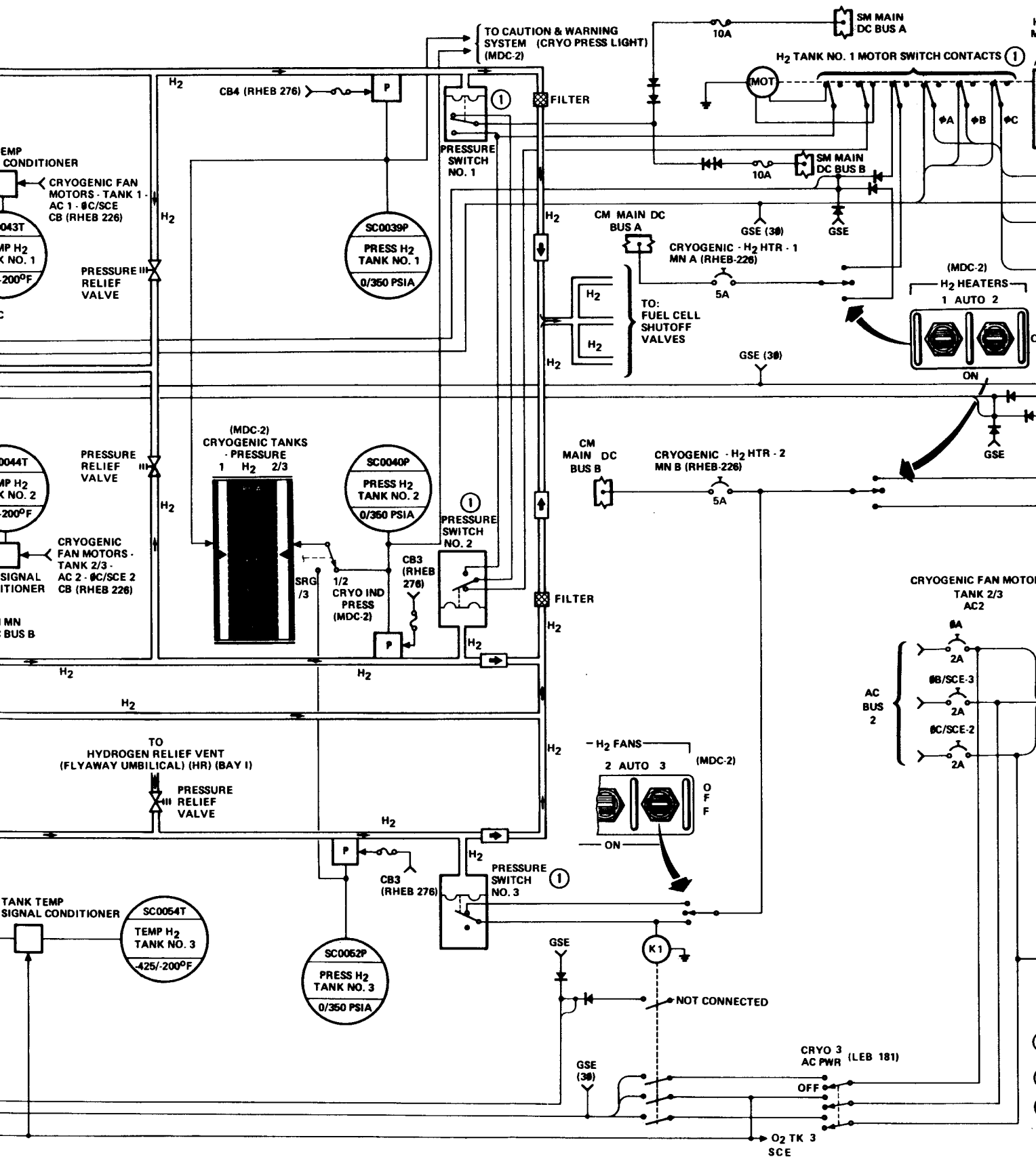


Figure 2.6-2. Hydrogen Storage System

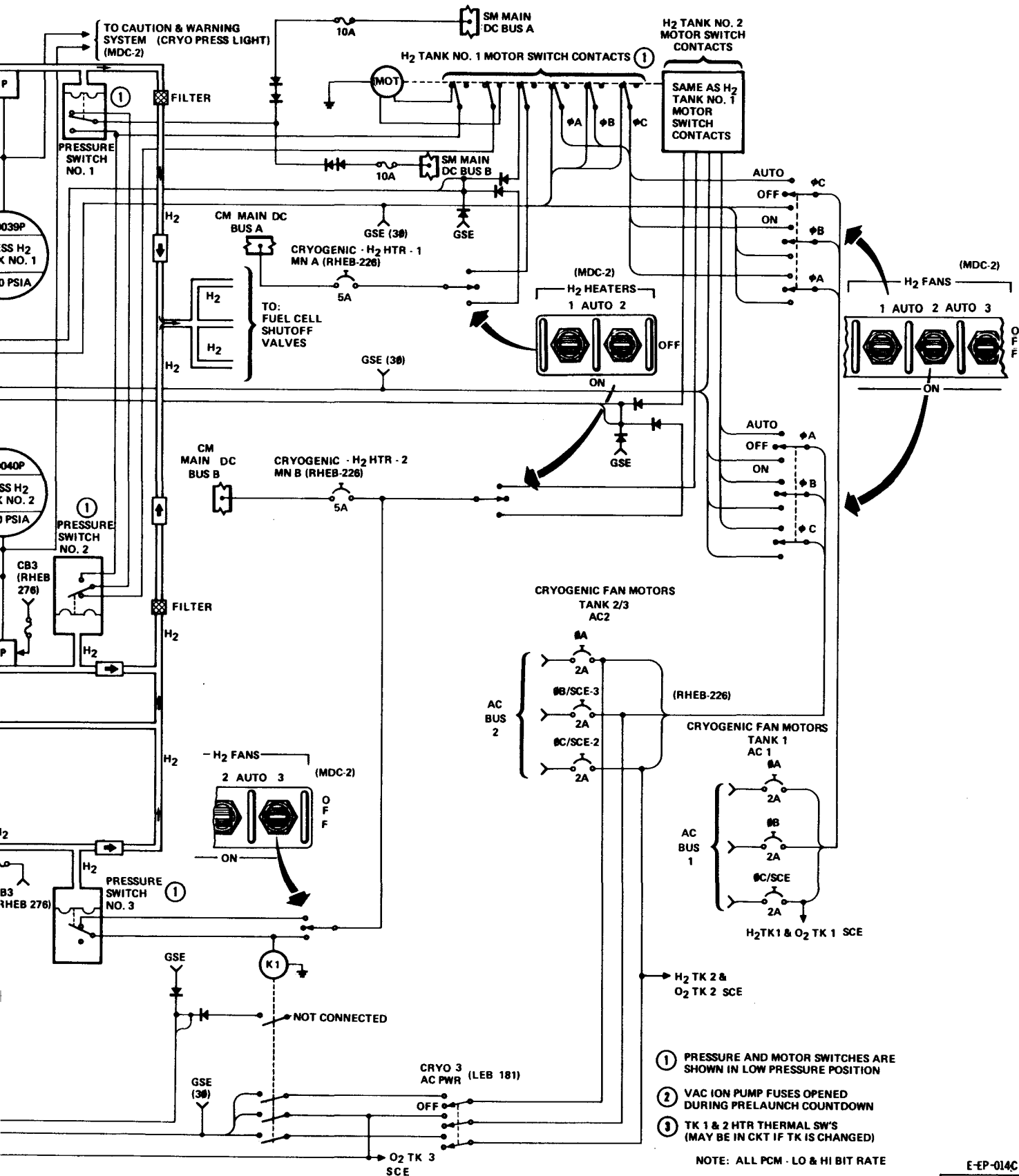
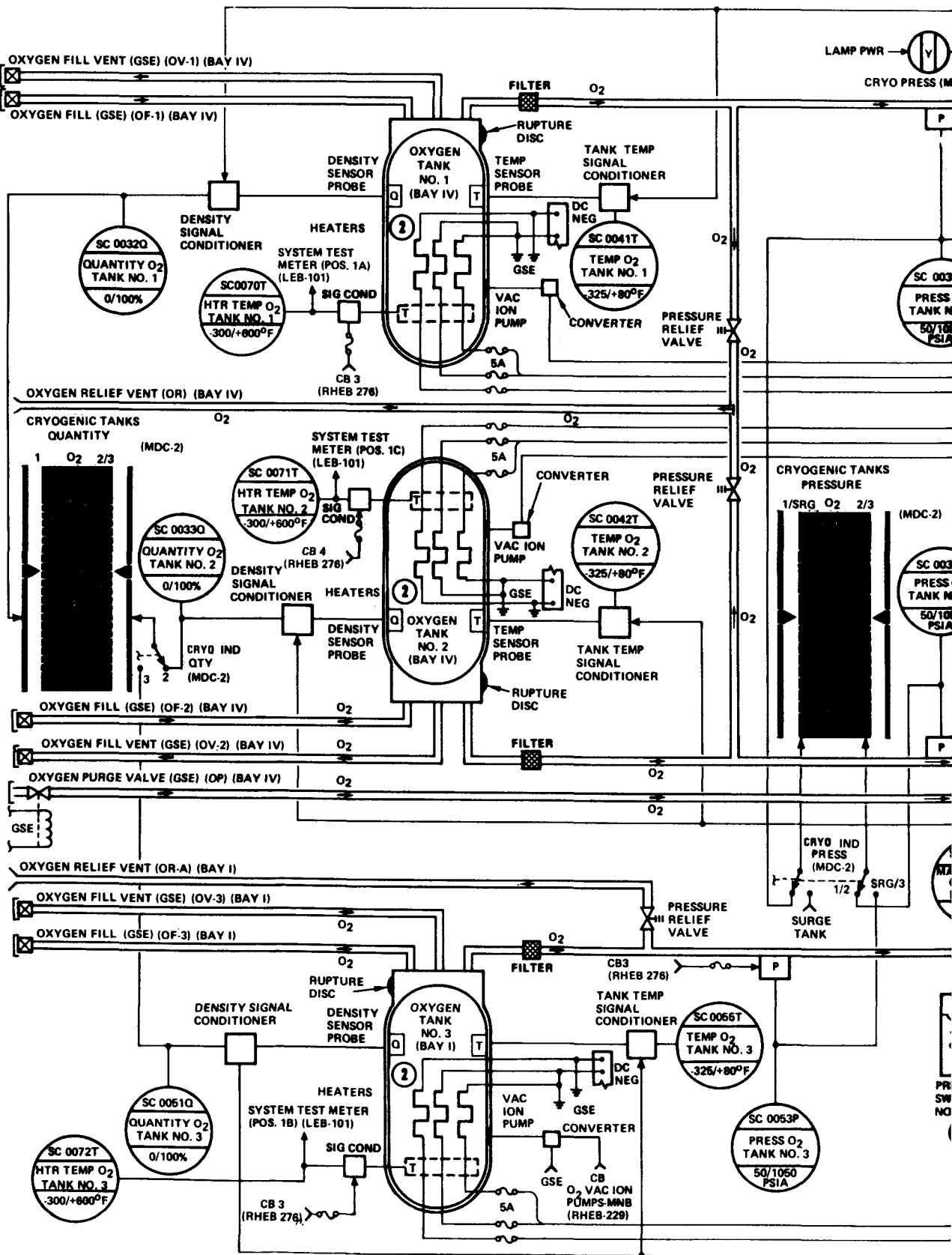


Figure 2.6-2. Hydrogen Storage - J-Mission



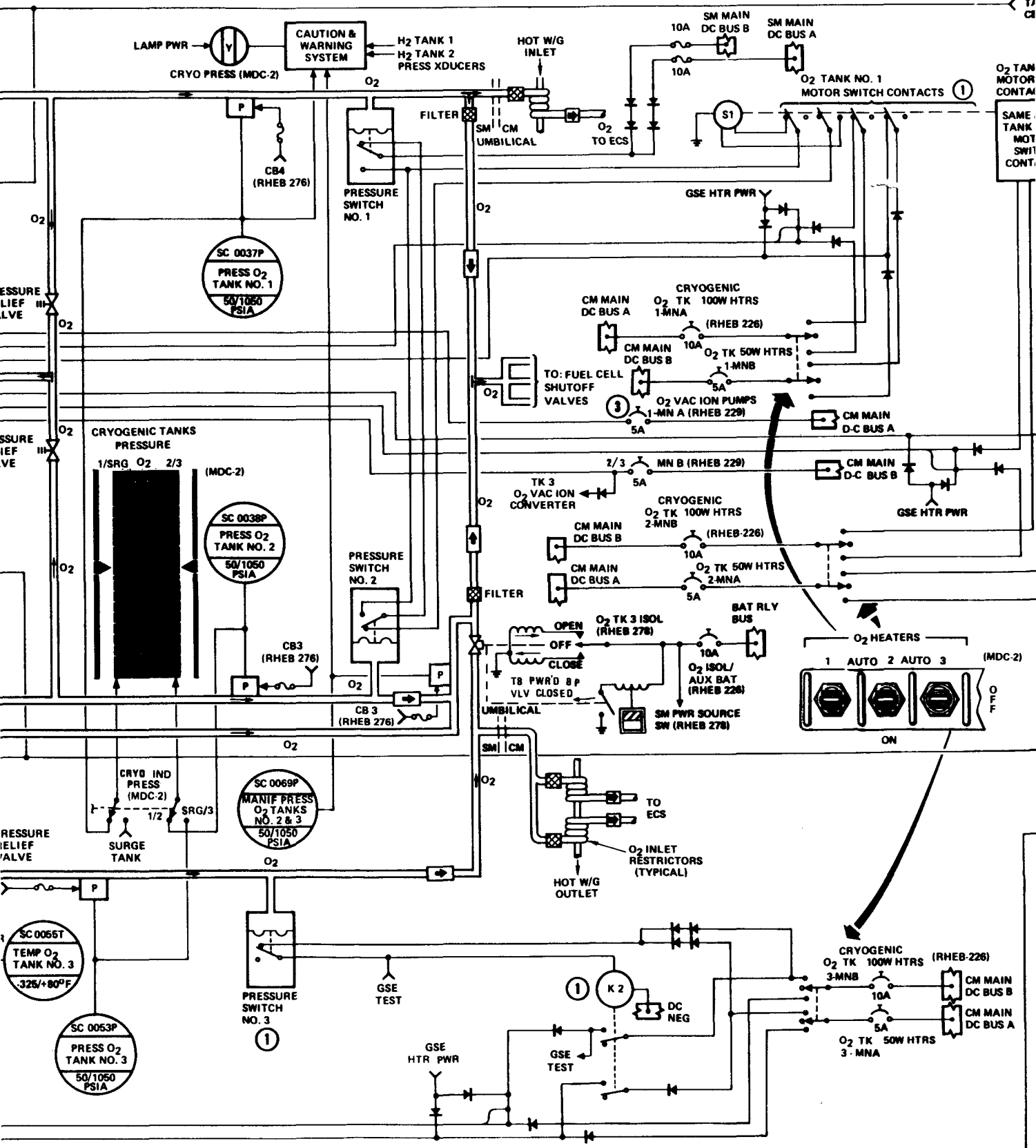


Figure 2.6-3. Oxygen Storage J-Mission

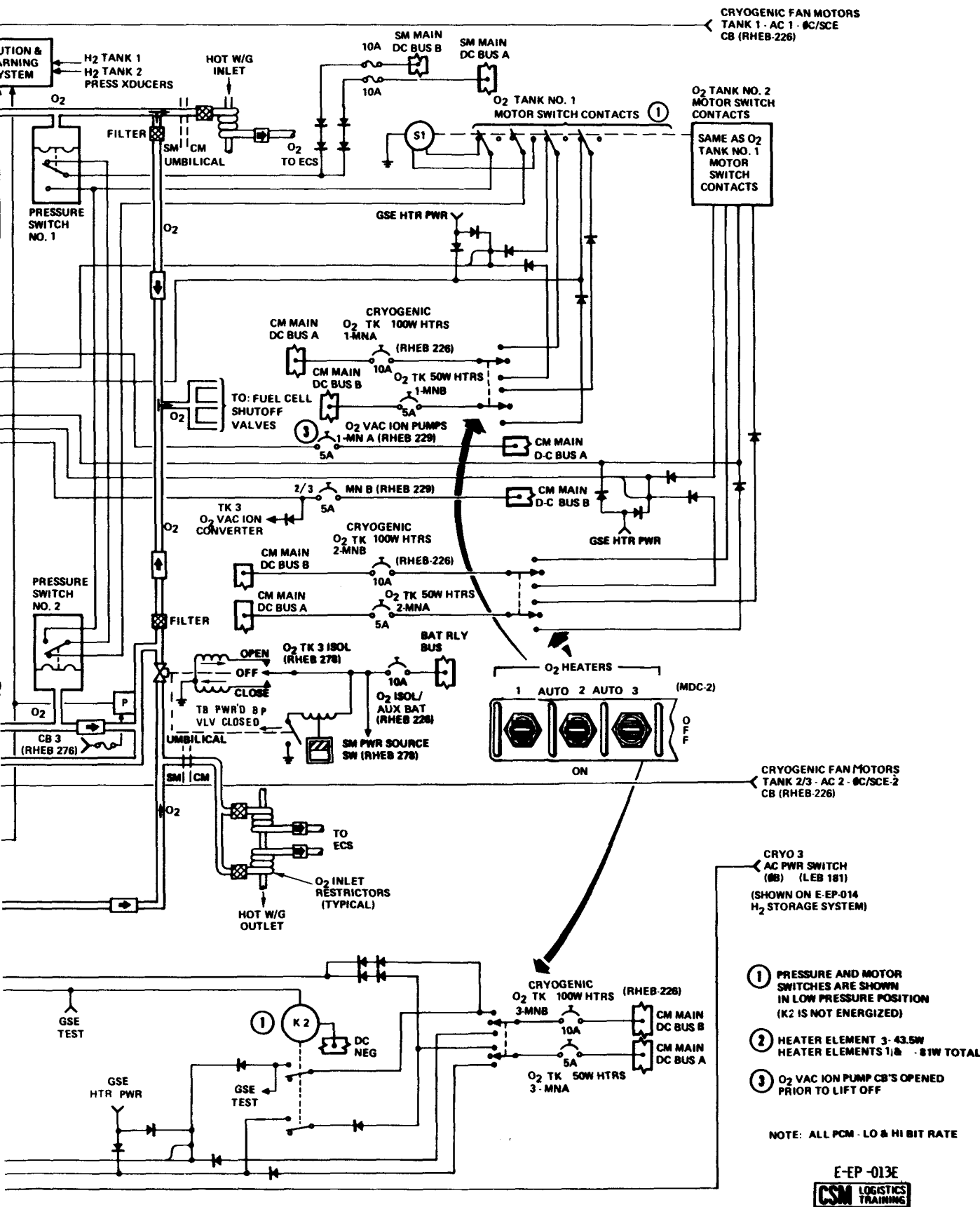
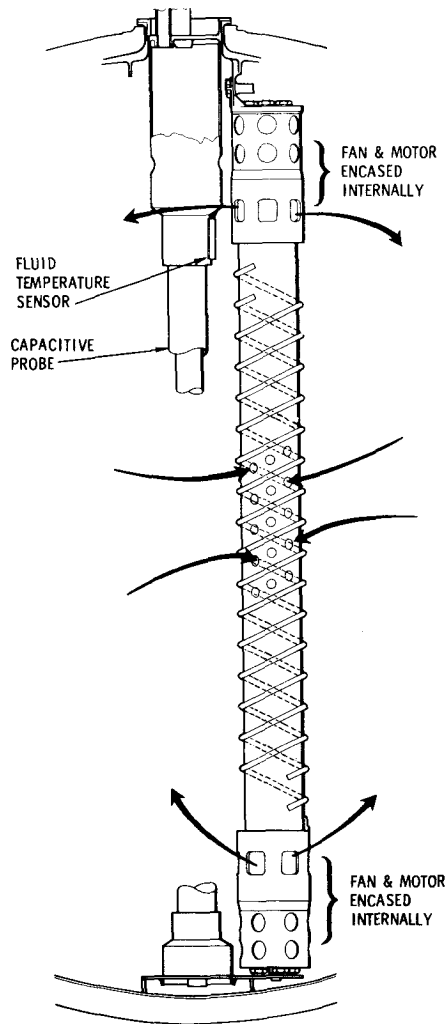


Figure 2.6-3. Oxygen Storage J-Mission

GSE on the launch pad for initial pressurization. Therefore, tank 3 in-flight pressurization will be maintained by two parallel 3-phase a-c fans, which will also provide the circulation required to maintain uniform density of the fluid and decrease stratification. The fans in tanks 1 and 2 will be periodically turned on manually at pre- and postsleep and prior to any SPS propulsion maneuver to minimize stratification. A typical installation of the heater/fan and quantity probes is illustrated in figure 2.6-4.



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Figure 2.6-4. Cryogenic Pressurization and Quantity Measurement Devices (H_2)

Repressurization can be performed by automatic or manual control. Although the tank 1 and 2 heater and fan circuits are designed for automatic operation, only the heaters are operated in the AUTO mode. Auto or manual selection is made with the H₂ HEATERS - 1 and 2 switches (MDC-2). Tank 3 auto or manual control is selected with the H₂ FANS switch (MDC-2). A-C power to the tank 3 circuits (which include the a-c powered instrumentation) is provided through the CRYO 3 - AC PWR switch (LEB 181). The automatic mode is designed to provide hydrogen flow into the feed lines at design pressures. Pressures in tanks 1 and 2 will be maintained at 225 psia at the respective quantity levels, provided flow from either tank does not exceed the approximations listed at the respective quantities in the following flow chart. The Fans Only column is primarily applicable to tank 3. Since the fans are the only means of repressurizing tank 3, it will repressurize at a considerably slower rate than tanks 1 and 2.

Available heat input sources into a hydrogen tank are:

Heat Source	Watts (at input voltage)	Btu
Heaters	17.0	58.02
Fan Motors	7.0	23.89
Heat leak		7.24

Flow availability at 225 psia is as follows:

Single Tank Flow at 225 PSIA
(heat leak included)

Quantity (percent)	Htrs & Fans	Htrs Only	Fans Only	Heat Leak Only
100	0.37	0.27	0.13	0.030
95	0.40	0.29	0.14	0.033
90	0.45	0.33	0.16	0.036
85	0.49	0.36	0.17	0.040
80	0.55	0.41	0.19	0.045
75	0.62	0.45	0.22	0.050
70	0.70	0.51	0.24	0.056
65	0.76	0.56	0.27	0.062
60	0.82	0.60	0.29	0.067
55	0.88	0.65	0.31	0.072
50	0.92	0.67	0.32	0.075
45	0.93	0.68	0.33	0.076
40	0.92	0.67	0.32	0.075
35	0.90	0.66	0.31	0.073
30	0.86	0.63	0.30	0.070
25	0.71	0.57	0.28	0.064
20	0.68	0.49	0.23	0.055
15	0.51	0.38	0.18	0.042
10	0.34	0.25	0.12	0.028
7.5	0.23	0.17	0.08	0.019
5	0.15	0.11	0.05	0.012

Automatic tank repressurization, when selected by the switches on MDC-2, is controlled by a pressure switch in each individual tank system. The series pressure switches in tanks 1 and 2 will energize the power line to the motor switch to supply power to both tank heater circuits at a minimum of 225 psia. When either tank pressurizes to 260 psia, its pressure switch will be positioned to supply power to the motor switch to open both tank heater circuits. Deadband tolerance of each individual pressure switch will largely determine the leading tank. The tank 3 pressure switch will energize the relay to power the fan motors at a minimum of 225 psia, and de-energize the relay, thus disconnecting power to the fan motors at a maximum of 260 psia.

The illustration does not show any thermal switches in the heater circuits; however, if tanks are replaced, there is a possibility the replacement tanks may be configured with thermal switches which are designed to open the heater circuit at 90°F maximum and close it at 70°F. Operation of the thermal switches would occur only at very low quantity levels when the internal temperature rises to this level because of fluid depletion.

One of the prime mission requirements is to maintain tank quantities at levels whereby an optimum position is retained to provide a return capability in the event of a hydrogen system contingency requiring early mission termination. Hydrogen system tank management will be performed with unbalanced tank quantities to preclude venting because of heat leak; however, the system will be configured to provide the safe return feature throughout a range of contingencies. System management will be dependent upon mission duration, which is based on studies in progress to determine the best mission length to satisfy the scientific objectives. Establishing desired tank quantity levels can be performed in the AUTO mode by positioning the tank 1 and/or 2 heater switches, and/or the tank 3 fan switch to AUTO on MDC-2. Manual operation of the heater and fan switches is available, as the ON position bypasses the pressure switches and provides power directly to the heaters in tanks 1 and 2, and energizes the relay to power the tank 3 fan motors. Manual operation can be used in the event of a malfunction in any of the three pressure switches, or the tank 1 and 2 motor switch control which are used for AUTO operation. Using the manual mode requires monitoring of tank pressures by the MSFN and/or on the meters on MDC-2 in order to maintain operation within the desired pressure range. Hydrogen pressures should be maintained above the critical pressure of 188 psia to assure fluid retention in a single-phase condition at all times.

At a set flow condition, each successive repressurization cycle is of generally longer duration. However, the periods between repressurizations lengthen in duration as fluid is depleted to the 43 percent (min dq/dm) level, and shorten in duration as fluid depletion continues. Heat leak has the most effect in the min dq/dm region, thus minimum heater operation is realized between 53 and 33 percent.

The tank 1 and 2 fan motors are operated manually at specified periods, namely pre-sleep, postsleep, and prior to any SPS propulsion maneuver. Operation of the fan motors may result in a pressure drop of several pounds depending on the degree of stratification in the tanks. The pressure drop may be great enough to illuminate the caution/warning CRYO PRESS light and the accompanying master alarms. The C/W light will be extinguished as

pressure increases in the tank because of fan motor heat input. The purpose of the fan motors is to decrease stratification, thus maintaining a uniform fluid density in the tanks. The most accurate quantity indication would be prevalent shortly after fan motor shutdown.

Each of the hydrogen tanks is configured with a vac-ion pump. The units are operated only on the launch pad, since the tank 1 and 2 circuits are deactivated prior to lift-off by opening the fuses in the power supply lines, and tank 3 can only be powered by GSE.

Control over repressurization of the hydrogen subsystem is exercised by use of the H₂ HEATERS - 1 and 2, and H₂ FANS - 1, 2 and 3 switches on MDC-2. AUTO, ON (manual), or OFF selection is provided. A-C power to the tank 3 fans is supplied through the CRYO 3 - AC PWR switch on LEB 181 and relay contact closure. Circuit protection for the preceding is provided by circuit breakers on RHEB 226. The CRYOGENIC - H₂ HTR 1 and 2 circuit breakers protect the tank 1 and 2 heater circuits and the CRYOGENIC FAN MOTORS - TANK 1-AC 1-ØA, ØB, ØC/SCE and TANK 2-AC 2-ØA, ØB/SCE 3, ØC/SCE 2 circuit breakers protect the fan motor and signal conditioning equipment circuits of all three tanks. In addition, each phase of a-c power to each fan motor is further protected by a 1-amp fuse. The d-c powered pressure transducer circuits are protected by fuses in each circuit, and further protected by circuit breakers on RHEB 276. Motor switch power for automatic mode operation of tanks 1 and 2 is supplied directly from the SM main d-c buses and protected by fuses in each power supply line. Tank 3 fan auto operation is performed through a pressure switch relay arrangement. The same relay is energized to operate the fans in the manual mode.

Pressure and quantity monitoring by the crew is provided by meters on MDC-2. Monitoring of tank 3 is shared with tank 2 on the right side of the H₂ quantity and pressure meters. Selection is made with the CRYO IND - QTY and PRESS switches which are also common to the O₂ meters. Out-of-limits pressures of tanks 1 and 2 are monitored by the caution/warning subsystem which will activate the CRYO PRESS light (MDC-2) when pressure in either of the two tanks exceeds 270 psia or decreases below 200 psia. Since the CRYO PRESS light is common to this portion of the H₂ and the O₂ system, reference to the individual meters must be made to determine the malfunctioning tank. H₂ tank 3 is not monitored by the C/W subsystem, but only on the meters or by telemetry. Should an overpressure condition occur, the relief valves in each tank system are designed to vent at a pressure between 273 and 283 psig. Full flow through a relief valve occurs approximately 2 pounds above the opening pressure. The valves reseal at 268 psig minimum.

2.6.3.1.2 Oxygen Storage

Three tanks, two in bay IV and one in bay I of the SM, are each capable of containing a minimum of 320 pounds of usable oxygen, thus providing approximately 960 pounds of oxygen for the mission, including launch pad usage. Each tank is configured with three heaters. Two are connected in parallel and the third isolated electrically. The heaters are capable of maintaining the design pressure of 900+35 psia. Repressurization can be performed by automatic or manual control. Repressurization will be performed

in a manner to provide unequal depletion to preclude overpressure overboard venting due to heat leak effect in the min dq/dm quantity regions. Quantities will be maintained to provide a safe return on tank 1 or tanks 2 and 3 in the event of partial subsystem failures. Tank 3 will always contain a sufficient quantity to supply ECS requirements in the event of a contingency requiring a return on the auxiliary battery.

Since the heater circuitry is of a nature to allow single, dual, or three heater operation by use of the circuit breakers on RHEB 226, the following chart lists the flow that can be provided by a single tank at minimum design pressure (865 psia) using the three variable heater operating modes. Each of the heaters is a 53-watt element at a 28-vdc input; however, after considering line losses, approximate wattages are 74w, 71w, 67w for the parallel heaters, and 36.5w, 37.5w, 36w for the single heaters in tanks 1, 2 and 3 respectively. The chart also includes nominal heat leak of 24 Btu/hr.

Quantity (percent)	FLOW (lbs/hr)									Heat Leak
	One Heater			Two Heaters			Three Heaters			24 Btu/hr
	Tk 1 149 Btu	Tk 2 152 Btu	Tk 3 147 Btu	Tk 1 276 Btu	Tk 2 266 Btu	Tk 3 253 Btu	Tk 1 401 Btu	Tk 2 394 Btu	Tk 3 376 Btu	
100	0.90	0.91	0.89	1.66	1.60	1.52	2.41	2.37	2.27	0.14
95	1.01	1.03	1.00	1.87	1.80	1.64	2.71	2.66	2.54	0.16
90	1.15	1.17	1.13	2.12	2.05	1.95	3.08	3.03	2.89	0.18
85	1.32	1.35	1.30	2.44	2.35	2.24	3.55	3.49	3.33	0.21
80	1.52	1.55	1.50	2.82	2.72	2.58	4.09	4.02	3.84	0.24
75	1.73	1.77	1.71	3.21	3.09	2.94	4.66	4.58	4.37	0.28
70	2.01	2.05	1.99	3.73	3.59	3.42	5.42	5.32	5.08	0.32
65	2.33	2.38	2.30	4.31	4.16	3.92	6.27	6.16	5.87	0.37
60	2.66	2.71	2.63	4.93	4.75	4.52	7.16	7.04	6.71	0.43
55	3.10	3.17	3.06	5.75	5.54	5.27	8.35	8.21	7.83	0.50
50	3.55	3.60	3.50	6.57	6.33	6.02	9.55	9.38	8.95	0.57
45	3.92	4.00	3.87	7.26	7.00	6.66	10.55	10.37	10.00	0.63
40	4.26	4.34	4.20	7.88	7.60	7.23	11.46	11.26	10.75	0.69
35	4.38	4.47	4.30	8.12	7.82	7.44	11.79	11.59	11.06	0.71
30	4.38	4.47	4.30	8.12	7.82	7.44	11.79	11.59	11.06	0.71
25	4.26	4.34	4.20	7.88	7.60	7.23	11.46	11.26	10.75	0.69
20	3.92	4.00	3.87	7.26	7.00	6.66	10.55	10.37	10.00	0.63
15	3.17	3.23	3.13	5.87	5.66	5.38	8.53	8.38	8.00	0.51
10	2.19	2.24	2.16	4.06	3.91	3.72	5.90	5.79	5.53	0.35
5	1.31	1.34	1.29	2.42	2.33	2.22	3.52	3.45	3.30	0.21

Automatic pressure control is selected with the O₂ HEATERS - 1, 2, 3 switches on MDC-2. The AUTO mode utilizes the pressure switches in each tank subsystem, with the tank 1 and 2 switches being in series, while the tank 3 pressure switch operates independently. However, assuming equal pressure switch deadband, if the three tanks are operated in AUTO simultaneously, all three tanks will have to decrease in pressure to energize the automatic circuits, because tank 3 feeds into a common line with tank 2.

The ON position of the O₂ HEATERS switches bypasses the pressure switches and provides power directly to the heaters. Manual operation requires monitoring of tank pressures by the MSFN and/or on the CRYOGENIC TANKS - PRESSURE - O₂ meters on MDC-2, in order not to exceed the high- or low-pressure limits. Oxygen-critical pressure is 730 psia; therefore, tank pressures should be maintained above this level to assure single phase fluid retention at all times.

Over- and under-pressure conditions are monitored by the caution/warning subsystem, which will be activated whenever pressure in either tank exceeds 950 psia, or when pressure decreases below 800 psia in tank 1, or tanks 2 and 3 combined. A low pressure in tank 2 or 3 will not energize the caution/warning subsystem as the signal input to the caution/warning is taken from the tank 2 and 3 manifold, so the higher pressure tank will mask out the low pressure tank. The CRYO PRESS lamp on MDC-2 being common to four signal inputs (two hydrogen and two oxygen), reference must be made to the meters (MDC-2) to determine the malfunctioning tank. Should an over-pressure condition occur, the relief valves in each tank system are designed to vent overboard at a pressure between 983 and 1008 psig. Full flow through the valves occurs at approximately 2 pounds above the opening pressure. Tanks 1 and 2 relieve through a common vent in bay IV, while tank 3 has a separate vent in bay I of the SM. The valves reseal at 965 psig minimum.

As in the hydrogen tanks, each successive repressurization cycle (at a set flow condition) will be of longer duration. However, the periods between repressurizations lengthen in duration as quantity decreases to the minimum dq/dm level (approximately 33 percent), and subsequently decrease in duration as fluid depletion continues. Heat leak has the greatest effect at the minimum dq/dm level. Heat input into the oxygen tanks is as previously outlined in the flow chart, consisting of the heaters (as selected by the circuit breakers), and heat leak.

Each of the oxygen tanks is configured with a vac-ion pump. Circuit protection and operational control are provided by the O₂ VAC ION PUMPS - 1-MNA and 2/3-MNB circuit breakers on RHEB-229. The pumps are operated on the launch pad to maintain heat leak into the oxygen tanks at acceptable levels. The circuit breakers are opened prior to lift-off, and remain open through the mission unless notified otherwise by the MSFN.

Control of the oxygen subsystem is exercised by the O₂ HEATERS - 1, 2 and 3 switches on MDC-2. Heater circuit protection, and selection of 1, 2, or 3 heater operation is provided by the O₂ TK 100W HTRS - 1 MNA, 2 MNB, 3 MNB and O₂ TK 50W HTRS - 1 MNB, 2 MNA, 3 MNA circuit breakers on RHEB 226. Each heater element circuit is further protected by a 5 ampere fuse. The ac powered signal conditioner (density and tank temp) circuits are protected by the CRYOGENIC FAN MOTORS - TANK 1 - AC 1 - ØC/SCE and the TANK 2/3 - AC 2 - ØB/SCE 3 and ØC/SCE 2 circuit breakers on RHEB 226. The d-c powered heater temperature sensors and signal conditioners are powered through both CM main d-c buses with circuit protection by fuses in the SM and circuit breakers on RHEB 276. The tank 1, 2, and 3 pressure transducers and the tank 2 and 3 manifold pressure transducer have internal signal conditioning and are powered through both CM main d-c buses with circuit protection by fuses in the SM and circuit breakers on RHEB 276. The tank 1 and the tank 2 and 3 manifold pressure transducers provide signals to illuminate the caution/warning light.

On-board monitoring of the oxygen subsystem is performed by quantity and pressure meters on MDC-2 and the caution/warning subsystem. Signal input for meter readings is selected by the O₂ IND - QTY switch which applies the tank 2 or 3 measurement to the right side of the CRYOGENIC TANKS - QUANTITY - O₂ meter. The left side of the meter provides a continuous indication of tank 1 quantity. Pressure signal inputs are selected by the O₂ IND - PRESS switch on MDC-2 with provisions for the tank 1 reading on the left side of the meter, while tank two is displayed on the right side. The SRG/3 position of the selector switch provides the surge tank reading on the left side and tank 3 on the right side. Oxygen tank 1, 2, and 3 heater temperatures can be monitored on the LEB 101 SYSTEM TEST METER with position 1A providing a measurement of tank 1, position 1C measuring tank 2, and position 1B measuring the tank 3 heater temperature. Normally, heater temperatures should not exceed +350°F at all quantity levels, thus the decal for LEB-101 establishes this as a precautionary limit based on tank fracture mechanics. Tests have indicated that exceeding the established limit up to the +500°F heater limit is not sufficient to create a detrimental effect on the tank; however, it would indicate an other than nominal condition existing, probably due to the effect of stratification. This creates a requirement for fluid agitation to decrease stratification.

Quantities, tank pressures, tank 2/3 manifold pressure, tank temperatures, and heater temperatures are telemetered to the MSFN.

There is a provision for isolating tank 3 from the remainder of the system. Control of the isolation valve is with the O₂ TK 3 ISOL switch on RHEB 278. Circuit protection is provided by the O₂ ISOL/AUX BAT circuit breaker on RHEB 226, which will be opened after transposition and docking. The purpose of the valve is for use in the event of either a tank 2/3 manifold line failure, or a failure at some point in the system which could result in a depletion of oxygen from all 3 tanks, which would also require a complete fuel cell shutdown. Closing of the isolation valve will retain tank 3 oxygen as an ECS supply into the CM. In this situation, the SM auxiliary battery (paragraph 2.6.3.2) would be used for emergency return power. If this type of return became necessary, the tank 3 heaters would not be operated since heat leak alone would be sufficient to maintain pressure and the flow required by the ECS.

2.6.3.2 Batteries

Six silver oxide-zinc storage batteries are incorporated in the EPS. Five of these batteries are located in the CM lower equipment bay and the sixth (aux battery) is on the aft bulkhead in bay IV of the SM.

Three rechargeable entry and postlanding batteries (A, B, and C) power CM systems after CSM separation and during postlanding. Prior to CSM separation, the batteries provide a secondary source of power while the fuel cells, or in contingencies the auxiliary battery, are the primary source. The entry batteries are used for the following purposes:

- Provide CM power after CSM separation
- Supplement fuel cell power during peak load periods (Delta V maneuvers)
- Provide power during emergency operations (failure of two fuel cells)
- Provide power for EPS control circuitry (relays, indicators, etc.)
- Provide sequencer logic power

- Provide power for recovery aids during postlanding
- Batteries A, B, or C can power pyro circuits by selection.

Each entry and postlanding battery is mounted in a vented plastic case and consists of 20 silver oxide-zinc cells connected in series. The cells are individually encased in plastic containers which contain relief valves that open at 35 ± 5 psig, venting during an overpressure into the battery case. The three cases can be vented overboard through a common manifold, the BATTERY VENT valve (RHEB-252), and the ECS waste water dump line.

Since the BATTERY VENT is closed prior to lift-off, the interior of the battery cases is at a pressure of one atmosphere. The pressure is relieved after earth orbit insertion and completion of cabin purge by positioning the control to VENT for 5 seconds. After completion, the control is closed, and pressure as read out on position 7A of the system test meter (LEB-101) should remain at zero unless there is battery outgassing. Outgassing can be caused by an internal battery failure, an abnormal high-rate discharge, or by overcharging. If a pressure increase is noted on the system test meter, the BATTERY VENT is positioned to VENT for 5 seconds, and reclosed. Normal battery charging procedures require a check of the battery manifold after completion of each recharge.

Since the battery vent line is connected to the waste water dump line, it provides a means of monitoring waste water dump line plugging, which would be indicated by a pressure rise in the battery manifold line when the BATTERY VENT control is positioned to VENT. Corrective procedures for dump line plugging are found in section 2.12.

Each battery is rated at 40-ampere hours (AH) minimum and will deliver this at a current output of 25 amps for 60 minutes and a subsequent output of 2 to 5 amps for the remainder of the rating.

At Apollo mission loads each battery is capable of providing 45 AH and will provide this amount after each complete recharge cycle. However, 40 AH is used in mission planning for in-flight capability, and 45 AH for post-landing capability of a fully charged battery.

Open circuit voltage is 37.1 volts. Sustained battery loads are extremely light (2 to 3 watts); therefore, a battery bus voltage of approximately 34 vdc will be indicated on the spacecraft voltmeter, except when the main bus tie switches have been activated to tie the battery outputs to the main d-c buses. Normally only batteries A and B will be connected to the main d-c buses. Battery C is isolated during prelaunch by opening the MAIN A-BAT C and MAIN B-BAT C circuit breakers (RHEB-275). Battery C will therefore provide a backup for main d-c bus power in case of failure of battery A or B, or during the time battery A or B is being recharged. The two-battery configuration provides more efficient use of fuel cell power during peak power loads and decreases overall battery recharge time. The MAIN A- and MAIN B-BAT C circuit breakers are closed prior to CSM separation or as required during recharge of battery A or B.

Battery C, through circuit breakers BAT C to BAT BUS A and BAT C to BAT BUS B (RHEB-250), provides backup power to the respective battery bus in the event of failure of entry battery A or B. These circuit breakers are normally open until a failure of battery A or B occurs. This circuit can also be used to recharge battery A or B in the event of a failure in the normal charging circuit.

The two pyrotechnic batteries supply power to initiate ordnance devices in the SC. The pyrotechnic batteries are isolated from the rest of the EPS to prevent the high-power surges in the pyrotechnic system from affecting the EPS, and to ensure source power when required. These batteries are not to be recharged in flight. Entry and postlanding battery A or B can be used as a redundant source of power for initiating pyro circuits in the respective A or B pyro system, if either pyro battery fails. This can be performed by proper manipulation of the circuit breakers on RHEB-250. Caution must be exercised to isolate the failed pyro battery by opening the PYRO A (B) SEQ A (B) circuit breaker, prior to closing the yellow colored BAT BUS A (B) to PYRO BUS TIE circuit breaker.

Performance characteristics of each SC battery are as follows:

Battery	Rated Capacity per Battery	Open Circuit Voltage (nominal)	Nominal Voltage (on load)	Minimum Voltage (on load)	Ambient Battery Temperature
Entry and Postlanding, A, B, and C (3)	40 amp-hrs (25 ampere rate)	37.1 vdc	28 vdc (25 amps load)	27 vdc (25 amps load)	50° to 110°F
Pyro A and B (2)	0.75 amp-hrs (75 amps for 36 seconds)	37.8 vdc max. (37.1 vdc in flight)	23 vdc (75 amps load)	20 vdc (75 amps load) (32 vdc open circuit)	60° to 110°F
Aux battery	400 amp-hrs	37.1 vdc	30 vdc	28 vdc	

NOTE: Pyro battery load voltage is not measurable in the SC because of the extremely short time they power pyro loads.

The 400-ampere-hour aux battery is provided to supply CSM power for an emergency return in the event some malfunction requires the complete shut-down, or results in the loss of the three fuel cells. Aux battery/fuel cell 2 selection is made with the SM PWR SOURCE switch on RHEB-278, with circuit protection provided by the O₂ ISOL/AUX BAT cb on RHEB-226 as illustrated in figure 2.6-5. The maintaining down position connects fuel cell 2 to the main bus A & B circuits and disconnects the auxiliary battery. The momentary up position disconnects fuel cell 2 and connects the auxiliary battery. The center position of the switch enables an overload/reverse current sensor, which is similar to the fuel cell main bus OL/RC sensors. This provides protection in the wiring between the battery, located on the SM aft bulkhead, and the aux bat/fuel cell 2 select motor switches which are located near the fuel cell shelf at the top of the SM. The FUEL CELL - MAIN BUS A-2 and MAIN BUS B-2 switches (MDC-3) are used to connect the aux battery to the main d-c buses. A contingency requiring use of the auxiliary battery because of loss of all fuel cells, coupled with a long duration return, requires the CSM to be dormant (powered down to absolute minimum loads) for extended periods of time. The auxiliary battery can be used with fuel cell 1 and/or 3 should an occasion arise necessitating this type of operation in order to conserve the CM entry batteries.

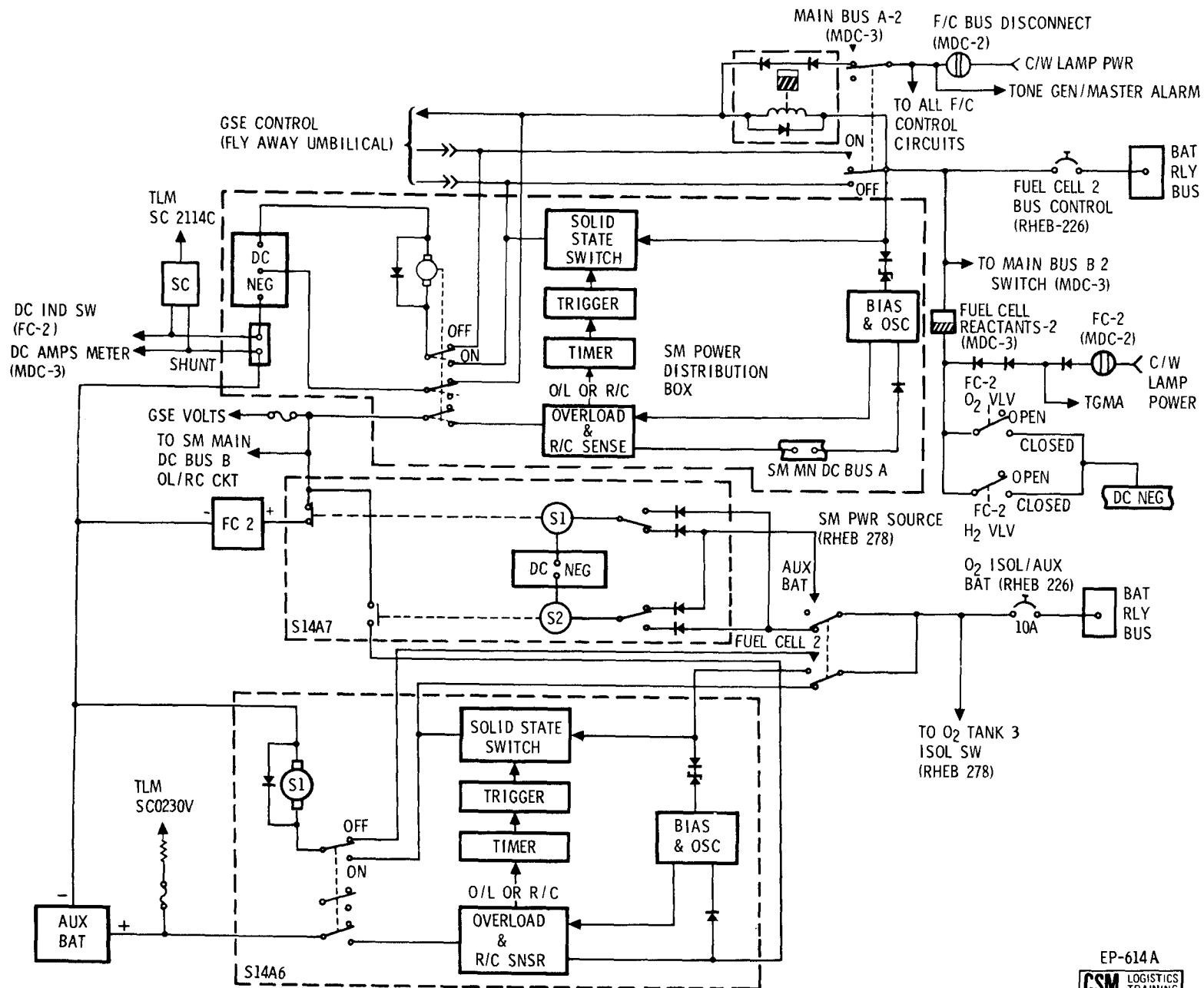


Figure 2.6-5. Fuel Cell 2/Auxiliary Battery Select Circuit

Each of the three Bacon-type fuel cell power plants is individually coupled to a heat rejection (radiator) system, the hydrogen and oxygen cryogenic storage systems, a water storage system, and a power distribution system. A typical power plant schematic is shown in figure 2.6-6.

The power plants generate d-c power on demand through an exothermic chemical reaction. The by-product water is fed to a potable water storage tank in the CM where it is used for astronaut consumption and for cooling purposes in the ECS. The amount of water produced is equivalent to the power produced which is relative to the reactant consumed.

REACTANT CONSUMPTION AND WATER PRODUCTION

Load (amps)	O ₂ lb/hr	H ₂ lb/hr	H ₂ O lb/hr	cc/hr
0.5	0.0102	0.001285	0.01149	5.21
1	0.0204	0.002570	0.02297	10.42
2	0.0408	0.005140	0.04594	20.84
3	0.0612	0.007710	0.06891	31.26
4	0.0816	0.010280	0.09188	41.68
5	0.1020	0.012850	0.11485	52.10
6	0.1224	0.015420	0.13782	62.52
7	0.1428	0.017990	0.16079	72.94
8	0.1632	0.020560	0.18376	83.36
9	0.1836	0.023130	0.20673	93.78
10	0.2040	0.025700	0.2297	104.20
15	0.3060	0.038550	0.34455	156.30
20	0.4080	0.051400	0.45940	208.40
25	0.5100	0.064250	0.57425	260.50
30	0.6120	0.077100	0.68910	312.60
35	0.7140	0.089950	0.80395	364.70
40	0.8160	0.10280	0.91880	416.80
45	0.9180	0.11565	1.03365	468.90
50	1.0200	0.12850	1.1485	521.00
55	1.1220	0.14135	1.26335	573.10
60	1.2240	0.15420	1.3782	625.20
65	1.3260	0.16705	1.49305	677.30
70	1.4280	0.17990	1.6079	729.40
75	1.5300	0.19275	1.72275	781.50
80	1.6320	0.20560	1.83760	833.60
85	1.7340	0.21845	1.95245	885.70
90	1.8360	0.23130	2.06730	937.90
95	1.9380	0.24415	2.18215	989.00
100	2.0400	0.25700	2.2970	1042.00

FORMULAS:

$$O_2 = 2.04 \times 10^{-2} I$$

$$H_2O = 10.42 \text{ cc/amp/hr}$$

$$H_2 = 2.57 \times 10^{-3} I$$

$$H_2O = 2.297 \times 10^2 \text{ lb/amp/hr}$$

2.6.3.3.1 Component Description

Each power plant consists of 31 single cells connected in series and enclosed in a titanium pressure jacket. The water separation, reactant control, and heat transfer components are mounted in a compact accessory section attached directly above the pressure jacket.

Power plant temperature is controlled by the primary (hydrogen) and secondary (glycol) loops. The hydrogen pump, providing continuous circulation of hydrogen in the primary loop, withdraws water vapor and heat from the stack of cells. The primary bypass valve regulates flow through the hydrogen regenerator to impart exhaust heat to the incoming hydrogen gas. Flow is regulated in accordance with skin temperature. The exhaust gas flows to the condenser where waste heat is transferred to the glycol; the resultant temperature decrease liquifying some of the water vapor. The motor-driven centrifugal water separator extracts the liquid and feeds it to the potable water tank in the CM. The cool gas is then pumped back to the fuel cell through the primary regenerator by a motor-driven vane pump, which also compensates for pressure losses because of water extraction and cooling. Waste heat, transferred to the glycol in the condenser, is transported to the radiators located on the fairing between the CM and SM, where it is radiated into space. Individual controls (FUEL CELL RADIATORS, MDC-3), can bypass 3/8 of the total radiator area for each power plant. Radiator area is varied dependent on power plant condenser exhaust and radiator exit temperatures which are relevant to loads and space environment. Internal fuel cell coolant temperature is controlled by a condenser exhaust sensor, which regulates flow through a secondary regenerator to maintain condenser exhaust within desired limits. When either condenser exhaust or radiator exit temperature falls below tolerance limits (150° and -30°F respectively), and the temperature is sustained, the respective FUEL CELL RADIATORS switch is positioned to EMERG BYPASS to decrease the radiator area in use, thus decreasing the amount of heat being radiated. Since the three power plants are relatively close in load sharing and temperature operating regimes, the effect on the other power plants must be monitored. Generally simultaneous control over all three power plants would be required. Use of the bypass should be minimal because of power-plant design to automatically retain heat at low loads, and expel more heat at higher loads. The bypass is primarily intended for use after failure of two power plants. Heat radiation effects on the single power plant require continuous use of the bypass.

Reactant valves provide the interface between the power plants and cryogenic system. They are opened during prelaunch and closed only after a power-plant malfunction necessitating its permanent isolation from the d-c system. Prior to launch, the FC REACS VALVES switch (MDC-3) is placed to the LATCH position. This applies a holding voltage to the open solenoids of the H₂ and O₂ reactant valves of the three power plants. This voltage is required only during boost and during transposition and docking to prevent inadvertent closure due to vibration. With the holding voltage applied, the reactant valves cannot be closed by use of the REACTANTS switches (MDC-3). The FC REACS VALVES switch is positioned to NORMAL after earth orbit

From: AC BUS 1 (3 ϕ)

From: AC BUS 2 (3 ϕ)

AC 1

AC 2

PWR FACTOR
CORRECTION
BOX
(IN SM)

FUEL CELL 3
PUMPS-AC
(RHEB-226)

MN DC BUS B

MN DC BUS A

MN DC BUS A

MN DC BUS B

MODULE TEMP
COND EXH

FUEL CELL PUMPS
(MDC-5)

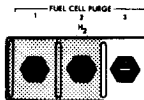


FUEL CELL
INDICATOR

SC 2081T
SC 2082T
SC 2083T

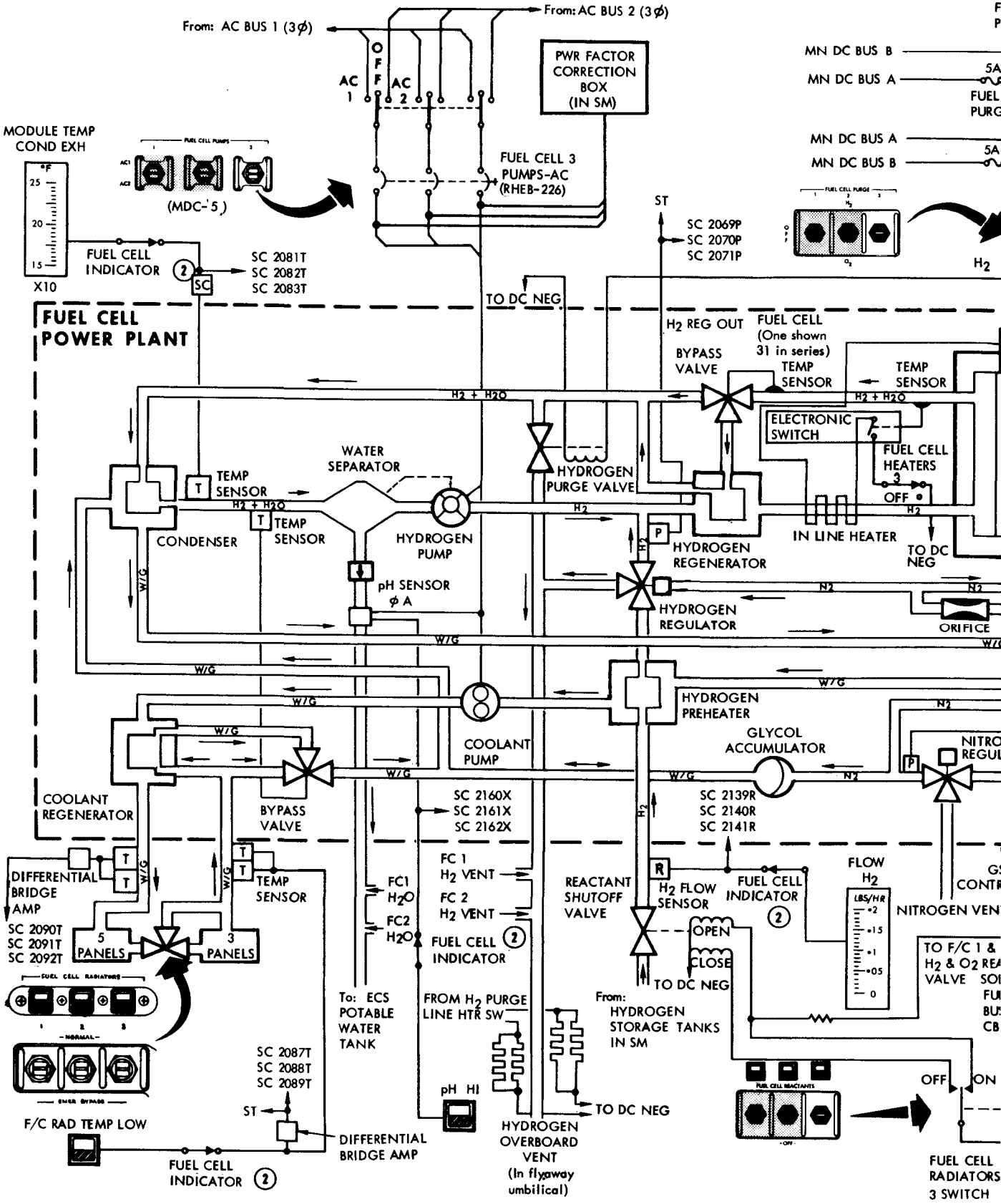
ST

SC 2069P
SC 2070P
SC 2071P



H₂

FUEL CELL POWER PLANT



FUEL CELL
RADIATORS
3 SWITCH

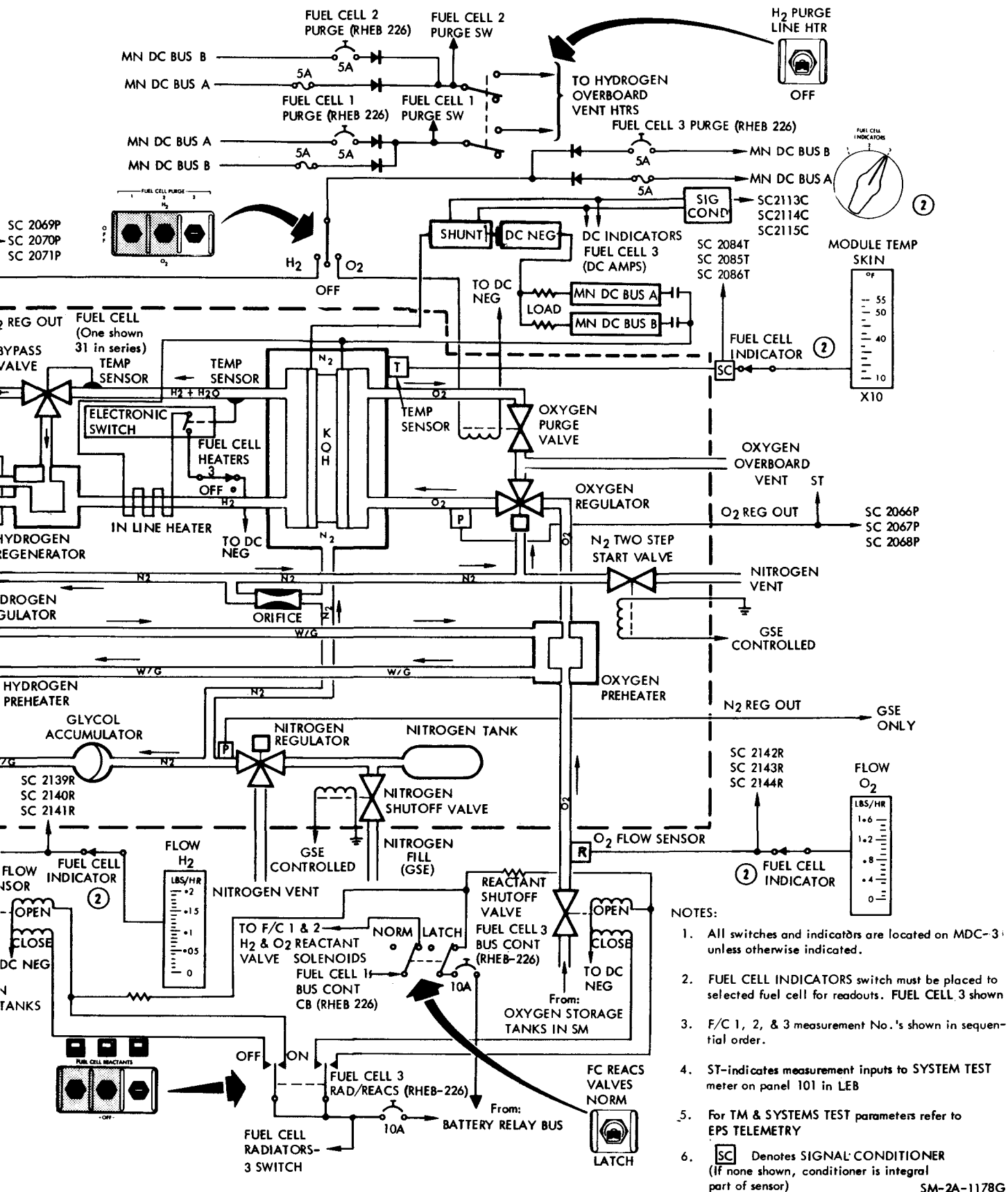


Figure 2.6-6. Fuel Cell Schematic

insertion; and again after use during transposition and docking. Should either the H₂ or O₂ valve close accidentally, the respective FC 1, FC 2 or FC 3 lamp will be illuminated in the caution and warning matrix (MDC-2), and the respective FUEL CELL REACTANTS (MDC-3) talkback indicator will show a striped indication. In the event of a FC 1, FC 2, or FC 3 caution/warning status light illumination, or master alarm activation with the status light previously illuminated, the FUEL CELL REACTANTS talkback indicators (MDC-3) should be checked first for a striped indication. If an inadvertent reactant valve closure is indicated by a striped talkback, rapid remedial action is necessary to preclude a resultant fuel cell failure. Remedial action consists of positioning the FUEL CELL REACTANTS switch (MDC-3) to the momentary UP position, and verifying valve opening by the gray talkback indicator and extinguishing of the applicable FC status light if illuminated by valve closure.

The following lists the fuel cell operating time remaining after a hydrogen reactant valve closure. The time is dependent on the flow into the fuel cell which is relative to fuel cell load. Hydrogen valve closure time is more critical than oxygen valve closure.

FC Load (amps)	Operating Time Remaining (seconds)
24	45.0
30	28.5
40	22.0
50	17.0
60	14.0

If valve closure is experienced during a hydrogen purge, a fuel cell failure (flooding) will be experienced in 2 to 3 seconds.

N₂ gas is individually stored in each power plant at 1500 psia and regulated to a pressure of 54±3 psia. Output of the regulator pressurizes the electrolyte in each cell, the coolant loop through an accumulator, and is coupled to the O₂ and H₂ regulators as a reference pressure.

Cryogenic oxygen, supplied to the power plants at 900±35 psia absorbs heat in the lines, absorbs additional heat in the preheater, and reaches the oxygen regulator in a gaseous form at temperatures above 100°F. The differential regulator reduces oxygen pressure to 9.0 psia above the N₂ reference, thus supplying it to the fuel cell stack at 63±2 psia. Within the porous oxygen electrodes, the O₂ reacts with the H₂O in the electrolyte and the electrons provided by the external circuit to produce hydroxyl ions ($O_2 + 2H_2O + 4e = 4OH^-$).

Cryogenic hydrogen, supplied to the power plants at 245 (+15, -20) psia, is heated in the same manner as the oxygen. The differential hydrogen regulator reduces the pressure to 9.0 psia above the reference N₂, thus supplying it in a gaseous form to the fuel cells at 63±2 psia. The hydrogen reacts in the porous hydrogen electrodes with the hydroxyl ions in the electrolyte to produce electrons, water vapor, and heat ($2H_2 + 4OH^- = 4H_2O + 4e + \text{heat}$). The nickel electrodes act as a catalyst in the reaction. The water vapor and heat is withdrawn by the circulation of hydrogen gas in the primary loop and the electrons are supplied to the load.

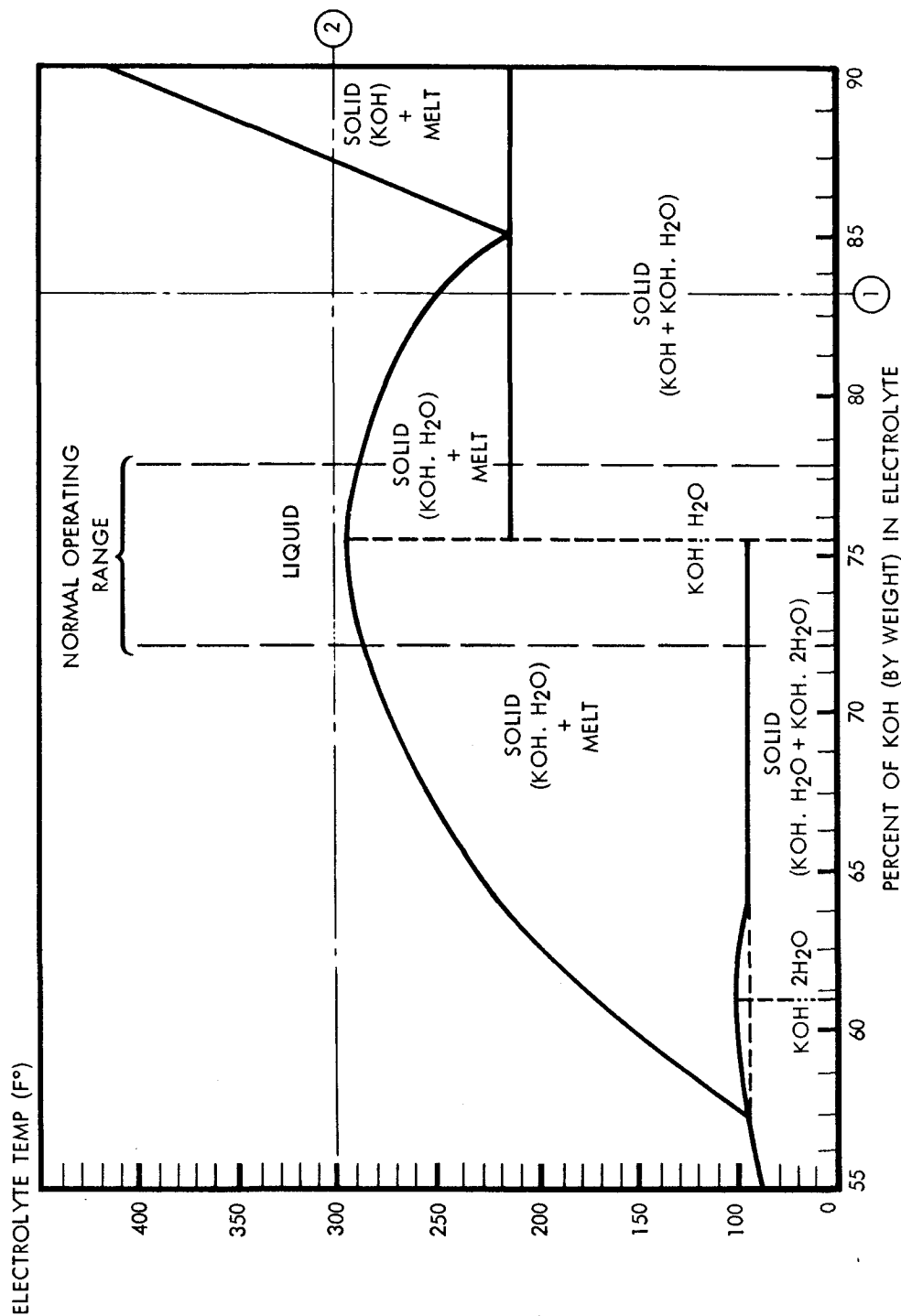
Each of the 31 cells comprising a power plant contains electrolyte which on initial fill consists of 83 percent potassium hydroxide (KOH) and 17 percent water by weight. The power plant is initially conditioned to increase the water ratio, and during normal operation, water content will vary between 23 and 28 percent. At this ratio, the electrolyte has a critical temperature of 300°F (figure 2.6-7). It solidifies at an approximate temperature of 220°F. Power plant electrochemical reaction becomes effective at the critical temperature. Bringing power plants to critical temperature is performed by GSE and cannot be performed from SC power sources. Placing a load on the power plant will maintain it above the critical temperature. The automatic in-line heater circuit will maintain power plant temperature at 385°F with no additional loads applied.

Purging is a function of power demand and gas purity. O₂ purging requires 2 minutes and H₂ purging 80 seconds. A hydrogen purge is preceded by activation of the H₂ PURGE LINE HTR switch (MDC-3) 20 minutes prior to the purge. The purge cycle is determined by the mission power profile and gas purity as sampled after spacecraft tank fill. Figures 2.6-8 and 2.6-9 can be used to calculate the purge cycles, dependent on gas purity and load. A degradation purge can be performed if power plant current output decreases approximately 3 to 5 amps during sustained operation. The O₂ purge has more effect during this type of purge, although it would be followed by an H₂ purge if recovery to normal was not realized after performing an O₂ purge. If the pH talkback indicator (MDC-3) is activated, a hydrogen purge will not be performed on the fuel cell with the high pH. This prevents the possibility of clogging the hydrogen vent line.

2.6.3.3.2 Fuel Cell Loading

The application and removal of fuel cell loads causes the terminal voltage to decrease and increase, respectively. A decrease in terminal voltage, resulting from an increased load, is followed by a gradual increase in fuel cell skin temperature which causes an increase in terminal voltage. Conversely, an increase in terminal voltage, resulting from a decreased load, is followed by a gradual decrease in fuel cell skin temperature which causes a decrease in terminal voltage.

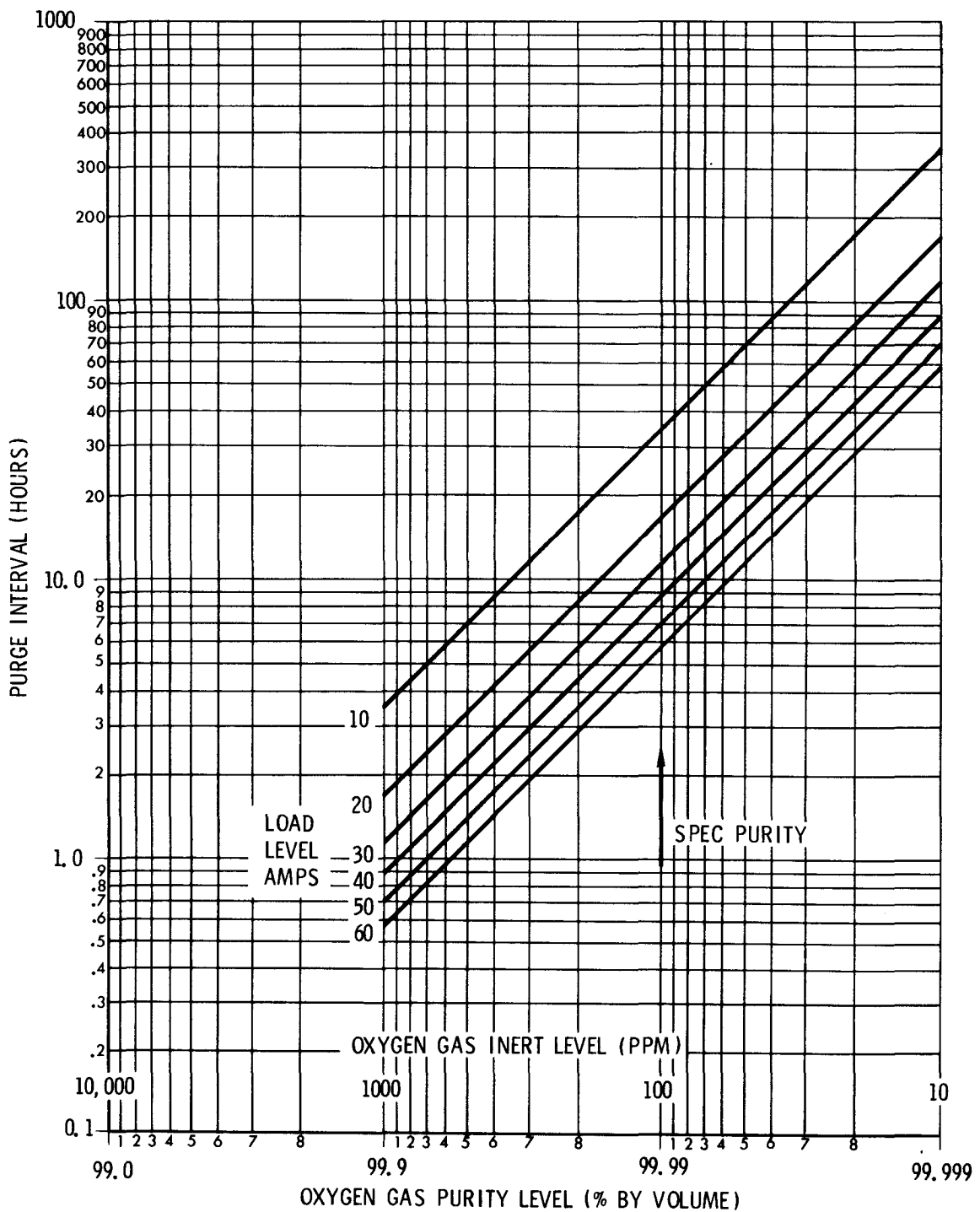
The range in which the terminal voltage is permitted to vary is determined by the high- and low-voltage input design limits of the components being powered. For most components the limits are 30 volts dc and 25 volts dc. To remain within these design limits, the d-c bus voltage must be maintained between 31.0 and 26.5 volts dc. To compensate for cyclic loads, it is recommended sustained bus voltage be maintained between 26.5 and 30.0 vdc. Bus voltage is maintained within prescribed limits by the application of entry and postlanding batteries during load increases (power up). Load increase or decrease falls well within the limits of power supply capability and, under normal conditions, should not require other than normal checklist procedures.



- NOTES:
1. Percent (83) of KOH in electrolyte at initial fill.
 2. Critical temperature (300°F) of electrolyte at which electrochemical reaction begins, on initial start-up of fuel cell.

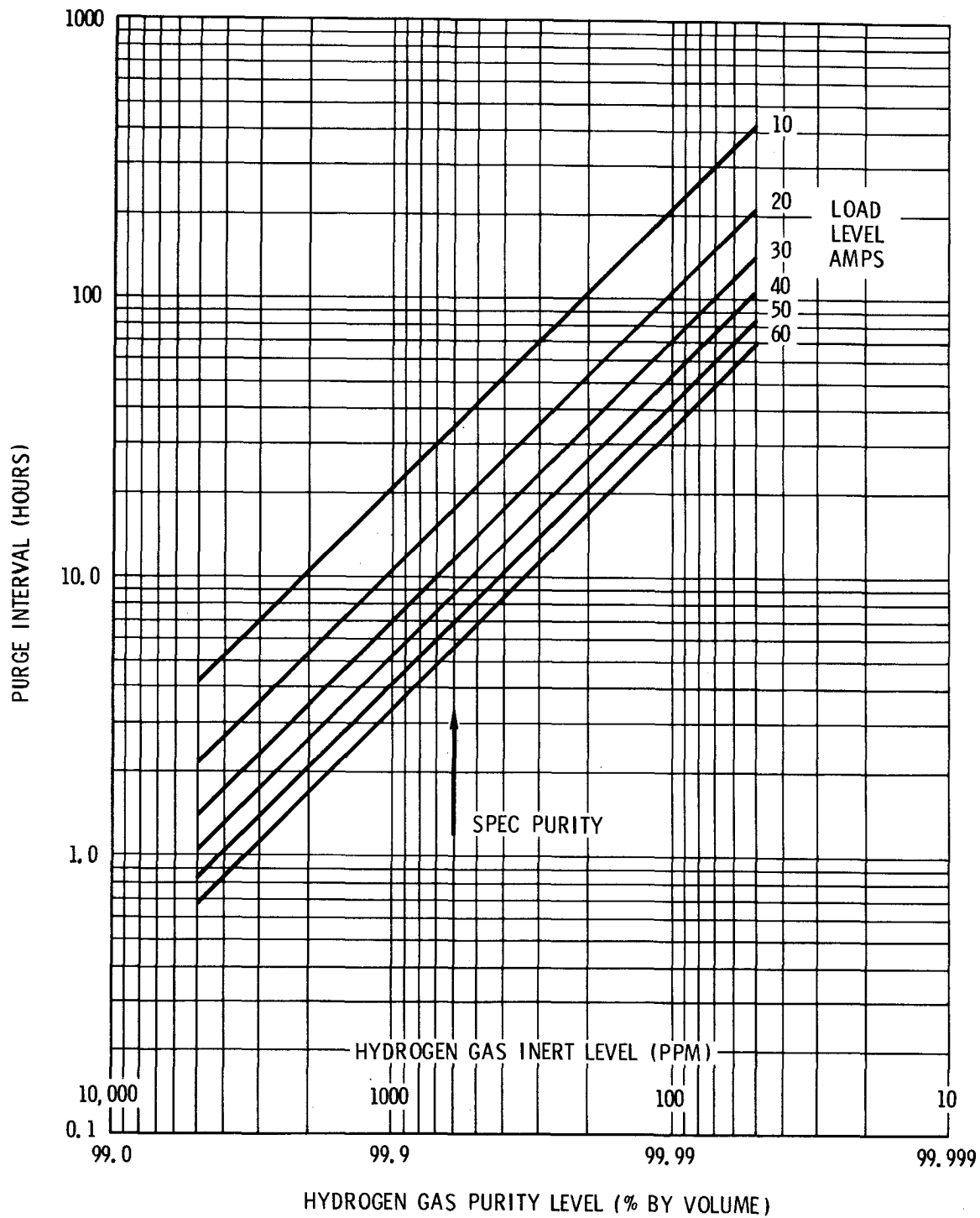
SM-2A-8838

Figure 2.6-7. KOH H₂O Phase Diagram



SM-2A-1214

Figure 2.6-8. O₂ Gas Purity Effect on Purge Interval



SM-2A-1215

Figure 2.6-9. H₂ Gas Purity Effect on Purge Level
(Percent by Volume)

Power Up. Powering up spacecraft systems is performed in one continuous sequence providing main bus voltage does not decrease below 26.5 volts. If bus voltage decreases to this level, the power-up sequence can be interrupted for the time required for fuel cell temperatures to increase with the resultant voltage increase or the batteries can be connected to the main buses thus reducing the fuel cell load. In most cases, powering up can be performed in one continuous sequence; however, when starting from an extremely low spacecraft load, it is probable that a power-up interruption or earlier battery coupling may be required. The greatest load increase occurs while powering up for a delta V maneuver.

Power Down. Powering down spacecraft systems is performed in one continuous sequence providing the main bus voltage does not increase above 31.0 volts. Powering down from relatively high spacecraft load levels, i.e., following a delta V, the sequence may have to be interrupted for the time required for fuel cell temperature and, as a result, bus voltage to decrease. To expedite power down, one fuel cell can be disconnected from the buses increasing the loads on the remaining fuel cells and decreasing bus voltage, thus allowing continuation of the power-down sequence.

Fuel Cell Disconnect. If the requirement arises to maintain a power plant on open circuit, temperature decay would occur at an average rate of approximately 6°/hr., with the automatic in-line heater circuit activating at a skin temperature of 385°F and maintaining power-plant temperature at 385°F. In-line heater activation can be confirmed by a 4.5 to 6 amp indication as observed on the d-c amps meter (MDC-3) with the d-c indicator switch positioned to the open circuited fuel cell position. Reactant valves remain open. Fuel cell pumps can be turned off until the in-line heater circuit activates, at which time they must be on.

Closing of reactant valves during a power-plant disconnect is dependent on the failure experienced. If power-plant failure is such as to allow future use, i.e., shutdown due to partially degraded output, it is recommended the reactant valves remain open to provide a positive reactant pressure. The valves should be closed after power-plant skin temperature decays below 300°F. The reactant valves are closed during initial shutdown if the failure is a reactant leak, an abnormally high regulator output pressure, or complete power-plant failure.

Prior to disconnecting a fuel cell, if a single inverter is being used, each of the remaining power plants is connected to both main d-c buses to enhance load sharing since bus loads are unbalanced. If two inverters are being used, main d-c bus loads are relatively equal; therefore, each of the remaining power plants is connected to a separate main d-c bus for bus isolation. If one power plant had been placed on open circuit for an extended period of time, prior to powering up to a configuration requiring three power plants, reconnecting is accomplished prior to the time of heavy load demands. This permits proper conditioning of the power plant which has been on open circuit. The time required for proper conditioning is a function of skin temperature increase and the load applied to the power plant.

Each inverter (figure 2.6-10) is composed of an oscillator, an eight-stage digital countdown section, a d-c line filter, two silicon-controlled rectifiers, a magnetic amplifier, a buck-boost amplifier, a demodulator, two d-c filters, an eight-stage power inversion section, a harmonic neutralization transformer, an a-c output filter, current sensing transformers, a Zener diode reference bridge, a low-voltage control, and an overcurrent trip circuit. The inverter normally uses a 6.4-kHz square wave synchronizing signal from the central timing equipment (CTE) which maintains inverter output of 400 Hz. If this external signal is completely lost, the free running oscillator within the inverter will provide pulses that will maintain inverter output within +7 Hz. The internal oscillator is normally synchronized by the external pulse. The subsequent paragraphs describe the function of the various stages of the inverter.

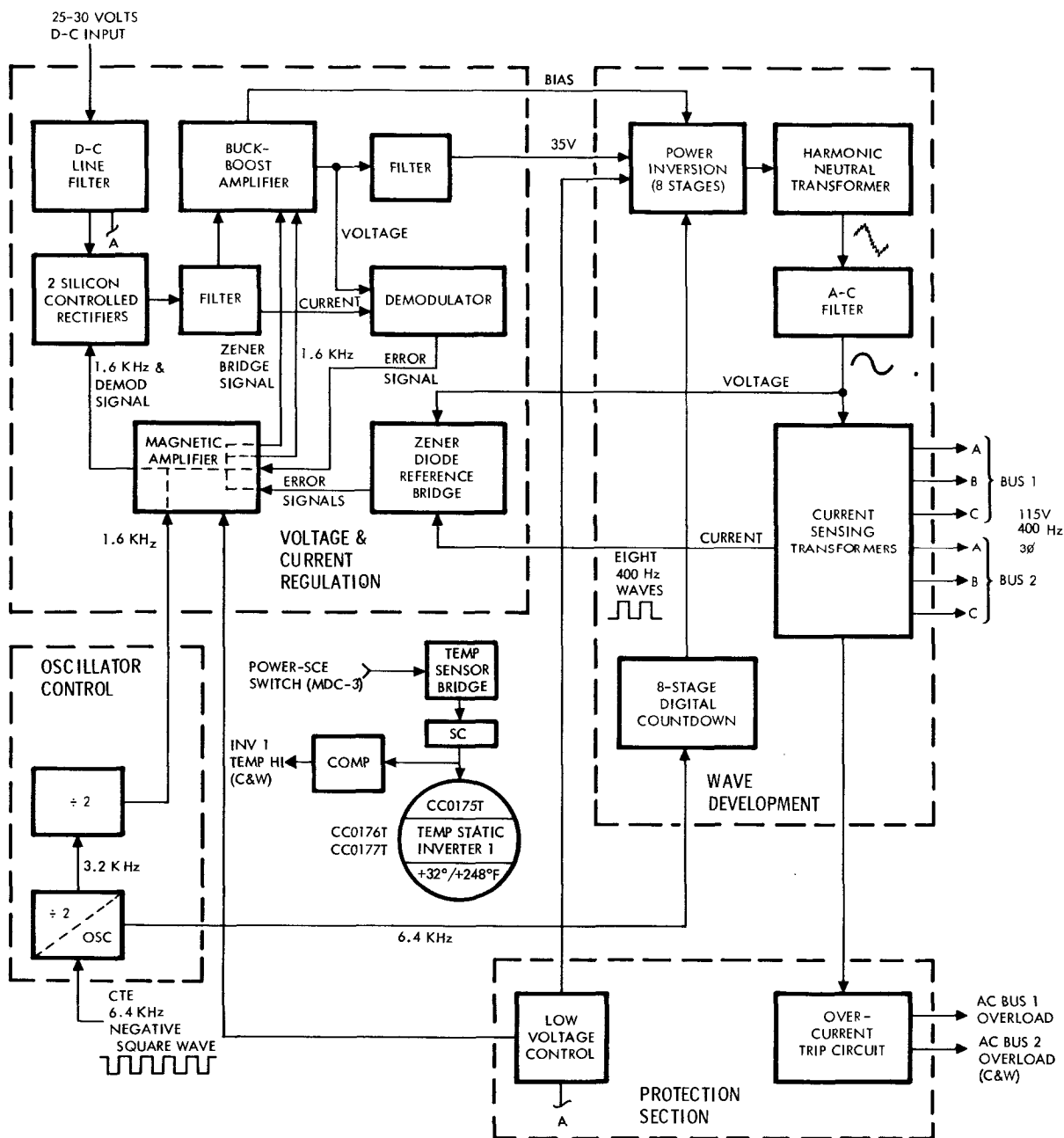
The 6.4-kHz squares wave provided by the CTE is applied through the internal oscillator to the eight-stage digital countdown section. The oscillator has two divider circuits which provide a 1600-Hz signal to the magnetic amplifier.

The eight-stage digital countdown section, triggered by the 6.4-kHz signal, produces eight 400-Hz square waves, each mutually displaced one pulse-time from the preceding and following wave. One pulse-time is 156 microseconds and represents 22.5 electrical degrees. The eight square waves are applied to the eight-stage power inversion section.

The eight-stage power inversion section, fed a controlled voltage from the buck-boost amplifier, amplifies the eight 400-Hz square waves produced by the eight-stage digital countdown section. The amplified square waves, still mutually displaced 22.5 electrical degrees, are next applied to the harmonic neutralization transformer.

The harmonic neutralization section consists of 31 transformer windings on one core. This section accepts the 400-Hz square-wave output of the eight-stage power inversion section and transforms it into a 3-phase 400-Hz 115-volt signal. The manner in which these transformers are wound on a single core produces flux cancellation which eliminates all harmonics up to and including the fifteenth of the fundamental frequency. The 22.5-degree displacement of the square waves provides a means of electrically rotating the square wave excited primary windings around the 3-phase, wye-connected secondary windings, thus producing the 3-phase 400-Hz sine wave output. This 115-volt signal is then applied to the a-c output filter.

The a-c output filter eliminates the remaining higher harmonics. Since the lower harmonics were eliminated by the harmonic neutral transformer, the size and weight of this output filter was reduced. Circuitry in this filter also produces a rectified signal which is applied to the Zener diode reference bridge for voltage regulation. The amplitude of this signal is a function of the amplitude of a-c output voltage. After filtering, the 3-phase 115-volt a-c 400-Hz sine wave is applied to the a-c buses through individual phase current-sensing transformers.



NOTE: Unless otherwise specified:
 1. Inverter 1 is shown.
 2. A denotes input voltage.

SM-2A-1229D

Figure 2.6-10. Inverter Block Diagram

The current-sensing transformers produce a rectified signal, the amplitude of which is a direct function of inverter output current magnitude. This d-c signal is applied to the Zener diode reference bridge to regulate inverter current output; it is also paralleled to an overcurrent sensing circuit.

The Zener diode reference bridge receives a rectified d-c signal, representing voltage output, from the circuitry in the a-c output filter. A variance in voltage output unbalances the bridge, providing an error signal of proper polarity and magnitude to the buck-boost amplifier via the magnetic amplifier. The buck-boost amplifier, through its bias voltage output, compensates for voltage variations. When inverter current output reaches 200 to 250 percent of rated current, the rectified signal applied to the bridge from the current sensing transformers is of sufficient magnitude to provide an error signal causing the buck-boost amplifier to operate in the same manner as during an overvoltage condition. The bias output of the buck-boost amplifier, controlled by the error signal, will be varied to correct for any variation in inverter voltage or a beyond tolerance increase in current output. When inverter current output exceeds 250 percent of rated current, the overcurrent sensing circuit is activated.

The overcurrent sensing circuit monitors a rectified d-c signal representing current output. When total inverter current output exceeds 250 percent of rated current, this circuit will illuminate an overload lamp in 15±5 seconds. If current output of any single phase exceeds 300 percent of rated current, this circuit will illuminate the overload lamp in 5±1 seconds. The AC BUS 1 OVERLOAD and AC BUS 2 OVERLOAD lamps are in the caution/warning matrix on MDC-2.

D-C power to the inverter is supplied from the main d-c buses through the d-c line filter. The filter reduces the high frequency ripple in the input, and the 25 to 30 volts dc is applied to two silicon-controlled rectifiers.

The silicon-controlled rectifiers are alternately set by the 1600-Hz signal from the magnetic amplifier to produce a d-c square wave with an on-time of greater than 90 degrees from each rectifier. This is filtered and supplied to the buck-boost amplifier where it is transformer-coupled with the amplified 1600-Hz output of the magnetic amplifier, to develop a filtered 35 volts dc which is used for amplification in the power inversion stages.

The buck-boost amplifier also provides a variable bias voltage to the eight-stage power inversion section. The amplitude of this bias voltage is controlled by the amplitude and polarity of the feedback signal from the Zener diode reference bridge which is referenced to output voltage and current. This bias signal is varied by the error signal to regulate inverter voltage and maintain current output within tolerance.

The demodulator circuit compensates for any low-frequency ripple (10 to 1000 Hz) in the d-c input to the inverter. The high-frequency ripple is attenuated by the input filters. The demodulator senses the

35-volt d-c output of the buck-boost amplifier and the current input to the buck-boost amplifier. An input d-c voltage drop or increase will be reflected in a drop or increase in the 35-volt d-c output of the buck-boost amplifier, as well as a drop or increase in current input to the buck-boost amplifier. A sensed decrease in the buck-boost amplifier voltage output is compensated for by a demodulator output, coupled through the magnetic amplifier to the silicon-controlled rectifiers. The demodulator output causes the SCRs to conduct for a longer time, thus increasing their filtered d-c output. A sensed increase in buck-boost amplifier voltage output, caused by an increase in d-c input to the inverter, is compensated for by a demodulator output coupled through the magnetic amplifier to the silicon-controlled rectifiers causing them to conduct for shorter periods, thus producing a lower filtered d-c output to the buck-boost amplifier. In this manner, the 35-volt d-c input to the power inversion section is maintained at a relatively constant level irrespective of the fluctuations in d-c input voltage to the inverter.

The low-voltage control circuit samples the input voltage to the inverter and can terminate inverter operation. Since the buck-boost amplifier provides a boost action during a decrease in input voltage to the inverter, in an attempt to maintain a constant 35 volts dc to the power inversion section and a regulated 115-volt inverter output, the high boost required during a low-voltage input would tend to overheat the solid-state buck-boost amplifier. As a precautionary measure, the low-voltage control will terminate inverter operation by disconnecting operating voltage to the magnetic amplifier and the first power inversion stage when input voltage decreases to between 16 and 19 volts dc.

A temperature sensor with a range of +32° to +248°F is installed in each inverter and provides an input to the C&WS which will illuminate a light at an inverter overtemperature of 190°F. Inverter temperature is telemetered to MSFN.

2.6.3.5 Battery Charger

A constant voltage, solid-state battery charger (figure 2.6-11), located in the CM lower equipment bay, is incorporated into the EPS. The BATTERY CHARGER selector switch (MDC-3) controls power input to the charger, as well as connecting the charger output to the selected battery (figure 2.6-14). When the BATTERY CHARGER selector switch is positioned to entry battery A, B, or C, a relay (K1) is activated completing circuits from a-c and d-c power sources to the battery charger. Battery charger output is also connected to the selected battery to be charged through contacts of the MAIN BUS TIE motor switch. Positioning the MAIN BUS TIE switch (A/C or B/C) to OFF for battery A or B, and both switches to OFF for battery C will disconnect main bus loads from the respective batteries and also complete the circuit from the charger to the battery.

The battery charger is provided 25 to 30 volts from both main d-c buses and 115-volt 400-Hz 3-phase from either of the a-c buses. All three phases of ac are used to boost the 25- to 30-volt d-c input and produce 40 volts dc for charging. In addition, phase A of the ac is used to supply

Figure 2.6-11. Battery Charger Functional Diagram

power for the charger circuitry. The logic network in the charger, which consists of a two-stage differential amplifier (comparator), Schmitt trigger, current sensing resistor, and a voltage amplifier, sets up the initial condition for operation. The first stage of the comparator is in the on mode, with the second stage off, thus setting the Schmitt trigger first stage to on with the second stage off. Maximum base drive is provided to the current amplifier which turns the switching transistor to the on mode. With the switching transistor on, current flows from the transformer rectifier through the switching transistor, current sensing resistor, and switch choke to the battery being charged. Current lags voltage because of switching choke action. As current flow increases, the voltage drop across the sensing resistor increases, and at a specific level sets the first stage of the comparator to off and the second stage to on. The voltage amplifier is set off to reverse the Schmitt trigger to first stage off and second stage on. This sets the current amplifier off, which in turn sets the switching transistor off. The switching transistor in the off mode terminates power from the source, causing the field in the choke to continue collapsing, discharging into the battery, then through the switching diode and the current sensing resistor to the opposite side of the choke. As the EMF in the choke decreases, current through the sensing resistor decreases, reducing the voltage drop across the resistor. At some point, the decrease in voltage drop across the sensing resistor reverses the comparator circuit, setting up the initial condition and completing one cycle of operation. The output load current, due to the choke action, remains relatively constant except for the small variation through the sensing resistor. This variation is required to set and reset the switching transistor and Schmitt trigger through the action of the comparator.

Battery charger output is regulated by the sensing resistor until battery voltage reaches approximately 37 volts. At this point, the biased voltage sensor circuit is unbiased, and in conjunction with the sensing resistor provides a signal for cycling the battery charger. As battery voltage increases, the internal impedance of the battery increases, decreasing current flow from the charger. At 39.8 volts, the battery is fully charged and current flow becomes negligible. Recharging the batteries until battery amp hour input equates amp hours previously discharged from the battery assures sufficient battery capacity for mission completion. The MSFN will monitor this function. If there is no contact with the MSFN, battery charging is terminated when the voltmeter indicates 39.5 vdc with the DC INDICATORS switch set to the BAT CHARGER position.

Charger voltage is monitored on the DC VOLTS METER (MDC-3). Current output is monitored on the inner scale of the DC AMPS meter (MDC-3) by placing the DC INDICATORS switch (MDC-3) to the BAT CHARGER position. Battery charger current output is telemetered to the MSFN.

When charging battery A or B, the respective BAT RLY BUS-BAT A or B circuit breaker (MDC-5) is opened to expedite recharge. During this period, only one battery will be powering the battery relay bus. Relay bus voltage can be monitored by selecting positions 5 and B on the systems test meter (LEB-101) and from the couches by the fuel cell-main bus B-1, B-2 and fuel cell - main bus A-3 talkback indicators (MDC-3) which will be barber-poled. If power is lost to the relay bus, these indicators will revert to the gray condition indicating loss of power to the relay bus and requiring remedial action.

Recharge of a battery immediately after it is exposed to any appreciable loads requires less time than recharge of a battery commencing 30 minutes or more after it is disconnected from these loads. Therefore, it is advantageous to connect batteries to the charger as soon as possible after they are disconnected from the main buses since this decreases overall recharge time.

2.6.3.6

Power Distribution

D-C and a-c power distribution to components of the EPS is provided by two redundant buses in each system. A single-point ground on the spacecraft structure is used to eliminate ground loop effects. Sensing and control circuits are provided for monitoring and protection of each system.

Distribution of d-c power (figure 2.6-12) is accomplished with a two-wire system and a series of interconnected buses, switches, circuit breakers, and isolation diodes. The d-c negative buses are connected to the vehicle ground point (VGP). The buses consist of the following:

- Two main d-c buses (A and B), powered by the three fuel cells or the aux battery, and/or entry and postlanding batteries A, B, and C.
- Two battery buses (A and B), each powered by its respective entry and postlanding battery A and B. Battery C can power either or both buses if batteries A and/or B fail.
- Flight and postlanding bus, powered through both main d-c buses and diodes, or directly by the three entry and postlanding batteries, A, B, and C, through dual diodes.
- Flight bus, powered through both main d-c buses and isolation diodes.
- Nonessential bus, powered through either d-c main bus A or B.
- Battery relay bus, powered by entry and postlanding batteries through the individual battery buses and isolation diodes.
- Pyro buses, isolated from the main electrical power system when powered by the pyro batteries. A capability is provided to connect an entry battery to the A or B pyro system in case of loss of a pyro battery.
- SM jettison controllers, completely isolated from the main electrical system, and powered by the fuel cells or aux battery after CM-SM separation.

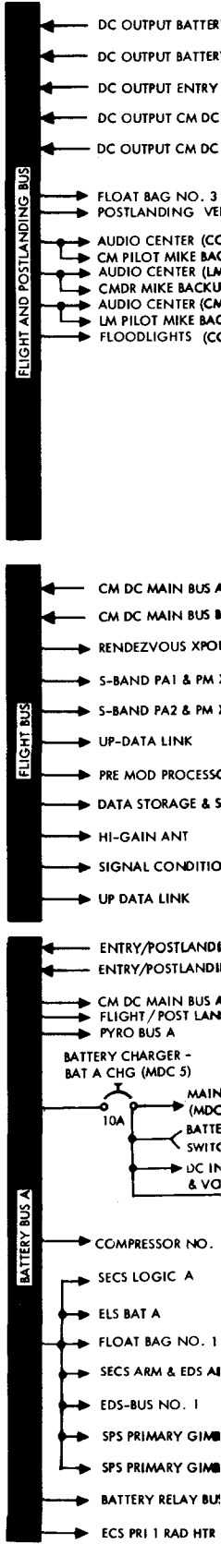
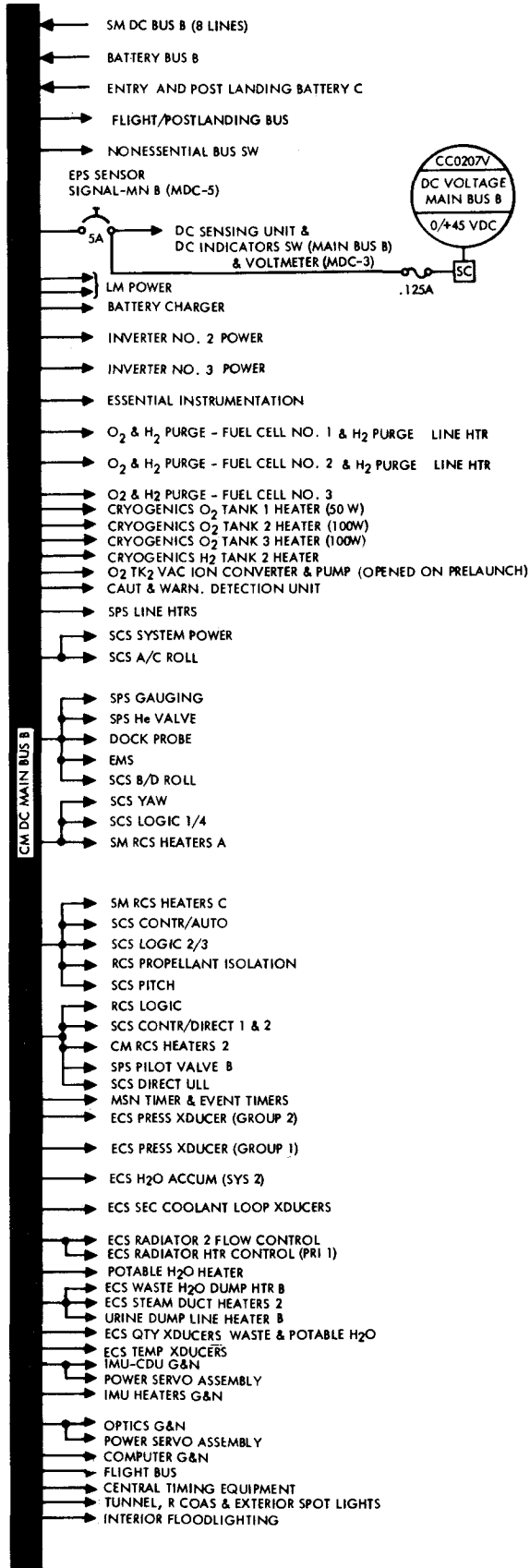
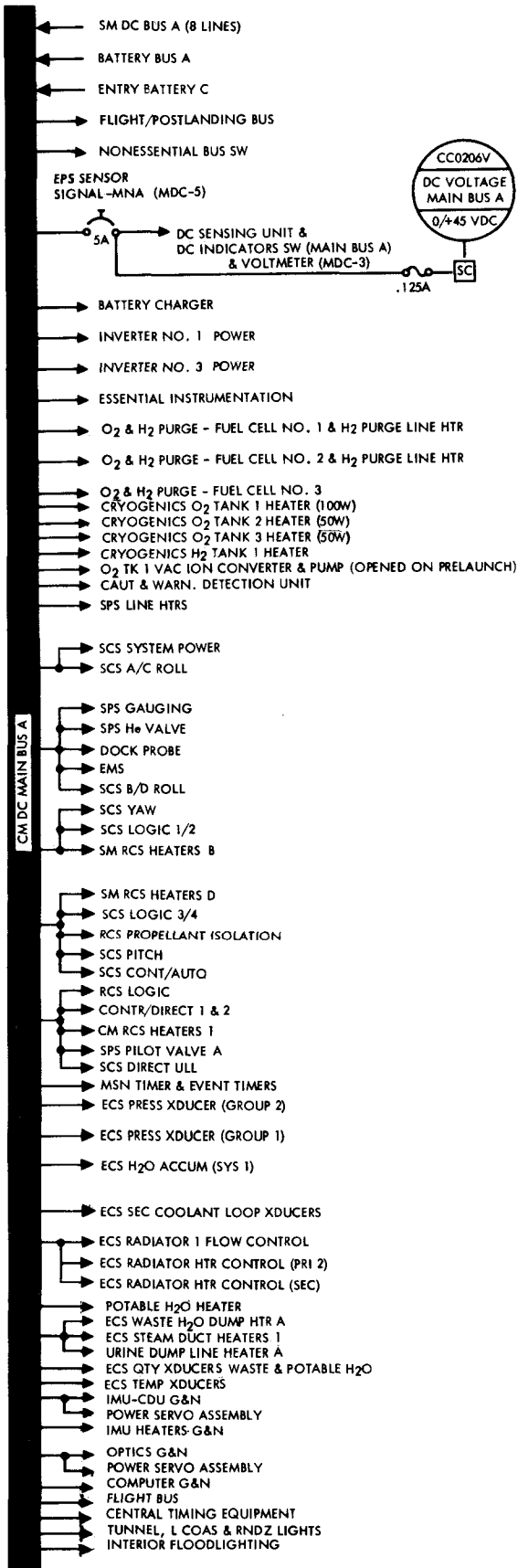
Power from the fuel cell power plants can be connected to the main d-c buses through six motor switches (part of overload/reverse current circuits in the SM) which are controlled by switches in the CM located on MDC-3. Fuel cell power can be selected to either or both of the main d-c buses. Six talkback indicators show gray when fuel cell output is connected and striped when disconnected. When an overload condition occurs, the overload-reverse current circuits in the SM automatically disconnect the fuel cell power plants from the overloaded bus and provide visual displays (talkback indicator and caution and warning lamp illumination) (FC BUS DISCONNECT) for isolation of the trouble. A reverse current condition will

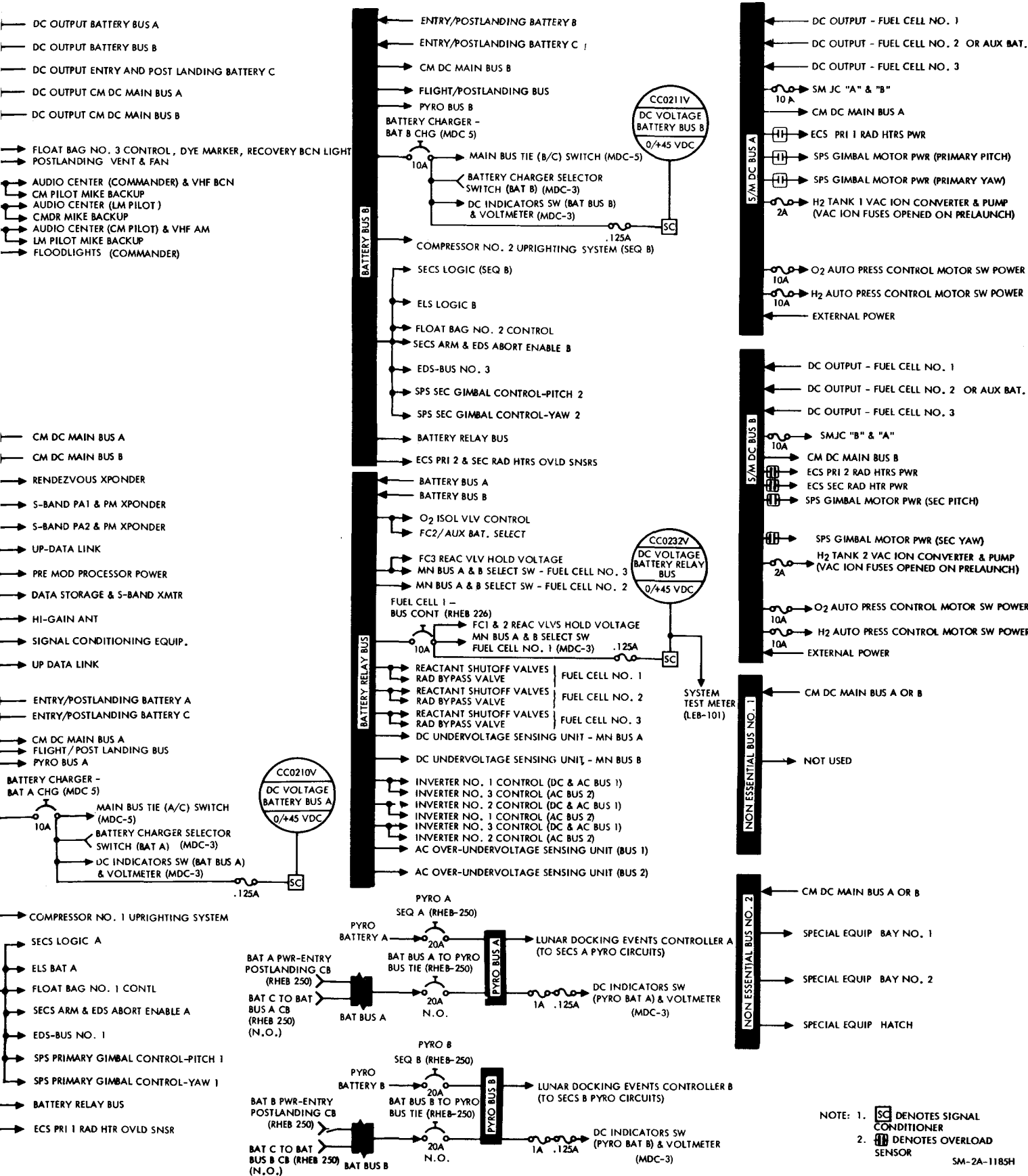
disconnect the malfunctioning power plant from the d-c system and activate the visual displays. The MAIN BUS A - 2 and MAIN BUS B - 2 control switches (MDC-3) are also used to connect the aux battery to the main d-c buses in the event a situation necessitating use of the battery has occurred. The main bus overload/reverse current sensors will provide power source protection. The battery output circuit also contains an overload/reverse current sensor which will disconnect the battery from a circuit fault between the battery and main bus control switches. A battery disconnect effected by this sensor would be indicated by loss of all power in the CSM if the entry batteries were not connected. Fuel cell 2 or aux battery selection is provided on RHEB-278. The auxiliary battery can be used as supplemental power to the main d-c buses together with fuel cells 1 and 3, if fuel cell 2 has failed.

D-C undervoltage sensing circuits (figure 2.6-13) are provided to indicate bus low-voltage conditions. If voltage drops below 26.25 volts dc, the applicable d-c undervoltage light on the caution and warning panel (MDC-2) will illuminate. Since each bus is capable of handling all EPS loads, an undervoltage condition should not occur except in an isolated instance; if too many electrical units are placed on the bus simultaneously or if a malfunction exists in the EPS. A voltmeter (MDC-3) is provided to monitor voltage of each main d-c bus, the battery charger, and each of the five batteries. An ammeter is provided (MDC-3) to monitor current output of fuel cells 1, 2, 3, batteries A, B, C, and the battery charger. Aux battery current, when the battery is used, is connected to the ammeter by the fuel cell 2 position of the DC INDICATORS switch.

During high power demand or emergencies, supplemental power to the main d-c buses can be supplied from batteries A and B via the battery buses and directly from battery C (figure 2.6-14). During entry, spacecraft power is provided by the three entry and postlanding batteries which are connected to the main d-c buses prior to CM-SM separation; placing the MAIN BUS TIE switches (MDC-5) to BAT A/C and BAT B/C provides this function after closing the MAIN A-BAT C and MAIN B-BAT C circuit breakers (RHEB-275). The switches are manually placed to OFF after completion of RCS purge and closing the FLIGHT AND POST LDG-BAT BUS A, BAT BUS B and BAT C circuit breakers (RHEB-275) during main chute descent. The AUTO position provides an automatic connection of the entry batteries to the main d-c buses at CM-SM separation. The auto function is used only on the launch pad after the spacecraft is configured for a LES pad abort.

A nonessential bus, as shown on figure 2.6-12 permits isolating experiments equipment during a shortage of power (two fuel cell power plants out). The flight bus distributes power to in-flight telecommunications equipment. The flight and postlanding bus distributes power to some of the in-flight telecommunications equipment, float bag No. 3 controls, the ECS postlanding vent and blower control, and postlanding communications and lighting equipment. In flight, the postlanding bus receives power through the main d-c buses. After completion of RCS purge during main chute descent, the entry batteries supply power to the postlanding bus directly through individual circuit breakers. These circuit breakers (FLIGHT & POST LANDING - BAT BUS A, BAT BUS B, and BAT C - RHEB-275) are normally open in flight and closed during main chute descent just prior to positioning the MAIN BUS TIE switches to OFF.





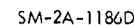


Figure 2.6-13. D-C and A-C Voltage Sensing

The battery relay bus provides d-c power to the a-c sensing units, the fuel cell and inverter control circuits, fuel cell reactant and radiator valves, and the fuel cell-main BUS A and B talkback indicators on MDC-3. The pyrotechnic batteries supply power to ordnance devices for separation of the LES, S-IVB, forward heat shield, SM from CM, and for deployment and release of the drogue and main parachutes during a pad abort, high-altitude abort, or normal mission progression. The three fuel cell power plants or auxiliary battery supply power to the SM jettison controllers for the SM separation maneuver.

Distribution of a-c power (figure 2.6-15) is accomplished with a four-wire system via two redundant buses, a-c bus 1 and a-c bus 2. The a-c neutral bus is connected to the vehicle ground point. A-C power is provided by one or two of the solid-state 115/200-volt 400-Hz 3-phase inverters. D-C power is routed to the inverters through the main d-c buses. Inverter No. 1 is powered through d-c main bus A, inverter No. 2 through d-c main bus B, and inverter No. 3 through either d-c main bus A or B by switch selection. Each of these circuits has a separate circuit breaker and a power control motor switch. Switches for applying power to the motor switches are located on MDC-3. All three inverters are identical and are provided with over-temperature sensing. A light indicator, in the caution/warning group on MDC-2, illuminates at $>190^{\circ}$ to indicate an overtemperature situation. Inverter output is routed through a series of control motor switches to the a-c buses. Six switches (MDC-3) control motor switches which operate contacts to connect or disconnect the inverters from the a-c buses. Inverter priority is 1 over 2, 2 over 3, and 3 over 1 on any one a-c bus. For example, this indicates that inverter 2 cannot be connected to the bus until the inverter 1 switch is positioned to OFF. Also, when the inverter 3 switch is positioned to ON, it will disconnect inverter 1 from the bus before the inverter 3 connection will be performed. The priority, and the motor switch circuits are designed to prevent having two inverters connected to the same a-c bus simultaneously. Most a-c loads receive power from either a-c bus through bus selector switches. In some instances, a single phase is used for operation of equipment and in others all three. Over-undervoltage and overload sensing circuits (figure 2.6-13) are provided for each bus. An automatic inverter disconnect is effected during an over-voltage. A-C bus voltage fail and overload lights in the caution/warning group (MDC-2) provide a visual indication of voltage or overload malfunctions. Monitoring voltage of each phase on each bus is accomplished by selection with the AC INDICATORS switch (MDC-3). Readings are displayed on the AC VOLTS meter (MDC-3). Phase A voltage of each bus is telemetered to MSFN stations.

Several precautions should be taken during any inverter switching. The first precaution is to completely disconnect the inverter being taken out of the circuit whether due to inverter transfer or malfunction prior to connecting the replacement inverter. The second precaution is to ensure that no more than one switch on AC BUS 1 or AC BUS 2 (MDC-3) is in the up position at the same time. These precautions are necessary to ensure positive power transfer since power to any one inverter control motor switch is routed in series through the switch of another inverter. A third precaution must be exercised to preclude a motor switch lockout when d-c power to inverter 3 is being transferred from d-c main bus A to d-c main bus B, or vice versa. The AC INVERTER 3 switch (MDC-3) should be held in the OFF position for one second when performing a power transfer operation from one main d-c bus to the other.

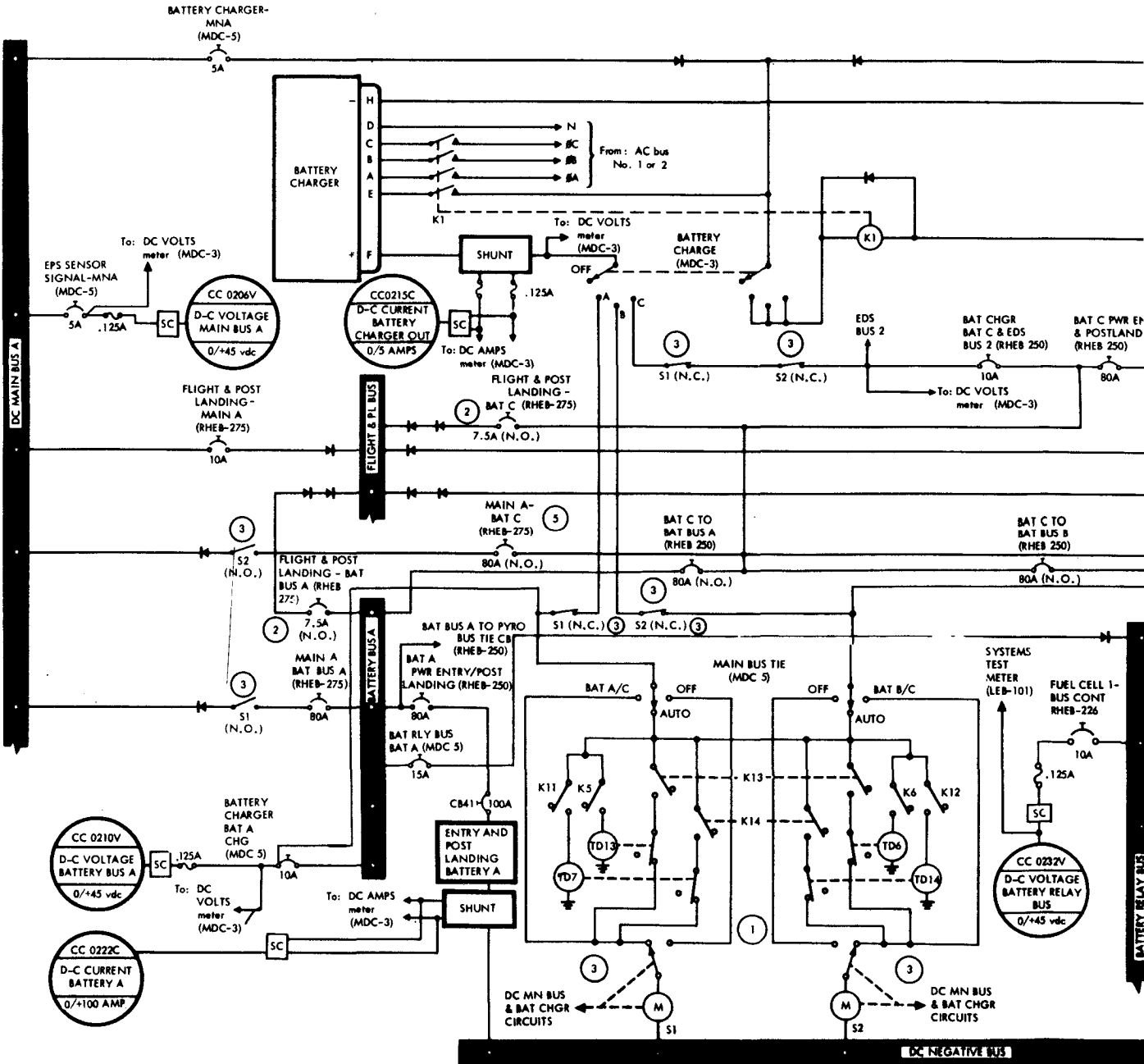


Figure 2.

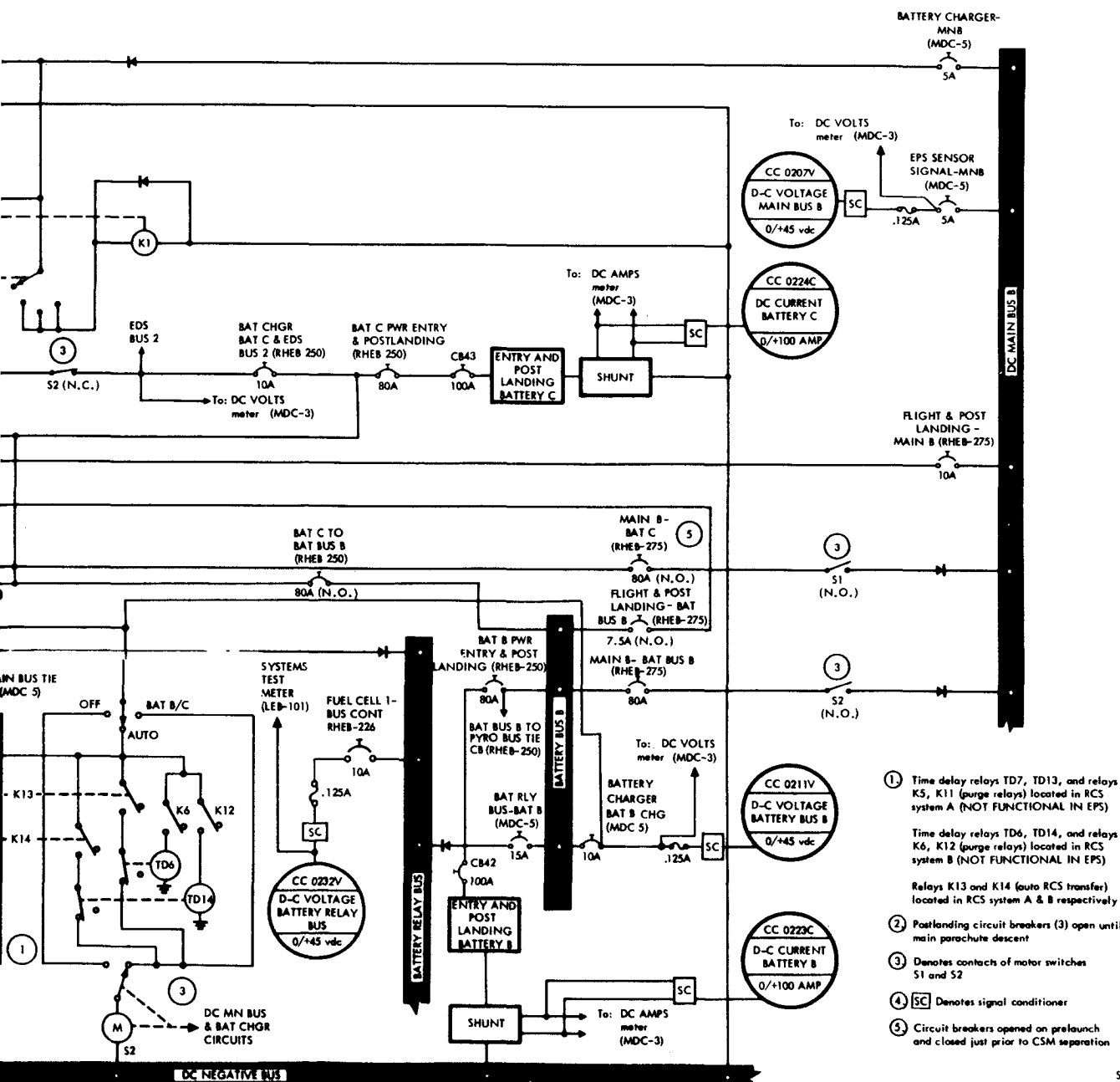


Figure 2.6-14. Battery Charger and CM D-C Bus Control Circuits

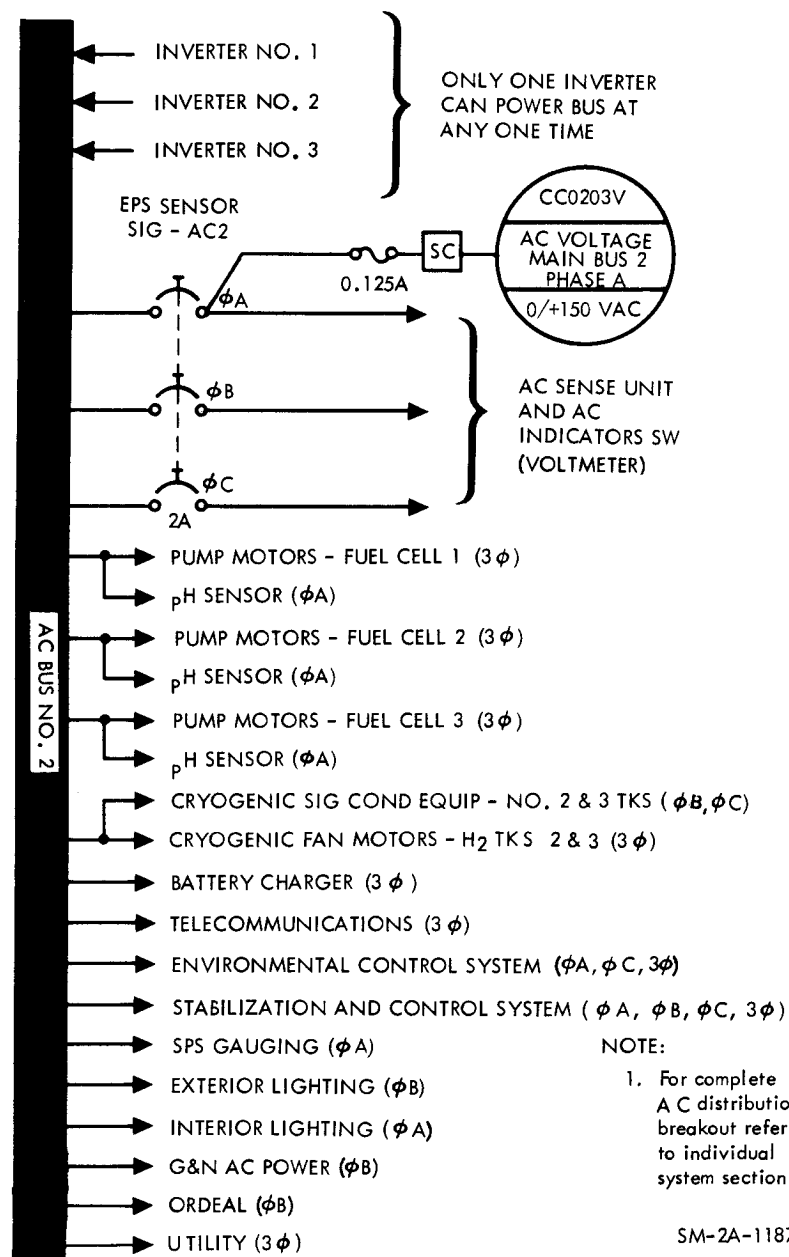
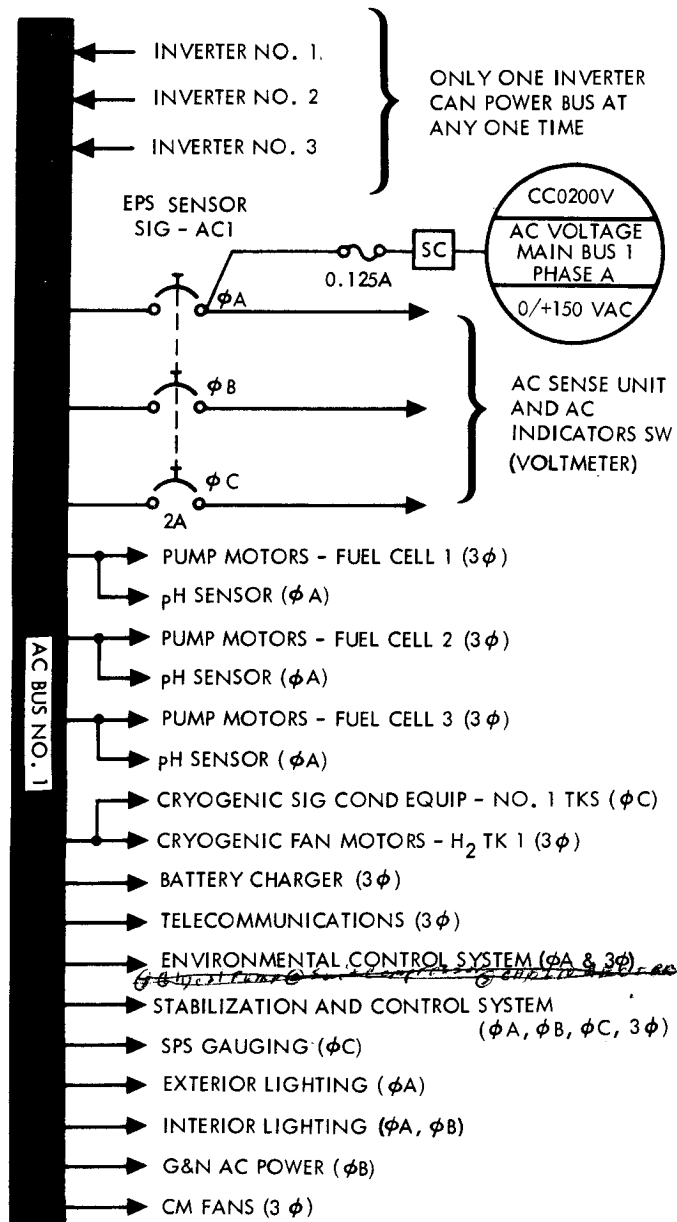


Figure 2.6-15. A-C Power Distribution

SM-2A-1187E

2.6.4 PERFORMANCE AND DESIGN DATA

2.6.4.1 A-C and D-C Data

A-C and d-c performance and design data for the EPS is as follows:

AC

Phases	3
Displacement	120 \pm 2 degrees
Steady-state voltage	115.5 (+1, -1.5) vac (average 3 phases)
Transient voltage	115 (+35, -65) vac
Recovery	To 115 \pm 10 v within 15 ms, steady state within 50 ms
Unbalance	2 vac (worst phase from average)
Frequency limits	
Normal (synchronized to central timing equipment)	400 \pm 3 Hz
Emergency (loss of central timing equipment)	400 \pm 7 Hz
Wave characteristics (sine wave)	
Maximum distortion	5 percent
Highest harmonic	4 percent
Crest factor	1.414 \pm 10 percent
Rating	1250 va

DC

Steady-state voltage limits	
Normal	29 \pm 2.0 vdc
Min Precautionary CM bus	26.5 vdc (allows for cyclic loads)
Max Precautionary CM bus	30.0 vdc (allows for cyclic loads)
During postlanding and preflight checkout periods	27 to 30 vdc
Ripple voltage	1v peak to peak

2.6.5 OPERATIONAL LIMITATIONS AND RESTRICTIONS

2.6.5.1 Fuel Cell Power Plants

Fuel cell power plants are designed to function under atmospheric and high-vacuum conditions. Each must be able to maintain itself at sustaining temperatures and minimum electrical loads at both environment extremes. To function properly, fuel cells must operate under the following limitations and restrictions:

External nonoperating temperature	-20° to +140°F
Operating temperature inside SM	+30° to 145°F
External nonoperating pressure	Atmospheric
Normal voltage	27 to 31 vdc
Minimum operating voltage at terminals	
Emergency operation	20.5 vdc at 2295 watts (gross power level)
Normal operation	27 vdc
Maximum operating voltage at terminals	31.5 vdc
Fuel cell disconnect overload	75 amperes no trip, 112 amperes disconnect after 25 to 300 seconds
Maximum reverse current	1 second minimum before disconnect
Minimum sustaining power/fuel cell power plant (with in-line heater OFF)	420 watts
In-line heater power (sustain F/C skin temp above 385°F min)	160 watts (5 to 6 amps)
Maximum gross power under emergency conditions	2295 watts at 20.5 vdc min
Nitrogen pressure	50.2 to 57.75 psia (54 psia, nominal)
Reactant pressure	
Oxygen	58.4 to 68.45 psia or 57.9 to 67.95 psia depending on FC installed (63 psia, nominal)
Hydrogen	57.3 to 67.0 psia or 57.9 to 67.6 psia depending on FC installed (63 psia, nominal)

Reactant consumption/fuel
cell power plant

Hydrogen	PPH = Amps x (2.57 x 10 ⁻³)
Oxygen	PPH = Amps x (2.04 x 10 ⁻²)
Minimum skin temperature for self-sustaining operation	+385°F
Minimum skin temperature for recovery in flight	+360°F
Maximum skin temperature	+500°F
Approximate external environ- ment temperature range outside SC (for radiation)	-260° to +400°F
Fuel cell power plant normal operating temperature range	+385° to +440°F
Condenser exhaust normal operating temperature	+150° to +175°F
Purging nominal frequency	Dependent on mission load profile and reactant purity after tank fill
O ₂ purge duration	2 minutes
H ₂ purge duration	80 seconds
Additional flow rate while purging	
O ₂	Up to 0.6 lb/hr
H ₂	Up to 0.75 lb/hr (nominal 0.67 lb/hr)

2.6.5.2 Cryogenic Storage Subsystem

The cryogenic storage subsystem must be able to meet the following requirements for proper operation of the fuel cell power plants and the ECS:

Minimum usable quantity	
Oxygen	320 lbs each tank (min)
Hydrogen	28 lbs each tank (min)
Temperature at time of fill	
Oxygen	-297°F (approx)
Hydrogen	-423°F (approx)

Operating pressure range

Oxygen

Normal

865 to 935 psia

Minimum

150 psia for CM ECS

865 psia for EVA

Hydrogen

Normal

225 to 260 psia

Minimum

100 psia for fuel cells

Temperature probe range

Oxygen

-325° to +80°F

Hydrogen

-425° to -200°F

Maximum allowable difference
in quantity balance between
tanks

Oxygen tanks

Dependent on mission profile

Hydrogen tanks

Dependent on mission profile

Pressure relief valve
operation

Crack pressure

Oxygen

983 psig min

Hydrogen

273 psig min

Full flow, maximum relief

Oxygen

1010 psig max

Hydrogen

285 psig max

Reseat pressure

Oxygen

965 psig min

Hydrogen

268 psig min

2.6.5.3 Additional Data

Additional data about limitations and restrictions may be found in the CSM/LM Spacecraft Operational Data Book SNA-8-D-027, Vol I, (CSM SD68-447).

2.6.6 SYSTEMS TEST METER

The SYSTEMS TEST meter and the alphabetical and numerical switches, located on panel 101 in the CM LEB, provide a means of monitoring various measurements within the SC, and verifying certain parameters displayed only by event indicators. The following decal is in the spacecraft.

Switch Position	Function	Range	Nominal Range	
			System	Range
1-A	O ₂ TK 1 HTR TEMP	-300 +600°F	<350°F	<3.6V
1-B	O ₂ TK 2 HTR TEMP	-300 +600°F	<350°F	<3.6V
1-C	O ₂ TK 3 HTR TEMP	-300 +600°F	<350°F	<3.6V
1-D	FC 1 O ₂ Press Reg	0 75 psia	58 69 psia	3.9 4.6V
2-A	FC 2 O ₂ Press Reg	0 75 psia	58 69 psia	3.9 4.6V
2-B	FC 3 O ₂ Press Reg	0 75 psia	58 69 psia	3.9 4.6V
2-C	FC 1 H ₂ Press Reg	0 75 psia	57 67 psia	3.8 4.5V
2-D	FC 2 H ₂ Press Reg	0 75 psia	57 67 psia	3.8 4.5V
3-A	FC 3 H ₂ Press Reg	0 75 psia	57 67 psia	3.8 4.5V
3-B	FC 1 RAD Outlet Temp	-50° +300°F	-10° +90°F	0.6 2.0V
3-C	FC 2 RAD Outlet Temp	-50° +300°F	-10° +90°F	0.6 2.0V
3-D	FC 3 RAD Outlet Temp	-50° +300°F	-10° +90°F	0.6 2.0V
4-A				
4-B				
4-C				
4-D				
5-A	SPS Eng Oxid Line Temp	0 +200°F	45 75°F	1.1 1.9V
5-B	Bat Relay Bus DC Volt	0 -45 vdc	30 37 vdc	3.4 4.1V
5-C	CM RCS Inj Temp 24	-50° +50°F	>28°F	>3.9V
5-D	CM RCS Inj Temp 25	-50° +50°F	>28°F	>3.9V
6-A	CM RCS Inj Temp 12	-50° +50°F	>28°F	>3.9V
6-B	CM RCS Inj Temp 14	-50° +50°F	>28°F	>3.9V
6-C	CM RCS Inj Temp 16	-50° +50°F	>28°F	>3.9V
6-D	CM RCS Inj Temp 21	-50° +50°F	>28°F	>3.9V
7-A	Bat Compt Press	0 20 psia	<1 psia	<0.2V
7-D	CSM to LM Current	0 10 amps	1.0 6.4 amp	0.5 3.2V
XPNDR-A	Pwr Output	0 0.48W	>0.24W	>1.0V
XPNDR-B	AGC Signal	Stimulus	Test	>1.0V
		-115 -25DBM	Operate	0.0 4.5V
XPNDR-C	Phase Lockup	4.0 5.0V	Locked	>4.0V
		0.0 0.8V	Unlocked	<0.8V

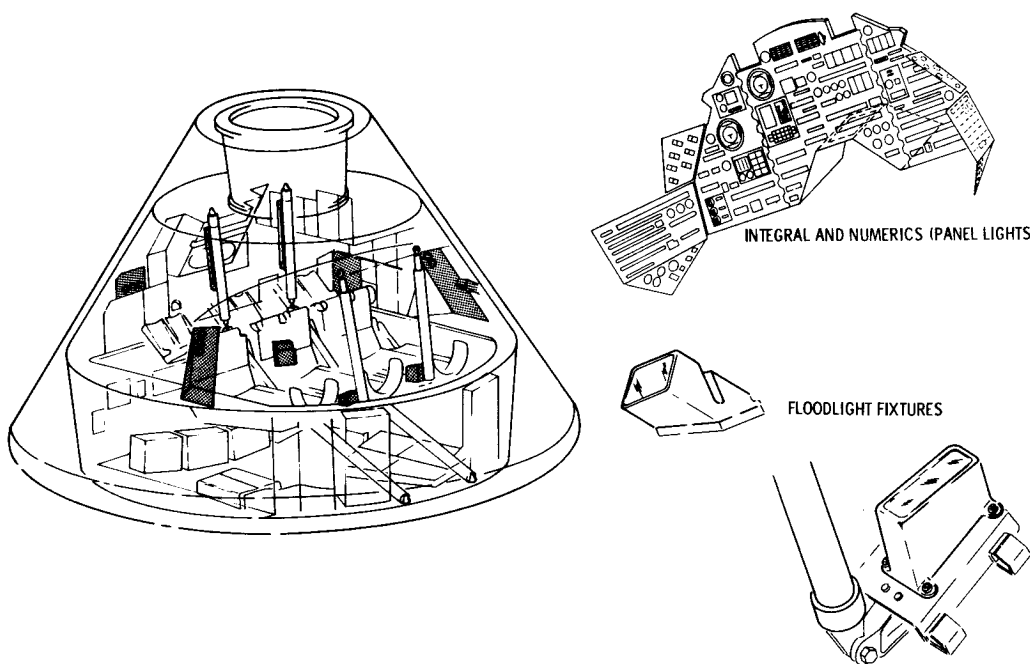
Conversion of the previously listed measurements to the SYSTEMS TEST meter indications are listed in the following chart (page 2.6-52). The XPNDR measurements are direct readouts and do not require conversion.

Systems Test Meter Display	O ₂ , H ₂ Pressure (psia)	EPS Radiator Outlet Temperature (°F)	CM-RCS Oxidizer Valve Temperature (°F)	LM Power (amps)	SPS Temperature (°F)	Battery Manifold Pressure (psia)	Battery Relay Bus (vdc)	O ₂ Heater Temperature (°F)
0.0	0	-50	-50	0	0	0.00	0	-300
0.2	3	-36	-46	0.4	8	0.80	1.8	-264
0.4	6	-22	-42	0.8	16	1.60	3.6	-228
0.6	9	-8	-38	1.2	24	2.40	5.4	-192
0.8	12	+6	-34	1.6	32	3.20	7.2	-156
1.0	15	+20	-30	2.0	40	4.00	9.0	-120
1.2	18	+34	-26	2.4	48	4.80	10.8	-84
1.4	21	+48	-22	2.8	56	5.60	12.6	-48
1.6	24	+62	-18	3.2	64	6.40	14.4	-12
1.8	27	+76	-14	3.6	72	7.20	16.2	+24
2.0	30	+90	-10	4.0	80	8.00	18.0	+60
2.2	33	+104	-6	4.4	88	8.80	19.8	+96
2.4	36	+118	-4	4.8	96	9.60	21.6	+132
2.6	39	+132	0	5.2	104	10.40	23.4	+168
2.8	42	+146	+4	5.6	112	11.20	25.2	+204
3.0	45	+160	+10	6.0	120	12.00	27.0	+240
3.2	48	+174	+14	6.4	128	12.80	28.8	+276
3.4	51	+188	+18	6.8	136	13.60	30.6	+312
3.6	54	+202	+22	7.2	144	14.40	32.4	+348
3.8	57	+216	+26	7.6	152	15.20	34.2	+384
4.0	60	+230	+30	8.0	160	16.00	36.0	+420
4.2	63	+244	+34	8.4	168	16.80	37.8	+456
4.4	66	+258	+38	8.8	176	17.60	39.6	+492
4.6	69	+272	+42	9.2	184	18.40	41.4	+528
4.8	72	+286	+46	9.6	192	19.20	43.2	+564
5.0	75	+300	+50	10.0	200	20.00	45.0	+600

The command module interior lighting system (figure 2.6-16) furnishes illumination for activities in the couch, lower equipment bay and tunnel areas, and back-lighted panel lighting to read nomenclature, indicators, and switch positions. Tunnel lighting is provided on SC which will be concerned with LM activity.

Floodlighting for illumination of work areas is provided by use of fluorescent lamps. Integral panel and numerics lighting is provided by electroluminescent materials. Tunnel lights are incandescent. Pen flashlights are provided for illuminating work areas which cannot be illuminated by the normal spacecraft systems, such as under the couches.

Electroluminescence (EL) is the phenomena whereby light is emitted from a crystalline phosphor (ZnS) placed as a thin layer between two closely spaced electrodes of an electrical capacitor. One of the electrodes is a transparent material. The light output varies with voltage and frequency and occurs as light pulses, which are in-phase with the input frequency. Advantageous characteristics of EL for spacecraft use are an "after-glow" of less than one second, low power consumption, and negligible heat dissipation.



EP-700

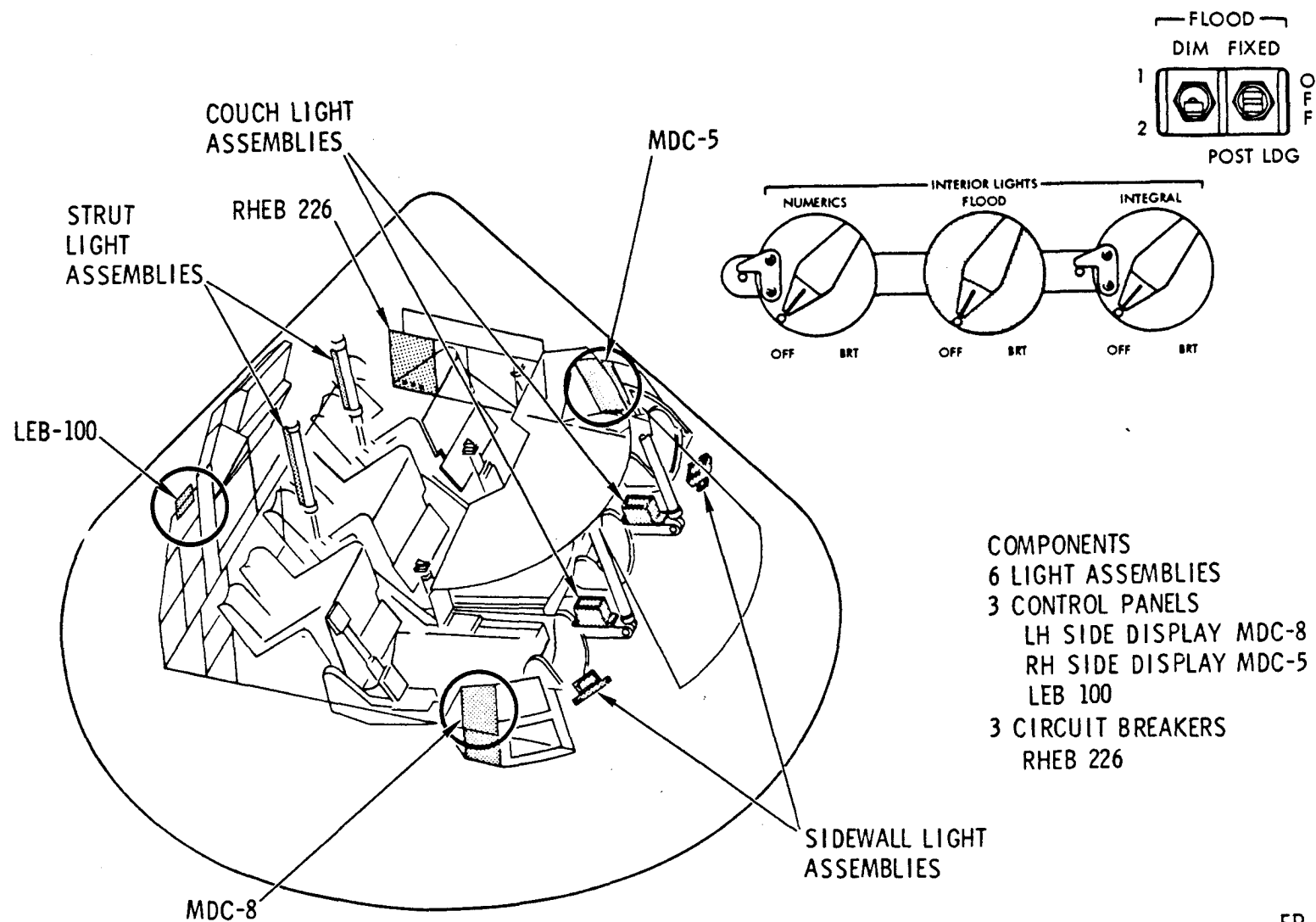
Figure 2.6-16. CM Interior Lighting

The interior floodlight system consists of six floodlight fixture assemblies and three control panels (figure 2.6-17). Each fixture assembly contains two fluorescent lamps (one primary and one secondary) and converters. The lamps are powered by 28 vdc from main d-c buses A and B (figure 2.6-18). This ensures a power source for lights in all areas in the event either bus fails. The converter in each floodlight fixture converts 28 vdc to a high voltage pulsating d-c for operation of the fluorescent lamps.

Floodlights are used to illuminate three specific areas: the left main display console, the right main display console, and the lower equipment bay. Switches on MDC-8 provide control of lighting of the left main display console area. Switches on MDC-5 provide control of lighting on the right main display console area. Switches for control of lighting of the lower equipment bay area are located on LEB-100. Protection for the floodlight circuits is provided by the LIGHTING - MN A and MN B circuit breakers on RHEB-226.

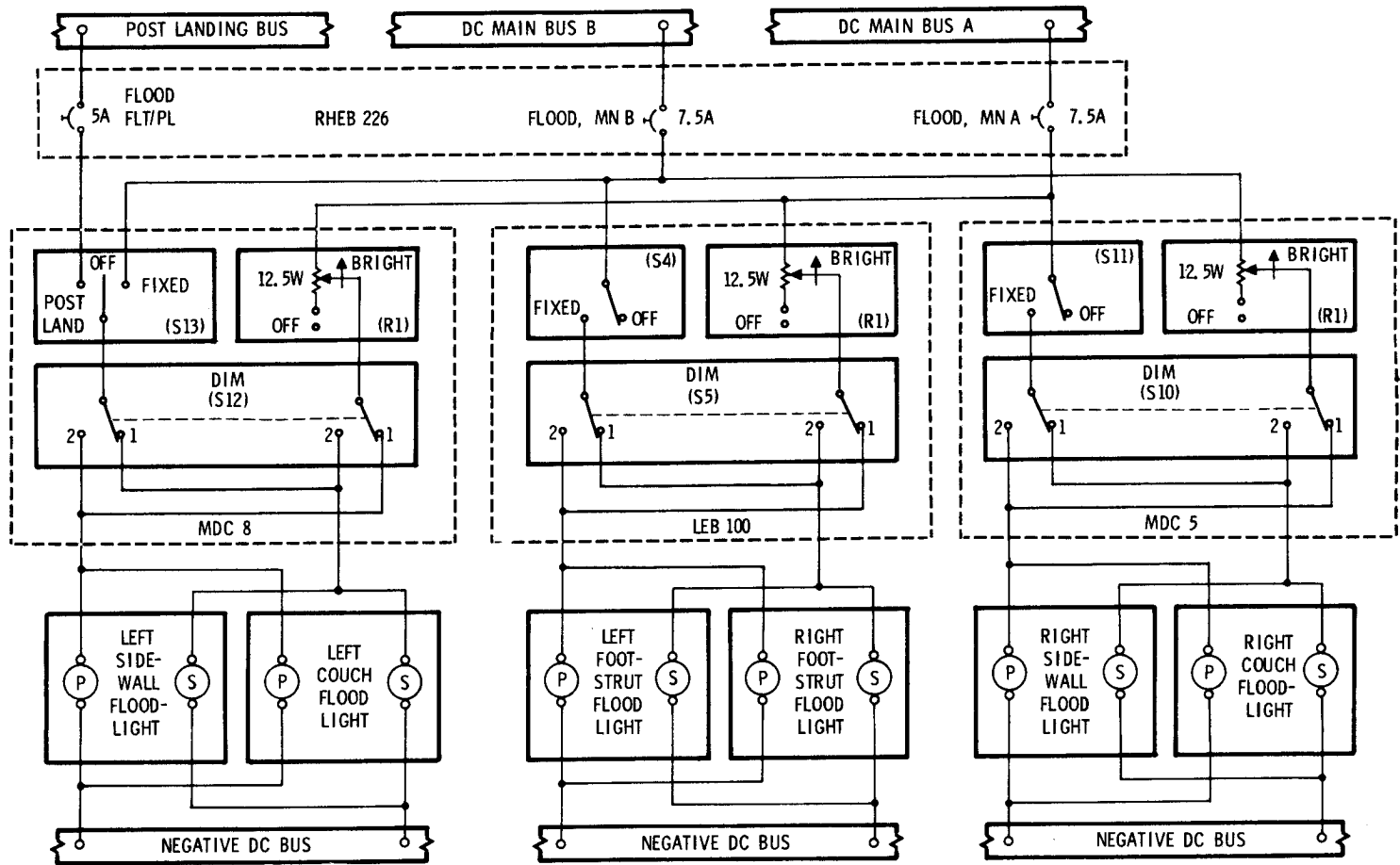
Each control panel has a dimming (DIM-1-2) toggle switch control, a rheostat (FLOOD-OFF-BRT) control, and an on/off (FIXED-OFF) toggle switch control. The DIM-1 position provides variable intensity control of the primary flood lamps through the FLOOD-OFF-BRT rheostat, and on-off control of the secondary lamps through the FIXED-OFF switch. The DIM-2 position provides variable intensity control of the secondary lamps through the FLOOD-OFF-BRT rheostat, and on-off control of the primary lamps through the FIXED-OFF switch. When operating the primary lamps under variable intensity control (DIM-1 position), turnon of the lamps is acquired after the FLOOD-OFF-BRT rheostat is moved past the mid point. In transferring variable intensity control to the secondary lamps, the FLOOD-OFF-BRT rheostat should first be rotated to the OFF position before placing the DIM switch to the DIM-2 position. The rheostat is then moved to the full bright setting and should remain in this position unless dimming is desired. Dimming of the secondary flood lamps should not be used unless dimming control of the primary floodlights is not available. Dimming of the secondary lamps results in approximately a 90-percent reduction in lamp life. The range of intensity variation is greater for the primary than the secondary floodlights.

The commander's control panel (MDC-8) has a POST LANDING-OFF-FIXED switch which connects the flight and postlanding bus to his floodlights (figure 2.6-18). The POST LANDING position provides single intensity lighting to the commander's primary or secondary lamps as selected by the DIM-1 or DIM-2 position respectively. It is for use during the latter stages of descent after main d-c bus power is disconnected, and during postlanding.



EP-701B

Figure 2.6-17. CM Floodlight Configuration



EP-702A

Figure 2.6-18. CM Floodlight System Schematic

2.6.7.2 Integral Lighting System

The integral lighting system controls the EL lamps behind the nomenclature and instrument dial faces on all MDC panels, and on specific panels in the lower equipment bay, left-hand equipment bay and right-hand equipment bay (figures 2.6-19 and 2.6-20). The controls (figure 2.6-19) are rotary switches controlling variable transformers powered through the appropriate a-c bus. Each rotary control switch has a mechanical stop which prevents the switch being positioned to OFF. Disabling of a circuit because of malfunctions is performed by opening the appropriate circuit breaker on RHEB-226. The INTEGRAL switch on MDC-8 controls the lighting of panels viewed by the commander, MDC-1, 7, 8, 9, 15, and the left half of 2. The INTEGRAL switch on MDC-5 controls the lighting of panels viewed by the LM pilot, MDC-3, 4, 5, 6, and 16, RHEB-229 and 275, and the right half of MDC-2. The INTEGRAL switch on LEB-100 controls the lighting of MDC-10, LEB-100, 101, 122 and the DSKY lights on 140, RHEB-225, 226 and LHEB 306. Intensity of the lighting can be individually controlled in each of the three areas.

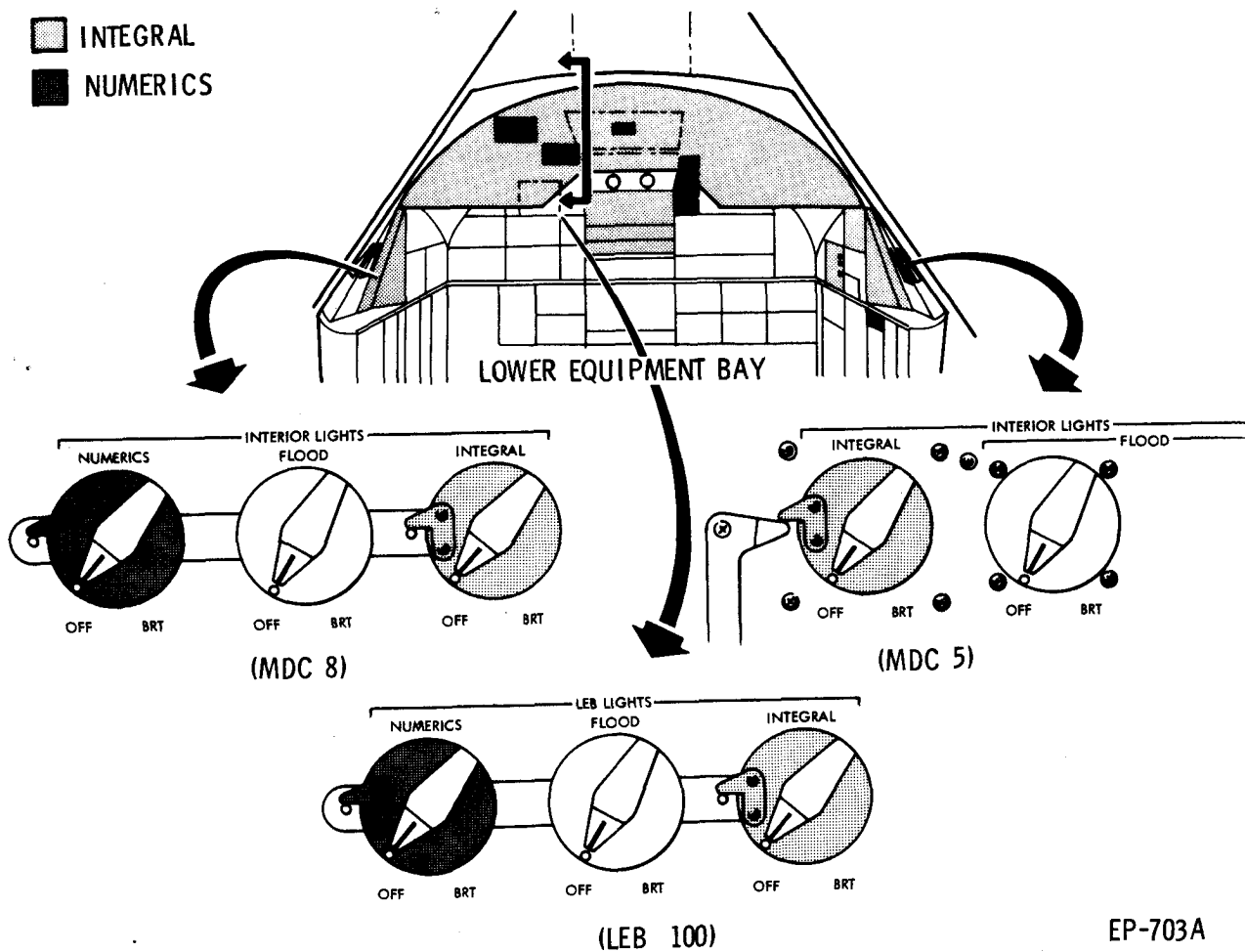
2.6.7.3 Numerics Lighting System

Numerics lighting control is provided over all electroluminescent digital readouts. The NUMERICS rotary switch on MDC-8 controls the off/intensity of numerals on the DSKY and mission timer on MDC-2, and the range and delta V indicators of the entry monitor system of MDC-1. The switch on LEB-100 controls the off/intensity of the numerals on the LEB-140 DSKY and the mission timer on LHEB-306. Protection for the integral and numerics circuits is provided by the LIGHTING-NUMERICS/INTEGRAL-LEB AC 2, L MDC AC 1, and R MDC AC 1 circuit breakers on RHEB-226. These circuit breakers are used to disable a circuit in case of a malfunction. The L MDC AC 1 circuit breakers also feed the EMS roll attitude and scroll incandescent lamps.

2.6.7.4 Tunnel Lighting

The six light fixtures in the CM tunnel provide illumination for tunnel activity during docking and undocking. Each of the fixtures, containing two incandescent lamps, is provided 28 vdc through a TUNNEL-LIGHTS-OFF switch on MDC-2 (figure 2.6-21). Main d-c bus A distributes power to one lamp in each fixture, and main d-c bus B to the other lamp. Protection is provided by the LIGHTING/COAS/TUNNEL/RNDZ/SPOT/MN A and MN B circuit breakers on RHEB-226.

□ INTEGRAL
 ■ NUMERICS



EP-703A

Figure 2.6-19. CM Integral/Numerics Illumination System

Figure 2.6-20. Integral and Numerics Panel Lighting Schematic

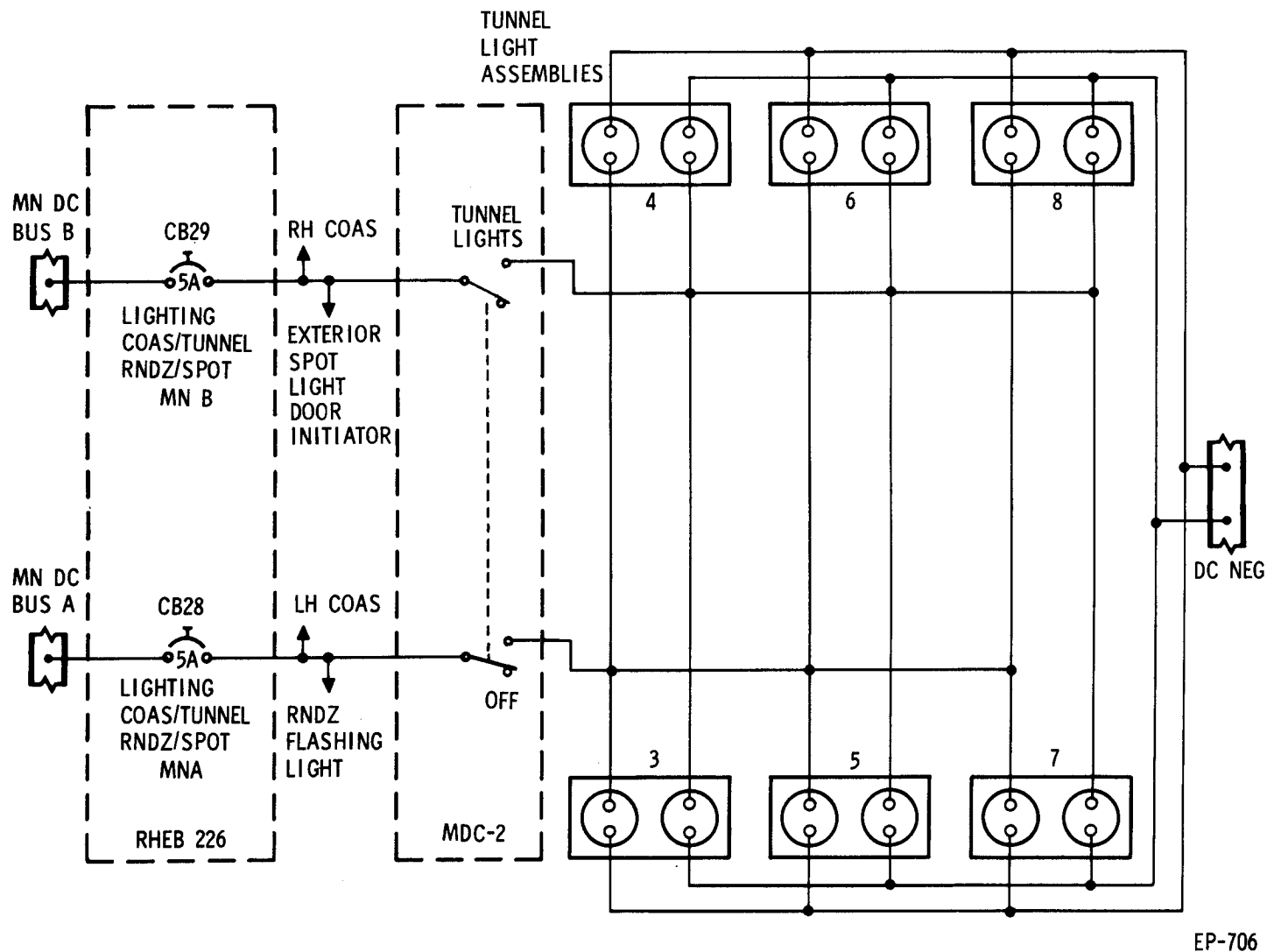


Figure 2.6-21. Tunnel Lighting Schematic