https://spaceflight.nasa.gov/shuttle/reference/shutref/orbiter/prop/flowsequence.html

Helium, Oxidizer and Fuel Flow Sequence

At T minus five hours 15 minutes, the fast-fill portion of the liquid oxygen and liquid hydrogen loading sequence begins under the control of the launch processing system.

At T minus five hours 50 minutes, the SSME liquid hydrogen chill-down sequence is initiated by the LPS. It opens the liquid hydrogen recirculation valves and starts the liquid hydrogen recirculation pumps. As part of the chill-down sequence, the liquid hydrogen prevalves are closed and remain closed until T minus 9.5 seconds.

At T minus three hours 45 seconds, the fast fill of the liquid hydrogen tank to 98 percent is complete, and a slow topping off process that stabilizes to 100 percent begins. At T minus three hours 30 minutes, the liquid oxygen fast fill is complete. At T minus three hours 15 minutes, liquid hydrogen replenishment begins and liquid oxygen replenishment begins at T minus three hours 10 minutes.

During prelaunch, the pneumatic helium supply provides pressure to operate the liquid oxygen and hydrogen prevalves and outboard and inboard fill and drain valves. The three engine helium supply systems are used to provide anti-icing purges.

When the flight crew enters the orbiter, all 10 helium supply tanks are fully pressurized to approximately 4,400 psi. The filling of the helium tanks from 2,000 psi to their full pressure begins at T minus three hours 20 minutes. This process is gradual to prevent excessive heat buildup in the supply tank. Regulated helium pressure is between 715 to 775 psi. The helium supply tank and regulated pressures are monitored on the MPS press, pneu, l, c, r meters on panel F7. The MPS press tank, reg switch positions on panel F7 select the supply or regulated pressures to be displayed on the meters. Engine helium and regulated pressures are also available on the CRT display.

When the flight crew enters the orbiter, the eight MPS He isolation A and B switches; the MPS pneumatics l eng to xovr and He isol switches; and the MPS He interconnect left, ctr, right switches on panel R2 are in the GPC position. With the switches in these positions, the eight helium isolation valves are open, and the left engine crossover and the six helium interconnect valves are closed.

At T minus 16 minutes, one of the first actions by the flight crew is to place the six MPS He isolation A and B switches and the MPS pneumatics He isol switch on panel R2 in the open position. This will not change the position of the helium isolation valves, but it inhibits LPS control of valve position.

During prelaunch, liquid oxygen from ground support equipment is loaded through the GSE liquid oxygen T-0 umbilical and passes through the liquid oxygen outboard fill and drain valve, the liquid oxygen inboard fill and drain valve and the orbiter liquid oxygen feed line manifold. The liquid oxygen exits the orbiter at the liquid oxygen feed line umbilical disconnect and enters the liquid oxygen tank in the external tank. During loading, the liquid oxygen tank's vent and relief valves are open to prevent pressure buildup in the tank due to liquid oxygen loading; and the main propulsion system propellant fill/drain LO 2 outbd and inbd switches on panel R4 are in the gnd (ground) position, which allows the LPS to control the positions of these valves as required. When liquid oxygen loading is complete, the LPS will first command the liquid oxygen inboard fill and drain valve to close. The liquid oxygen in the line between the inboard and outboard fill and drain valves is then allowed to drain back into the GSE, and the LPS commands the outboard fill and drain valve to close.

Also during prelaunch, liquid hydrogen supplied through the GSE liquid hydrogen T-0 umbilical passes through the liquid hydrogen outboard fill and drain valve, the liquid hydrogen inboard fill and drain valve and the liquid hydrogen feed line manifold. The liquid hydrogen then exits the orbiter at the liquid hydrogen feed line umbilical disconnect and enters the liquid hydrogen tank in the external tank. During loading, the liquid hydrogen tank's vent valve is left open to prevent pressure buildup in the tank due to boiloff. The main propulsion system propellant fill/drain LH_2 inbd and outbd switches on panel R4 are in the gnd position, which allows the LPS to control the position of these valves as required.

At T minus four minutes, the fuel system purge begins, followed at T minus three minutes 25 seconds by the beginning of the engine gimbal tests. During the tests, each gimbal actuator is operated through a canned profile of extensions and retractions. If all actuators function satisfactorily, the engines are gimbaled to predefined positions at T minus two minutes 15 seconds. The engines remain in these positions until engine ignition. In the predefined start positions, the engines are gimbaled in an outward direction (away from one another) so that the engine start transient will not cause the engine bells to contact one another during the start sequence.

At T minus two minutes 55 seconds, the LPS closes the liquid oxygen tank vent valve, and the tank is pressurized to 21 psi with GSE-supplied helium. The liquid oxygen tank's pressure can be monitored on the MPS press eng manf LO_2 meter on panel F7 as well as on the CRT. The 21-psi pressure corresponds to a liquid oxygen engine manifold pressure of 105 psia.

At T minus one minute 57 seconds, the LPS closes the liquid hydrogen tank's vent valve, and the tank is pressurized to 44 psia with GSE-supplied helium. The pressure is monitored on the MPS press eng manf LH_2 meter on panel F7 as well as on the CRT display. A liquid hydrogen tank pressure of 44 psia corresponds to a liquid hydrogen engine manifold pressure of 44.96 psia.

At T minus 31 seconds, the onboard redundant set launch sequence is enabled by the LPS. From this point on, all sequencing is performed by the orbiter GPCs in the redundant set, based on the onboard clock time. The GPCs still respond, however, to hold, resume count and recycle commands from the LPS.

At T minus 16 seconds, the GPCs begin to issue arming commands for the SRB ignition pyro initiator controllers, the hold-down release PICs and the T-0 umbilical release PICs.

At T minus 9.5 seconds, the engine chill-down sequence is complete, and the GPCs command the liquid hydrogen prevalves to open (the liquid oxygen prevalves are open during loading to permit engine chill-down). The main propulsion system LO_2 and LH_2 prevalve left, ctr, right switches on panel R4 are in the GPC position.

At T minus 16 seconds, helium flows out of the nine helium supply tanks through the helium isolation valves, regulators and check valves and enters the engine at the inlet of the pneumatic control assembly. The PCA is a manifold containing solenoid valves that control and direct helium pressure under the control of the engine controller to perform various essential functions. The valves are energized by discrete on/off commands from the output electronics of the engine controller. One essential function from T minus 6.6 seconds to main engine cutoff plus six seconds is the purging of the high-pressure oxidizer turbopump's intermediate seal cavity. This cavity is between two seals, one of which contains the hot, fuel-rich gas in the oxidizer turbine. The other seal contains the liquid oxygen in the oxidizer turbopump. Leakage through one or both of the seals and mixing of the propellants could result in a catastrophic explosion. Continuous overload purging of this area prevents the propellants from mixing as they are dumped overboard through drain lines. The PCA also functions as an emergency backup for closing the engine propellant valves with helium pressure. In a normal engine shutdown, the engine propellant valves are hydraulically actuated.

At T minus 6.6 seconds, the GPCs issue the engine start command, and the main fuel valve in each engine opens. Between the opening of the main fuel valve and MECO, liquid hydrogen flows out of the external tank/orbiter liquid hydrogen disconnect valves into the liquid hydrogen feed line manifold. From this manifold, liquid hydrogen is distributed to the engines through the three engine liquid hydrogen feed lines. In each line, liquid hydrogen passes through the prevalve and enters the main engine at the inlet to the low-pressure fuel turbopump. In the engine, the liquid hydrogen cools various engine components and in the process is converted to gaseous hydrogen. The majority of this gaseous hydrogen is burned in the engine; the smaller portion is directed back to the external tank to maintain liquid hydrogen tank pressure. The flow of gaseous hydrogen back to the external tank begins at the turbine outlet of the LPFT. Gaseous hydrogen tapped from this line first passes through two check valves and then splits into two paths, each containing a flow control orifice. One of these paths also contains a valve normally controlled by one of three pressure transducers located in the liquid hydrogen tank.

When the GPCs issue the engine start command, the main oxidizer valve in each engine also opens. Between the opening of the main engine oxidizer valve and MECO, liquid oxygen flows out of the external tank and through the external tank/orbiter liquid oxygen umbilical disconnect valves into the liquid oxygen feed line manifold. From this manifold, liquid oxygen is distributed to the engines through the three engine liquid oxygen feed lines. In each line, liquid oxygen passes through the prevalve and enters the main engine at the inlet to the low-pressure oxidizer turbopump. In the engine, a small portion of the liquid oxygen is diverted into the oxidizer heat exchanger. In the heat exchanger, heat generated by the high-pressure oxidizer turbopump is used to convert liquid oxygen into gaseous oxygen, which is directed back to the external tank to maintain oxidizer tank pressure. The flow of gaseous oxygen back to the external tank begins at the outlet of the heat exchanger. From this point, gaseous oxygen passes through a check valve and then splits into two paths, each containing a flow control orifice. One of these paths also contains a valve that normally is controlled by one of three pressure transducers located in the liquid oxygen tank. Downstream of the two flow control orifices and the pressure control valves, the gaseous oxygen lines empty into the orbiter gaseous oxygen pressurization manifold. This single line exits the orbiter at the gaseous oxygen pressurization disconnect and passes through the orbiter/external tank gaseous oxygen umbilical into the top of the liquid oxygen tank.

At T minus 6.6 seconds, if the PIC voltages are within limits and all three engine controllers are indicating engine ready, the GPCs issue the engine start commands to the three main engines. If the PIC conditions are not met in four seconds, the engine start commands are not issued, and the GPCs proceed to a countdown hold.

If all three SSMEs reach 90 percent of their rated thrust by T minus three seconds, then at T minus zero the GPCs will issue the commands to fire the SRB ignition PICs, the hold-down release PICs and the T-0 umbilical release PICs. Lift-off occurs almost immediately because of the extremely rapid thrust buildup of the SRBs. The three seconds to T minus zero allow the vehicle base bending loads to return to minimum by T minus zero.

If one or more of the three main engines do not reach 90 percent of their rated thrust at T minus three seconds, all SSMEs are shut down, the SRBs are not ignited, and a pad abort condition exists.

Beginning at T minus zero, the SSME gimbal actuators, which were locked in their special preignition positions, are first commanded to their null positions for SRB start and then allowed to operate as needed for thrust vector control.

Between lift-off and MECO, as long as the SSMEs perform nominally, all MPS sequencing and control functions are executed automatically by the GPCs. During this period, the flight crew monitors MPS performance; backs up automatic functions, if required; and provides manual inputs in the event of MPS malfunctions.

During ascent, the liquid hydrogen tank's pressure is maintained between 33 and 35 psig by the orifices in the two lines and the action of the flow control valve. There are three such systems, one for each SSME. When the pressure in the liquid hydrogen tank reaches 35 psig, the valve closes. It opens when the pressure drops below 33 psig. Tank pressure greater than 38 psia will cause the tank to relieve through the tank vent valve. If tank pressure falls below 33 psia, the flight crew positions the MPS LH 2 ullage press switch on panel R2 to open . This allows the three flow control valves to go to the full-open position. Normally, the MPS LH 2 ullage press switch is in the auto position. Downstream of the two flow control orifices and the flow control valves, the gaseous hydrogen line empties into the gaseous hydrogen pressurization manifold. This single line then exits the orbiter at the gaseous hydrogen umbilical and enters the top of the liquid hydrogen tank. During ascent, the liquid oxygen tank's pressure is maintained between 20 and 22 psig by the orifices in the two lines and the action of the flow control valve. When the pressure in the tank reaches 22 psig, the valve closes. It opens when pressure drops below 20 psig. A pressure greater than 25 psig will cause the tank to relieve through its vent and relief valve.

The SSME thrust level depends on the flight: it may be 100 percent or 104 percent for some missions involving heavy payloads or may require the maximum thrust setting of 109 percent for emergency situations. The initial thrust level normally is maintained until approximately 31 seconds into the mission, when the GPCs throttle the engines to a lower thrust to minimize structural loading while the orbiter is passing through the region of maximum aerodynamic pressure. This normally occurs around 63 seconds, mission elapsed time. At approximately 65 seconds, the engines are once again throttled to the appropriate higher percent and remain at that setting for a normal mission until 3-g throttling is initiated.

The solid rocket boosters burn out at approximately two minutes, mission elapsed time, and are separated from the orbiter by a GPC command sent via the mission events controller and by the SRB separation PICs. The flight crew can initiate SRB separation manually if the automatic sequence fails; however, the manual separation sequence does not bypass the separation sequence logic circuitry.

Beginning at approximately seven minutes 40 seconds, mission elapsed time, the engines are throttled back to maintain vehicle acceleration at 3 g's or less. Three g's is an operational limit devised to prevent physical stresses on the flight crew. Approximately eight seconds before main engine cutoff, the engines are throttled back to 65 percent.

Although MECO is based on the attainment of a specified velocity, the engines can also be shut down due to the depletion of liquid oxygen or liquid hydrogen before the specified velocity of MECO is reached. Liquid oxygen depletion is sensed by four sensors in the liquid oxygen feed line manifold. Liquid hydrogen depletion is sensed by four sensors in the bottom of the liquid hydrogen tank. If any two of the four sensors in either system indicate a dry condition, the GPCs will issue a MECO command to the engine controller.

Once MECO has been confirmed, the GPCs execute the external tank separation sequence. The sequence takes approximately 18 seconds and includes arming the external tank separation PICs, closing the liquid oxygen and liquid hydrogen prevalves, firing the external tank tumble system pyrotechnic, closing the liquid hydrogen and liquid oxygen feed line 17-inch disconnect valves, gimbaling the SSMEs to the MPS propellant dump position (full down), turning the external tank signal conditioners' power off (deadfacing), firing the umbilical unlatch pyrotechnics, and retracting the umbilical plates hydraulically.

At this point, the computers check for external tank separation inhibits. If the vehicle's pitch, roll and yaw rates are not less than 0.2 degree per second, automatic external tank separation is inhibited. If these conditions are met, the GPCs issue the commands to the external tank separation pyrotechnics. In crew-initiated external tank separation or return-to-launch-site aborts, the inhibits are overriden.

At separation, the orbiter begins a reaction control system minus Z translation separation maneuver to move it away from the external tank. This maneuver takes approximately 13 seconds and results in a negative Z-delta component of approximately 11 feet per second.

After MECO occurs (whether because the specified velocity is attained or the liquid oxygen or liquid hydrogen is depleted) and before external tank separation, the GPCs isolate the orbiter liquid hydrogen feed line from the external tank by closing the two liquid hydrogen 17-inch disconnect valves (one on each side of the separation interface) and the two liquid oxygen 17-inch disconnect valves (one on each side of the separation interface). At orbiter/external tank separation, the gaseous oxygen and gaseous hydrogen feed lines are sealed at the umbilicals by the self-sealing quick disconnects.

The MPS pneumatic control assembly on each main engine provides an emergency backup method of closing the engine propellant valves pneumatically using helium pressure. The normal engine shutdown of the engine propellant valves is by hydraulic actuation.

At MECO, the GPCs open the liquid oxygen feed line relief isolation valve, allowing any pressure buildup generated by oxidizer trapped in the orbiter liquid oxygen feed line manifold to be vented overboard through the relief valve provided the main propulsion system feedline rlf isol LH2 switch on panel R4 is in the GPC position. The GPCs also open the liquid hydrogen feed line relief isolation valve, and any pressure buildup from fuel trapped in the orbiter liquid hydrogen feed line manifold is vented overboard through the relief valve provided the main propulsion system feedline rlf isol LH 2 switch on panel R4 is in the GPC position.

At MECO, the pneumatic control assembly for each engine performs a 16-second purge of the engine preburner oxidizer domes and a two-second postcharge of the pogo accumulator. This purge ensures that no residual propellant remains in these areas to cause an unsafe condition and prevents a water hammer effect in the liquid oxygen manifolds of the main engines. This helium usage and the purge of the high-pressure oxidizer turbopump's intermediate seal cavity can be observed on the MPS helium l, c, r meters on panel F7 and are also available on the CRT.

Ten seconds after main engine cutoff, the RTLS liquid hydrogen dump valves are opened for 30 seconds to ensure that the liquid hydrogen manifold pressure does not result in operation of the liquid hydrogen feed line relief valve.

After the completion of the 16-second purge, the GPCs interconnect the pneumatic helium and engine helium supply system by opening the three out interconnect valves provided the MPS He interconnect left, center, right switches on panel R2 are in the GPC position. This connects all 10 helium supply tanks to the common manifold and ensures sufficient helium is available to perform the liquid oxygen and liquid hydrogen propellant dumps, which are required after external tank separation.

After external tank separation, approximately 1,700 pounds of propellant is still trapped in the SSMEs and an additional 3,700 pounds of propellant remains trapped in the orbiter's MPS feed lines. This 5,400 pounds of propellant represents an overall center-of-gravity shift for the orbiter of approximately 7 inches. Non-nominal center-of-gravity locations can create major guidance problems during re-entry. The residual liquid oxygen, by far the heavier of the two propellants, poses the greatest impact on center-of-gravity travel. The greatest hazard from the trapped liquid hydrogen occurs during re-entry, when any liquid or gaseous hydrogen remaining in the propellant lines may combine with atmospheric oxygen to form a potentially explosive mixture. In addition, if the trapped propellants are not dumped overboard, they will sporadically outgas through the orbiter liquid oxygen and liquid hydrogen feed line relief valves, causing vehicle accelerations of such a low level that they cannot be sensed by onboard guidance, yet represent a significant source of navigation error when applied over an entire mission. Outgassing propellants are also a potential source of contamination of scientific experiments contained in the payload bay.

Approximately 18 seconds after MECO occurs, the external tank separates from the orbiter. Approximately 102 seconds later, at MECO plus two minutes, the first thrusting period of the orbital maneuvering system begins. Coincident with the start of the OMS-1 thrusting, the GPCs automatically initiate the liquid oxygen dump provided the MPS prplt dump sequence LO2 switch on panel R2 is in the GPC position. The computers command the two liquid oxygen manifold repressurization valves to open (the main propulsion system manf press LO 2 switch on panel R4 must be in the GPC position), command each engine controller to open its SSME main oxidizer valve, and command the three liquid oxygen prevalves to open (the main propulsion system LO 2 prevalves left, ctr, right switch must be in the GPC position). The liquid oxygen trapped in the feed line manifolds is expelled under pressure from the helium subsystem through the nozzles of the SSMEs. If the main propulsion system manf press LO2 switch on panel R4 is left in the GPC position, the pressurized liquid oxygen dump continues for 90 seconds. At the end of this period, the GPCs automatically terminate the dump by closing the two liquid oxygen manifold repressurization valves, wait 30 seconds and then command the engine controllers to close their SSME main oxidizer valve. The three liquid oxygen prevalves remain open.

If necessary, the crew can perform the liquid oxygen dump manually utilizing the start and stop positions of the MPS prplt dump sequence LO 2 switch on panel R2. When the liquid oxygen dump is initiated manually, all valve opening and closing sequences are still automatic. Positioning the MPS prplt dump sequence LO 2 switch to start causes the GPCs to immediately begin commanding all of the required valves to open automatically and in the proper sequence. The liquid oxygen dump will continue as long as the switch is in the start position, but the pressurized portion with the two liquid oxygen manifold repressurization valves open is still limited to 90 seconds. Placing the switch in the stop position causes the GPCs to begin commanding all of the required valves to close automatically and in the proper sequence. The earliest a manual liquid oxygen dump can be performed is MECO plus 20 seconds since the SSMEs require a cool-down of at least 20 seconds after MECO.

The GPC software's MPS dump sequence automatically initiates the liquid oxygen dump at one time only-the beginning of the OMS-1 thrusting period. If the MPS prplt dump sequence LO 2 switch on panel R2 is not in the GPC position at that time, the liquid oxygen dump must be initiated manually. In addition, once the liquid oxygen dump has been initiated and the MPS prplt dump sequence LO 2 switch is placed in the stop position, the GPCs no longer monitor any of the positions of this switch. For this reason, the liquid oxygen dump cannot be reinitiated, manually or automatically.

Simultaneously with the liquid oxygen dump, the GPCs automatically initiate the MPS liquid hydrogen dump provided the MPS prplt dump sequence LH2 switch on panel R2 is in the GPC position. The GPCs command each engine controller to command a 10-second helium purge of its SSME's fuel lines downstream of the main engine fuel valves, command the liquid hydrogen manifold repressurization valve to open provided the main propulsion system manf press LH_2 switch on panel R4 is in the GPC position, and command the two liquid hydrogen fill and drain valves (inboard and outboard) to open.

The liquid hydrogen trapped in the orbiter feed line manifold is expelled overboard under pressure from the helium subsystem through the liquid hydrogen fill and drain valves for six seconds. Then the inboard fill and drain valve is closed; the three liquid hydrogen prevalves are opened; and liquid hydrogen flows through the engine bleed valves into the orbiter MPS, through the topping valve, between the inboard and outboard fill and drain valves, and overboard through the outboard fill and drain valve for approximately 88 seconds. The GPCs automatically terminate the dump by closing the two liquid hydrogen manifold repressurization valves and 30 seconds later closing the liquid hydrogen topping and outboard fill and drain valves.

If necessary, the flight crew can perform the liquid hydrogen dump manually utilizing the start and stop positions of the MPS prplt dump sequence LH_2 switch on panel R2. When the liquid hydrogen dump is initiated manually, all valve opening and closing sequences are still automatic. Placing the MPS prplt dump sequence switch in the start position causes the GPCs immediately to begin commanding all the required valves to open automatically and in the proper sequence. The liquid hydrogen dump continues as long as the switch is in the start position, but the pressurized portion of the dump with the two liquid hydrogen manifold repressurization valves open is still limited to 88 seconds. Placing the switch in the stop position causes the GPCs to begin commanding all of the required valves to close automatically and in the proper sequence.

At the end of the liquid oxygen and liquid hydrogen dumps, the GPCs close the helium out interconnect valves and all of the supply tank isolation valves provided the MPS He isolation left ctr, right A and B; pneumatic He isol; and He interconnect left, ctr, right switches on panel R2 are in the GPC position. After the dumps are complete, the space shuttle main engines are gimbaled to their entry positions with the engine nozzles moved inward (toward one another) to reduce aerodynamic heating.

Approximately 19 minutes into the mission and after the MPS liquid oxygen and liquid hydrogen dumps, the flight crew initiates the procedure for vacuum inerting the orbiter's liquid oxygen and liquid hydrogen lines. Vacuum inerting allows any traces of liquid oxygen or liquid hydrogen remaining after the propellant dumps to be vented into space.

The liquid oxygen vacuum inerting is accomplished by opening the liquid oxygen inboard and the outboard fill and drain valves. They are opened by placing the main propulsion system propellant fill/drain LO_2 outbd, inbd switch on panel R4 to the open position.

For liquid hydrogen vacuum inerting, the liquid hydrogen inboard and outboard fill and drain valves are opened by placing the main propulsion system propellant fill/drain LH_2 outbd, inbd switch on panel R4 to open. The external tank gaseous hydrogen pressurization manifold also is vacuum inerted by opening the hydrogen pressurization line vent valve by placing the main propulsion system H_2 line vent switch on panel R4 to open.

Helium for actuating the valves is provided by the two pneumatic helium isolation valves by placing the MPS pneumatic He isol switch on panel R2 to open. These isolation valves are closed by the GPCs at the end of the MPS liquid hydrogen dump. If additional helium is required to open and close the fill and drain valves, it can be obtained by opening the helium out interconnect valves by placing the MPS He interconnect left, ctr, right switches on panel R2 in the in close/out open position. These valves also are closed by the GPCs at the end of the MPS liquid hydrogen dump.

The liquid oxygen and liquid hydrogen lines are inerted simultaneously. Approximately 30 minutes is allowed for vacuum inerting. At the end of the 30 minutes, the flight crew closes the liquid oxygen outboard fill and drain valve by placing the main propulsion system propellant fill/drain LO2 switch on panel R4 to close . The inboard fill and drain valve is left open. To conserve electrical power after the completion of the liquid oxygen vacuum inerting sequence, the main propulsion system propellant fill/drain LO 2 outbd, inbd switch on panel R4 is placed in the gnd position. This position removes power from the opening and closing solenoids of the corresponding valves; and because they are pneumatically actuated, the valves remain in their last commanded position. At the end of the same 30-minute period, the liquid hydrogen outboard fill and drain valve and the hydrogen pressurization line vent valve are closed by positioning the main propulsion system propellant fill/drain LH2 outbd switch and the main propulsion system H 2 press line vent switch on panel R4 to close . The liquid hydrogen inboard fill and drain valve is left open. The main propulsion system propellant fill/drain LH 2 inbd, outbd and H 2 press line vent switches on panel R4 are positioned to gnd to conserve power. The hydrogen pressurization vent line valve is electrically activated; however, it is normally closed (spring loaded to the closed position), and removing power from the valve solenoid leaves the valve closed.

After vacuum inerting, the helium isolation valves and interconnect valves (if they were used) are closed by placing the MPS He isolation pneumatics He isol switch on panel R2 to close and the He interconnect left, ctr, right switches on panel R2 to GPC . This ensures that the helium supply tanks are isolated from any leakage in the downstream lines during orbital operations.

The electrical power to each engine controller and engine interface unit is turned off by positioning the MPS engine power left, ctr, right switches on panel R2 to off ; and the engine controller heaters are turned on by positioning the main propulsion system engine cntlr htr, left, ctr, right switches on panel R4 to auto .

During the early portion of the entry time line, the propellant feed line manifolds and the external tank pressurization lines are repressurized with helium from the helium subsystem. This prevents atmospheric contamination from being drawn into the manifolds and feed lines during entry. Removing contamination from the manifolds or feed lines can be a long and costly process since it involves disassembly of the affected part. Manifold repressurization is an automatic sequence performed by the GPCs.

After the orbital maneuvering system engines have been fired for deorbit and the orbiter begins to sense the presence of atmosphere, the GPCs start another vacuum inerting sequence. The liquid oxygen and liquid hydrogen prevalves that were left open at the end of the liquid oxygen and liquid hydrogen dump sequences remained open during the entire mission. Similarly, the liquid oxygen and liquid hydrogen inboard fill and drain valves that were left open at the end of the manual vacuum inerting sequence remained open during the entire mission. As re-entry begins, the left engine's helium isolation valve B and the pneumatic helium isolation valves are opened providing the MPS He isolation left B and the MPS pneumatic He isol switches on panel R2 are in the GPC position; the left engine's pneumatic crossover valve and in interconnect valve are opened; and the center and right engines' out interconnect valves are opened providing the MPS pneumatics l eng He xovr and MPS He interconnect left, ctr and right switches on panel R2 are in the GPC position. Also, the MPS liquid hydrogen topping valve, outboard fill and drain valves, and inboard and outboard RTLS drain valves are opened providing the propellant fill/drain LO 2 and LH2 outbd and inbd switches are in the gnd position. As orbiter re-entry continues, its velocity decreases. When the velocity drops below 20,000 feet per second, the liquid oxygen outboard fill and drain valve opens.

This vacuum inerting continues until the orbiter's velocity drops below 4,500 feet per second (between 110,000 and 130,000 feet altitude depending on the re-entry trajectory). Then the MPS liquid oxygen and liquid hydrogen outboard fill and drain valves, the liquid hydrogen inboard and outboard RTLS drain valves, and the liquid oxygen prevalves are closed; the MPS liquid oxygen and liquid hydrogen manifold repressurization valves and the MPS helium blowdown supply valves are opened; and a 650-second timer is started. This provides a positive pressure in the liquid oxygen and liquid hydrogen manifolds and in the aft fuselage and the OMS/RCS pods and prevents contamination. The 650-second timer runs out approximately one minute after touchdown. After the timer expires, the purge of the aft fuselage and OMS/RCS pods is terminated when the MPS helium supply blowdown valves are closed. The manifold repressurization continues until the ground crews install the throat plugs in the main engine nozzles.

If MECO is preceded by an RTLS abort, the subsequent MPS liquid oxygen dump will begin 10 seconds after the external tank separation command is issued, and the liquid hydrogen dump will begin simultaneously. The liquid oxygen and liquid hydrogen dumps are initiated and terminated automatically by the GPCs regardless of the positions of the MPS prplt dump sequence LO2 and LH2 switches on panel R2.

During an RTLS abort, liquid oxygen initially is dumped through the SSMEs and 30 seconds later via the liquid oxygen fill and drain valves. This dump is performed without helium pressurization and relies on the self-boiling of the trapped liquid.

In the RTLS liquid oxygen dump, the GPCs terminate the dump whenever the orbiter's velocity drops below 3,800 feet per second. The liquid oxygen is dumped through the nozzles of the main engines; however, each engine is gimbaled to the entry position rather than the normal dump position. The liquid oxygen feed line manifold is not pressurized in this mode, and the two liquid oxygen manifold repressurization valves remain closed throughout the entire dump. The liquid oxygen system is repres surized when the 3,800-feet-per-second velocity is attained, and repressurization continues as in a nominal entry. The main propulsion system prevalves LO2, left, ctr, right switches on panel R4 are in the GPC position, and the GPCs command the engine controllers to open each engine main oxidizer valve for the dump.

In the RTLS mode, the liquid hydrogen dump is initiated and terminated automatically by the GPCs simultaneously with the liquid oxygen dump regardless of the position of the MPS prplt dump sequence LH 2 switch on panel R2. The two RTLS dump valves and the two RTLS manifold repressurization valves are opened, and the liquid hydrogen trapped in the feed line manifold is expelled under pressure from the helium subsystem for 80 seconds through a special opening on the port side of the orbiter between the wing and the OMS/RCS pod. After 80 seconds, the liquid hydrogen fill and drain valves are opened, resulting in vacuum inerting of residual liquid hydrogen through bulk boiling. The GPCs terminate the liquid hydrogen dump and vacuum inerting automatically when the orbiter reaches the 3,800-feet-per-second velocity. At that time, the inboard and outboard RTLS dump valves, the inboard and outboard fill and drain valves, and the two RTLS manifold repressurization valves are closed. The liquid hydrogen system is repressurized after an RTLS liquid hydrogen dump, and repressurization continues as in a nominal entry.
