APPENDIX B

REPORT OF MISSION EVENTS PANEL

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PART B1

TASK ASSIGNMENT

Panel 1 was assigned the task to develop a detailed and accurate chronology of mission events directly related to the flight of Apollo 13. This event sequence would then form a baseline of data for analytical use by Panel 1, other Panels, and the Review Board.

To provide such a chronology, Panel 1 worked to produce a consolidated sequence of all data whether derived from telemetry records, crew observations, inflight photographs, air-to-ground communications, or other sources of information. Of special significance to Panel 1 was the requirement to correlate data taken from different sources, such as crew observations and telemetry, in order to provide greater assurance of the validity of data wherever possible.

In order to provide meaningful boundary conditions for its work, Panel 1 divided its effort into three areas:

1. Preincident events, which covered the flight from countdown to the time of the inflight accident.

2. Incident events, which covered the flight from approximately 55 hours and 52 minutes to the conclusion of immediately related data events.

3. Postincident events, which covered the subsequent mission period to splashdown.

In each of the three areas the main purpose of the Panel was to provide the most efficient presentation of events for the Board's use in reviewing, evaluating, and interpreting the significance of mission events. Consequently, Panel 1 devoted a considerable portion of its time to the task of data interpretation and verification. As was intended from the Charter of the Board, the primary focus of the Panel's work was the period of time during which the service module encountered serious inflight difficulties, and its presentation of data reflects this particular emphasis.

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PART B2

PANEL ORGANIZATION

Panel 1 was chaired by Mr. Francis B. Smith, Assistant Administrator for University Affairs, NASA Headquarters, Washington, D.C. The Board Monitor was Mr. Neil Armstrong from the Manned Spacecraft Center. Additional Panel Members were:

Mr. John J. Williams, Kennedy Space Center, for preincident events

Dr. Thomas B. Ballard, Langley Research Center, for incident events

Mr. M. P. Frank, Manned Spacecraft Center, for postincident events

Although each of the above specialized in one phase of the Panel's total assignment, the Panel acted as one unit in the review and assessment of data and in the analysis and interpretation of those events identified with the accident.

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PART B3

SUMMARY OF EVENTS

Apollo 13 was launched on schedule from Kennedy Space Center at 2:13:00 e.s.t. on April 11, 1970. The crew consisted of James E. Lovell, Commander (CDR); John L. Swigert, Command Module Pilot (CMP); and Fred W. Haise, Lunar Module Pilot (LMP). The preflight countdown was routine and although some malfunctions and anomalies occurred during boost and earlier portions of the flight, none except the premature cutoff of one of the S-II engines was considered at the time to be of a serious nature.

At about 55:54, the crew had just completed a television broadcast; CMP Swigert was in the left seat of the command module, LMP Haise was in the lunar module, and CDR Lovell was in the CM lower equipment bay, when all three heard a loud bang. At about the same time in Mission Control in Houston, the Guidance Officer (GUIDO) noted on his console display that there had been a momentary interruption of the spacecraft computer. He told the Flight Director, "We've had a hardware restart. I don't know what it was." At almost the same time, CDR Lovell, talking to Mission Control, said, "I believe we've had a problem here." Also at about the same time, the Electrical, Environmental, and Communications Engineer (EECOM) in Mission Control noticed on his console display the sudden appearance of limit sensing lights indicating that a few of the telemetered quantities relating to the spacecraft's cryogenic, fuel cell, and electrical system had suddenly gone beyond pre-set limits. Astronaut Swigert in the command module, noting a master alarm about 2 seconds after the bang, moved from the left seat to the right seat where he could see the instruments indicating conditions of the electrical system, and noticed a caution light indicating low voltage on main bus B, one of the two busses supplying electrical power for the command module. At that time, he reported to Mission Control, "We've had a problem. We've had a main B bus undervolt." At the same time, however, he reported the voltage on fuel cell 3, which supplied power to main bus B, looked good and assumed that the main bus B undervolt condition had been a transient one. However, 2 or 3 minutes later, when another master alarm sounded, LMP Haise moved into the right-hand seat to recheck the fuel cells and noted that two of the three fuel cells (no. 1 and no. 3) were showing no hydrogen or oxygen flow and no electrical output and that fuel cell 2 was carrying the command module's total electrical load through bus A. Bus B was dead. In addition, several other electrical and cryogenic system abnormalities were evident.

Detailed studies and analyses of telemetry records made since the flight indicated that during the 90 seconds before the "bang", several abnormal events occurred. At about 55:53:23, within a few seconds after the crew had turned on two fan motors which stir the supercritical cryogenic oxygen in oxygen tank no. 2, electrical "glitches" (transient high-amplitude current and voltage fluctuations) occurred which could be indicative of momentary electrical short circuits. Analyses of telemetry data also indicate that first one fan motor and then the other probably became disconnected from the electrical bus concurrently with the glitches. Thirteen seconds after the first glitch (16 seconds after the fans were turned on) the pressure in oxygen tank no. 2 started to rise; during the next 24 seconds it increased from a normal value of 891 psia to 954 psia; it remained at that pressure for approximately 21 seconds and then again increased to a maximum value of 1008 psia (approximately the pressure at which the relief valve was set to open), at which point the relief valve apparently opened and pressure began decreasing. During the last 23 seconds of this period, during the second oxygen pressure increase, telemetry indicated that oxygen tank no. 2 temperature also began to increase sharply; and concurrently with the sudden temperature rise, the oxygen tank no. 2 quantity gage, which had been inoperative for the previous 9 hours, began to show fluctuating readings. At about 90 seconds after the start of the pressure rise, telemetry transmission from the spacecraft was suddently interrupted for a period of 1.8 seconds.

Putting all of this and other information together with the service module photographs taken later by the crew and with subsequent changes in the condition of the spacecraft system leads to a determination that immediately before and during this 1.8-second interval the following things happened:

1. The oxygen tank no. 2 system failed, leading to loss of all oxygen pressure.

2. The service module panel covering bay 4 blew off, possibly producing the "bang" heard by the crew.

3. The spacecraft's velocity changed by 0.5 fps.

4. Transmission of telemetry from the spacecraft was interrupted (possibly caused by the panel striking and damaging the high-gain antenna through which data were being telemetered).

5. Various valves in the reaction control systems (RCS) were shocked closed (contributing to some difficulties in maintaining automatic attitude control).

6. Valves controlling oxygen flow to fuel cells 1 and 3 were shocked closed (leading to failure of both fuel cells 2-1/2 minutes later for lack of oxygen).

7. Oxygen tank no. 1 started leaking oxygen.

8. Venting of oxygen produced forces on the spacecraft which the automatic stabilization system counteracted by firing opposing spacecraft reaction control thrusters.

9. Various sensors or their wiring were damaged to cause subsequent erroneous readings.

These changes occurred so rapidly, of course, that neither the crew nor the mission controllers could have had a clear picture of specifically what had happened.

In the Mission Control Center, after the 1.8-second data loss, the EECOM first suspected an instrumentation failure since earlier in the flight (46:40) the oxygen tank no. 2 quantity gage had failed and since other pressures, temperatures, voltages, and current readings were so abnormal (e.g., more than 100 percent or less than 0 percent of full scale) as to appear unrealistic. They appeared more indicative of an instrumentation failure than of real quantities. The Flight Director also initially believed, from the information available to him in the Control Center, that the difficulty was electrical or electronic in nature. Consequently, Mission Control Center's initial efforts during the first 3 or 4 minutes after the malfunction were to validate instrument readings and to identify a possible instrumentation failure. During the next several minutes, both the flightcrew and the ground controllers worked at switching fuel cell bus power configurations in an attempt to understand what had happened and to get fuel cells 1 and 3 back on line. They determined that fuel cell 1 had no output and disconnected it from the bus. Later they also disconnected fuel cell 3 for the same reason. For several minutes they connected the command module's entry battery to bus A to aid fuel cell 2 in supplying electrical power and to insure against further failures due to low voltage.

Shortly after the malfunction, while the Apollo 13 crew and the EECOM were trying unsuccessfully to restore electrical power output from fuel cells 1 and 3, the Guidance and Navigation Officer (GNC) reported an unusually high level of attitude control thruster activity on the spacecraft. This added to their problems, since it indicated other abnormal conditions aboard the spacecraft and used excessive thruster fuel. Consequently, during the next hour the ground control and the crew were required to pay a great deal of attention to maintaining attitude control of the spacecraft and to identifying and eliminating the cause of the instability. At the same time, the Flight Director began to suspect that the genesis of the problem might lie in the RCS, rather than in the high-gain antenna or instrumentation.

During this period (about 14 minutes after the accident) CDR Lovell reported, "...it looks to me, looking out the hatch, that we are venting something. We are venting something out into space......it's a gas of some sort." He subsequently described this venting as extremely heavy and unlike anything he had seen in his three previous space flights.

For about 1 hour 45 minutes after the accident, the crew and ground controllers wrestled with electrical problems caused by oxygen supply and fuel cell failures and with attitude stability problems caused by the venting of oxygen, the shock closing of thruster system valves, and electrical system failures. During this period they went through a series of control system reconfigurations until automatic control was finally established at 57:32. In the meantime, as it became more apparent that the loss of oxygen from oxygen tank no. 1 could not be stopped and that fuel cell 2 would soon expire, the LM was powered up (57:40), LM telemetry was turned on (57:57) and attitude control was transferred from the CM to the LM (58:34). At 58:40, 2 hours 45 minutes after the accident, the CM was completely powered down.

One of the main concerns then was to make the trajectory changes that would return the spacecraft safely to Earth within the lifetime of the onboard consumables--water, oxygen, thruster fuel, and electric power. At the time of the accident the spacecraft was on a trajectory which would have swung it around the Moon (about 21 hours after the accident) and returned it to Earth where it would have been left in a highly elliptical orbit about the Earth with a perigee (nearest approach to Earth) of about 2400 miles. Four trajectory correction burns were made during the remainder of the flight as illustrated in figure B6-9.

61:30 - A 38 fps incremental velocity (delta V) burn using the descent propulsion system (DPS) engine and the LM primary guidance and navigation system (PGNS). This burn was performed 16 hours before they swung around the Moon, and was targeted to place the spacecraft on a trajectory which would return it to the atmospheric Earth reentry corridor rather than the 2400-mile perigee.

79:28 - A 861 fps delta V burn using the DPS 2 hours after swinging around the Moon to speed up return to Earth by about 9 hours (143 versus 152 g.e.t.) and to move the landing point from the Indian Ocean to the Pacific Ocean where the primary recovery forces were located.

105:18 - A 7.8 fps delta V burn using DPS to lower perigee altitude from 87 miles to about 21 miles.

137:40 - A 3.2 fps delta V final burn using LM RCS thruster to correct for small dispersions in previous burns and assure that the spacecraft would reenter in the center of its entry corridor.

During the remainder of the flight there were several other unusual situations which the crew and Mission Control successfully contended with. The use of electrical power aboard the LM had to be managed very carefully to conserve not only the LM batteries but also the water supply, since water was used to dissipate heat generated by the electrical equipment. The LM LiOH was not adequate to remove carbon dioxide for three men for the duration of the return trip, so a method was devised to circulate the LM cabin oxygen through the CM's LiOH filters. Since the CM had to be used for reentry, its main bus B had to be checked out very carefully to assure that there were no electrical shorts and the CM entry battery which had been used earlier to supply power for the ailing CM had to be recharged from the LM batteries.

Several actions essential to reentry and landing were undertaken during the last 9 hours of the flight as illustrated in figure B6-10. The SM was jettisoned a few minutes after the last midcourse correction, about 4-1/2 hours before reentry. In viewing and photographing the SM, the crew realized for the first time the extensiveness of the physical damage (panel blown off, Mylar strips hanging from antenna, etc.). At about 2-1/2 hours before reentry, the CM's inertial platform was powered up and aligned and the LM was jettisoned about 1/2 hour later. Reentry was at 142:40 and splashdown at 142:54 g.e.t.

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PART B4

PRELAUNCH AND MISSION EVENTS PRIOR TO THE ACCIDENT

This section of the report contains significant events prior to the accident with emphasis placed on the spacecraft and particularly on the cryogenic system. It starts with the launch count (T - 98:00:00) and ends prior to the significant events of the accident (55:52:00).

LAUNCH COUNTDOWN

Countdown operations for both the command service module (CSM) and lunar module (LM) were started at approximately 10:00 a.m. e.s.t. on Monday, April 6, 1970. The start of the countdown was delayed approximately 8 hours because of a pad clear operation involving a special test of the LM supercritical helium (SHe) system. A timeline of significant countdown milestones is shown in figure B4-1.

Mechanical Build-up and Gas Servicing

Following completion of CSM powerup, water servicing, and securing of the LM SHe operation, installation of the CSM heavy ordnance initiators was started at approximately 3:00 p.m. e.s.t. The ordnance operation and remote resistance checks of the launch escape rocket initiators were completed by 9:30 p.m. e.s.t., April 6, after being slightly delayed to correct a mechanical interference problem (incorrect thread depth) with the initiator in the launch escape rocket motor. Combined CSM and LM helium and gaseous oxygen (GOX) servicing was started at 2:00 a.m. e.s.t. on April 7, and was successfully completed by noon that day. At this time, both the CSM and LM were functional at T - 66:00:00, at which point a built-in hold of 12 hours had been originally planned. As a result of the late countdown start, both the LM and CSM spacecrafts experienced only a 6-hour built-in hold.

From noon Tuesday, April 7, through 11:00 a.m. Thursday, April 9, mechanical build-up operations (panel closure, LM thermal blanket installation, etc.) were conducted on the CSM and LM. The CSM fuel cells were activated and preparations were completed for CSM cryo loading, that is, filling the cryogenic oxygen and hydrogen tanks. Details of this operation are covered below. During this time the LM SHe tank was initially loaded and a 24-hour cold soak period started. All of these operations were completed without a significant problem, with the

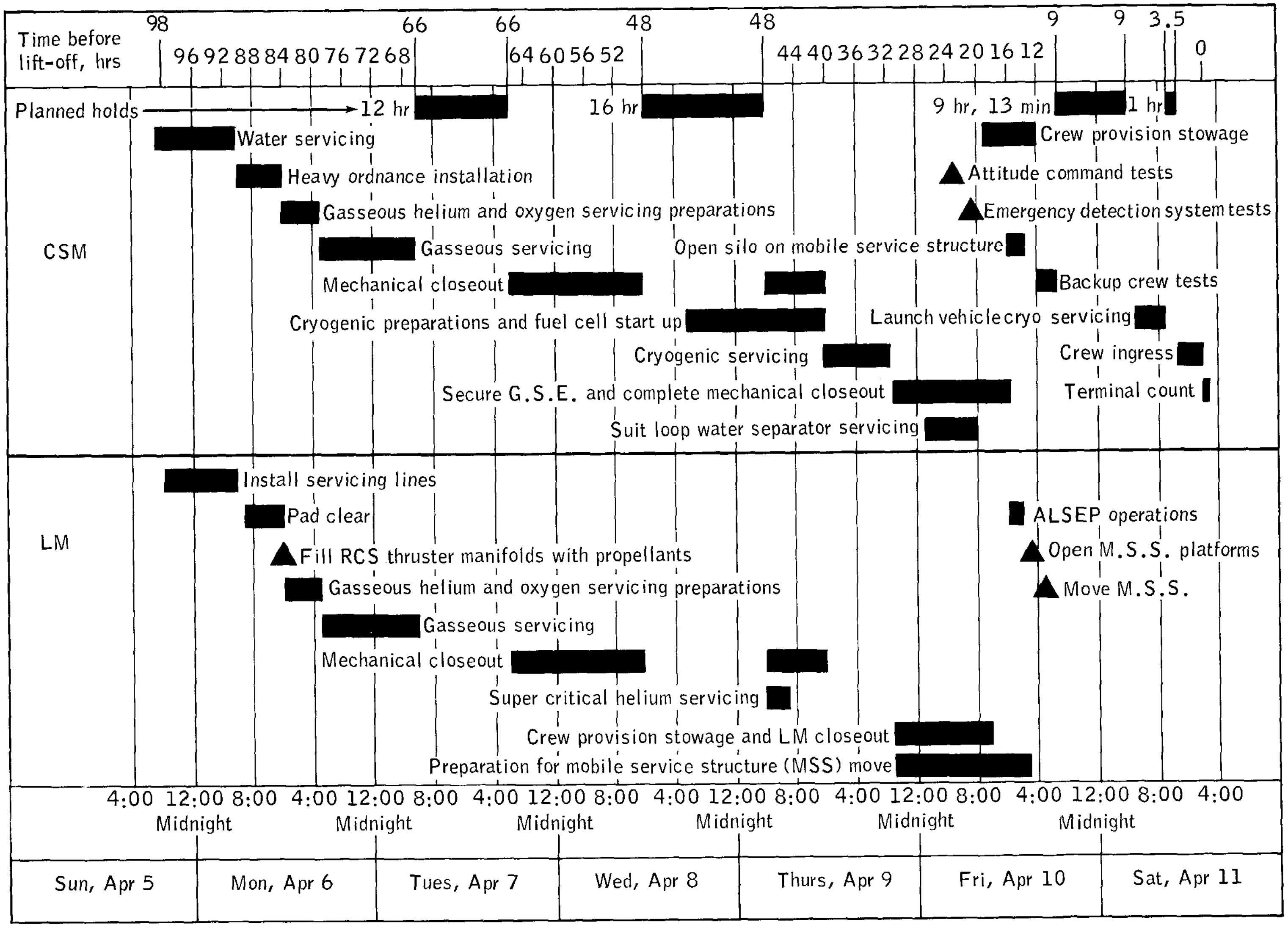

Figure B4-1.- Planned launch countdown timeline, e.s.t.

spacecraft progressing functionally from T - 66:00:00 to T - 41:00:00; including completion of the built-in hold at T - 66:00:00 and another planned 16-hour built-in hold at T - 48:00:00.

Cryogenic Servicing

CSM cryo loading or flowing liquid hydrogen and liquid oxygen was scheduled to be performed from 11:00 a.m. e.s.t. through 7:00 p.m. e.s.t. Thursday, April 9, 1970. A timeline of significant milestones, including preliminary preparations, is shown in figure B4-2. (See Appendix A, Part A5 for a description of the fuel cell and cryogenic systems.) The configuration of the cryogenic and fuel cell systems was as follows:

1. The fuel cell gaseous oxygen and hydrogen systems were at a pressure of 28 psia with oxygen and hydrogen gases. The fuel cells had been operated in the countdown demonstration test (CDDT) and were left pressurized with reactant gases (gaseous oxygen and hydrogen) to maintain system integrity between CDDT and countdown.

2. The oxygen and hydrogen tanks were at a pressure of 80 psia with oxygen and hydrogen gases. The tanks had been evacuated (less than 5mm Hg for 2 hours minimum) and serviced during CDDT, with reactant gas left in the system after detanking to maintain system integrity between CDDT and countdown.

3. The ground support equipment (GSE) lines were connected to the spacecraft and had been previously evacuated, pulse purged, and then pressurized with reactant gas to 80 psia. Purity samples taken of the gases from the GSE were within specification. The pressure-operated disconnects (POD's) that connect the GSE to the spacecraft had been leak checked at 80 psia with reactant gas and indicated no leakage.

4. The portable oxygen dewar used to service the spacecraft oxygen tanks was serviced on April 7, 1970. Liquid samples taken from the vent line of the dewar during servicing were within specification. All of the preceding activities were accomplished without undue delay or difficulty.

The first activity for the fuel cell and cryogenic system in the countdown started at approximately 3:00 p.m. e.s.t. on April 8, 1970. The move of the liquid hydrogen and liquid oxygen dewars from the cryogenic buildings to the pad had been completed. The primary oxygen, backup oxygen, and backup hydrogen dewars were located on the pad at the base of the mobile service structure (MSS) while the primary hydrogen dewar was moved to level 4A of the MSS. The hydrogen and oxygen GSE configuration is shown in figures B4-3 and B4-4, respectively.

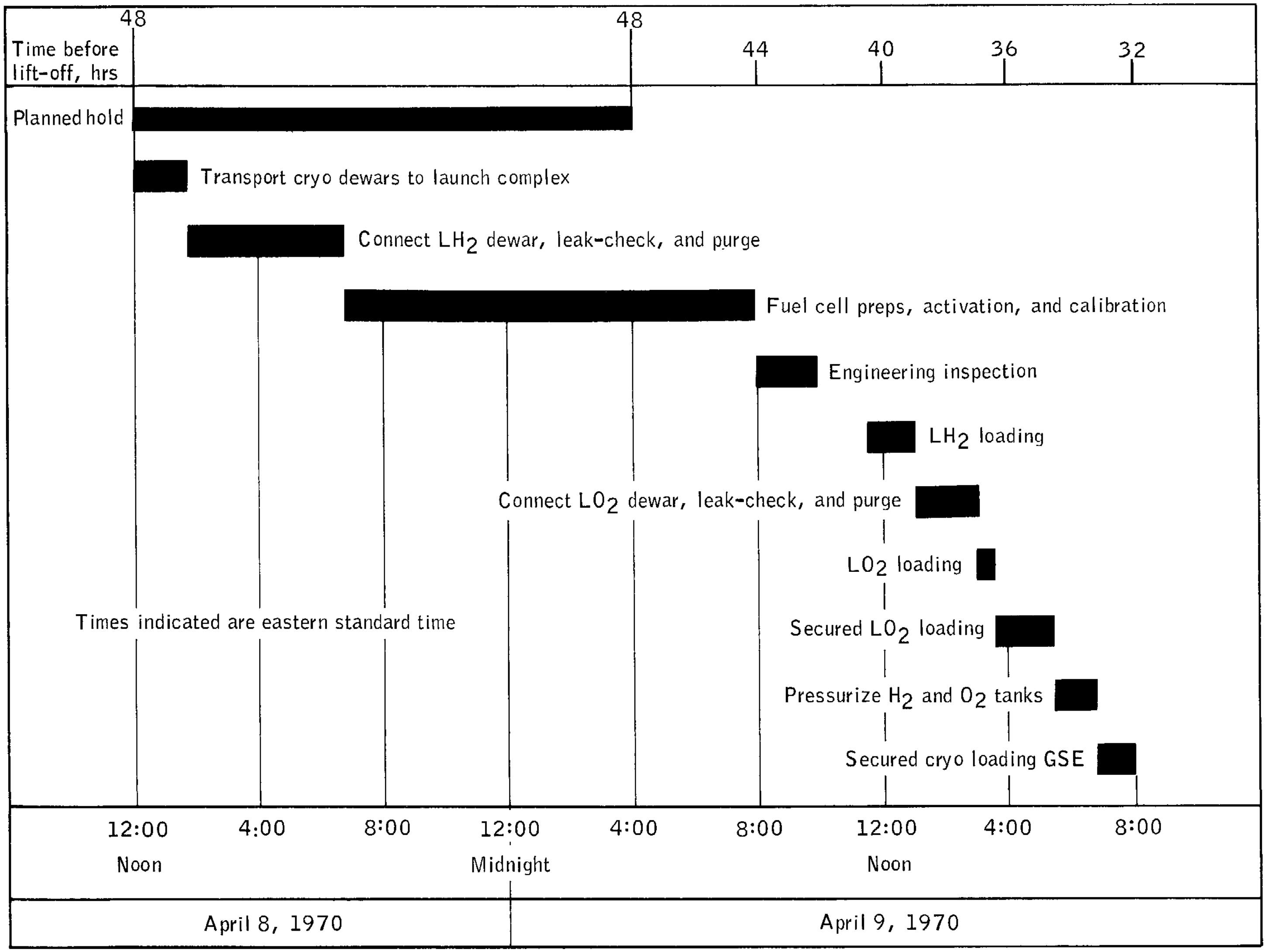

Figure B4-2.- Fuel cell activation and cryogenic servicing timeline.

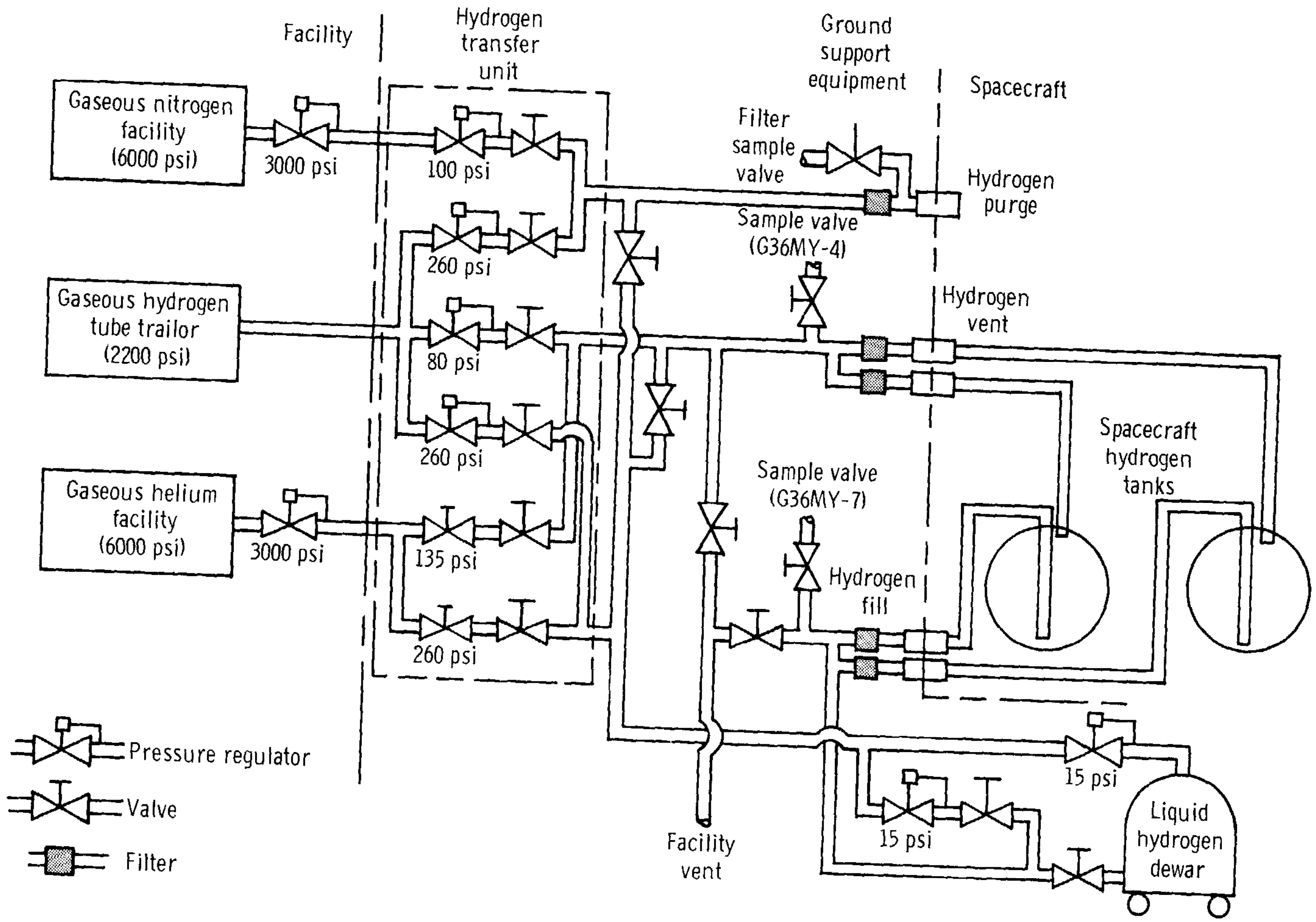

Figure B4-3.- Hydrogen servicing configuration.

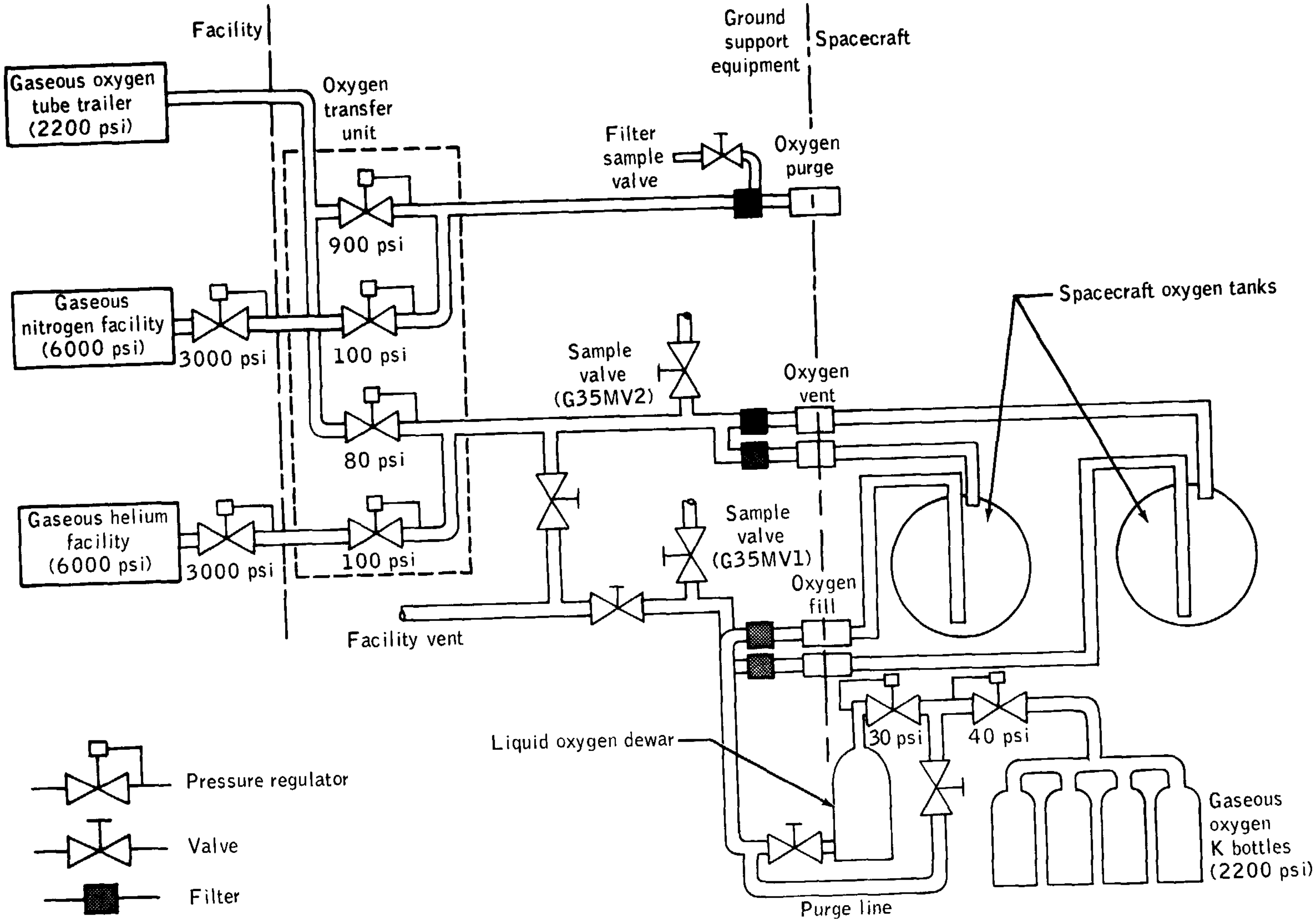

Figure B4-4.- Oxygen servicing configuration.

Pictures of the servicing dewars, valve boxes, and pressurizing equipment are shown in figures B4-5 through B4-10.

Dewpoint samples of the oxygen and hydrogen spacecraft tanks were obtained. This was accomplished by pressurizing the tanks with reactant gas to 80 psia through the vent line and then venting the tank back through the vent line and obtaining a moisture sample at the vent line sample valve. Both the oxygen and hydrogen tanks met the requirements that the moisture content be less than 25 parts per million (ppm). Oxygen tanks no. 1 and no. 2 read less than 2 ppm.

After the dewpoint samples of the tanks were obtained, sample bottles were installed on the tank vent lines. The sample bottles were flow purged with reactant gases at 80 psia for 5 minutes, followed by 10 pulse purges ranging in pressure from 80 psia to 20 psia.

The hydrogen dewar was then connected to the servicing GSE. The fill line between the dewar and the spacecraft was flow purged with 55 psia of helium gas for 15 minutes, and a moisture sample taken from the fill line. A sample result of 2 ppm was obtained. An additional flow purge using gaseous hydrogen at 55 psia was then performed for 10 minutes, followed by 13 pulse purges ranging in pressure from 55 psia to 20 psia (Note: This cleans the dead-end areas at the manifold).

The fuel cells were then pressurized to their operating pressure (62 psia oxygen and hydrogen). Heat was applied electrically to the fuel cells from external GSE to melt the potassium hydroxide. Fuel cell 3 heater current, supplied from GSE for heatup, was slightly low (1.2 amps vs. 1.4 amps). This heater current was adjusted after the heatup and calibration of the fuel cells was completed.

With the fuel cells at operating temperature (420° F) and pressures, a calibration test on each fuel cell was performed. Fuel cells were calibrated by applying loads in approximately 10-amp increments until a maximum current of 60 amps was reached while monitoring the output voltage. The fuel cell loads were supplied by GSE load banks. After calibration, the fuel cells were connected to the spacecraft busses and 40-amp GSE load applied to each cell for fuel cell water conditioning (approximately 4 hours). After these loads were removed from each fuel cell, 6-amp in-line heater loads with a 50-percent duty cycle were applied. With the fuel cells in this configuration a visual engineering inspection of the liquid hydrogen and liquid oxygen loading systems was performed with the exception of the liquid oxygen dewar, not yet connected.

Immediately prior to flowing liquid hydrogen, the spacecraft hydrogen and oxygen tank fans and quantity probe circuit breakers were

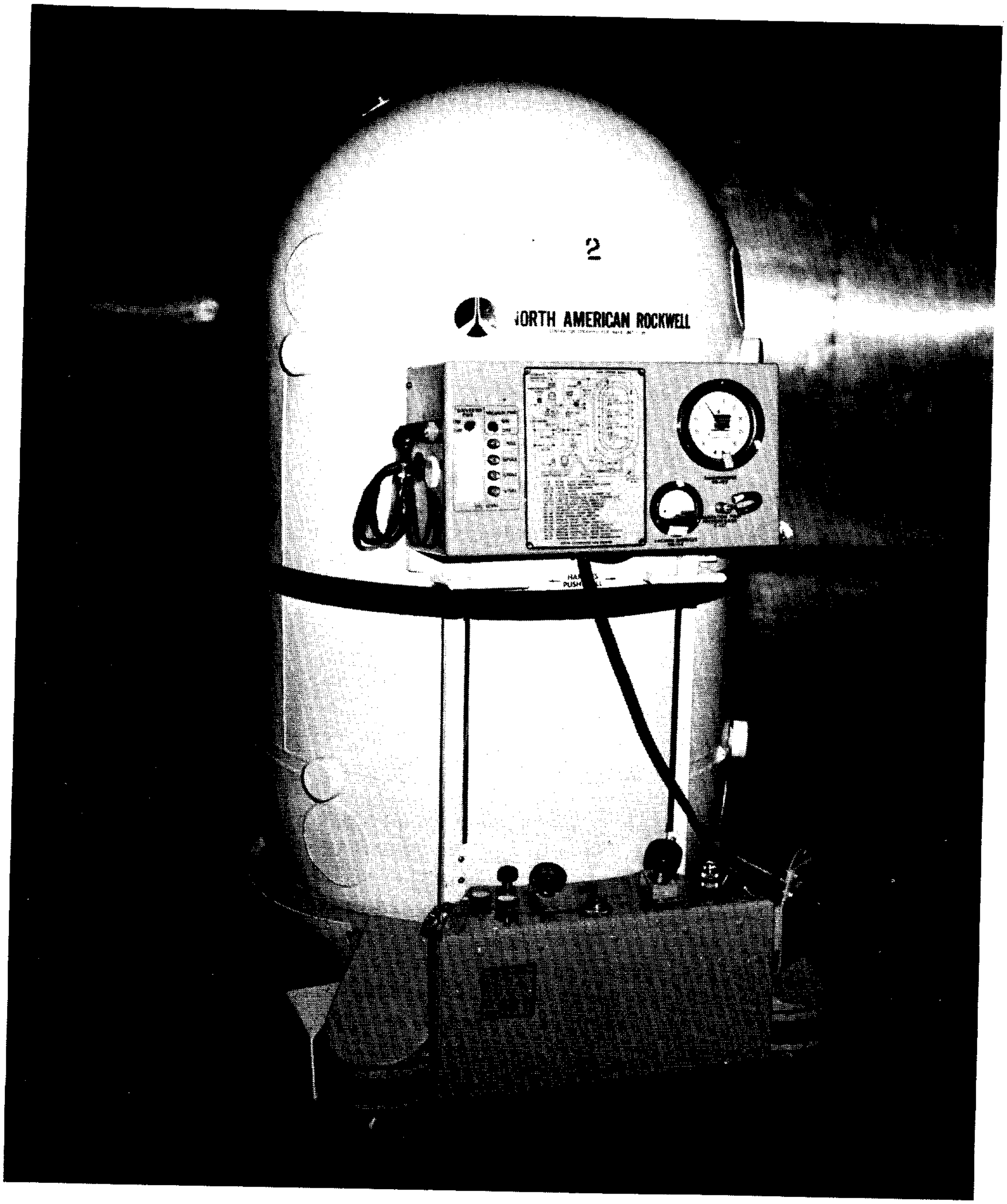

Figure B4-5.- Liquid hydrogen dewar.

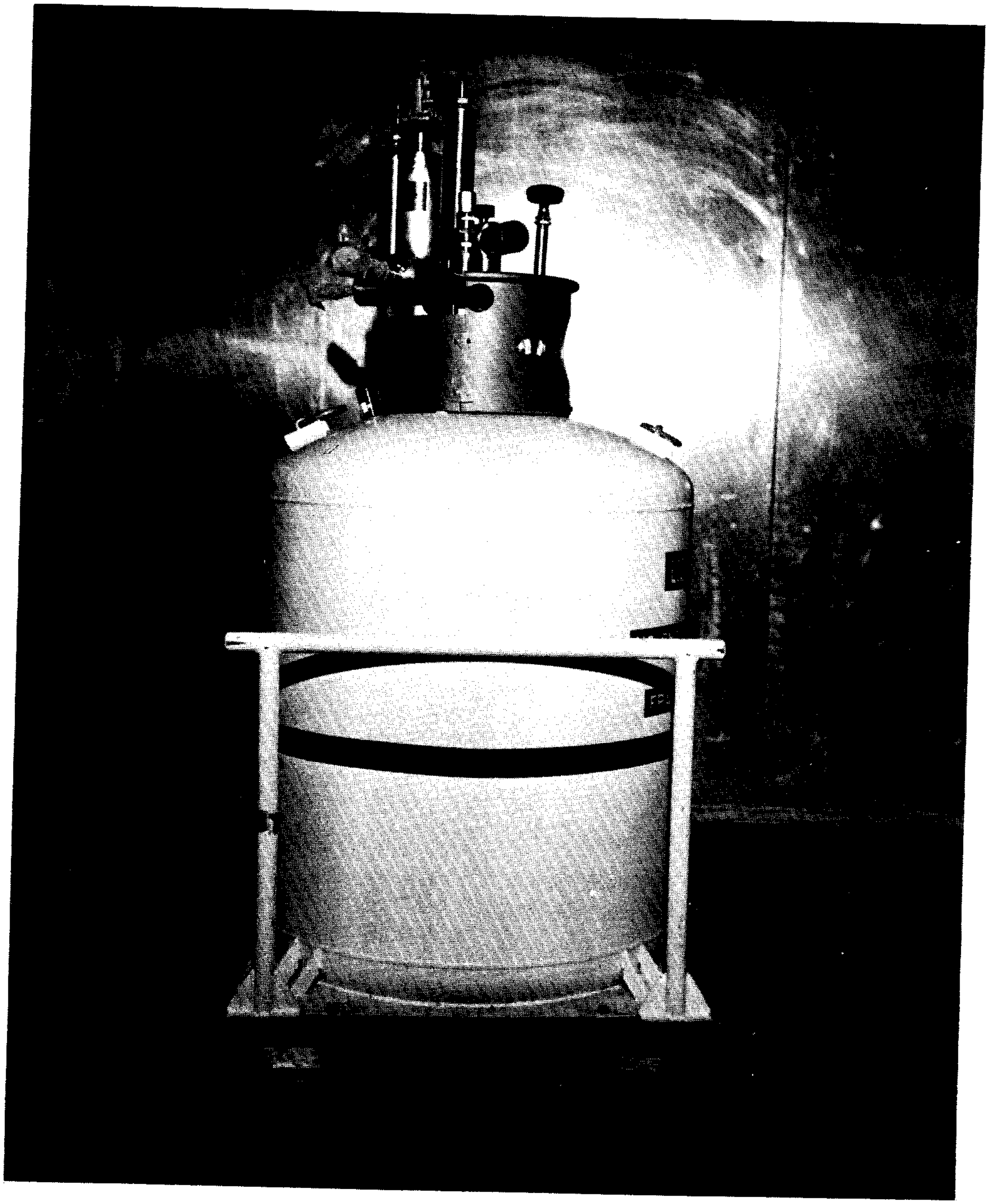

Figure B4-6.- Liquid oxygen dewar.

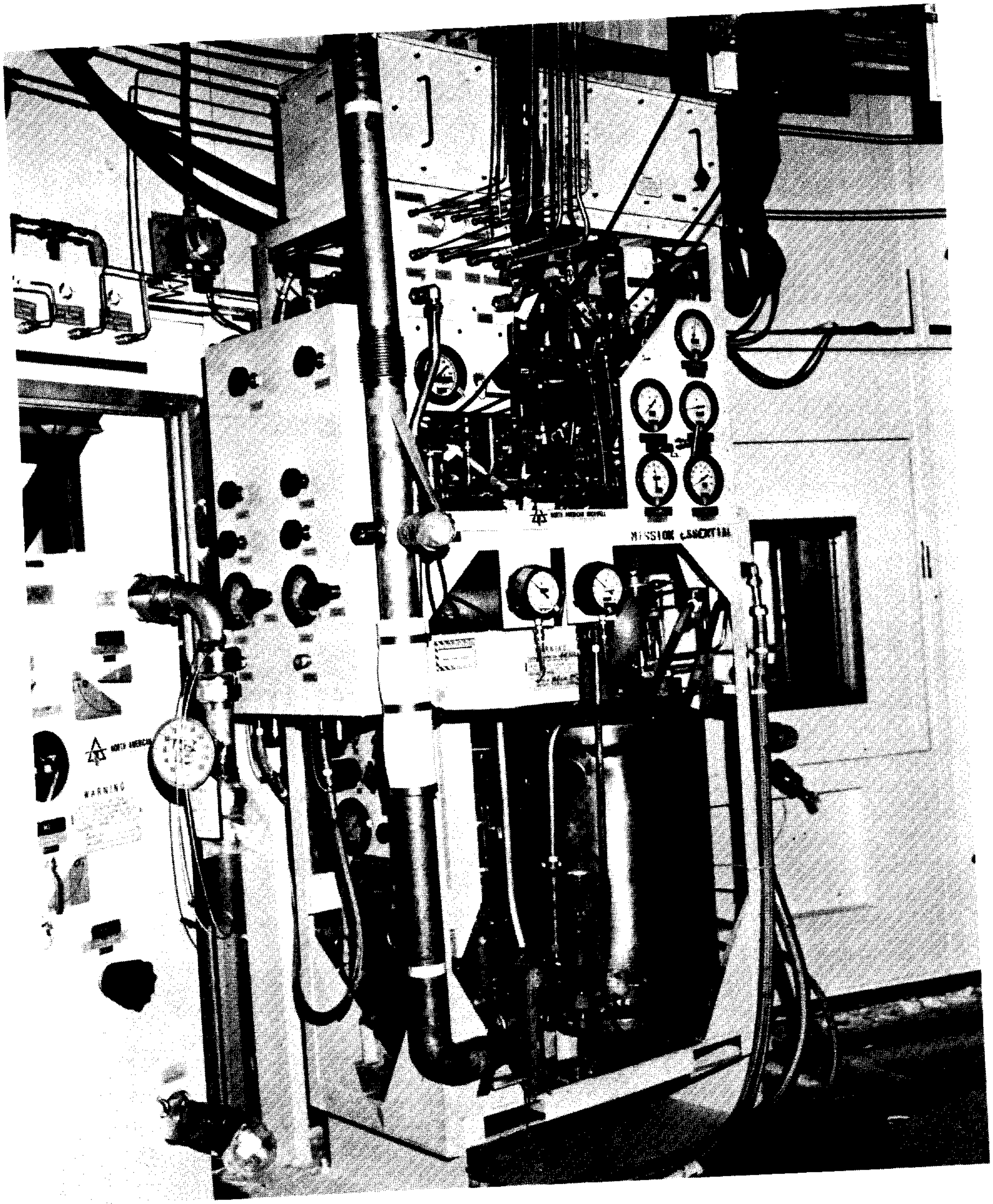

Figure B4-7.- Hydrogen valve box at Launch Complex 39.

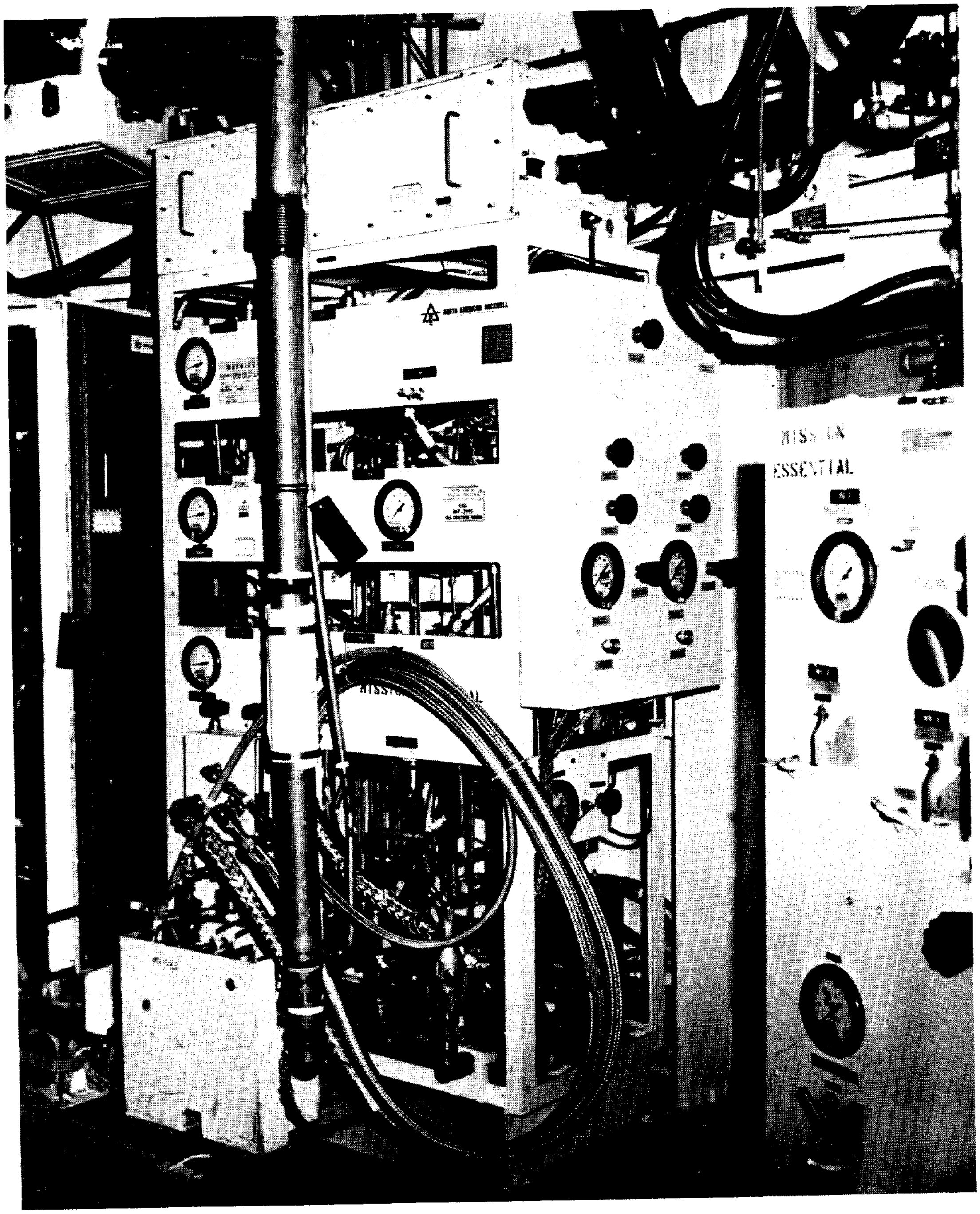

Figure B4-8.- Oxygen valve box at Launch Complex 39.

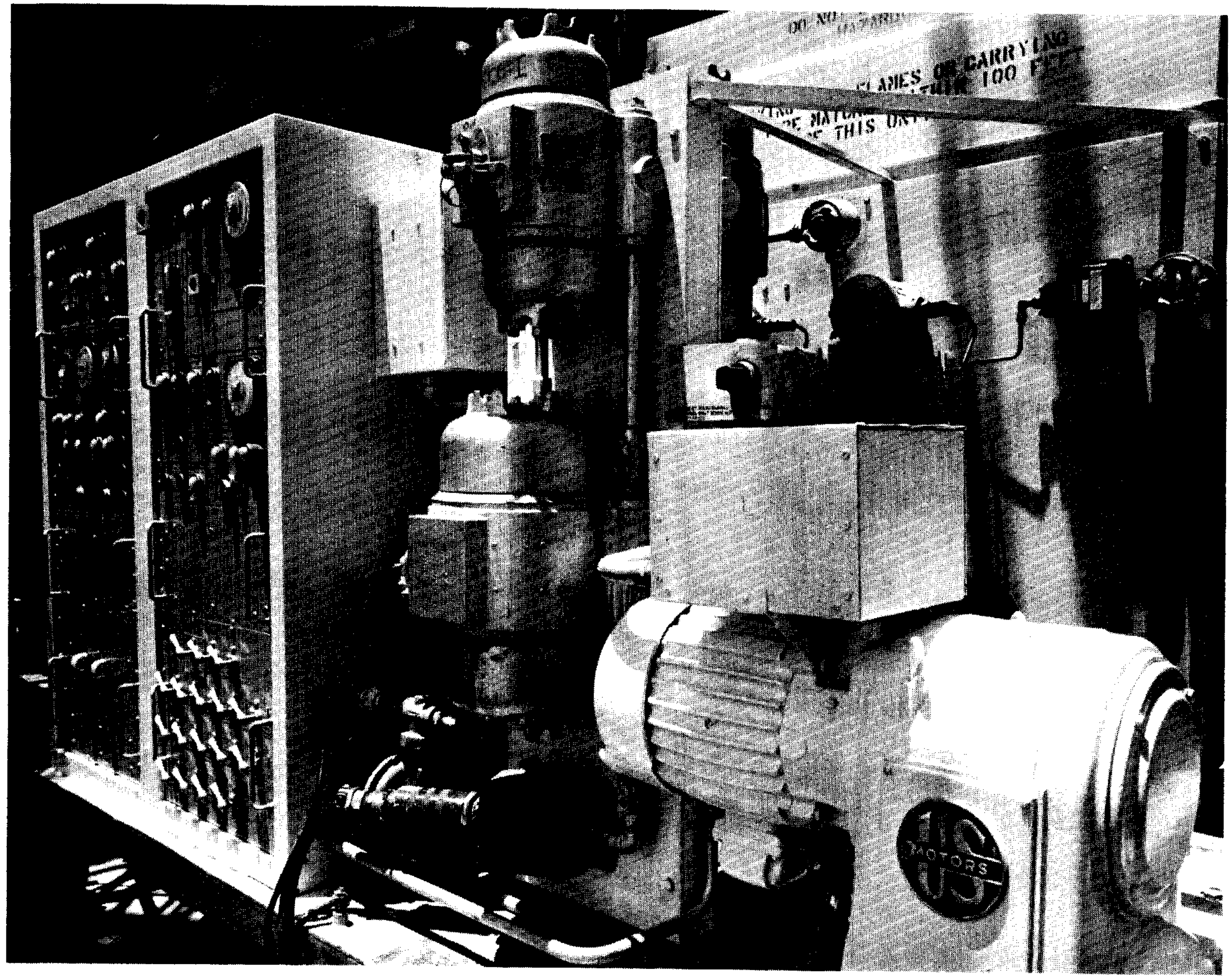

Figure B4-9.- Hydrogen transfer unit at Launch Complex 39.

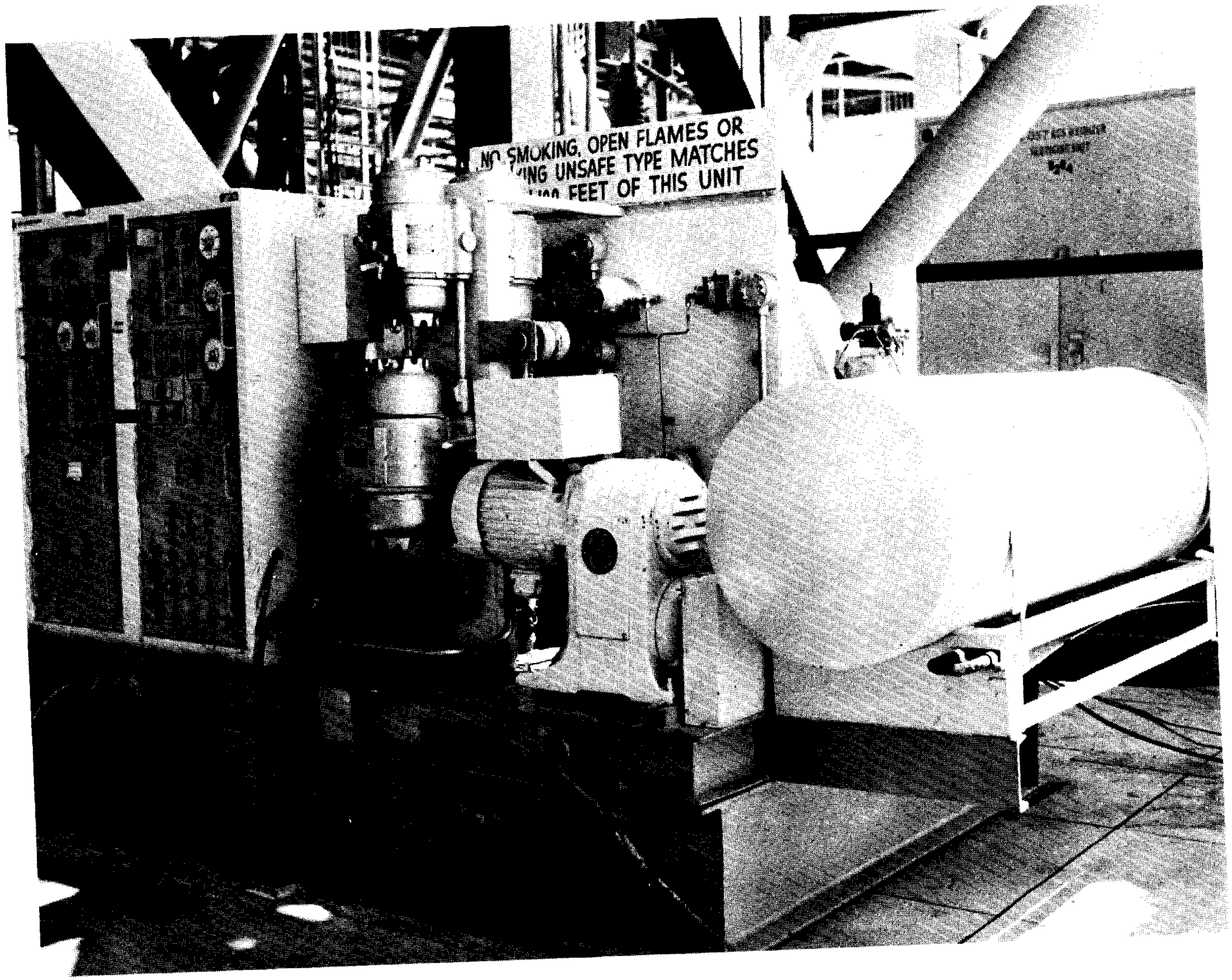

Figure B4-10.- Oxygen transfer unit at Launch Complex 39.

closed. (See Appendix A, Part A5, for description of the oxygen and hydrogen tanks.) The hydrogen dewar was pressurized to approximately 30 psia prior to servicing. Hydrogen was flowed through both tanks for 10 minutes (normal) prior to obtaining an increase in tank quantity. This period is required to chill the system. The flow rate during servicing was approximately 2.1 pounds per minute for 22 minutes (both tanks). The flow was stopped for 30 minutes when the tank quantity reached 85-percent and the dewar and spacecraft tanks vented to ambient pressure. The fans were turned off during this period. This time period is required to chill the hydrogen tank. The dewar was again pressurized to approximately 30 psia, and flow (at normal rates) began through the fill manifold detank line for 2 minutes to chill the GSE prior to then opening the spacecraft fill POD's. When the quantity gage stabilized (about 98-percent) the dewar pressure was increased to approximately 35 psia and the vent POD's closed, followed closely by the closure of the fill POD's. The GSE vent valve was closed simultaneously with the closing of the spacecraft vent POD's. This operation traps cold gas between the spacecraft vent POD's and the GSE vent valve. As the cold gas warms and expands, it is vented into the two sample containers connected to the vent line sample valve. The samples were analyzed for helium, nitrogen, and total hydrocarbons. Both samples were within specifications.

The hydrogen dewar was removed and the prime oxygen dewar was brought up to level 4A of the MSS. The oxygen dewar was connected to the servicing GSE. The fill line between the dewar and the spacecraft was flow purged with 55 psia of oxygen gas for 15 minutes, and a moisture sample taken from the fill line. A sample result of less than 2 ppm was obtained. After sampling, 13 pulse purges from a pressure of 55 psia to a slight positive pressure to maintain flow were performed. The spacecraft oxygen tank fans were turned on prior to oxygen flow. The oxygen dewar was pressurized to approximately 45 psia. Oxygen was flowed through both tanks for approximately 2 minutes (normal) before an indication was noted on the quantity probe. The flow rate during servicing was 25 pounds per minute for approximately 25 minutes (both tanks). After the tank quantity reached 100 percent, flow was continued for an additional 10 minutes, to further chill the tanks. The spacecraft vent POD's and the GSE vent were then closed, followed immediately by the closure of the fill POD's. The spacecraft tank fans were turned off at this time. The cold gas trapped in the vent line was sampled. The oxygen is sampled for helium, nitrogen, and total hydrocarbons. Both samples were within specification. The service module supply valve was opened to allow the CM surge tank to pressurize for flight.

While pressurizing the surge tank, fuel cell 1 was connected to dc bus A to minimize the usage of liquid hydrogen. A constant flow from the liquid hydrogen tanks equal to the heat gained by the tank results in minimum liquid hydrogen usage. The load on the fuel cell was approximately 20 amps. This configuration was maintained until 4 hours before launch, at which time fuel cells 2 and 3 were connected to the busses. Fuel cells 1 and 2 were connected to bus A with fuel cell 3 supplying power to bus B. The fuel cells supplied power to the spacecraft from this time through launch.

Ground electrical power was supplied to the tank heaters to bring the tanks to flight pressure. The liquid oxygen system pressurization to approximately 935 psia and the liquid hydrogen system to approximately 235 psia was completed by 6:40 p.m. on April 9, 1970. The fuel cells were supplied by onboard reactants from this period through launch. Fan motor checks were performed, and the GSE and airborne systems closed out for flight.

The entire CSM cryo loading operation was normal except that liquid hydrogen tank no. 1 was loaded to 98.7 percent instead of the desired minimum 99 percent (reason for this is still under study by both the Manned Spacecraft Center and the Kennedy Space Center) and a slight leak developed through the liquid oxygen tank no. 2 vent quick disconnect. The leak was stopped by the installation of the flight cap prior to tank pressurization. These conditions were determined to be acceptable for flight.

Spacecraft Closeout and Terminal Count

Following completion of the cryo loading operation the countdown proceeded normally from T - 32:00:00 through such milestones as: LM crew provision stowage and final closeout; LM SHe servicing; launch vehicle battery installation and electrical systems checks; CSM crew provision stowage; backup astronaut crew checks; and ALSEP fuel cask installation.

At 7:00 p.m. e.s.t. on April 10, 1970, the countdown clock was held at T - 9:00:00 for a planned built-in hold of 9 hours and 13 minutes. Following resumption of the countdown at 4:13 a.m. e.s.t. on April 11, 1970, final launch vehicle cryogenic loading preparations were completed and launch vehicle cryogenic loading was successfully conducted through 9:30 a.m. e.s.t.

The remainder of the countdown activities, including flightcrew ingress, final CSM cabin closeout, and the space vehicle terminal count, progressed normally with the exception of a minor problem with a broken key in the CSM pyro guard, and a stuck open no. 2 liquid oxygen vent valve in the S-IC stage. Both problems were satisfactorily resolved within the planned countdown time, which included a final built-in hold of 1 hour at T - 3:30:00 minutes.

LAUNCH AND TRANSLUNAR COAST PHASE PRIOR TO THE ACCIDENT

Launch and Flight Summary

The space vehicle was launched at 2:13:00 e.s.t., April 11, 1970. The only unexpected occurrence during the boost phase was an early shutdown of the S-II inboard engine. Low frequency oscillations (approximately 16 hertz) occurred on the S-II stage, resulting in a 132-second premature center engine cutoff. Preliminary analysis indicates that an engine pressure sensor detected a varying engine thrust chamber pressure resulting from a large pressure oscillation in the liquid oxygen system and turned the engine off. The four remaining engines burned approximately 34 seconds longer than normal, and the S-IVB orbital insertion burn was approximately 9 seconds longer to achieve the required velocity. The cause of the liquid oxygen system oscillation is presently being studied by the Marshall Space Flight Center. A parking orbit with an apogee of 100.2 nautical miles and a perigee of 98.0 nautical miles was obtained.

After orbital insertion, all launch vehicle and spacecraft systems were verified and preparations were made for translunar injection. The second S-IVB burn was initiated on schedule for translunar injection.

All major systems operated satisfactorily and conditions were nominal for a free-return circumlunar trajectory. With the spacecraft in a free-return trajectory, and with no further major propulsion burns, the spacecraft would pass around the Moon and reenter the Earth's atmosphere.

The command service module (CSM) separated from the service module LM adapter (SLA) at 3:06:39. The spacecraft was maneuvered and docked with the lunar module (LM) at 3:19:09 and the LM separated from the SLA at 04:01:00. The S-IVB was then maneuvered using residual propellants to impact the lunar surface. The first midcourse correction (23.1 fps), performed at 30:40:50 using the service propulsion system, inserted the spacecraft into a non-free-return trajectory with a pericynthian altitude close to the planned value of about 60 miles. Under these conditions, with no further propulsion engine burns, the spacecraft would orbit the Earth in a highly elliptical orbit. These trajectories are discussed in more detail in Part B6 of this Appendix.

The mission was routine and generally proceeded according to the timeline. Because the crew was ahead of schedule and midcourse correction number 3 was cancelled, an early entry into the lunar module was made at 55:00:00. A scheduled television broadcast to the Earth was made between 55:15 and 55:46, and at the time of the accident, both the Commander and Command Module Pilot were in the command module while the Lunar Module Pilot was just entering the command module from the lunar module.

Spacecraft Systems Operation

This section of the report will deal only with problems and events in the various systems encountered with the CSM during the powered phase, parking orbit, and translunar coast phase of the mission up to the time of the accident. The systems will be treated separately except that electrical current and voltage fluctuations associated with the operation of the fans to stir the supercritical oxygen and hydrogen will be covered under the cryogenic section.

CSM structural-mechanical.- Structural loads during boost phases of the flight were within acceptable limits. Command module structural oscillations of less than 0.1g at 16 hertz in all directions were measured during the period of S-II longitudinal oscillations (POGO) prior to the center engine cutoff. The levels of these oscillations were comparable to those measured during ground test and on previous Apollo missions.

At approximately 00:25:00 minutes, a computer program was entered into the computer to align the inertial measuring unit. During this alignment, the sextant is rotated, which in turn releases the external ablative optics covers. The optics covers are spring loaded, and held in place by clips. When the sextant is rotated, an arm located on the sextant engages a cam that releases the clips and jettisons both covers. Minor difficulty was experienced in jettisoning the two covers. The optics were rotated twice manually to 90 degrees according to the checklist, but the covers did not jettison. The optics were then rotated in the automatic mode (past 90 degrees) and the covers jettisoned. The cause of the covers not jettisoning was that the sextant was not rotated far enough in the manual mode to completely engage the cam.

After CSM/LM docking, the crew reported that two docking latches were not fully engaged. Both latches were opened and reset. There are 12 docking latches on the command module. Each latch has a trigger that is engaged when the lunar module docking ring comes in contact with the CSM docking ring. The handle has a red indicator that indicates when the latch is engaged. On several spacecraft during ground checkout one or two of the latches had to be reset manually, as in the case of Apollo 13. The prime cause is not having the two docking rings perfectly parallel at the time of engagement. The manual resetting of one or two of the latches is considered satisfactory.

The crew reported a slight "burnt" smell in the tunnel area between the CSM/LM when entering the tunnel, which is normal.

Electrical power.- The electrical power distribution and sequential system, except for the fuel cells, operated as expected until the time of the accident. The electrical parameters associated with the fan turnon and turnoff times will be discussed in Part B9.

At about 30:45:00 the fuel cell 3 condenser exit temperature pattern was observed to change to a sinusoidal ripple with a frequency of 1 cycle every 30 seconds and a peak-to-peak amplitude of 6.2° F. The oscillations continued for approximately 9 hours and then stopped. Similar oscillations had been observed on Apollo 10 during lunar orbit, and subsequent analyses and tests showed that the oscillations were not detrimental to the performance or life of the fuel cells. These transients are attributed to slugs of cold water leaving the condenser.

Instrumentation.- Four discrepancies in the instrumentation system were noted. At 46:40:06 the oxygen quantity measurement located in oxygen tank no. 2 indicated 100 percent. This anomaly will be discussed in detail in Part B9. The cabin pressure indicated 1/2 psi above the suit pressure until powerdown of the CSM after the incident. (Should be approximately the same with the crew out of the suits.) During the boost phase, when the cabin vented the transducer did not follow the cabin pressure and operated erratically for the remainder of the flight. This erratic operation was very similar to the erratic operation of the identical transducer on Apollo 12. Failure analysis of the Apollo 12 transducer indicated contamination inside the transducer.

Early in the mission (22:38 and 37:38) the potable water quantity transducer acted erratically for a brief period. This instrument has operated erratically on other spacecraft during ground checkout and flight due to oxidation of electrical winding on the transducer potentiometer. This oxidation causes intermittent contact between the wiper arm and the wiring on the potentiometer, thus giving erratic readings.

At approximately T + 32 hours, the crew reported that the spacecraft panel meters indicating fuel cell hydrogen versus oxygen flow were not exactly matched for fuel cell 3. All indications on the ground were normal. Prelaunch ground data once indicated a mismatch in panel indication on fuel cell 2. Since the instrumentation data in both cases were correct, the most probable cause was an intermittent fault in the meter circuitry causing the shift.

Communications.- At 55:05:32 the crew reported that they could not operate the high-gain antenna (HGA) in narrow beamwidth auto track or reacquisition modes. A maneuver to the passive thermal control (PTC) attitude was prescribed and as the maneuver was initiated, the crew manually positioned the antenna and acquired automatic tracking in the narrow beamwidth mode. The antenna operated normally until the accident. When troubleshooting (before lockup) both the primary and secondary electronics and both the automatic and reacquisition tracking modes were unsuccessfully attempted. Analysis indicates an effective misalignment existed between the boresight of the wide and narrow beams. The beam effective misalignment could have been caused by a defective radio frequency (RF) stripline coaxial cable, mechanical failure, or RF feed lines. A boresight shift was not indicated during antenna acceptance testing or during KSC ground checkout.

Service module propulsion and reaction control.- The service module propulsion system was used only once during the mission at 30:40:50 to place the spacecraft into a non-free-return trajectory. The engine burned for 3.6 seconds, and all parameters were nominal. The thrust chamber pressure seemed about 4 percent below preflight prediction, but within acceptable limits.

Guidance and control.- Guidance and control system performance was satisfactory, with the exception of small fluctuations of the optic shaft when in the zero optics mode and in establishing passive thermal control (PTC). At approximately 7:30:00 the crew reported difficulty in establishing PTC. The attempt resulted in a very wide and diverging coning angle. It was determined that the digital autopilot was incorrectly loaded and all roll thrusters were not enabled. The checklist did not call out the correct autopilot load and the thruster enabling was a late pen-and-ink change to the onboard checklist. Using the revised procedure, the PTC mode was successfuly established.

At about 40:00 the ground controllers noticed small fluctuations of the optic shaft when in zero optics mode. As on Apollo 12, the ground data showed a slight jitter in the optics shaft angle from 0 to 0.6 degree. A special test was conducted at 49 hours to verify the shaft oscillations. The crew compared the shaft and trunnion angles to the mechanical counters on the optics. The oscillation was evident from both sources and occurred in the optics zero mode only. The optics jitter presented no constraint to the operation of the optical system; however, at 49:51:37 the ground requested the crew to turn off optics power to guard against possible degradation of the system.