2.8 ELECTRICAL POWER SYSTEM (EPS)

CONTENTS

Description

The electrical power system (EPS) consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter vehicle, and fulfill all the orbiter external tank, solid rocket booster, and payload power requirements, when not connected to ground support equipment. The EPS operates during all flight phases. For nominal operations, very little flight crew interaction is required by the EPS.

The EPS is functionally divided into three subsystems: power reactants storage and distribution (PRSD), three fuel cell power plants (fuel cells), and electrical power distribution and control (EPDC).

Through a chemical reaction, the three fuel cells generate all 28-volt direct-current electrical power for the vehicle from launch minus 3 minutes and 30 seconds through landing roll-out. Prior to that, electrical power is provided by ground power supplies and the onboard fuel cells.

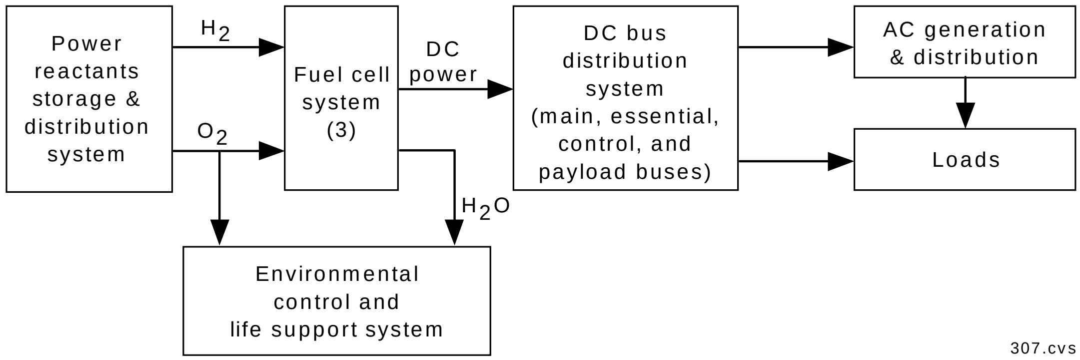
Power is controlled and distributed by assemblies located in the forward, mid, and aft sections of the orbiter. Each assembly is a housing for electrical components such as remote switching devices, buses, resistors, diodes, and fuses. Each assembly usually contains a power bus or buses and remote switching devices for distributing bus power to subsystems located in its area.

Power Reactants Storage and Distribution System

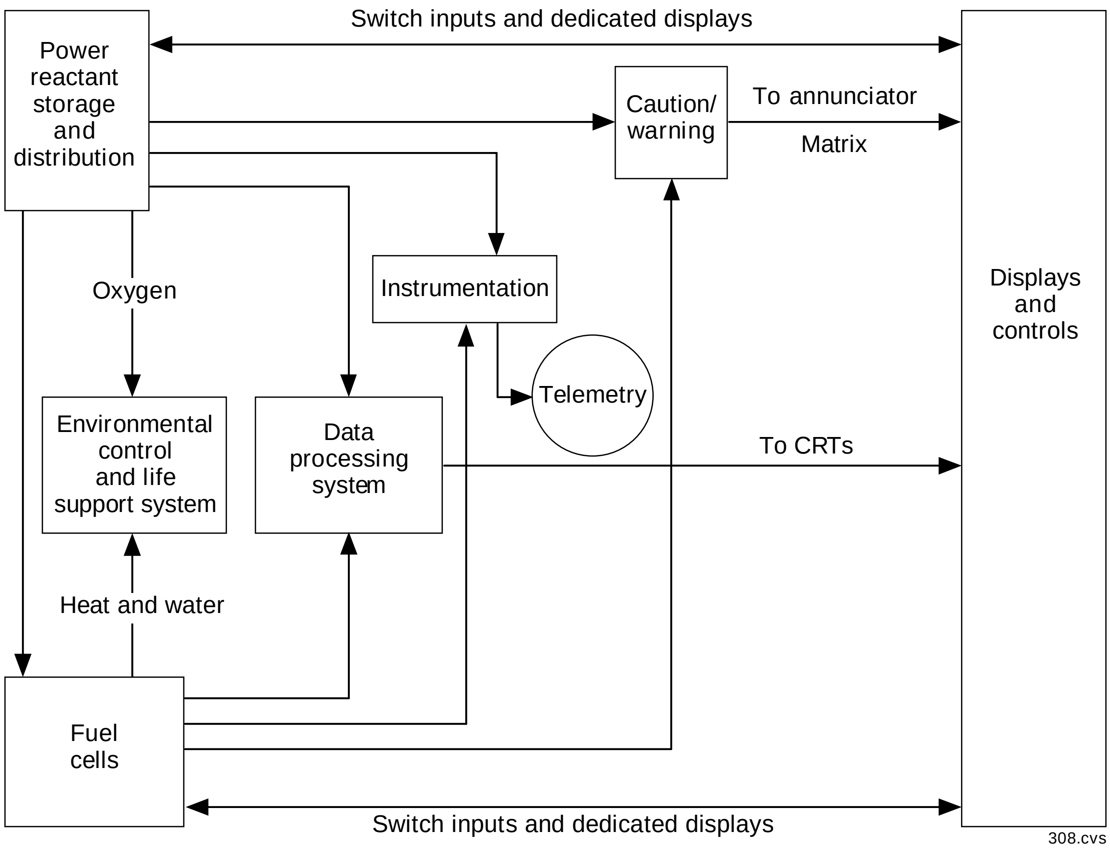
The power reactants storage and distribution system stores the reactants (cryogenic hydrogen and oxygen) and supplies them to the three fuel cells that generate all the electrical power for the vehicle during all mission phases. In addition, the subsystem supplies cryogenic oxygen to the environmental control and life support system (ECLSS) for crew cabin pressurization. The hydrogen and oxygen are stored in tanks at cryogenic temperatures (-285°F for liquid oxygen and -420° F for liquid hydrogen) and supercritical pressures (above 731 psia for oxygen and above 188 psia for hydrogen).

The PRSD system components are located in the orbiter midbody underneath the payload bay or on a payload bay pallet for 10+ day missions in extended duration orbiter (EDO) vehicles. The system stores the reactants hydrogen and oxygen in double-walled, thermally insulated spherical tanks with a vacuum annulus between the inner pressure vessel and outer tank shell. Each tank has heaters to add energy to the reactants during depletion to control pressure. Each tank is capable of measuring quantity remaining.

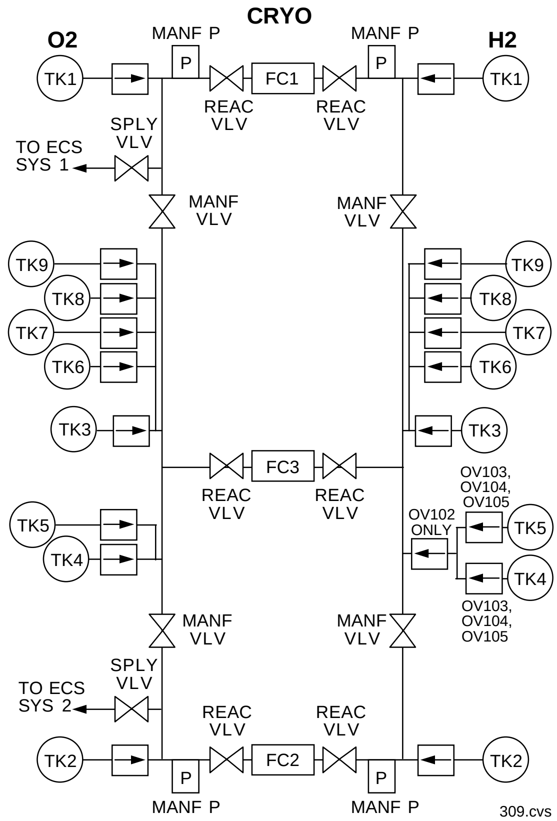
The tanks are grouped in sets of one hydrogen and one oxygen tank. The number of tank sets installed depends on the specific mission requirement and vehicle. Up to five tank sets can be installed in the midfuselage under the payload bay liner of OVs-102, -103, -104, and -105. Up to four additional tank sets can be flown on the EDO pallet in the payload bay of OV-102 and -105. OV-105 may be configured at a later date to fly up to four additional tank sets (total of eight additional sets). Switches to control these tanks are already installed.



The Electrical Power System



Electrical Power System Interfaces



The PDRS System

Cryogenic Storage Tanks

All oxygen tanks are identical and consist of inner pressure vessels of Inconel 718 and outer shells of aluminum 2219. The inner vessel is 33.435 inches in diameter and the outer shell is 36.8 inches in diameter. Each tank has a volume of 11.2 cubic feet and stores up to 781 pounds of oxygen. The dry weight of each tank is 215 pounds. Maximum fill time is 45 minutes.

All hydrogen tanks also are identical. Both the inner pressure vessel and the outer shell are constructed of aluminum 2219. The inner vessel's diameter is 41.51 inches and the outer shell's is 45.5 inches. The volume of each tank is 21.39 cubic feet, and each stores up to 92 pounds of hydrogen. Each tank weighs 227 pounds dry. Maximum fill time is 45 minutes.

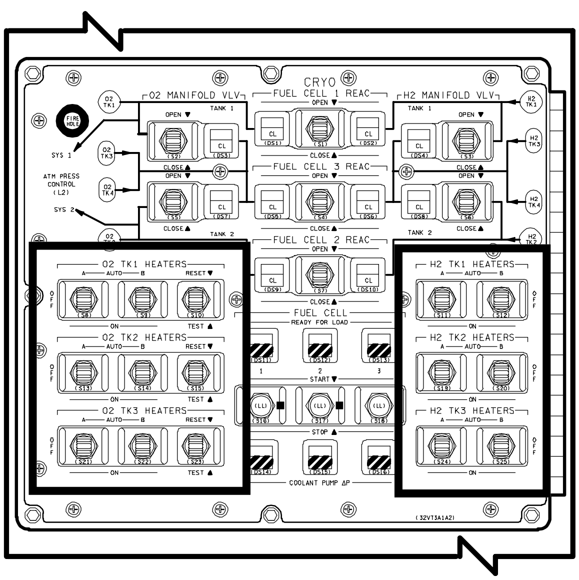
The inner pressure vessels are kept supercold by minimizing conductive, convective, and radiant heat transfer. Twelve low-conductive supports suspend the inner vessel within the outer shell. Radiant heat transfer is reduced by a shield between the inner vessel and outer shell (hydrogen tanks only), and convective heat transfer is minimized by maintaining a vacuum between the vessel and shell. During ground operations, a vacuum ion pump maintains the required vacuum level and is also used as a vacuum gauge to determine the vacuum's integrity. The pump consists of an electrical power supply and an anode, which absorbs free ions between the tank walls.

Cryogenic Tank Heaters

Each hydrogen tank has one heater probe with two elements; each oxygen tank has two heater probes with two elements on each probe. As the reactants are depleted, the heaters add heat energy to maintain a constant pressure in the tanks.

The heaters operate in automatic and manual modes. In the automatic mode, the heater is controlled by a tank heater controller. Each heater controller receives a signal from a tank pressure sensor. If pressure in a tank is less than or equal to a specific pressure, the controller turns the heater on. When the pressure in the tanks goes above the upper limit, the respective controller turns the heater off. The O2 TK1, 2, 3, and H2 TK1, 2, 3 heater switches are located on panel R1; switches for the O2 and H2 TK4 heaters (tanks 4/5 on OV-102) are on panel A11. (On OV-102, the oxygen and hydrogen tank 4 B heaters are disconnected, and the logic and power are used for the tank 5 A heaters.) OV-103, -104, and -105 heater switches for tank set 5 are on panel A15. The heater switches for EDO pallet tanks 6-9 are located on panel A15 in both EDO configured vehicles. OV-105 also has heater switches for tank sets 10-13 on panel A11 for the future use of a second EDO pallet.

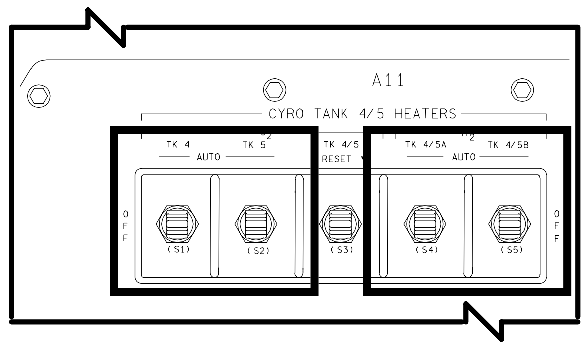
Heater controller pasia		
Pressure limits (psia)	Low	High
H_2 tank 1, 2	200-206	220-226
H_2 tank 3-9	217-223	237-243
O_2 tank 1,2	803-819	838-854
O_2 tank 3-9	832-848	866-882



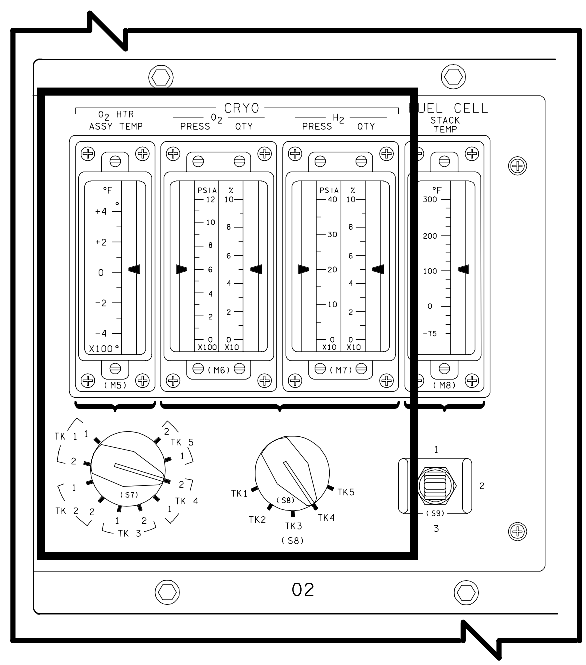
O2 and H2 TK HEATERS Switches on Panel R1

Dual-mode heater operation is available for pairs of oxygen and hydrogen tanks. If the heaters of both tanks 1 and 2, or tanks 3 and 4, are placed in the automatic mode, the tank heater logic is interconnected. In this case, the heater controllers of both tanks must sense a low pressure before the heaters will turn on. Once the heaters are on, a high pressure signal from either tank will turn off the heaters in both tanks.

In the manual mode, the flight crew controls the heaters by using the *ON OFF* positions for each heaters switch on panel R1, A11, or A15. Pressure in each tank is shown as O2 TK P and H2 TK P on the DISP 68 CRYO SYSTEM or DISP 168 CRYO PALLET displays. Pressure is also displayed on the CRYO O_2 and H_2 PRESS meters on panel O2. The specific tank (1, 2, 3, or 4) is selected by the rotary switch below the meters. Tank 5 TK P is also displayed on OV-105.



CRYO TANK 4 HEATER Switches on Panel A11



Cryogenic System Meters and Switches on Panel O2

Each tank set has a hydrogen/oxygen control box that contains the electrical logic for the hydrogen and oxygen heaters and controllers. The control box is located on cold plates in the midbody under the payload bay envelope. On OV-102, a single control box controls tanks 4 and 5.

2011/ /068 CRYO SYSTEM 4 000/02:34:40
000/00:00:00

TK					
O2	1	2	3	4	5
P	827	826	871	826	826
TK P	828	828	871	828	828
QTY	99	99	100	100	100
T	-249	-249	-249	-249	-249
HTR T 1	-249	-249	-182	-249	-249
2	-249	-249	-182	-249	-249
HTR 1A					
CUR 1B				4/5	
SNSR 2A					
2B				4/5	
MANF P	871	871			
VLV	OP	OP			
H2					
P	215	213	224	213	213
TK P	215	214	224	214	214
QTY	97	97	99	99	99
T	-417L	-417L	-417L	-417L	-417L
HTR T	-417L	-417L	-417L	-417L	-417L
MANF P	222	222			
VLV	OP	OP			

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DISP 68 CRYO SYSTEM Display (on orbit)

The CRYO O_2 HTR ASSY TEMP meter on panel O2, in conjunction with the rotary switch below it, selects one of the two heaters in each tank and permits the temperature of the heater element to be displayed. The range of the display is from -425° F to +475° F. The temperature sensor in each heater also is hardwired directly to the caution and warning system, which drives the yellow *O_2 HEATER TEMP* light on panel F7. This light is illuminated if the temperature is at or above 344° F. A signal also is sent to the GPCs where software checks the limit; if the temperature is at or above 349° F, the *BACKUP C/W ALARM* light on panel F7 is illuminated. This signal also is displayed on DISP 68 CRYO SYSTEM and transmitted to the ground.

2011/ /168 CRYO PALLET 4 000/02:38:52
000/00:00:00

TK					
O2	6	7	8	9	
P	515L	515L	515L	515L	PALLET
TK P	0L	0L	0L	0L	STB
QTY	- 5L	- 5L	- 5L	- 5L	STB
T	-417L	-417L	-417L	-417L	POP
HTR T 1	-417L	-417L	-417L	-417L	POP
2	-417L	-417L	-417L	-417L	
HTR 1A					PALLET
CUR 1B					PPO
SNSR 2A					
2B					
H2					
P	145L	145L	145L	145L	
TK P	0L	0L	0L	0L	
QTY	- 6L	- 6L	- 6L	- 6L	
T	-417L	-417L	-417L	-417L	
HTR T	-417L	-417L	-417L	-417L	

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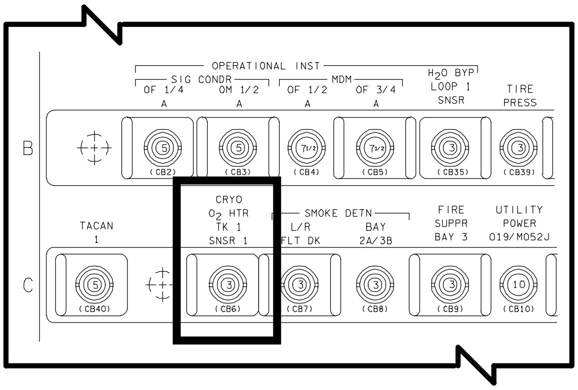
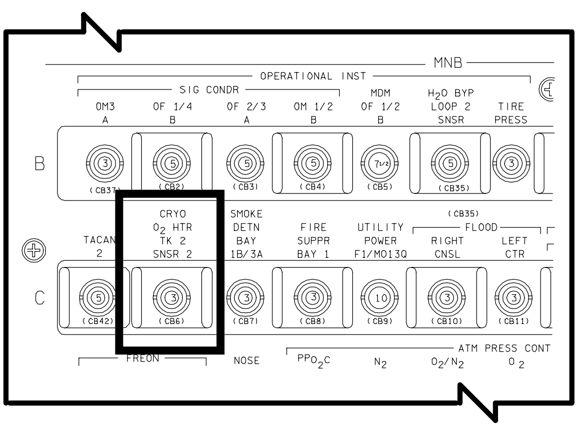
DISP 168 (CRYO PALLET)

Two current level detectors are built into the circuit of each oxygen tank heater to interrupt power in case of electrical shorts. The second detector is redundant. Each detector is divided into A and B detectors, which monitor the heater A current and the heater B current respectively. The detectors are powered by circuit breakers on panels O14, O15, O16, and ML86B. The detectors monitor the current in and out of a heater. If the current difference is 0.9 amp or greater for 1.5 milliseconds, a trip signal is sent to the heater logic to remove power from the heaters regardless of the heater switch position. If one element of a heater causes a "trip-out," power to both elements is removed. The *O_2 TK 1, 2, 3 HEATERS RESET/TEST* switches on panel R1 and the *O_2 RESET/TEST* switches on panels A11 and A15 can be used to reapply power to that heater by positioning them to *RESET*. The *TEST* position will cause a 1.5-amp delta current to flow through all four detectors of a specified oxygen tank, causing them to trip out. During on-orbit operations, the flight crew will be alerted to a current level detector trip-out by an *SM ALERT*, S68 CRY0 02 message, or S168 CRYO message.

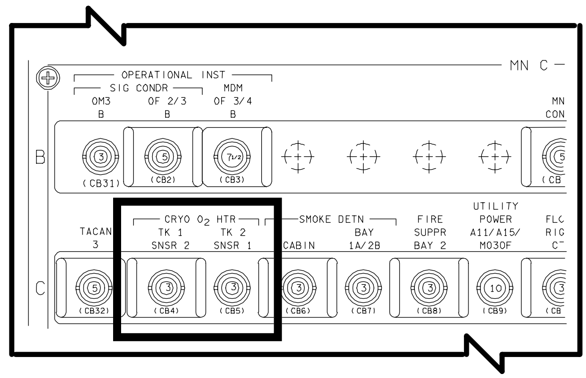


Cryogenic System Heater Sensor Circuit Breaker on Panel O14

Each oxygen and hydrogen tank has a quantity sensor powered by a circuit breaker. These are identified on panel O13 as *CRYO QTY* O_2 *(or* H_2*) TK 1* and *TK 2* and on panel ML86B as *CRYO QTY* O_2 (or H_2*) TK 3*, *TK 4*, and *TK 5*. Data from the quantity sensors are sent to panel O2, where the rotary switch below the meters is used to select the tank for display on the CRYO O_2 (or H_2) QTY meters. The range of the meters is zero to 100 percent. The data are also displayed on DISP 68 or DISP 168.



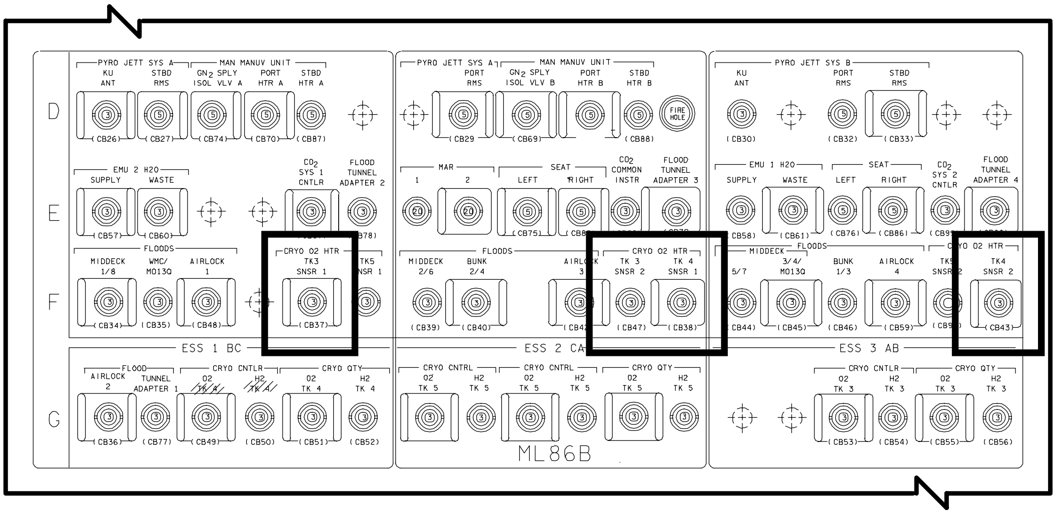
Cryogenic System Heater Sensor Circuit Breaker on Panel O15



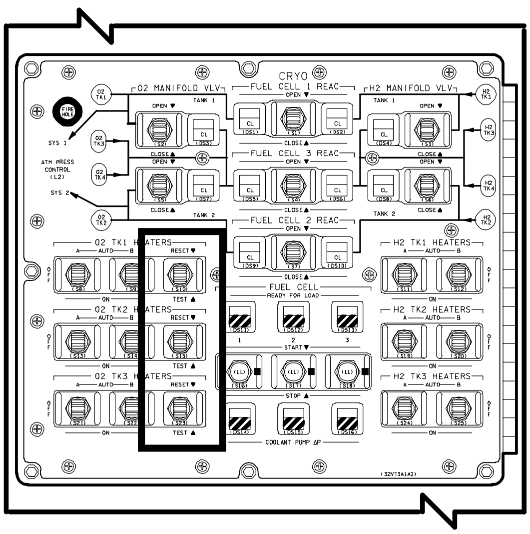
Cryogenic System Heater Sensor Circuit Breaker on Panel O16

There are two pressure sensors for each oxygen and hydrogen tank. One sensor transmits its data to the tank heater controllers, the caution and warning matrix on panel F7, and is displayed as "P" on DISPs 68 and 168. The yellow O_2 *PRESS* light is illuminated if oxygen tank pressure is below 540 psia or above 985 psia. The yellow H_2 *PRESS* light illuminates if hydrogen tank pressure is below 153 psia or above 293.8 psia. Data from the other sensor is displayed as TK P on DISPs 68 and 168 and the PRESS meters on panel O2. The *SM ALERT* and *BACKUP C/W ALARM* lights on panel F7 are also driven by the data. The range of the O_2 meter is 0 to 1,200 psia. The H_2 meter's range is 0 to 400 psia. The range of "P" displayed on the PASS and BFS SM SYS SUMM 1 and DISPs 68 and 168 is 515 to 1,215 psia for oxygen and 145 to 305 psia for hydrogen.

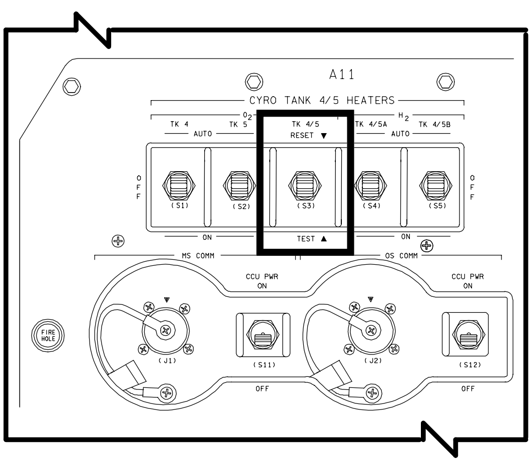
The data from oxygen and hydrogen fluid temperature sensors is displayed on DISP 68 or DISP 168 and transmitted to the ground.



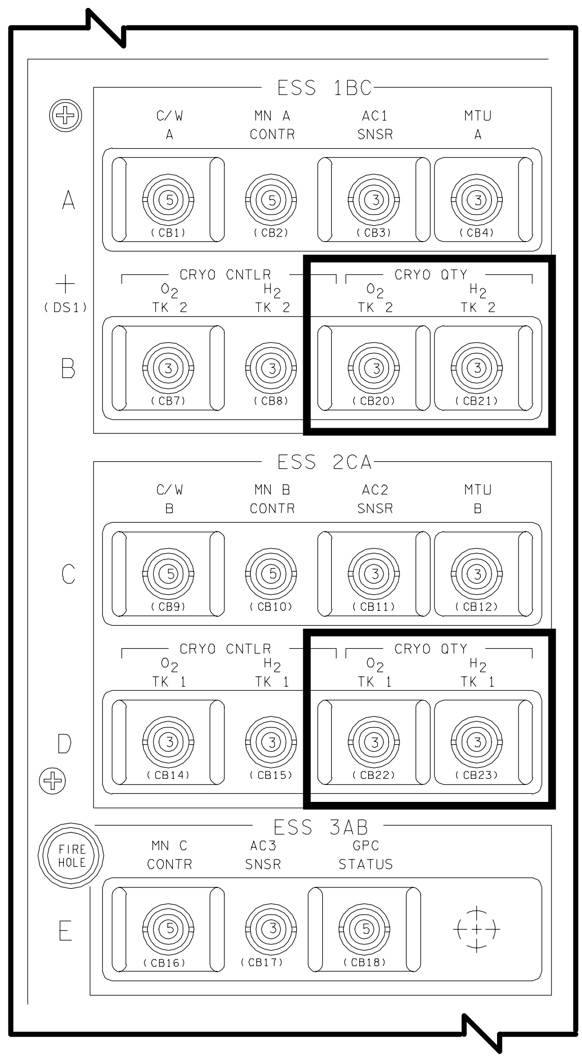
Cryogenic System Heater Sensor Circuit Breaker on Panel ML86B



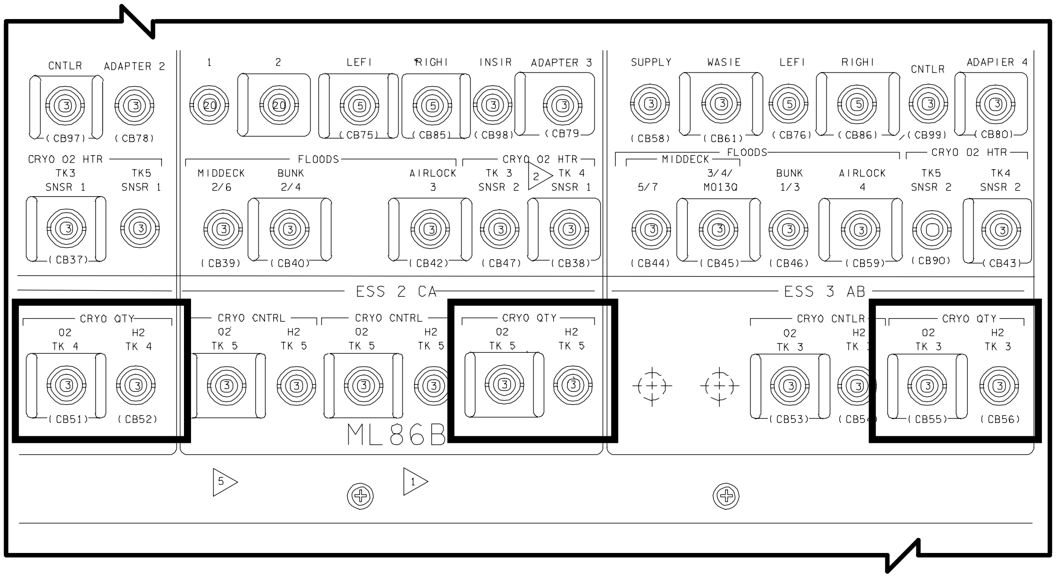
O2 TK1, TK 2 HEATERS RESET/TEST Switches on Panel R1



O2 TK 4/5 RESEST/TEST SWITCH ON Panel A11 (OV-102)



Cryogenic Tank Quantity Sensor Circuit Breakers on Panel O13



Cryogenic Tank Quantity Sensor Circuit Breakers on Panel ML86B

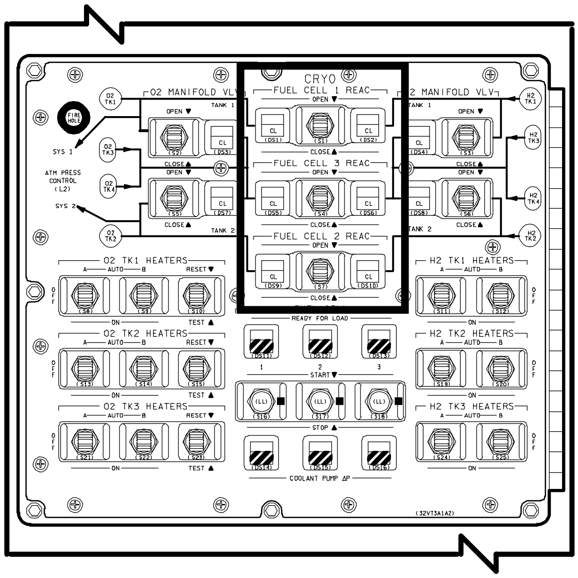
Reactant Distribution

The cryogenic reactants flow from the tanks through a relief valve/filter package module and a valve module. They then flow to the fuel cells through a common manifold. Hydrogen is supplied to the manifold from the tank at a pressure of 200 to 243 psia and oxygen is supplied at 803 to 883 psia. The pressure of the reactants will be essentially the same at the fuel cell interface as it is in the tanks, since only a small decrease in pressure occurs in the distribution system.

Each tank has a relief valve/filter package module that contains the tank relief valve and a 12-micron filter. The filter removes contaminants that could affect the performance of components within the PRSD and the fuel cells. The valve relieves excessive pressure overboard that builds up in the tank. The oxygen tank relief valve relieves at 1,005 psia and the hydrogen tank relief valve relieves at 302 psia. Tanks one and two also have a manifold relief valve that relieves pressure in the manifold lines. The manifold relief valves are a built-in safety device in the event a manifold valve and fuel cell reactant valve are closed because of a malfunction. The reactants trapped in the manifold lines would be warmed up by the internal heat of the orbiter and overpressurize. The manifold relief valve will open at 290 psi for hydrogen and 975 psi for oxygen to relieve pressure and allow the trapped reactants to flow back to their tanks.

The reactants flow from the relief valve/filter packages through four reactant valve modules: two hydrogen (hydrogen valve modules 1 and 2) and two oxygen (oxygen valve modules 1 and 2). The valve modules contain a check valve for each cryogenic tank line to prevent the reactants from flowing from one tank to another in the event of a leak. (This prevents a total loss of reactants. However, hydrogen tank 5 on OV-102 shares a common check valve with tank 4. A leak in either tank will drain the other as well. For this reason, unless the EDO pallet is flown on OV-102, hydrogen tanks 4 and 5 are used first.) The oxygen valve modules also contain the environmental control and life support system atmosphere pressure control system 1 and 2 oxygen supply valves. Each module also contains a manifold valve and fuel cell reactant valves.

Each fuel cell has two reactant valves—one for hydrogen and one for oxygen. The valves are controlled by the *FUEL CELL 1, 3, 2 REAC* switches on panel R1. When the switch is positioned to *OPEN*, the hydrogen and oxygen reactant valves for that fuel cell are opened and reactants are allowed to flow from the manifold into the fuel cell. When the switch is positioned to *CLOSE*, the hydrogen and oxygen reactant valves for that fuel cell are closed, isolating the reactants from the fuel cell and rendering that fuel cell inoperative. Each *FUEL CELL REAC* switch on panel R1 also has two talkback indicators, one on each side of the switch. The corresponding talkback indicates *OP* when the valve is *OPEN* and *CL* when the valve is closed. There is redundant capability to close the *REAC VALVES* via the *FUEL CELL REAC VLV* circuit breakers and switches on panel C3.



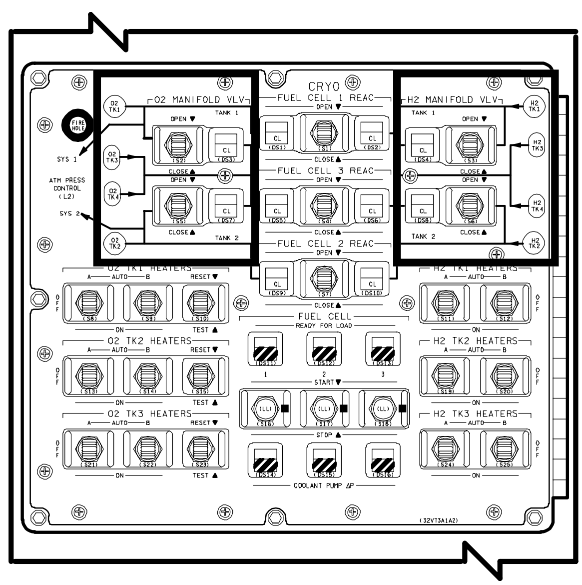
FUEL CELL 1, 3, 2 REAC Switches and Talkbacks on Panel R1

> **WARNING**
> The *FUEL CELL REAC* switches on panel R1 are in a vertical column with *FUEL CELL 1 REAC* on top, *FUEL CELL 3 REAC* in the middle, and *FUEL CELL 2 REAC* on the bottom. This was done to allow the schematic to be placed on the panel. Because the switches are not in numerical order, it is possible to inadvertently close the wrong fuel cell reactant valve when shutting down a fuel cell.

It is critical to have reactants available to the fuel cells. When any fuel cell reactant valve is closed, the red *FUEL CELL REAC* light on panel F7 is illuminated and a caution/warning tone is sounded. The computers sense the closed valve, which causes the *BACKUP C/W ALARM* light on panel F7 to be illuminated, an *SM ALERT* to occur, and a closed indication to be displayed on DISP 69 and SM SYS SUMM 1. This alerts the flight crew that the fuel cell will be inoperative within approximately 20 to 30 seconds for a hydrogen valve closure and 130 seconds for an oxygen valve closure. The time varies with power loading.

The O_2 and H_2 *MANIFOLD VLV* switches on panel R1 control the respective hydrogen and oxygen manifold valves. When the two hydrogen and two oxygen manifold valves are in the *CLOSE* position, fuel cell 1 receives reactants from cryogenic tank set 1, fuel cell 2 receives reactants from cryogenic tank set 2, and fuel cell 3 receives reactants from cryogenic tank sets 3 and above. ECLSS atmosphere pressure control system 1 receives oxygen from oxygen tank 1, and system 2 receives oxygen from oxygen tank 2. When the switches are positioned to *CLOSE*, the talkback indicator associated with each switch indicates *CL*.

With both H_2 and O_2 *MANIFOLD VLV 1* switches positioned to *OPEN* and the *MANIFOLD VLV 2* switches positioned to *CLOSE*, cryogenic tanks 1, 3 and above supply hydrogen to fuel cells 1 and 3, and oxygen cryogenic tanks 1, 3 and above supply oxygen to fuel cells 1 and 3, as well as to ECLSS atmosphere pressure control system 1. The talkback indicator associated with each MANF VLV 1, 2 switch indicates *OP, CL,* respectively. O_2 and H_2 TK 2 continue to supply fuel cell 2.



O2 and H2 MANIFOLD VLV Switches and Talkbacks on Panel R1

CAUTION

There are no relief valves for O_2 and H_2 manifold 3's with manifold valves 1 and 2 closed. This configuration should be avoided except for leak isolation and troubleshooting

When the H_2 and O_2 MANIFOLD VLV 2 switches are positioned to OPEN, and the MANIFOLD VLV 1 switches are positioned to CLOSE, hydrogen cryogenic tanks 2 and 3 and above supply hydrogen to fuel cells 2, 3, and oxygen cryogenic tanks 2 and 3 and above supply oxygen to fuel cells 2 and 3, as well as to ECLSS atmosphere pressure control system 2. The talkback indicator associated with each MANF VLV 1, 2 switch indicates OP, CL, respectively. *H_2* and *O_2* tank 1 continue to supply fuel cell 1.

With the *H_2* and *O_2 MANIFOLD VLV 1* and *2* switches positioned to *OPEN*, all hydrogen cryogenic tanks are available to supply hydrogen to all three fuel cells, and all oxygen cryogenic tanks are available to supply oxygen to all three fuel cells, as well as to ECLSS atmosphere pressure control systems 1 and 2. Because tank sets 1 and 2 are regulated at a slightly lower pressure, tank sets 3 and above will feed before tank set 1 and 2. Reactants will be supplied to the fuel cells by the tank(s) with the highest pressure.

Manifold pressure data from two pressure sensors located in the respective hydrogen and oxygen valve modules is displayed on DISP 68 CRYO SYSTEM. This information is also sent to the systems management computer where its lower limit is checked. If the respective hydrogen and oxygen manifold pressures are below 150 psia and 200 psia respectively, an *SM ALERT* will occur.

Data for installed EDO pallet cryo tank sets can be monitored during ascent and entry on CRT display BFS SPEC 168 CRYO PALLET. On orbit the data is available on SM SPEC 168 CRYO PALLET.

Fuel Cell System

The three fuel cells are located under the payload bay area in the forward portion of the orbiter's midfuselage. Each fuel cell is 14 inches high, 15 inches wide, 40 inches long, and weighs 255 pounds. Each fuel cell is reusable and restartable.

The three fuel cells are individually coupled to the PRSD subsystem, the active thermal control system (ATCS), the supply water storage subsystem, and the electrical power distribution and control (EPDC) subsystem. The fuel cells generate heat and water as by-products of electrical power generation. The excess heat is directed to fuel cell heat exchanger, where it is rejected to the Freon coolant loops. The water is directed to the supply water storage subsystem for the environmental control and life support system.

ACCESSORIES	POWER
• Reactant flow monitor • Heat rejection • Water rejection • Thermal control • Cell performance monitor • Electrical control unit	96 cells Converts H2 & O2 into: • Power • Potable water • Heat

Fuel Cell Block Diagram

The nominal voltage and current range of each fuel cell is 2 kW at 32.5 volts dc, 61.5 amps to 12 kW at 27.5 volts dc, 436 amps. Each is capable of supplying up to 10 kW maximum continuous power in nominal situations, 12 kW continuously in off-nominal situations (with one or more fuel cells failed), and up to 16 kW for 10 minutes. The average on-orbit power consumption of the orbiter is approximately 14 kW, leaving additional capability available for payloads. Each fuel cell is serviced between flights and reused until it has accumulated 2,000 hours of on-line service.

The orbiter's three fuel cells operate as independent electrical power sources, each supplying its own isolated, simultaneously operating dc bus. Each fuel cell consists of a power section and an accessory section. The power section, where hydrogen and oxygen are transformed into electrical power, water, and heat, consists of 96 cells contained in three substacks. Manifolds run the length of these substacks and distribute hydrogen, oxygen, and coolant to the cells. The cells contain an oxygen electrode (cathode), and a hydrogen electrode (anode) that are separated by a porous matrix saturated with potassium hydroxide electrolyte.

The accessory section monitors the reactant flow, removes waste heat and water from the chemical reaction, and controls the temperature of the stack. The accessory section consists of the hydrogen and oxygen flow system, the coolant loop, and the electrical control unit.

The fuel cell generates power through an electrochemical reaction of hydrogen and oxygen. At the hydrogen electrode (anode), hydrogen is oxidized according to the following reaction:

$$2H_2 + 4OH^- \longrightarrow 4H_2O + 4e^-$$

forming water and releasing electrons. At the oxygen electrode (cathode), oxygen is reduced in the presence of water. It forms hydroxyl ions according to the following relationship:

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

The net reaction consumes one oxygen molecule and two hydrogen atoms in the production of two water molecules, with electricity and heat formed as by-products of the reaction.

The fuel cell coolant system circulates a liquid fluorinated hydrocarbon and transfers the waste heat from the cell stack through the fuel cell heat exchanger to the Freon coolant loop system in the midfuselage. Internal control of the circulating fluid maintains the cell stack at a load-dependent operating temperature of approximately 200° F.

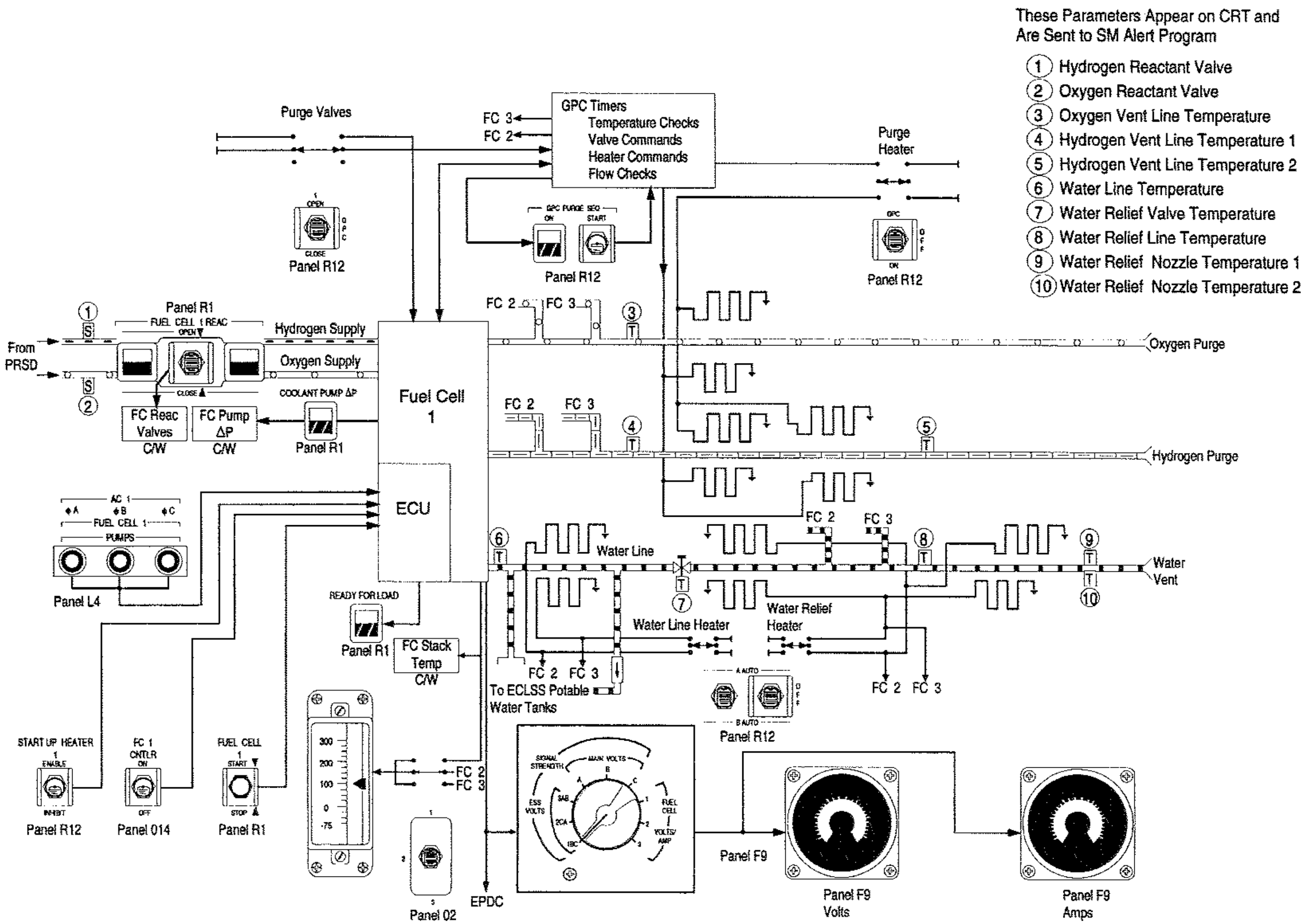
When the reactants enter the fuel cells, they flow through a preheater (where they are warmed from a cryogenic temperature to 40° F or greater), a 6-micron filter, and a two-stage, integrated dual gas regulator module. The first stage of the regulator reduces the pressure of the hydrogen and oxygen to 100 to 120 psia. The second stage reduces the oxygen pressure to a range of 60 to 62 psia and maintains the hydrogen pressure at 4.5 to 6 psia differential below the oxygen pressure. The regulated oxygen lines are connected to the accumulator, which maintains an equalized pressure between the oxygen and the fuel cell coolant. If oxygen and hydrogen pressure decrease, the coolant's pressure is also decreased to prevent a large differential pressure inside the stack that could deform the cell stack structural elements.

Upon leaving the dual gas regulator module, the incoming hydrogen mixes with the hydrogen-water vapor exhaust from the fuel cell stack. This saturated gas mixture is routed through a condenser, where the temperature of the mixture is reduced, condensing a portion of the water vapor to form liquid water droplets. The liquid water is then separated from the hydrogen-water mixture by the hydrogen pump /water separator. A centrifugal water separator extracts the liquid water and pressure-feeds it to potable tanks in the lower deck of the pressurized crew cabin. Water from the potable water storage tanks can be used for crew consumption and for cooling the Freon loops by feeding the flash evaporator system.

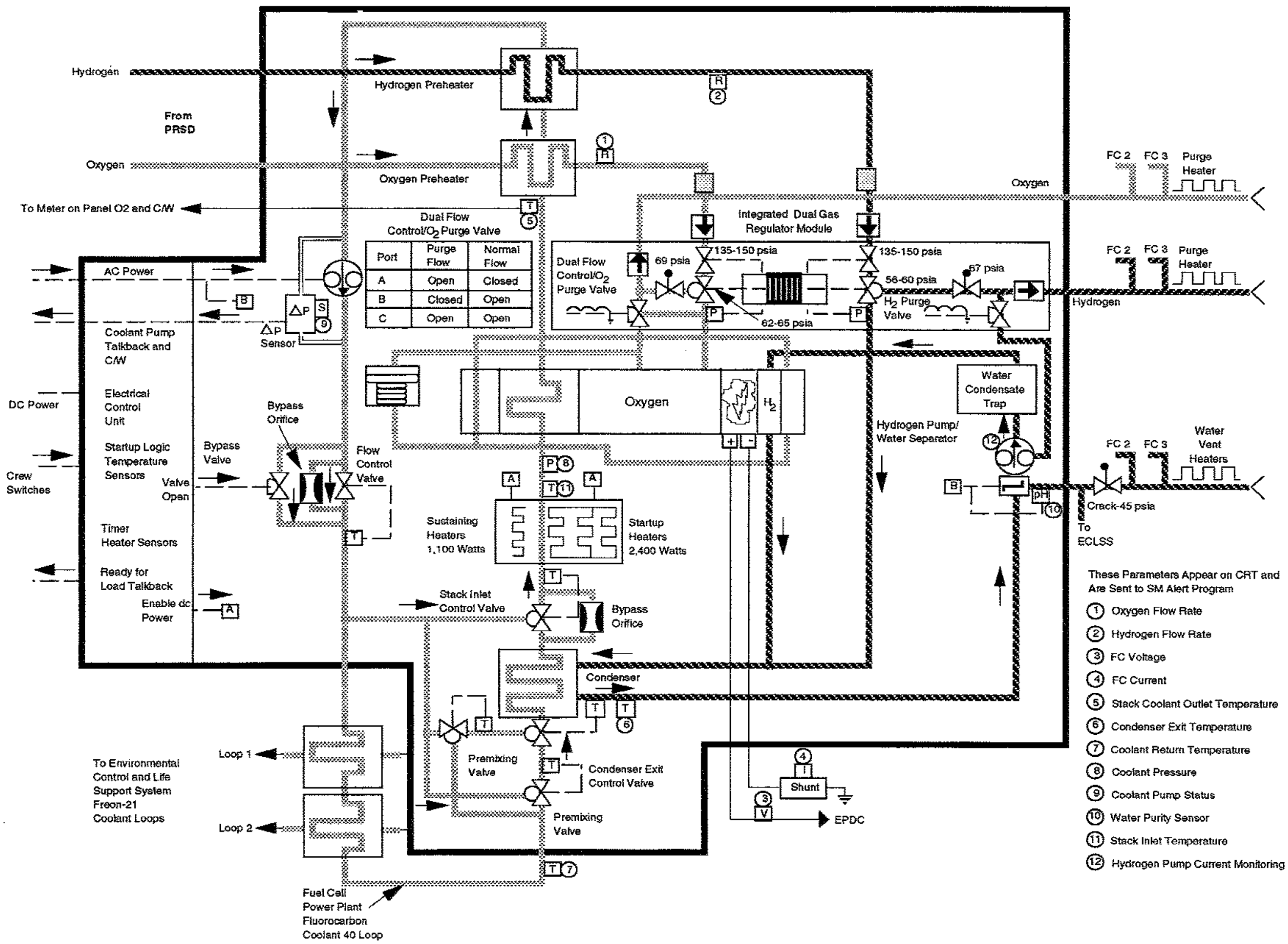
The hydrogen pump uses three-phase ac power to circulate the hydrogen gas back to the fuel cell stack, where some of the hydrogen is consumed in the reaction. The remainder flows through the fuel cell stack, removing the product water vapor formed at the hydrogen electrode. The hydrogen-water vapor mixture then combines with the regulated hydrogen from the dual gas generator module and the loop begins again. The performance at the pump is monitored via the H_2 pump status voltage display on DISP 69.

The oxygen from the dual gas regulator module flows directly through two ports into a closed-end manifold in the fuel cell stack, achieving optimum oxygen distribution in the cells. All oxygen that flows into the stack is consumed, except during purge operations.

Reactant consumption is directly related to the electrical current produced: if there are no internal or external loads on the fuel cell, no reactants will be used. Because of this direct proportion, leaks may be detected by comparing reactant consumption with current produced. An appreciable amount of excess reactants used indicates a probable leak.



Fuel Cell 1 Typical Display and Controls



Fuel Cell - Typical

Water Removal

Water and electricity are the products of the oxidation/reduction reaction of oxygen and hydrogen that takes place in the fuel cells. The water must be removed or the cells will become saturated with water, decreasing reaction efficiency. With an operating load of about 7 kW, it takes only 110 amp-hr or approximately 20 minutes to flood the fuel cell with produced water, thus effectively halting power generation. Hydrogen is pumped through the stack and the portion that is not consumed in the reaction acts as a carrier gas, picking up and removing water vapor on the way. After being condensed, the liquid water is separated from the hydrogen by the hydrogen pump/water separator and discharged from the fuel cell to be stored in the ECLSS potable water storage tanks.

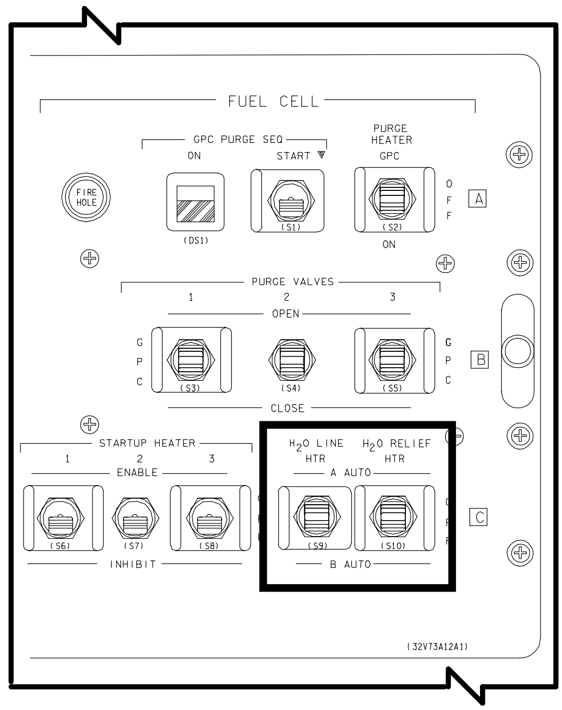
Product water is routed to tank A; when tank A is full, it is routed to tank B, then tanks C and D. An alternate water delivery path is also available to deliver water to the ECLSS tanks if the primary path is lost. If water tanks are full, or there is line blockage, the water relief valves open at 45 psia to allow the water to vent overboard through the water relief line and nozzle. Check valves prevent water tanks from discharging through an open relief valve.

For redundancy, two thermostatically activated heaters are wrapped around the discharge and relief lines to prevent blockage caused by the formation of ice in the lines. Two switches on panel R11U, *H_2O LINE HTR* and *H_2O RELIEF HTR*, provide the flight crew with the capability to select either *A AUTO* or *B AUTO* for the fuel cell water discharge line heaters and the water relief line and vent heaters respectively.

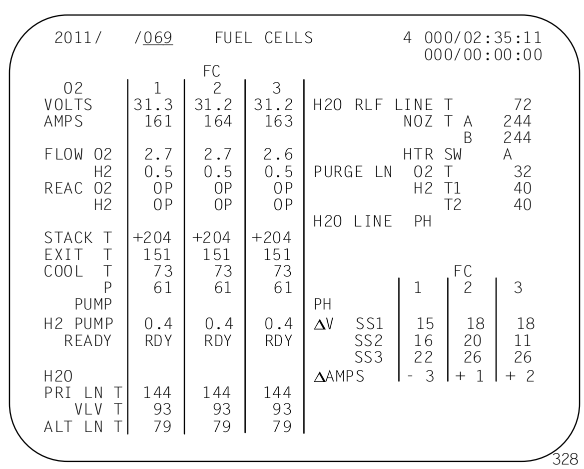
Thermostatically controlled heaters will maintain the water line temperature above 53° F when required. The normal temperature of product water is approximately 140° to 150° F. Thermostatically controlled heaters also maintain the water relief valve's temperature when in use between 70° to 100° F.

Fuel cell 1, 2, or 3 dc voltage and current can be monitored on the DC VOLTS and DC AMPS/SIG STR meters on panel F9, using the rotary switch below the meters to select a specific fuel cell, and on DISP 69. Temperature sensors located on the fuel cell water discharge line, relief valve, relief line, and vent nozzle are displayed on the DISP 69 FUEL CELLS .

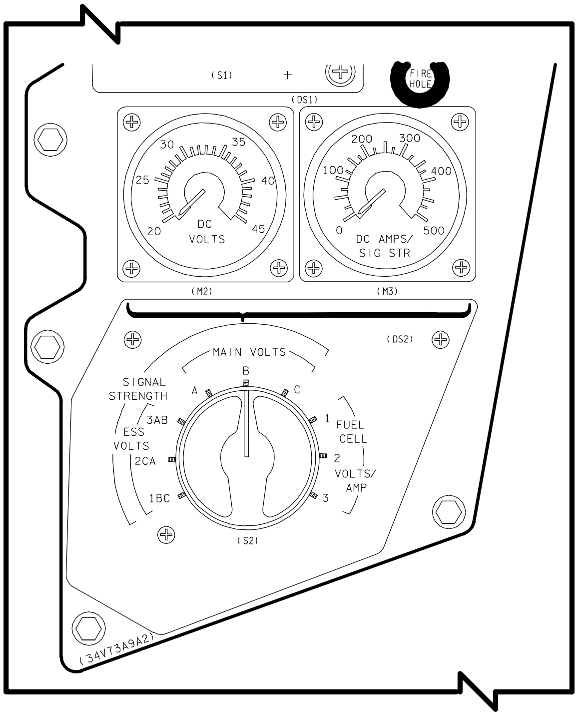
If the potassium hydroxide electrolyte in any fuel cell migrates into the product water, a pH sensor located downstream of the hydrogen pump/water separator will sense the presence of the electrolyte and alert the crew via an *SM ALERT* and display on DISP 69. A common pH sensor is located downstream of the interface between each fuel cell's primary water path, prior to entering the ECLSS supply H_2O tanks.



H_2O LINE and H_2O RELIEF HTR Switches On Panel R11U



FUEL CELLS CRT Display (DISP 69)



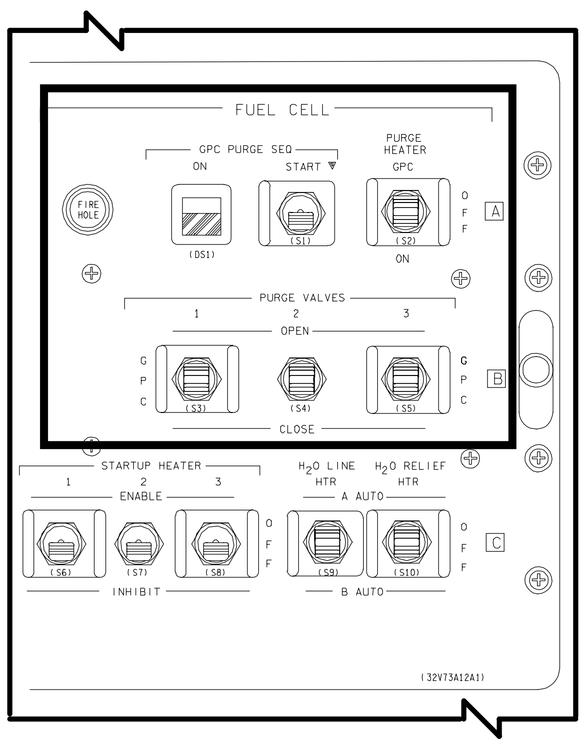
DC VOLTS and DC AMPS Meters and Rotary Switch on Panel F9

Fuel Cell Purge

During normal fuel cell operation, the reactants are present in a closed-loop system and either consumed in the production of electricity or recirculated through the stack. Any inert gases or other contaminants will accumulate in and around the porous electrodes in the cells and reduce the reaction efficiency and electrical load support capability. Purging is performed periodically to cleanse the cells. The purge sequence can be controlled manually by the crew, automatically by flight software, or via commands sent by Mission Control. When a purge is initiated by opening the purge valves, the oxygen and hydrogen systems become open-loop systems; increased flows allow the reactants to circulate through the stack, pick up the contaminants, and blow them overboard through the purge lines and vents. Electrical power is produced throughout the purge sequence. No more than 10 kilowatts (350 amps) should be required from a fuel cell being purged because of the increased reactant flow and preheater limitations.

Fuel cell purge can be activated automatically or manually by the use of switches on panel R11U.

At the initiation of either an auto or manual purge, the purge line heaters are turned on to heat the purge lines and ensure that the reactants will not freeze in the lines. The hydrogen reactant is the more likely to freeze because it is saturated with water vapor. Depending on the orbit trajectory and vehicle orientation, the heaters may require 27 minutes to heat the lines to the required temperatures. Due to limitations on the hydrogen and oxygen preheaters in the fuel cells, the crew checks the fuel cell current to ensure each fuel cell has a load of less than 350 amps. As the current output of the fuel cell increases, the reactant flow rates increase and the preheaters raise the temperature of the reactants to a minimum of 40° F in order to prevent the seals in the dual gas regulator from freezing prior to purging. At loads greater than 350 amps, additional flow during a purge would exceed the maximum flow the preheaters are capable of warming. The crew also checks that the fuel cell is not shut down, that time to deorbit is more than 3 hours, and, for an automatic purge, that an SM OPS transition is not scheduled within the next hour. An SM OPS transition will halt the automatic purge sequence.



FUEL CELL Purge Switches on Panel R11U

The purge lines from all three fuel cells are manifolded together downstream of their purge valves and associated check valves. The line leading to the purge outlet is sized to permit unrestricted flow from only one fuel cell at a time.

NOTE

If more than one fuel cell is purged simultaneously, back pressure may build in the purge line. Due to the sizing of the hydrogen and oxygen purge lines, the back pressure in the H_2 line can cause the hydrogen pressure to rise above the oxygen pressure. Although the dual gas regulator is designed to prevent this from happening, it would not be advisable to expose all three fuel cells to this condition at the same time. If there is a generic problem with the dual gas regulator, this could cause all three fuel cells to fail simultaneously.

For an automatic purge, the FUEL CELL PURGE heater switch is positioned to GPC and the *FUEL CELL PURGE VALVES 1, 2,* and *3* switches on panel R11U are positioned to *GPC*. The *FUEL CELL GPC PURGE SEQ* switch is then positioned to *START* and must be held until 3 seconds after the talkback indicator beside the switch indicates gray. The automatic purge sequence will not begin if the indicator indicates barberpole. First, the GPC turns the purge line heaters on and monitors the temperature of the lines. The one oxygen line temperature sensor must register at least 69° F and the two hydrogen line temperature sensors 79° F and 40° F respectively, before the purge valves will open. When the proper temperatures have been attained, the GPC will open the hydrogen and oxygen purge valves for fuel cell 1 for 2 minutes and then close them, and repeat the process for fuel cells 2 and 3. If the temperatures are not up to the minimum limit after 27 minutes, the GPC will issue an *SM ALERT,* display the data on DISP 69, and stop the auto sequence. Thirty minutes after the fuel cell 3 purge valves have been closed (to ensure that the purge lines have been totally evacuated of water vapor by the heaters), the GPC will turn off the purge line heaters. This provides sufficient time and heat to bake out any remaining water vapor. If the heaters are turned off before 30 minutes have elapsed, water vapor left in the lines may freeze. The GPC purge sequence start can also be initiated using the SPEC 60 SM TABLE MAINT display. The sequence is normally performed by Mission Control uplink on orbit.

A manual fuel cell purge would also be initiated by the flight crew using the switches on panel R11U. In the manual mode, the three fuel cells must be purged separately. The *FUEL CELL PURGE HEATER* switch is positioned to *ON* for the same purpose as in the automatic mode, and the flight crew verifies that the temperatures of the oxygen line and two hydrogen lines are at the same minimum temperatures as in the automatic mode before the purge sequence is initiated. The *FUEL CELL PURGE VALVE 1* switch is then positioned to *OPEN* for 2 minutes and the flight crew observes that the oxygen and hydrogen flow rates increase on DISP 69. The switch is then positioned to *CLOSE*, and a decrease in the oxygen and hydrogen flow rates is observed on DISP 69, confirming the purge valves are closed. Fuel cell 2 is purged in the same manner using the *FUEL CELL PURGE VALVES 2* switch. Fuel cell 3 is then purged in the same manner using the *FUEL CELL PURGE VALVES 3* switch. After the 30-minute line bakeout period, the *FUEL CELL PURGE HEATER* switch is positioned to *OFF*. Manual purges use different heaters than automatic purges. At least one manual purge is scheduled per flight

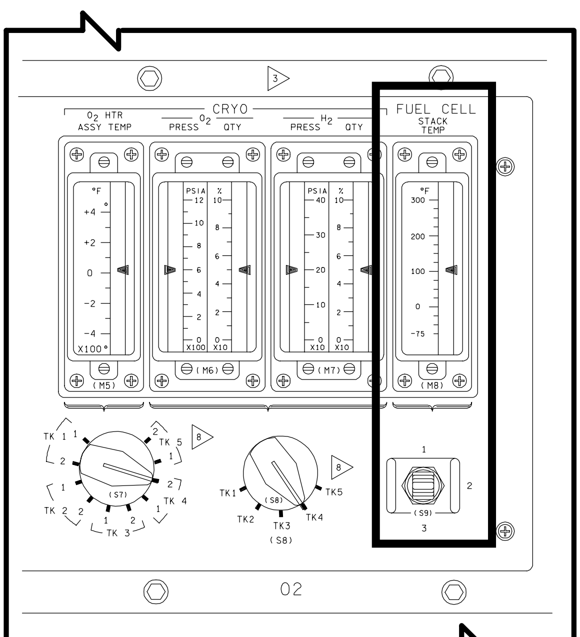
Fuel Cell Cooling/Temperature Control

In order to cool the fuel cell stack during its operations, distribute heat during fuel cell start-up, and warm the cryogenic reactants entering the stack, the fuel cell circulates fluorinated hydrocarbon throughout the fuel cell. The fuel cell coolant loop and its interface with the ECLSS Freon coolant loops are identical in fuel cells 1, 2, and 3.

The temperature of the coolant returning from the Freon coolant loops is sensed before it enters the fuel cell. This is displayed as COOL T on DISP 69. It then enters the fuel cell and passes through a 75-micron filter. After the filter, two temperature-controlled mixing valves allow some of the hot coolant to mix with the cool returning coolant to prevent the condenser exit control valve from oscillating. The control valve adjusts the flow of the coolant through the condenser to maintain the hydrogen-water vapor exiting the condenser at a temperature between 148° and 153° F.

The stack inlet control valve maintains the temperature of the coolant entering the stack between 177° and 187° F. The accumulator interfaces with the oxygen cryogenic reactant to maintain an equalized pressure between the oxygen and the coolant (the oxygen and hydrogen pressures are controlled at the dual gas regulator) to preclude a high pressure differential in the stack. The pressure in the coolant loop is sensed before the coolant enters the stack and is displayed as COOL P on DISP 69.

The coolant is circulated through the fuel cell stack to absorb the waste heat from the hydrogen/oxygen reaction occurring in the individual cells. After the coolant leaves the stack, its temperature is sensed and the data is displayed on the FUEL CELL STACK TEMP meter through the three-position switch located below the meter on panel O2 and on the DISP 69 display as STACK T. The yellow *FUEL CELL STACK TEMP*, the red *BACKUP C/W ALARM* light, and the *SM ALERT* light on panel F7 will be illuminated if fuel cell and stack temperatures exceed upper or lower limits. The hot coolant from the stack flows through the oxygen and hydrogen preheaters where it warms the cryogenic reactants before they enter the stack.



FUEL CELL STACK TEMP Meter and FUEL CELL 1, 2, 3 Switch on Panel O2

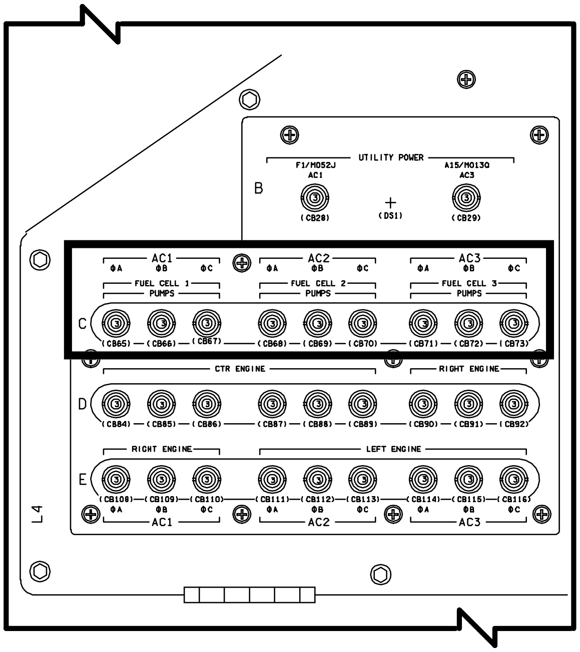
The coolant pump utilizes three-phase ac power to circulate the coolant through the loop. The differential pressure sensor senses a pressure differential across the pump to determine the status of the pump. The *FUEL CELL PUMP* light on panel F7 will be illuminated if fuel cell 1, 2, or 3 coolant pump delta pressure is lost and a fault message will be sent to the CRT. If the coolant pump for fuel cell 1, 2, or 3 is off, the *BACKUP C/W ALARM* light will be illuminated and a fault message and a $\Delta P \downarrow$ will be displayed.

The temperature-actuated flow control valve downstream from the pump adjusts the coolant flow to maintain the fuel cell coolant exit temperature between 190° and 210° F. The stack inlet control valve and flow control valve have bypass orifices to allow coolant flow through the coolant pump and to maintain some coolant flow through the condenser for water condensation, even when the valves are fully closed due to the requirements of thermal conditioning. The hot coolant that is not used at the mixing valves exits the fuel cells to the fuel cell heat exchanger where it transfers its excess heat to be dissipated through the ECLSS Freon coolant loop systems in the midfuselage.

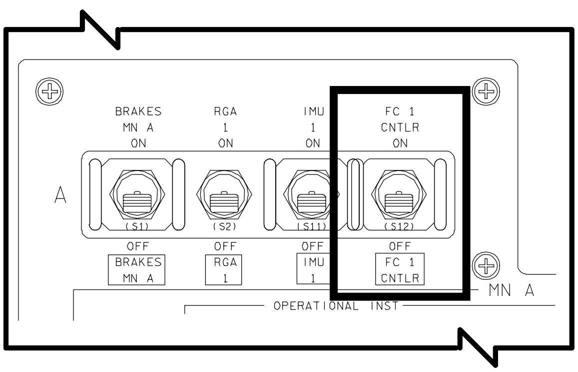
Electrical Control Unit

The electrical control unit located in each fuel cell power plant contains the startup logic, heater thermostats, 30-second timer, and interfaces with the controls and displays for fuel cell startup, operation, and shutdown. The unit controls the supply of ac power to the coolant pump, hydrogen pump/water separator and the pH sensor. It also controls the dc power supplied to the flow control bypass valve (open only during startup) and the internal startup and sustaining heaters. It also controls the status of the *FUEL CELL 1, 2, 3 READY FOR LOAD* and *COOLANT PUMP ÆP* talkback indicators on panel R1.

The nine fuel cell circuit breakers that connect three-phase ac power to the three fuel cells are located on panel L4. Each fuel cell electrical control unit receives its power from an essential bus through the *FC CNTLR* switch on panels O14, O15 and O16.



FUEL CELL Circuit Breakers on Panel L4



FC1 CNTRL Switch on Panel O14

Cell Performance Monitor

As fuel cell life increased with the introduction of the third substack, the likelihood of individual cell failures caused by "wearout" or age increased. Consequently, the cell performance monitor (CPM) was designed to detect individual cell performance problems or imminent failures such as cell crossover.

Crossover is defined as an uncontrolled mixing of the reactants that results in the generation of excessive product heat. The combination of hydrogen and oxygen requires little heat to explode. During normal fuel cell operation, hydrogen and oxygen are diffusely mixed to produce electricity. The matrix, a fibrous asbestos blotter device within each cell, holds the KOH electrolyte and limits the H_2/O_2 mixing. A crossover occurs when the matrix fails to do its job. A manufacturing flaw in the matrix or an impurity in the matrix fibers may cause a pin hole to develop after hours and hours of exposure to the caustic KOH in the presence of the waste heat within the cell.

As the direct combination of the reactant molecules occurs at the pin hole, increased waste heat may cause the pin hole to burn and enlarge allowing more reactants to combine. If this reaction continues, it might uncontrollably propagate and possibly result in a violent explosion. A crossover may proceed rapidly or gradually. Before the introduction of the cell performance monitor prior to STS-9, the electrical performance indicators of a crossover-distressed cell were not detectable, since the lost electrical performance of the substack with the degraded cell was picked up by the healthy substacks.

The cell performance monitor compares each half substack voltage and calculates a delta volts measurement. By comparing both halves of a substack, the cell performance monitor can detect cell changes. Since all the cells in a substack are producing the same current, both halves of the substack should be at approximately identical voltages. Ideally $\Delta V = 0$ but small fluctuations are common. A significant voltage loss in any one cell will produce a change in the ΔV with 300 mV being a critical performance loss. ΔV can be either positive or negative, so the cell performance monitor converts the positive/negative ΔV between the upper and lower substack halves to an absolute value and then outputs that value (0 to 500 mV). To provide margin and accommodate the absolute value, the C/W limit is set at 150 mV. The output is then converted to a 0 to 5 V dc signal for telemetry and crew display systems by a "times 10" amplifier. Calibration curves rescale this to electronic units (EU) (0 to 50 mV).

Every 7.5 minutes the cell performance monitor performs a self-test to ensure data accuracy and to prevent fuel cell shutdown due to faulty data. During the self-test period:

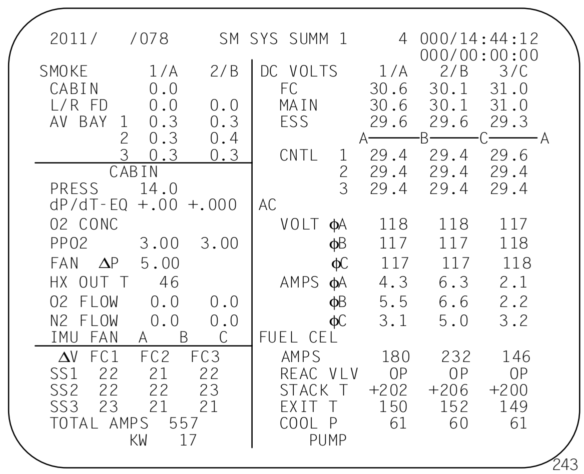
- The voltage measurement of the substack halves ceases.

- A test signal of 50 mV is input to the voltage measurement logic.
- The output of the "times 10" amplifier is examined for 425 to 575 mV.
- If the test fails, the output voltage is driven to 5 volts until the next self-test is performed 7 ± 1 minute later. A test voltage of 50 mV is introduced and the sequence repeats itself.
- If the self-test is passed, the unit resumes substack half voltage measurements.

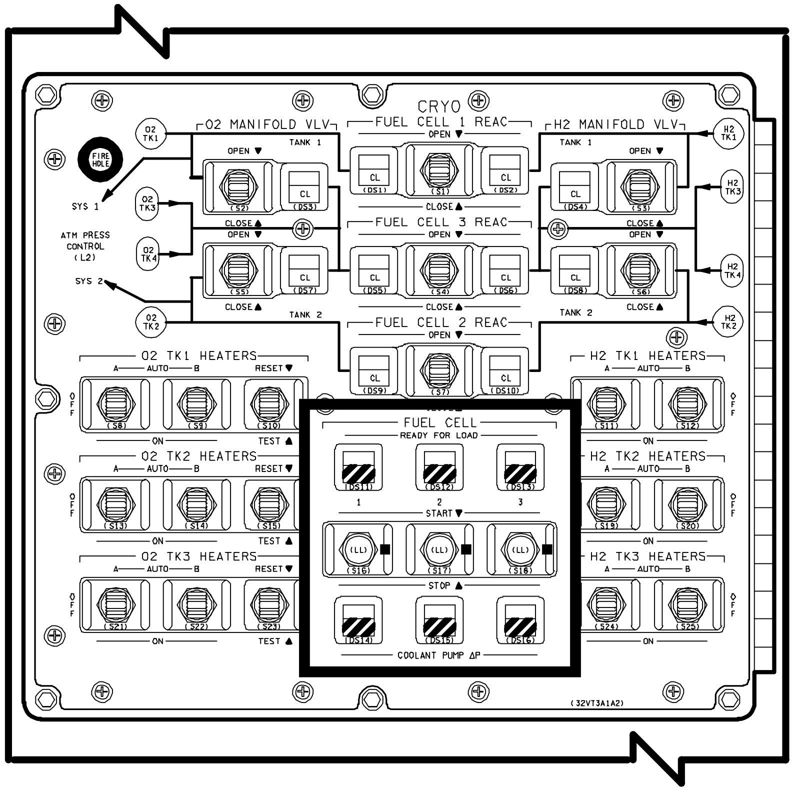
Fuel Cell Start

The *FUEL CELL START/STOP* switches on panel R1 are used to initiate the start sequence or stop the fuel cell operation. When a switch is held in its momentary *START* position, the control unit connects the three-phase ac power to the coolant pump and hydrogen pump/water separator (allowing the coolant and the hydrogen-water vapor to circulate through these loops) and connects the dc power to the internal startup and sustaining heaters and the flow control bypass valve. The switch must be held in the *START* position until the *COOLANT PUMP ÆP* talkback shows gray (approximately three to four seconds), which indicates that the coolant pump is functioning properly by creating a differential pressure across the pump. When the *COOLANT PUMP ÆP* talkback indicates barberpole, the coolant pump is not running.

The *READY FOR LOAD* talkback for each fuel cell will show gray after the 30-second timer times out or when the stack-out temperature is above 187° F, whichever occurs last. Stack-out temperature can be monitored on the SM SYS SUMM 1 (STACK T) and DISP 69 FUEL CELLS displays (STACK T). It can also be monitored on the FUEL CELL STACK OUT TEMP meter on panel O2, using the switch beneath the meter to select the fuel cell. When the READY FOR LOAD talkback shows gray, the fuel cell is up to the proper operating temperature and is ready for loads to be attached to it. It should not take longer than 25 minutes for the fuel cell to warm up and become fully operational; the actual time depends on the fuel cell's initial temperature. The READY FOR LOAD indicator remains gray until the FUEL CELL START/STOP switch for each fuel cell is placed to STOP, the FC CNTLR switch on the overhead panel is placed to OFF or the essential bus power is lost to the electrical control unit.



SM SYS SUMM 1 (DISP 78)



FUEL CELL START/STOP Switches and READY FOR LOAD and COOLANT PUMP P Talkback Indicators on Panel R1

Electrical Power Distribution and Control

The electrical power distribution and control subsystem controls and distributes ac and dc electrical power to the orbiter subsystems, the solid rocket boosters, the external tank, and payloads. The 28 volts dc generated by each of the three fuel cells is distributed to a main dc bus. The three main dc buses (MN A, MN B, and MN C) are the prime sources of power for the vehicle's dc loads. Each of the three dc main buses supplies power to three solid-state (static), single-phase inverters, each of which powers one three-phase alternating-current bus; thus, the nine inverters convert dc power to 117 +3. -1 volt rms, 400-hertz ac power for distribution to three ac buses (AC 1, AC 2, and AC 3) for the vehicle's ac loads.

Bus System

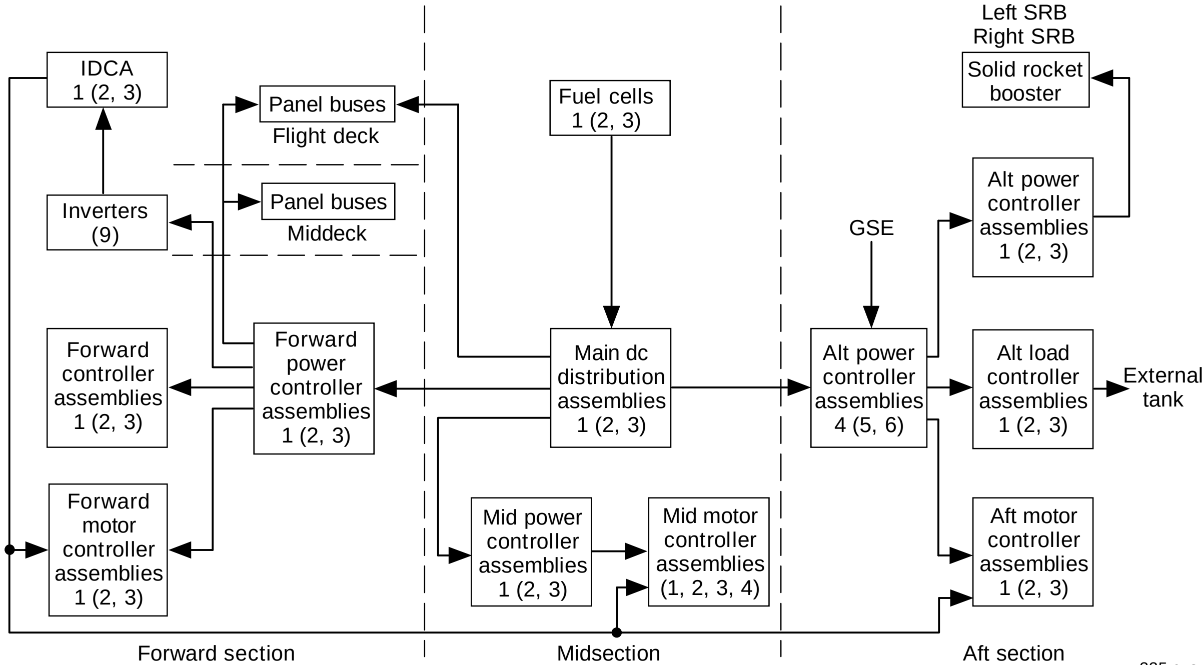
The three main dc buses are main A (MN A), main B (MN B), and main C (MN C). Three ac buses, AC 1, AC 2, and AC 3, supply ac power to the ac loads. Three essential buses, ESS1BC, ESS2CA, and ESS3AB, supply dc power to selected flight crew controls and electrical loads that are deemed essential. Nine control buses - CNTL AB 1, 2, 3; CNTL BC 1, 2, 3; and CNTL CA 1, 2, 3 - are used to supply control power to flight crew controls. Two preflight buses, PREFLT 1 and PREFLT 2, are used only during ground operations.

Depending on the criticality of orbiter electrical equipment, some electrical loads may receive redundant power from two or three main buses. If an electrical load receives power from two or three sources, it is for redundancy only and not for total power consumption.

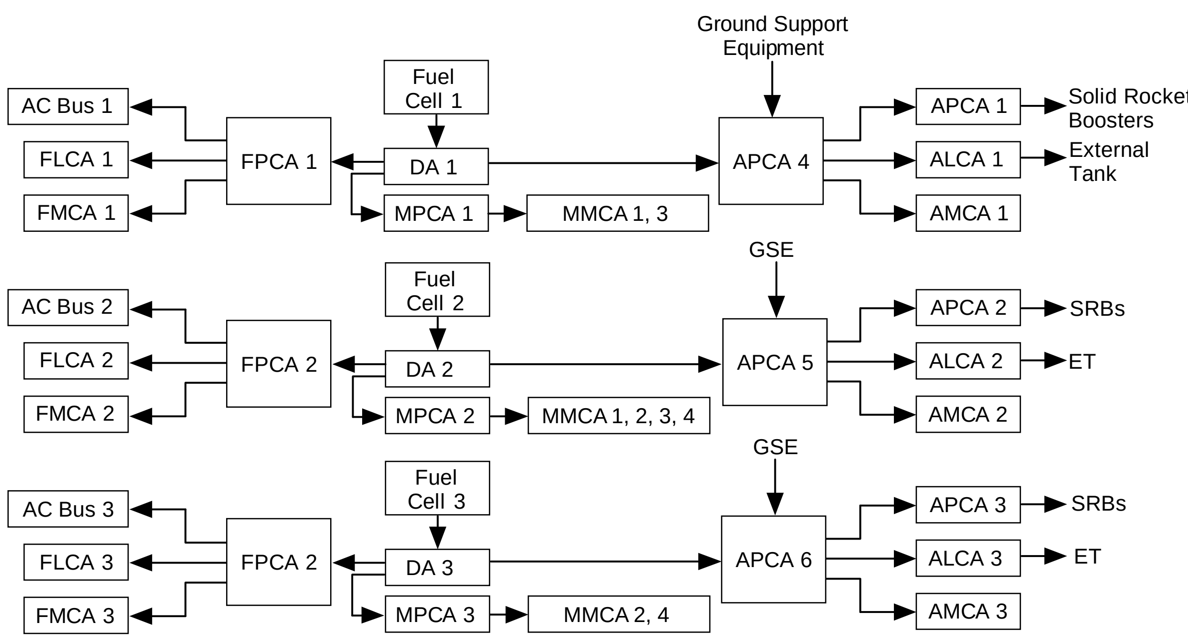
DC Power

Main Buses

The main buses distribute dc electrical power from the fuel cells to locations throughout the orbiter. Distribution assemblies handle the routing of main bus power.



Electrical Power Distribution Block Diagram



DA - Distribution Assembly
FLCA - Forward Load Controller Assembly
FMCA - Forward Motor Controller Assembly
FPCA - Forward Power Controller Assembly
MPCA - Mid Power Controller Assembly
MMCA - Mid Motor Controller Assembly
APCA - Aft Power Controller Assembly
ALCA - Aft Load Controller Assembly
AMCA - Aft Motor Controller Assembly

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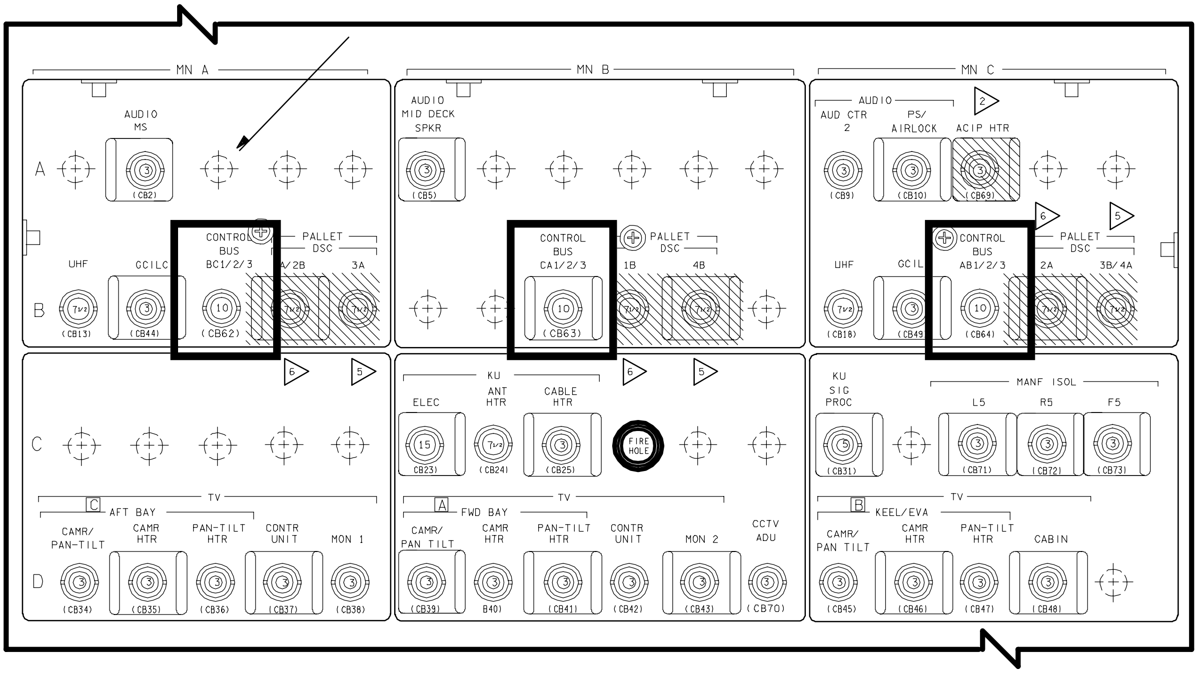
Direct Current Power Distribution Diagram



CONTROL BUS Circuit Breakers on Panel R15

Essential Buses

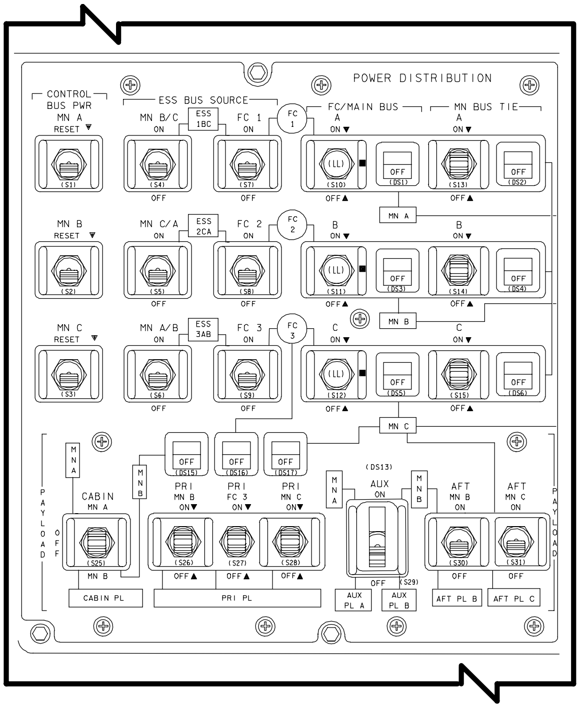
Essential buses supply power to switches that are necessary to restore power to a failed main dc or ac bus and to essential electrical loads and switches. In some cases, essential buses are used to power switching discretes to multiplexers/demultiplexers. Examples of the selected flight crew switches and loads are the EPS switches, GPC switches, TACAN, radar altimeter and microwave scan beam landing system power switches, the caution and warning system, emergency lighting, audio control panel, and master timing unit.

Three essential buses, ESS1BC, ESS2CA, and ESS3AB receive power from three redundant sources. For example, ESS1BC receives dc power from fuel cell 1 through the ESS BUS SOURCE FC 1 switch on panel R1 via a fuse when the switch is positioned to ON, and from main dc buses B and C through remote power controllers (RPC) when the ESS BUS SOURCE MN B/C switch on panel R1 is positioned to ON. Electrical power is then distributed from the essential bus in distribution assembly 1 through fuses to the corresponding controller assemblies and to the flight and middeck panels.

Control Buses

Nine control buses supply control power to the display and control panel switches on the flight deck and in the middeck area. A control bus does not supply operational power to any system loads. Each control bus receives power from each main dc bus for redundancy. The main buses identified in the control bus name are connected through RPCs and diodes. For example, CNTL BC1 is powered by MN B and MN C through remote power controllers. The "unnamed bus", which in this example is MN A, provides power to the control bus through a circuit breaker and a fuse. The number in each control bus name does not refer to a power source for the bus; it is merely a numeric designator for the bus.

The control buses are enabled by the CONTROL BUS PWR MN A, MN B, and MN C switches on panel R1 and the MN A CONTROL BUS BC1/2/3, the MN B CONTROL BUS CA1/2/3 and the MN C CONTROL BUS AB1/2/3 circuit breakers on panel R15.



Bus Control Switches and Talkbacks on Panel R1

The RPCs are powered continuously unless one of the *CONTROL BUS PWR MN A, MN B, MN C* momentary switches on panel R1 is positioned to the RESET position, which turns the corresponding RPCs power off and resets the RPC if it has been tripped off. An *SM ALERT* light is illuminated if the control bus voltage is less than 24.5 volts dc and a fault message is sent to the CRT. The Mission Control Center can monitor the status of each RPC.

Payload Buses

Payload buses are provided to supply dc electrical power to the payloads. Fuel cell 3 may be connected to the primary payload bus by positioning the *PRI FC3* momentary switch on panel R1 to the *ON* position. The talkback indicator above the switch will indicate *ON* when fuel cell 3 is connected to the PRI PL bus. The PRI PL bus is the prime bus for supplying power to the payloads. Fuel cell 3 may be disconnected from the payload bus by positioning the *PRI FC3* switch to the *OFF* position. The talkback indicator above the switch will indicate *OFF*.

A second source of electrical power for the PRI PL bus may be supplied from the MN B bus by positioning the *PRI MN B* momentary switch on panel R1 to the *ON* position. The talkback indicator above this switch will indicate *ON*. The MN B bus may be removed from the PRI PL bus by positioning the switch momentarily to OFF. The talkback indicator will indicate *OFF*. A third possible source of electrical power for the PRI PL bus may be supplied from the MN C bus through the *PRI MN C* switch on panel R1, positioned momentarily to the ON position. The talkback indicator will indicate *ON*. The MN C bus may be removed from the PRI PL bus by positioning the switch momentarily to *OFF*. The talkback indicator will indicate *OFF*.

NOTE

Main buses B and C can be tied via the PRI PL bus. This is referred to as a "backdoor bus tie."

Two additional payload buses are located in the aft section of the payload bay at the aft bulkhead station. The aft payload B bus may be powered up by positioning the *AFT MN B* switch on panel R1 to *ON*. The aft payload C bus may be powered up by positioning the *AFT MN C* switch on panel R1 to *ON*. The *OFF* position of each switch removes power from the corresponding aft payload bus.

The *AUX* switch on panel R1 permits main bus A and main bus B power to be supplied to the AUX PL A and AUX PL B buses when the switch is positioned to *ON*. The auxiliary payload buses can provide power for emergency equipment or controls associated with payloads. The *OFF* position removes power from the AUX PL A and PL B buses. The two auxiliary payload buses may be dioded together to form one bus for redundancy.

The *CABIN* switch on panel R1 provides MN A or MN B power to patch panels located behind the payload specialist and mission specialist stations on the aft flight deck. These patch panels supply power to the payload-related equipment located on panels at these stations. Two three-phase circuit breakers, *AC 2 PAYLOAD 3ϕ and AC 3 PAYLOAD 3ϕ* on panel MA73C, provide ac power to the payload patch panels.

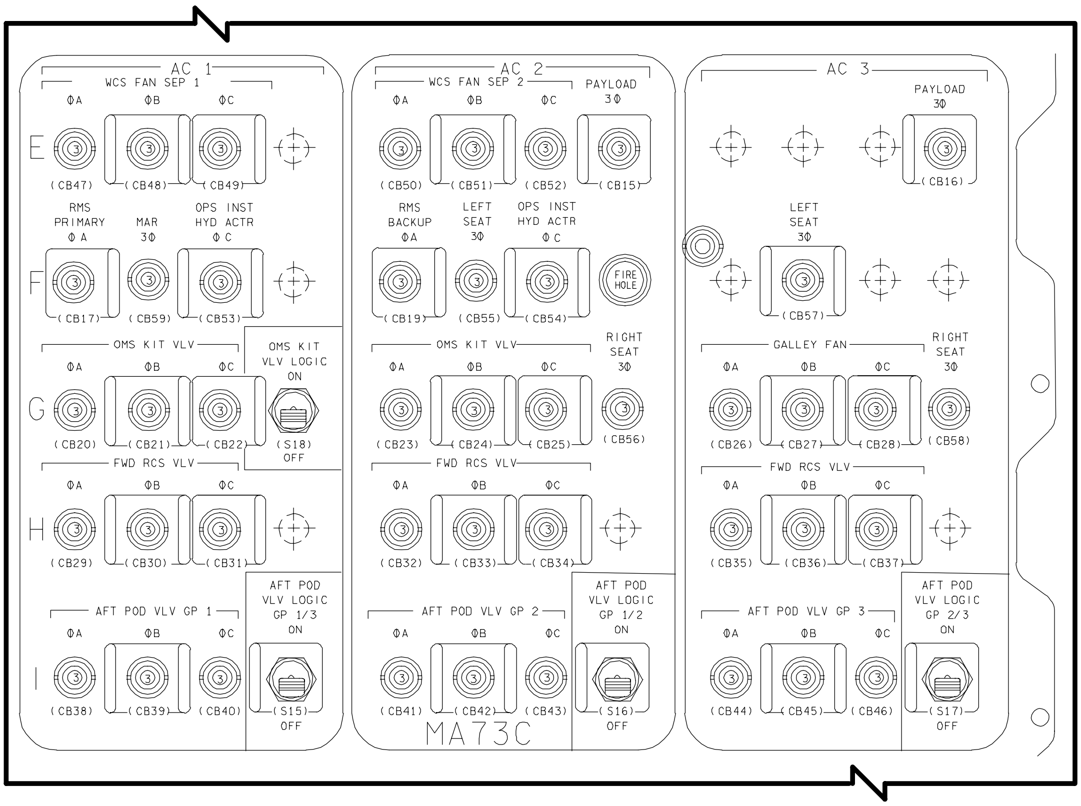
AC Power Generation

Alternating-current power is generated and made available to system loads by the electrical power distribution and control subsystem using three independent ac buses, AC 1, AC 2, and AC 3. The ac power system includes the ac inverters for dc conversion to ac and inverter distribution and control assemblies containing the ac buses and the ac bus sensors. The ac power is distributed from the inverter distribution and controller assemblies to the flight and middeck display and control panels and from the motor controller assemblies to the three-phase motor loads.

Each ac bus consists of three separate phases connected in a three-phase array. Static inverters, one for each phase, are located in the forward avionics bays. Each inverter has an output voltage of 116 to 120 volts rms at 400 hertz, ±7 hertz.

Input power to the inverters is controlled by the INV PWR 1, 2, 3 switches on panel R1. INV PWR 1 routes power to AC 1 from MN A, INV PWR 2 to AC 2 from MN B, and INV PWR 3 to AC 3 from MN C. All three inverters of AC 1 receive MN A bus power when the INV PWR 1 switch is positioned to ON, and all three must be in operation before the talkbacks above the switches indicate ON. The indicators will show OFF when main bus power is not connected to the inverters. The INV/AC BUS 1, 2, 3 switches on panel R1 are used to apply each inverter's output to its respective ac bus. An indicator above each switch shows its status, and all three inverters must be connected to their respective ac buses before the indicators show ON. The talkback indicators will show OFF when any of the phases are not connected to their respective ac bus.

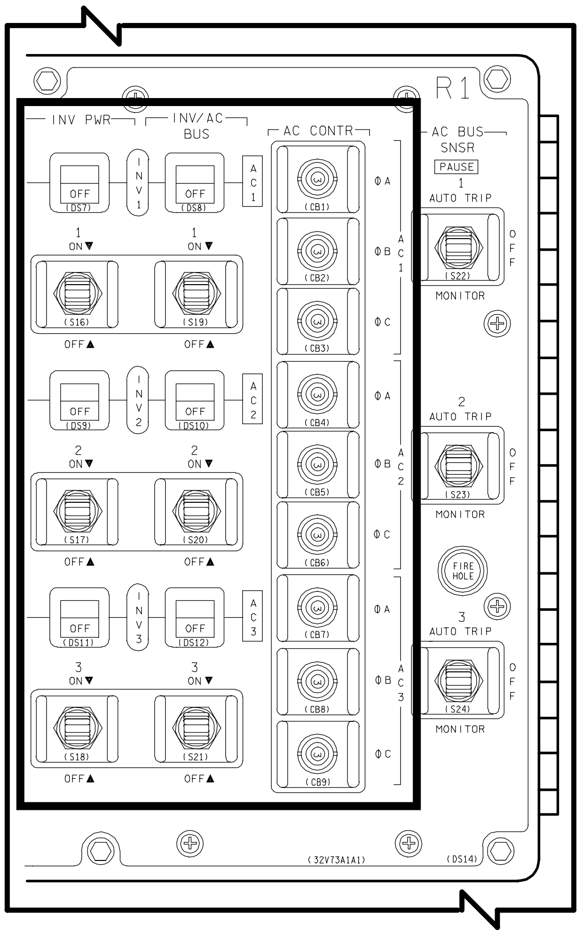
The INV PWR and INV/AC BUS switches and talkbacks must have control power from the AC CONTR circuit breakers on panel R1 in order to operate. Once ac power has been established, these circuit breakers are opened to prevent any inadvertent disconnection, whether by switch failure or accidental movement of the INV PWR or INV/AC BUS switches.



AC2 Cabin PAYLOAD 3∅ AND AC3 Cabin PAYLOAD 3∅ Circuit Breakers on Panel MA73C

Electrical Power Distribution and Control Assemblies

Electrical power is controlled and distributed by assemblies. Each assembly (main distribution assembly, power controller assembly, load controller assembly, and motor controller assembly) is in an electrical equipment container.



INV PWR and INV/AC BUS Switches and Talkbacks, and AC CONTR Circuit Breakers on Panel R1

Distribution Assemblies

The dc power generated by each of the fuel cells is supplied to a corresponding distribution assembly (DA). Fuel cell 1 powers DA 1, fuel cell 2 powers DA 2, and fuel cell 3 powers DA 3. Each distribution assembly contains remotely controlled motor-driven switches called power contactors used for loads larger than 125 amps. The power contactors are rated at 500 amps. They control and distribute dc power to a corresponding mid power controller assembly, forward power controller assembly, and aft power controller assembly.

The FC MAIN BUS A switch on panel R1 positioned to ON connects fuel cell 1 to the MN A DA 1 and controllers and disconnects fuel cell 1 from the MN A DA 1 and controllers when positioned to OFF. The talkback indicator next to the FC MAIN BUS A switch will indicate ON when fuel cell 1 is connected to main bus A distribution assembly and controllers, and OFF when fuel cell 1 is disconnected from main bus A distribution assembly and controllers. The FC MAIN BUS B and C switches and talkback indicators on panel R1 function in the same manner. The No. 1 distribution assembly and all No. 1 controllers go with fuel cell 1 and MN A bus, all No. 2 controllers and DA 2 go with fuel cell 2 and MN B, and all No. 3 controllers and DA 3 go with fuel cell 3 and MN C.

Power Controllers

Power contactors are also located in the aft power controller assemblies to control and distribute ground-supplied 28-volt dc power to the orbiter through the T-0 umbilical before the fuel cells take over the supply of orbiter dc power.

Each of the mid, forward, and aft power controller assemblies supplies and distributes dc power to a corresponding motor controller assembly and dc power to the orbiter through the T-0 umbilical before the fuel cells take over the supply of orbiter dc power.

Each of the mid, forward, and aft power controller assemblies supplies and distributes dc power to a corresponding motor controller assembly and dc power to activate the corresponding ac power system.

Remote Power Controllers

Each power controller assembly contains RPCs and relays. The RPCs are solid-state switching devices used for loads requiring current in a range of 3 to 20 amps. The RPCs are current protected by internal fuses and also have the capability to limit the output current to a maximum of 150 percent of rated value for 2 to 3 seconds. Within 3 seconds, the RPC will trip out, removing the output current. To restore power to the load, the RPC must be reset. This is accomplished by cycling a control switch. If multiple control inputs are required before a RPC is turned on, hybrid drivers are usually used as a logic switch, which then drives the control input of the RPC.

Load Controllers

Each load controller assembly contains hybrid drivers, which are solid-state switching devices (no mechanical parts) used as logic switches and for low-power electrical loads of less than 5 amps. When the drivers are used as a logic switch, several control inputs are required to turn on a load. Hybrid drivers are also used in the mid power controller assemblies. The hybrid drivers are current protected by internal fuses. Hybrid relays requiring multiple control inputs are used to switch three-phase ac power to motors.

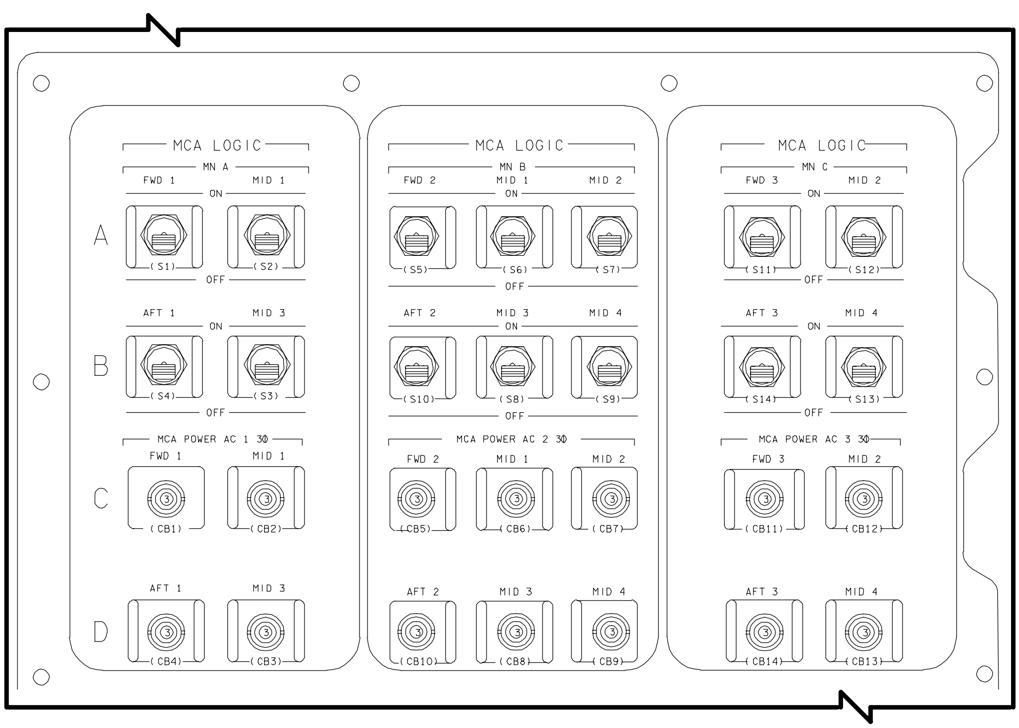
Relays are also used for loads between 20 amps and 135 amps in power controller assemblies and motor controller assemblies.

In the midbody, there are no load controller assemblies; therefore, the mid power controller assemblies contain remote power controllers, relays, and hybrid drivers.

Aft power controller assemblies 4, 5, and 6 were added to accommodate additional electrical loads in the aft section. Assemblies 4, 5, and 6 are powered by fuel cell 1/MN A, fuel cell 2/MN B, and fuel cell 3/MN C respectively.

Motor Controllers

There are 10 motor controller assemblies used on the orbiter: three are in the forward area, four are in the midbody area, and three are in the aft area. Panel MA73C contains the controls for the motor controller assemblies. Their only function is to supply ac power to noncontinuous ac loads for ac motors used for vent doors, air data doors, star tracker doors, payload bay doors, payload bay latches, ET doors and latches, RMS deploy motors and latches, and reaction control system/orbital maneuvering system motor-actuated valves. Each motor controller assembly contains main dc buses, ac buses, and hybrid relays that are remotely controlled for the application or removal of ac power to ac motors. The main dc bus is used only to supply control or logic power to the hybrid relays so the ac power can be switched on or off. The hybrid relays permit major electrical power distribution buses to be located close to the major electrical loads, which



Motor Controller Assembly Controls on Panel MA37C

minimizes use of heavy electrical feeders to and from the pressurized crew compartment display and control panels. This reduces the amount of spacecraft wiring and weight, and permits more flexible electrical load management. If a main bus is lost, the hybrid relays using that main bus will not operate. In some cases, the hybrid relays will use logic power from a switch instead of the motor controller assembly bus.

The three forward motor controller assemblies (FMC 1, FMC 2, and FMC 3) correspond to MN A/AC 1, MN B/AC 2, and MN C/AC 3 respectively. Each FMC contains a main bus, an ac bus, and an RCS ac bus. The main bus supplies control or logic power to the relays associated with both the ac bus and RCS ac bus. The ac bus supplies power to the forward left and right vent doors, the star tracker Y and Z doors, and the air data left and right doors. The RCS ac bus supplies power to the forward RCS manifold and tank isolation valves.

The aft motor controller assemblies (AMC 1, AMC 2, and AMC 3) correspond to MN A/AC 1, MN B/AC 2, and MN C/AC 3 respectively. Each aft motor controller assembly contains a main bus and its corresponding ac bus and a main RCS/OMS bus and its corresponding RCS/OMS ac bus. Both main buses are used for control or logic power for the hybrid relays. The ac bus is used by the aft RCS/OMS manifold and tank isolation and crossfeed valves, the aft left and right vent doors, and the ET umbilical doors.

The mid motor controller assemblies (MMC 1, MMC 2, MMC 3, and MMC 4) contain two main dc buses and two corresponding ac buses. MMC 1 contains main bus A and B and their corresponding buses, AC 1 and AC 2. MMC 2 contains MN B and C and AC 2 and AC 3 buses. MMC 3 contains the same buses as MMC 1, and MMC 4 contains the same buses as MMC 2. Loads for the main buses/ac buses are vent doors, payload bay doors and latches, radiator panel deployment actuator and latches, RMS deploy motors and latches, and payload retention latches.

Component Cooling

The electrical components in the midbody are mounted on cold plates and cooled by the Freon coolant loops. The power controller assemblies, load controller assemblies, motor controller assemblies, and inverters located in forward avionics bays 1, 2, and 3 are mounted on cold plates and cooled by the water coolant loops. The inverter distribution assemblies in forward avionics bays 1, 2, and 3 are air-cooled. The load controller assemblies, power controller assemblies, and motor controller assemblies located in the aft avionics bays are mounted on cold plates and cooled by the Freon system coolant loops.

Bus Tie

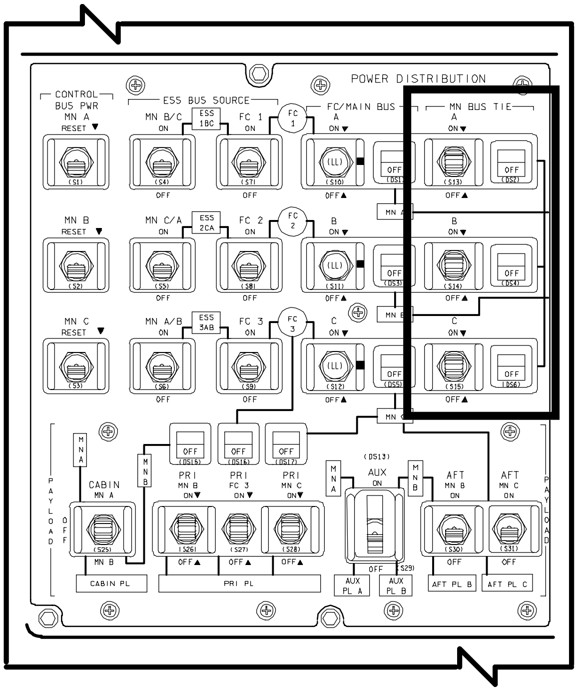
In the event of an electrical failure, or to load share between fuel cells, any main bus can be connected to another main bus through the use of the *MN BUS TIE* switches on panel R1 and power contactors in the distribution assemblies. For example, main bus A can be connected to main bus B by positioning both the *MN BUS TIE A* and the *MN BUS TIE B* switch to *ON*. The talkback indicators next to the switches will indicate *ON* when main bus A is connected to main bus B. Other indications of an effective bus tie are matching voltages for the two buses. To disconnect main bus A from main bus B, the *MN BUS TIE A* and *B* switches must be positioned to *OFF*; the talkback indicators next to the switches will then indicate *OFF*.

NOTE

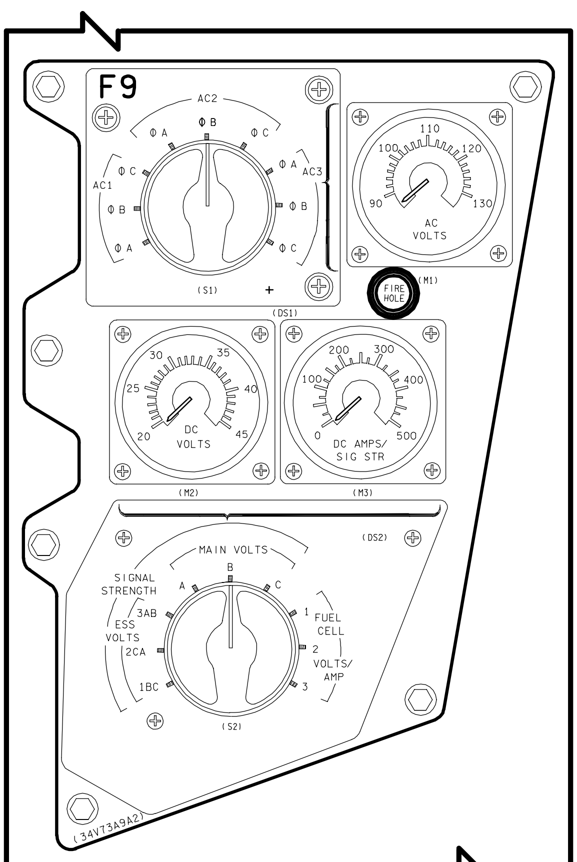
> It is also possible to tie the main buses B and C together via the PRI switches. This is done by connecting each main bus to the primary payload bus.

Instrumentation and System Monitoring

Main bus A, B, or C voltages can be displayed on the DC VOLTS meter on panel F9 by selecting *MAIN VOLTS* A, B, or C on the rotary switch beneath the meter. The *MAIN BUS UNDERVOLT* red caution and warning light on panel F7 will be illuminated if main bus A, B, or C voltage is 26.4 volts dc, informing the crew that the minimum equipment operating voltage limit of 24 volts dc is being approached. A *BACKUP C/W ALARM* light will also be illuminated at 26.4 volts dc. An *SM ALERT* light will be illuminated at 27 volts dc or less, alerting the flight crew to the possibility of a future low-voltage problem. A fault message also is transmitted to the CRT.



MN BUS TIE Switches on Panel R1



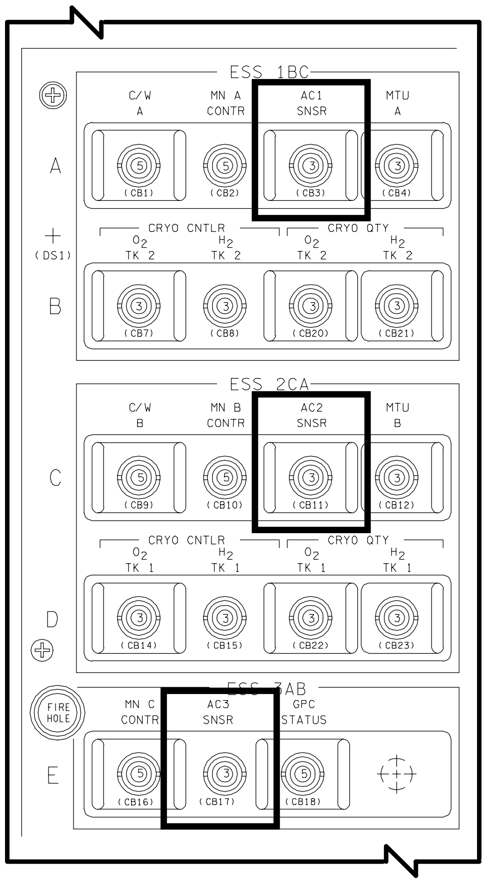
EPS Meters and Switches on Panel F9

The nominal fuel cell voltage is 27.5 to 32.5 volts dc, and the nominal main bus voltage range is 27 to 32 volts dc, which corresponds to 12- and 2-kilowatt loads respectively. If buses are tied, they will indicate the same voltage.

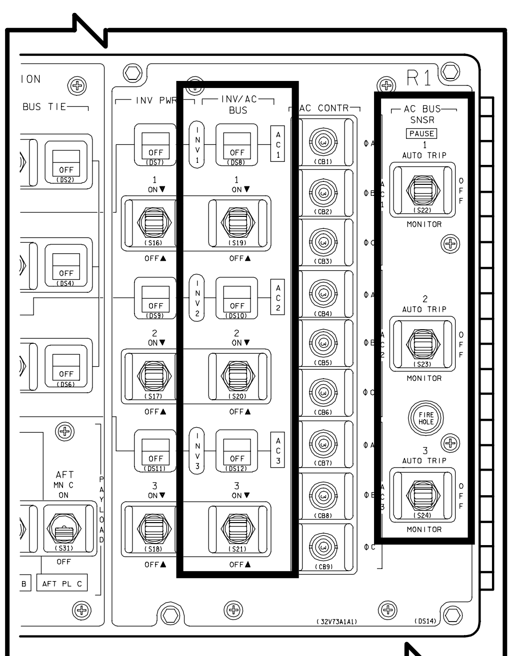
The ESS bus voltage can be monitored on the DC VOLTS meter on panel F9 by selecting *ESS VOLTS 1BC, 2CA, 3AB* on the rotary switch below the meter. An *SM ALERT* light will be illuminated to inform the flight crew if the essential bus voltage is less than 25 volts dc. A fault message also is displayed on the CRT.

Each ac bus has a sensor, switch, and circuit breaker for flight crew control. The *AC 1, 2*, and *3 SNSR* circuit breakers located on panel O13 apply essential bus power to their *respective AC BUS SNSR 1, 2, 3* switch on panel R1 and operational power to the respective *INV/AC BUS* switch and indicator. The *AC BUS SENSR 1, 2, 3* switch selects the mode of operation of the ac bus sensor: *AUTO TRIP, MONITOR*, or *OFF*. The ac bus sensor monitors each ac phase bus for over- or undervoltage, and each phase inverter for an overload signal. The overvoltage limits are bus voltages greater than 123 to 127 volts ac for 50 to 90 milliseconds. The undervoltage limits are bus voltages less than 102 to 108 volts ac for 6.5 to 8.5 milliseconds. An overload occurs when any ac phase current is greater than 14.5 amps for 10 to 20 seconds, or is greater than 17.3 to 21.1 amps for 4 to 6 seconds.

When the respective *AC BUS SNSR* switch is in the *AUTO TRIP* position, and an overload or overvoltage condition occurs, the ac bus sensor will illuminate the respective yellow *AC OVERLOAD* or *AC VOLTAGE* caution and warning light on panel F7 and trip off (disconnect) the inverter from its respective phase bus for the bus/inverter causing the problem. There is only one *AC VOLTAGE* and one *AC OVERLOAD* caution and warning light; as a result, all nine inverters/ac phase buses can illuminate the lights. The CRT or the AC VOLTS meter and rotary switch beside it on panel F9 would be used to determine which inverter or phase bus caused the light to illuminate. The phase causing the problem would approach 0 amps after the bus sensor disconnects the inverter from the bus. Because of the various three-phase motors throughout the vehicle, there will be an induced voltage on the disconnected phase if only one phase has loss of power.



AC 1, 2, 3 SNSR Circuit Breakers on Panel O13



AC BUS SNSR Switches and INV/AC BUT Switches and Talkback Indicators on Panel R1

Before power can be restored to the tripped bus, the trip signal to the *INV/AC BUS* switch must be removed by positioning the *AC BUS SNSR* switch to OFF, then back to the *AUTO TRIP* position, which extinguishes the caution and warning light. The *INV/AC BUS* switch is then positioned to ON, restoring power to the failed bus. If the problem is still present, the sensor trip sequence will be repeated.

If an undervoltage exists, the yellow *AC VOLTAGE* caution and warning light on panel F7 will be illuminated, but the inverter will not be disconnected from its phase bus.

When the *AC BUS SENSR 1, 2, 3* switches are in the *MONITOR* position, the ac bus sensor will monitor for an overload, overvoltage, and undervoltage and illuminate the applicable caution and warning light; but it will not trip out the phase bus/inverter causing the problem.

NOTE

> *AC BUS SNSR* switches are placed in *MONITOR* for ascent and entry to prevent an AC bus problem from causing an AUTO-TRIP, which could result in the loss of SSME controllers on ascent, or landing gear prox boxes on entry.

When the *AC BUS SNSR* switches are *OFF*, the ac bus sensors are non-operational, and all hardware caution and warning and trip-out capabilities are inhibited. The *BACKUP C/W ALARM* light will be illuminated for overload or over- and undervoltage conditions. The *SM ALERT* will occur for over- and undervoltage conditions. A fault message also is sent to the CRT.

Operations

Prelaunch

During prelaunch operations, the onboard fuel cell reactants (oxygen and hydrogen) are supplied by ground support equipment to assure a full load of onboard reactants before lift-off. At T minus 2 minutes 35 seconds, the ground support equipment filling operation is terminated. The ground support equipment supplies hydrogen and oxygen to the PRSD manifold at pressures greater than the tank heater control range pressures (approximately 280 psia for hydrogen and 960 psia for oxygen). This helps to prevent cryo tank heater cycling during powered flight. The ground support equipment supply valves close automatically to transfer to onboard reactants.

The fuel cells will be on when the crew boards the vehicle. Until T minus 3 minutes and 30 seconds, power to the orbiter is load shared with the fuel cells and ground support equipment, even though the fuel cells are on and capable of supplying power. Main bus power is supplied through the T-0 umbilicals, MN A through the left-side umbilical and MN B and C through the right-side umbilical to aft power controllers (APCs) 4, 5, and 6. From APCs 4, 5, and 6, the ground support equipment power is directed to the distribution assembly where the power is distributed throughout the vehicle. The power for the PREFLT 1 and PREFLT 2 test buses is also supplied through the T-0 umbilical. These test buses are scattered throughout the orbiter and are used to support launch processing system control of critical orbiter loads, although they also power up the essential buses in the APCs when on ground support equipment. As in the main bus distribution, essential bus power from the APCs is directed to the distribution assemblies and then distributed throughout the vehicle. At T minus 3 minutes 30 seconds, the ground turns off the ground support equipment power to the main buses, and the fuel cells automatically pick up the vehicle electrical loads.

Indication of the switchover can be noted on the CRT display and the DC AMPS meter. The fuel cell current will increase to approximately 220 amps; the oxygen and hydrogen flow will increase to approximately 4.6 and 0.6 pound per hour respectively; and the fuel cell stack temperature will increase slightly. At T minus zero, the T-0 umbilical is disconnected with the preflight test bus wires live.

Prelaunch and On-Orbit Tank Heater Management

Before lift-off, the *O2 TK1 HEATERS A*, *O2 TK2 HEATERS A*, *H2 TK1 HEATERS A*, and *H2 TK 2 HEATERS A* switches on panel R1 are set on *AUTO*. As part of the Post OMS 1 Burn procedures, all the switches on O2 and H2 tanks 1 & 2 are positioned to AUTO, while the other tank heaters remain *OFF*. On orbit, the cryo tank heaters are managed to provide for tank quantity balancing. When hydrogen tanks 4 and 5 are installed on OV-102, they are depleted first due to their common check valve. Because the tank 3 and 4/5 heater controller pressure limits are higher than those of tanks 1 and 2, tanks 3 and 4/5 supply the reactants to the fuel cells when all tank heaters are set to *AUTO*. For entry, tanks 1 and 2 supply the reactants to the fuel cells.

Fuel Cell Operating Modes

Fuel cell standby consists of removing the electrical loads from a fuel cell but continuing operation of the fuel cell pumps, controls, instrumentation, and valves, while electrical power is supplied by the remaining fuel cells. A small amount of reactants is used to generate power for the fuel cell internal heaters. If the temperature in the fuel cell compartment beneath the payload bay is lower than 40° F, the fuel cell should be left in STANDBY instead of being shut down to prevent it from freezing.

Fuel cell shutdown, after standby, consists of stopping the coolant pump and hydrogen pump/water separator by positioning that *FUEL CELL START/STOP* switch on panel R1 to the *STOP* position.

Fuel cell safing consists of closing the fuel cell reactant valves and consuming the reactants inside the fuel cell by either leaving the fuel cell connected to its main bus or by keeping the pump package operating with the internal heaters.

EPS Caution and Warning Summary

- The *SM ALERT* will illuminate if a cryo heater current level sensor detects a short on a heater circuit.

- The yellow *O_2 PRESS* and the red BACKUP C/W ALARM lights illuminate if oxygen tank pressure is below 540 psia or above 985 psia.

- The yellow *H_2 PRESS* and the red *BACKUP C/W ALARM* lights illuminate if hydrogen tank pressure is below 153 psia or above 293.8 psia.

- When any fuel cell reactant valve is closed, the red *FUEL CELL REAC* light is illuminated, a tone is sounded and the *BACKUP C/W ALARM* is illuminated.

- The yellow *FUEL CELL STACK TEMP* light will illuminate if fuel cell and stack temperatures are below 170.7° F or above 241.9° F. The red *BACKUP C/W ALARM* and blue *SM ALERT* will also light for similar limits.

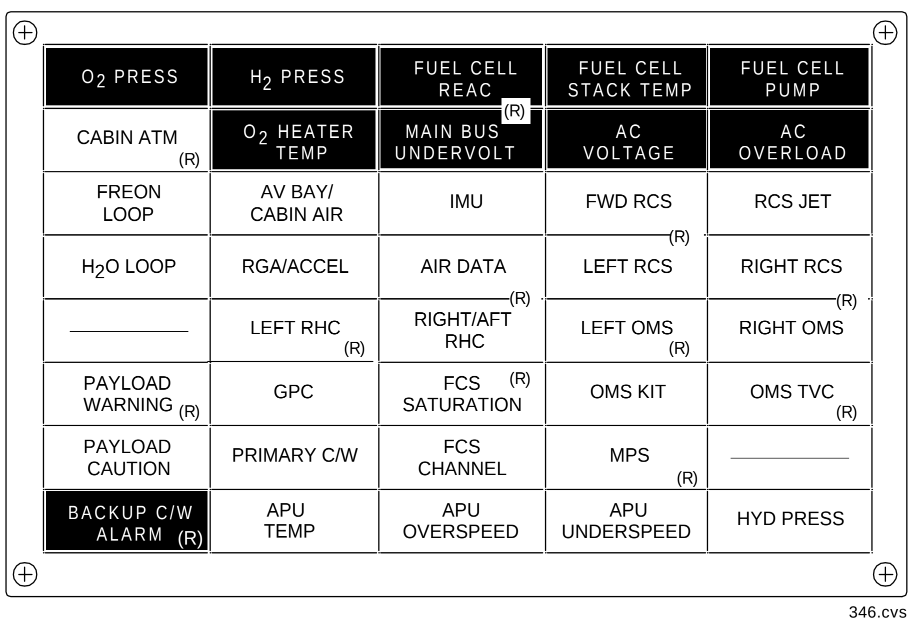
- The yellow *FUEL CELL PUMP* light will illuminate if fuel cell 1, 2, or 3 coolant pump delta pressure is lost. If the coolant pump for fuel cell 1, 2, or 3 is off, the *BACKUP C/W ALARM* will be illuminated.

- The yellow *O_2 HEATER TEMP* light on panel F7 illuminates if the temperature sensor senses the oxygen tank temperature is at or above 344° F. Software checks the limit; if it is above 349°F, the *BACKUP C/W ALARM* light illuminates as well.

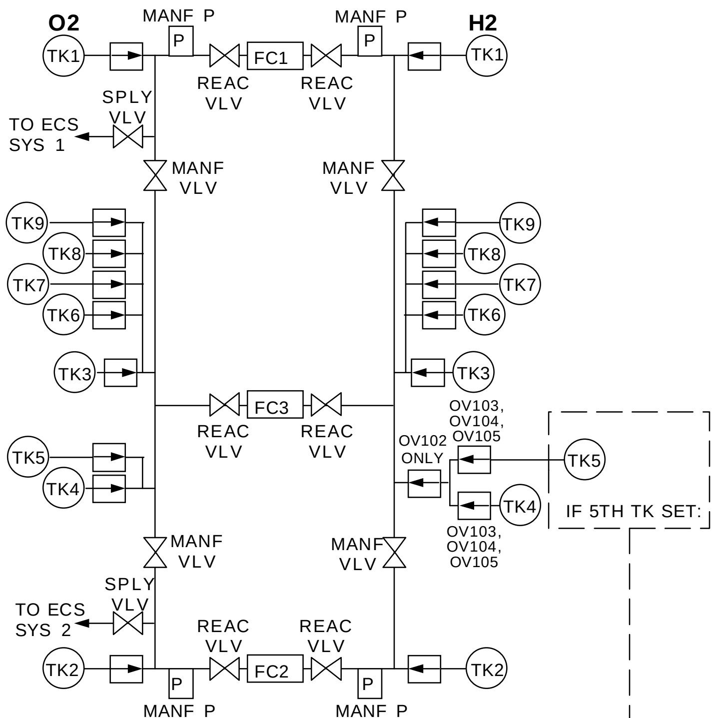
- The red *MAIN BUS UNDERVOLT* light and the *BACKUP C/W ALARM* illuminate if main bus A, B, or C voltage is 26.4 volts dc.

- The yellow *AC VOLTAGE* light illuminates for an overvoltage or undervoltage condition in the ac bus. The red *BACKUP C/W ALARM* will also illuminate.

- The yellow *AC OVERLOAD* light illuminates for an overload condition in the ac bus.



EPS Caution and Warning Lights on Panel F7



02/H2 HTR LOSS (ALL EXCEPT OV 102)

BUS LOSS	PAIRED				PAIRED					
	TK1		TK2		TK3		TK4		TK5	
	A	B	A	B	A	B	A	B	A	B
MNA DA1	A/M				A/M				A/M	
MNB DA2			AUTO	A/M	AUTO	A/M	AUTO	A/M		
MNC DA3	AUTO	A/M	A/M				A/M		AUTO	A/M
CNTL AB1		MAN			MAN					
AB2		A/M			A/M					
CNTL BC1			MAN				MAN			MAN
BC2			A/M				A/M			
BC3				MAN				MAN		A/M
CNTL CA1	MAN					MAN			MAN	
CA2	A/M					A/M			A/M	
CA3				A/M				A/M		
ESS 1BC	AUTO*	AUTO*	AUTO	AUTO	AUTO*	AUTO*	AUTO	AUTO		
2CA	AUTO	AUTO	AUTO*	AUTO*					AUTO	AUTO
3AB					AUTO	AUTO	AUTO*	AUTO*		

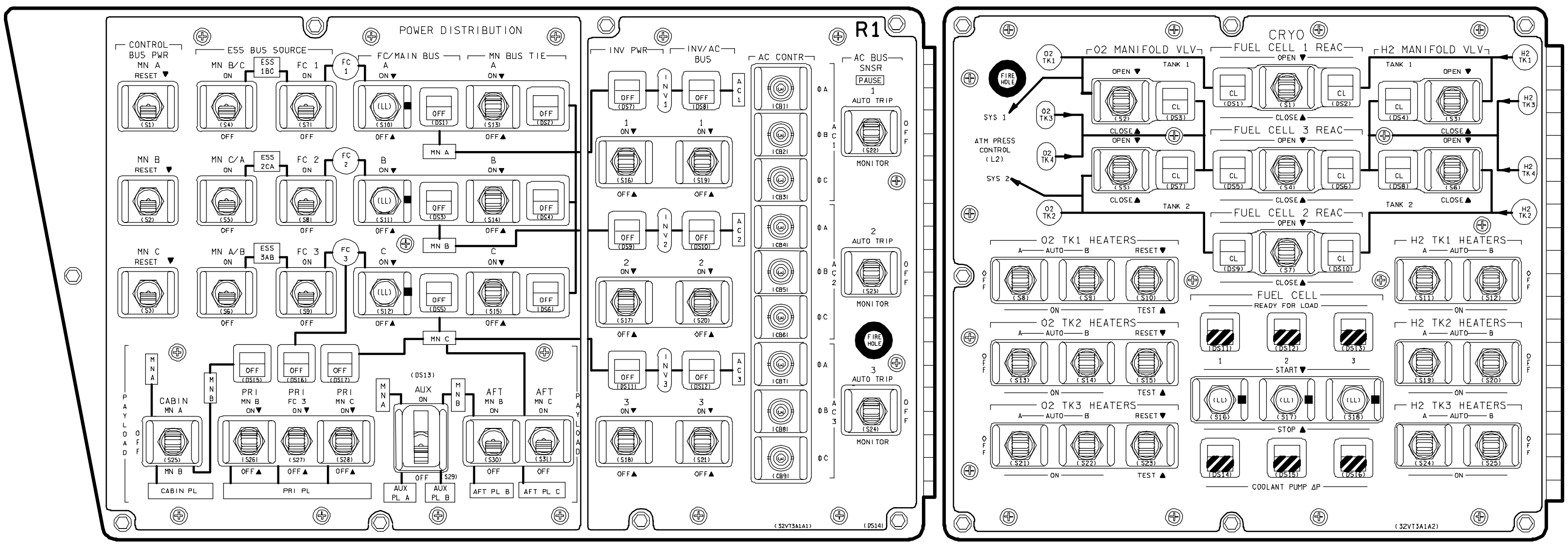
* Auto operation regained if both A and B HTR SW of other paired tank(s) are not in auto. A/M = Auto and manual loss.

02/H2 HTR LOSS (OV 102 ONLY)

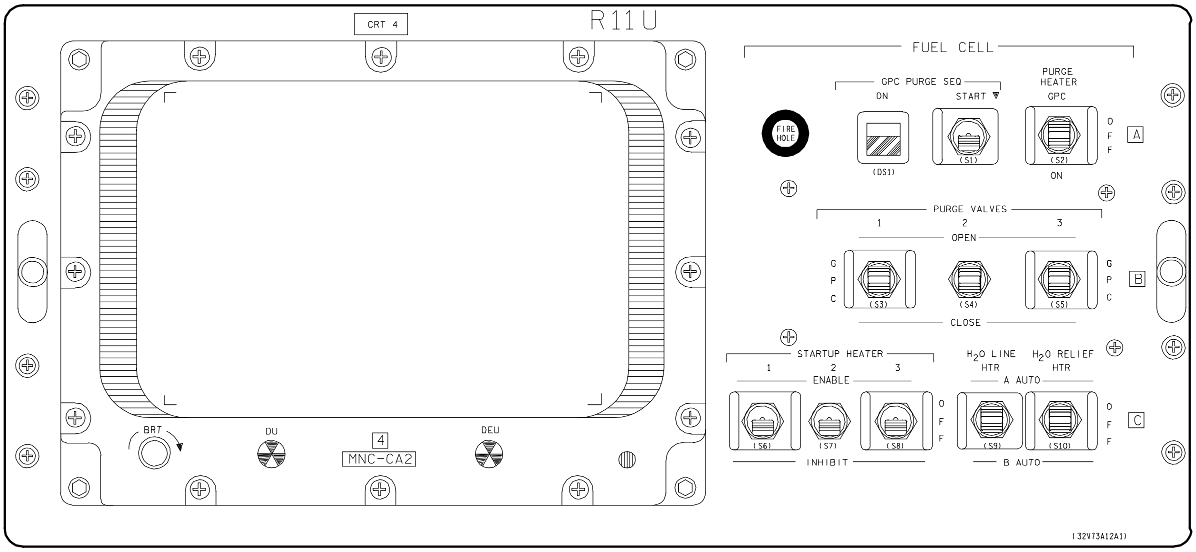
BUS LOSS	PAIRED				PAIRED										PAIRED				PAIRED			
	TK1		TK2		TK3		TK4 ←→			TK5			TK6		TK7		TK8		TK9	
	A	B	A	B	A	B	O2	H2A	H2B	O2	H2A	H2B	A	B	A	B	A	B	A	B
MNA DA1	A/M				A/M								A/M		A/M		A/M		A/M	
MNB DA2			AUTO	A/M	AUTO	A/M	AUTO	AUTO	A/M	A/M	AUTO	A/M								
MNC DA3	AUTO	A/M	A/M				A/M	A/M			A/M									
CNTL AB1		MAN			MAN															
AB2		A/M			A/M								MAN		MAN		MAN		MAN	
AB3													A/M		A/M		A/M		A/M	
CNTL BC1			MAN				MAN	MAN			MAN									
BC2			A/M				A/M	A/M		AUTO	A/M									
BC3				MAN					MAN	MAN		MAN								
CNTL CA1	MAN					MAN								MAN		MAN		MAN		MAN
CA2	A/M					A/M								A/M		A/M		A/M		A/M
CA3				A/M					A/M	A/M		A/M								
ESS 1BC	AUTO*	AUTO*	AUTO	AUTO	AUTO*	AUTO*	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO				
2CA	AUTO	AUTO	AUTO*	AUTO*													AUTO	AUTO	AUTO	AUTO
3AB					AUTO	AUTO	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*	AUTO*								

* Auto operation regained if both A and B HTR SW of other paired tank(s) are not in auto. TK1 paired with TK2, and TK3 paired with TK4/5. A/M = Auto and manual loss.

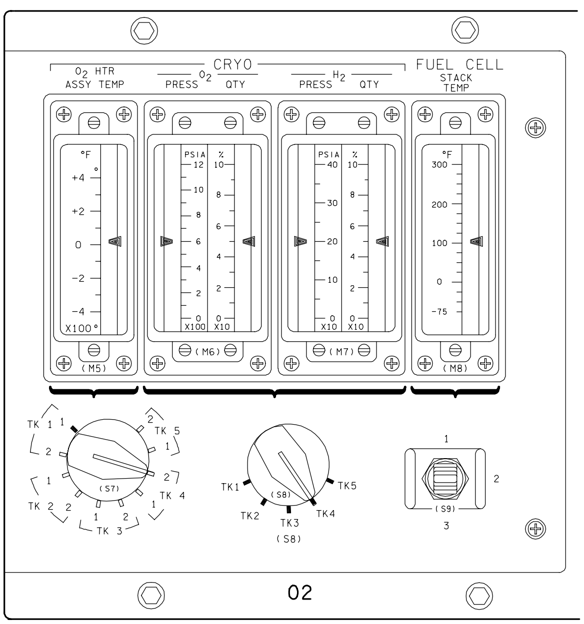
347.cvs


POWER DISTRIBUTION
R1
CONTROL BUS PWR
ESS BUS SOURCE
FC/MAIN BUS
MN BUS TIE
INV PWR
INV/AC BUS
AC CONTR
AC BUS SNSR
CRYO
O2 MANIFOLD VLV
FUEL CELL 1 REAC
H2 MANIFOLD VLV
FUEL CELL 3 REAC
FUEL CELL 2 REAC
O2 TK1 HEATERS
O2 TK2 HEATERS
O2 TK3 HEATERS
H2 TK1 HEATERS
H2 TK2 HEATERS
H2 TK3 HEATERS
FUEL CELL
READY FOR LOAD
START
STOP
COOLANT PUMP ΔP
ATM PRESS CONTROL (L2)
CABIN PL
PRI PL
AUX PL A
AUX PL B
AFT PL B
AFT PL C

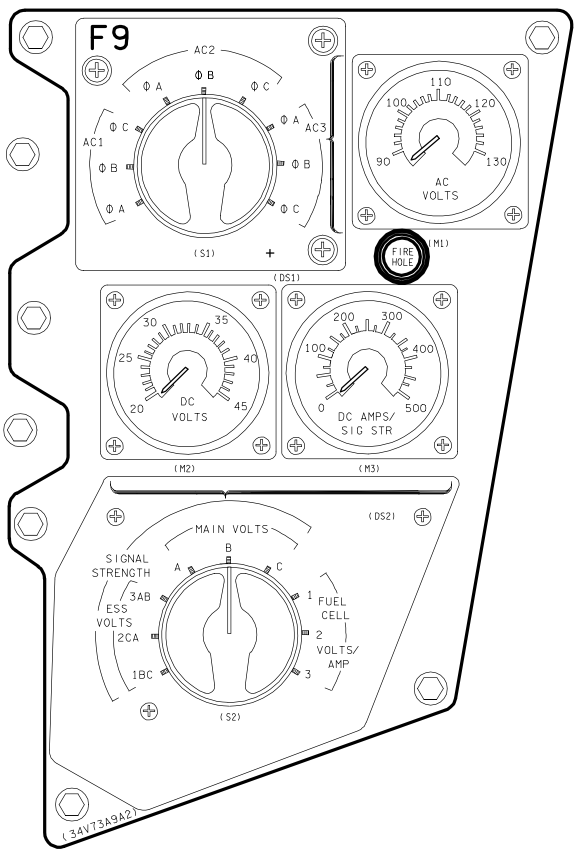
Panel R1



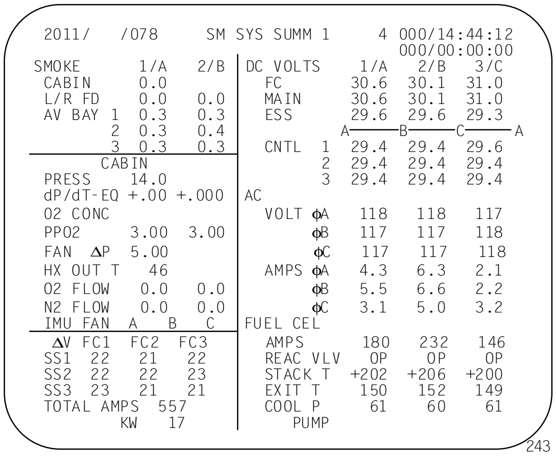
Panel R11U



Panel O2

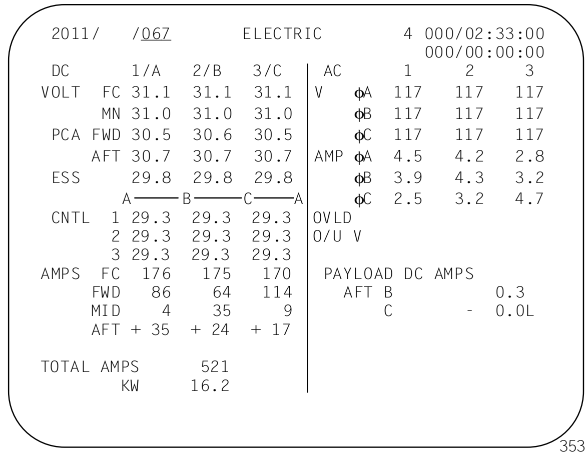


Panel F9



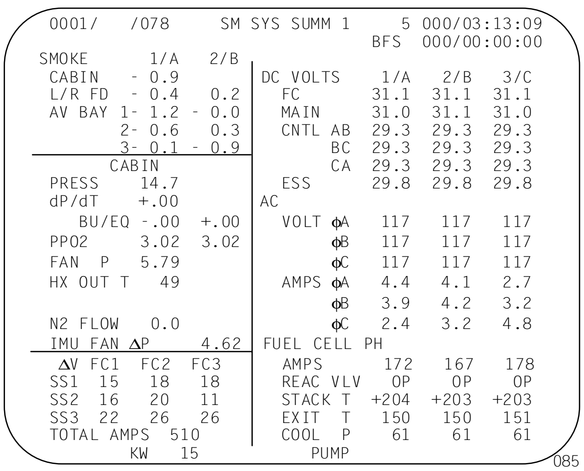
243

PASS SM SYS SUMM 1



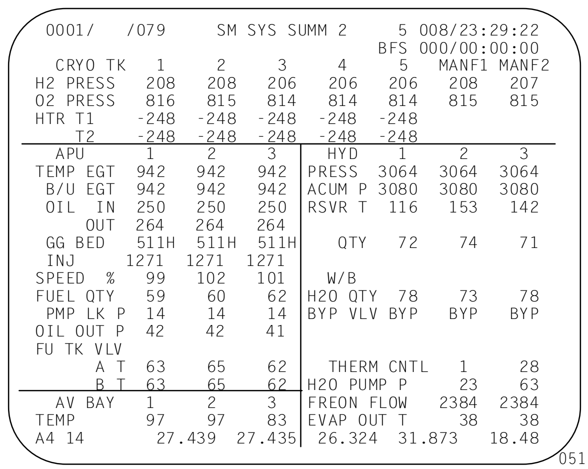
353

DISP 67 (ELECTRIC)



085

BFS SM SYS SUMM 1



051

BFS SM SYS SUMM 2

2011/ /068 CRYO SYSTEM 4 000/02:34:40
000/00:00:00

	TK 1	2	3	4	5
O2					
P	827	826	871	826	826
TK P	828	828	871	828	828
QTY	99	99	100	100	100
T	-249	-249	-249	-249	-249
HTR T 1	-249	-249	-182	-249	-249
2	-249	-249	-182	-249	-249
HTR 1A					
CUR 1B				4/5	
SNSR 2A					
2B				4/5	
MANF P	871	871			
VLV	OP	OP			
H2					
P	215	213	224	213	213
TK P	215	214	224	214	214
QTY	97	97	99	99	99
T	-417L	-417L	-417L	-417L	-417L
HTR T	-417L	-417L	-417L	-417L	-417L
MANF P	222	222			
VLV	OP	OP			

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DISP 68 (CRYO SYSTEM)

2011/ /168 CRYO PALLET 4 000/02:38:52
000/00:00:00

	TK 6	7	8	9	
O2					
P	515L	515L	515L	515L	PALLET
TK P	0L	0L	0L	0L	STB
QTY	- 5L	- 5L	0L	- 5L	STB
T	-417L	-417L	-417L	-417L	POP
HTR T 1	-417L	-417L	-417L	-417L	POP
2	-417L	-417L	-417L	-417L	
HTR 1A					PALLET
CUR 1B					PPO
SNSR 2A					
2B					
H2					
P	145L	145L	145L	145L	
TK P	0L	0L	0L	0L	
QTY	- 6L	- 6L	- 6L	- 6L	
T	-417L	-417L	-417L	-417L	
HTR T	-417L	-417L	-417L	-417L	

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DISP 168 (CRYO PALLET)

2011/ /069 FUEL CELLS 4 000/02:35:11
000/00:00:00

	FC 1	2	3
O2			
VOLTS	31.3	31.2	31.2
AMPS	161	164	163
FLOW O2	2.7	2.7	2.6
H2	0.5	0.5	0.5
REAC O2	OP	OP	OP
H2	OP	OP	OP
STACK T	+204	+204	+204
EXIT T	151	151	151
COOL T	73	73	73
P	61	61	61
PUMP			
H2 PUMP	0.4	0.4	0.4
READY	RDY	RDY	RDY
H2O			
PRI LN T	144	144	144
VLV T	93	93	93
ALT LN T	79	79	79

H2O RLF LINE T	72
NOZ T A	244
B	244
HTR SW	A
PURGE LN O2 T	32
H2 T1	40
T2	40
H2O LINE PH	

	FC 1	2	3
PH			
ΔV SS1	15	18	18
SS2	16	20	11
SS3	22	26	26
ΔAMPS	- 3	+ 1	+ 2

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DISP 69 (FUEL CELLS)

EPS Summary Data

- The EPS, which operates during all flight phases, consists of the equipment and reactants that produce electrical power for distribution throughout the orbiter vehicle.
- The fuel cell picks up full power load support after ground equipment is turned off at T minus 3 minutes 30 seconds, supporting power requirements for the solid rocket booster, orbiter, and some payloads.
- EPS subsystems are: power reactants storage and distribution, fuel cells, and electrical power distribution and control.
- The power reactants storage and distribution system stores cryogenic hydrogen and oxygen and supplies them to the fuel cells. It also supplies oxygen to the ECLSS. The components are located in the orbiter midbody underneath the payload bay.
- The fuel cell system (three fuel cells) transforms hydrogen and oxygen to electricity through a chemical reaction. The system also supplies potable water to the ECLSS. It consists of a power and an accessory section.
- The electrical power distribution and control system distributes electrical power throughout the orbiter. It has five types of assemblies: power control, load control, motor control, main dc distribution, and ac distribution and control.
- The EPS requires very little flight crew interaction during nominal operations.
- The majority of the EPS controls are on panels R1 and R11U. Power sources and circuit breakers are distributed on panels O13, O14, O15, O16, ML86B, R15, and MA73C. Heaters are controlled from panel R1, A11 and A15.
- Meters for monitoring EPS parameters are located on panels F9 and O2.
- CRTs that display EPS data are BFS SM SYS SUMM 1 & 2, DISP 67 (ELECTRIC), DISP 68 (CRYO SYSTEM), DISP 69 (FUEL CELLS), PASS SM SYS SUMM 1 & 2, and DISP 168 (CRYO PALLET).

EPS Rules of Thumb

- Never close a circuit breaker or reset an RPC found out of configuration without MCC coordination.
- Loss of cooling to a fuel cell requires crew action within 9 minutes to prevent a catastrophic loss of crew/vehicle due to possible fuel cell fire and explosion.
- Fuel cell run limit prior to shutdown for loss of cooling is 9 minutes at a 7 kW nominal load. Run time is inversely proportional to fuel cell load.
- Any interruption of continuous ac power during ascent may result in the loss of main engine controller redundancy. Reconfiguration of ac powered equipment prior to MECO should be avoided.
- Never connect or reconnect power to a known shorted or failed component; this includes switch throws, circuit protection device resets, or bus ties.
- Three oxygen and hydrogen tanks are good for up to 8 days on orbit; five oxygen and hydrogen tanks are good for up to 12 days on orbit; eight oxygen and hydrogen tanks are good for up to 18 days on orbit. Exact duration varies with crew complement and power load.
- A fuel cell hydrogen pump uses 0.3 amps/AC phase; a coolant pump uses 0.5 amps/AC phase.