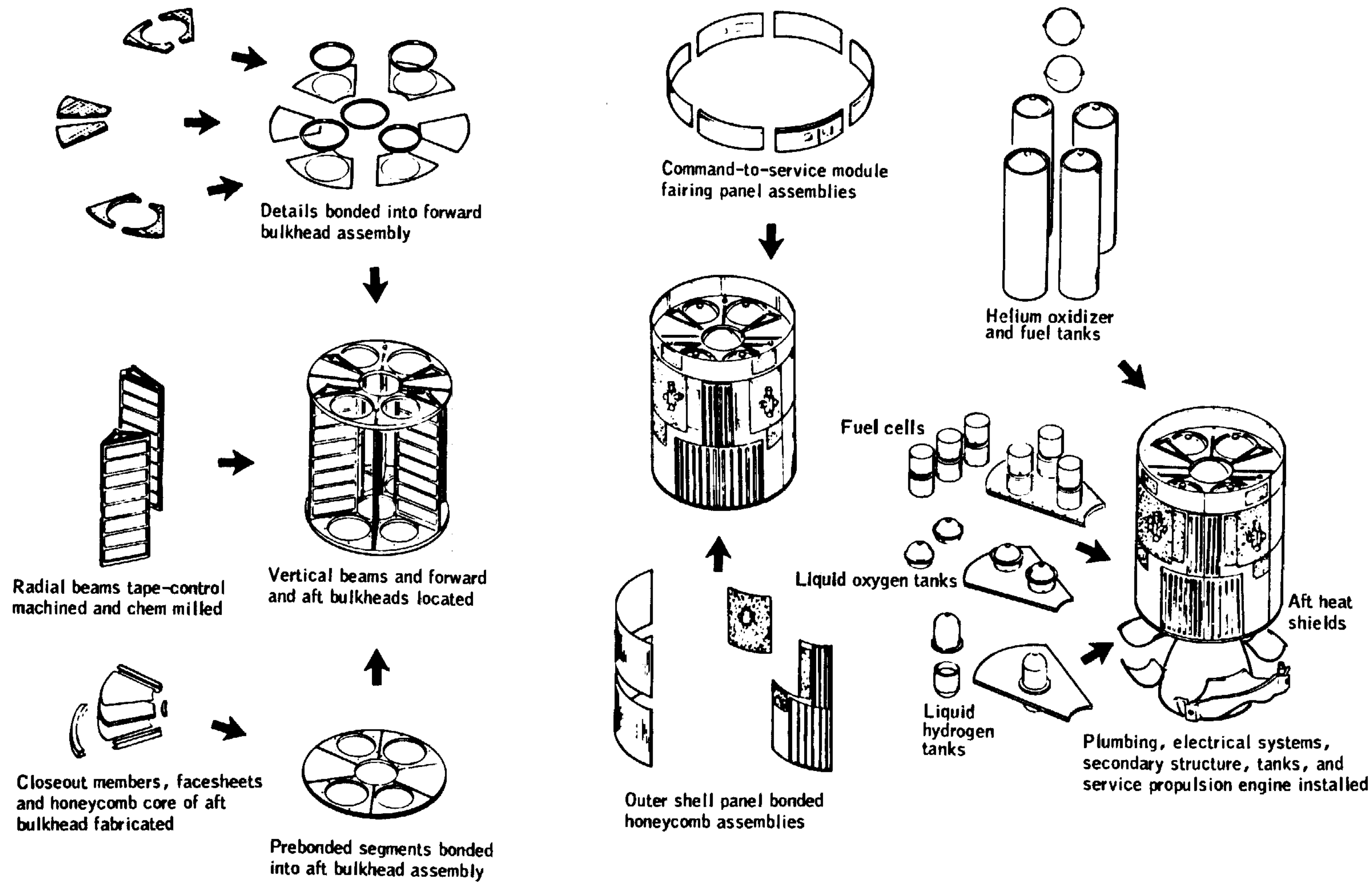


Figure 9-3.- Service module assembly flow.

The service module was then transferred to pressure test cells where each fluids system was subjected to a series of carefully controlled functional tests that demonstrated proper operation in the prime, backup, contingency, and redundant modes. Examples of operations performed to ensure vehicle integrity were proof tests, leak tests at joints (brazed and mechanical), overall systems leakage checks, flow checks, pressure regulator checks, relief valve functional checks, transducer verification, and cryogenic tests.

Following the tests, the vehicle was cycled through the tumble-and-clean positioner to dislodge and remove debris. The cleaned vehicle was then weighed and its center of gravity determined. On completion of these operations, the vehicle was placed in the integrated test stand for the integrated test series described in section 9.1.5. The integrated test completed the manufacturing, test, and checkout operations, and the vehicle was mounted on a shipping pallet and prepared for shipment.

9.1.3 Launch Escape System Assembly and Checkout

The launch escape system consisted of a nose cone, a canard system, launch escape and tower jettison motors, skirt and tower structures, and soft and hard boost protective covers. Subcontractors fabricated and assembled the nose cone, the launch escape motor, and the tower jettison motor. These units were installed as components at final assembly of the launch escape system. A generalized flow of components and subassemblies as they were manufactured is shown in figure 9-4.

9.1.3.1 Canard assembly.- The canard assembly consisted of rings, longerons, a bulkhead, outer skins, an actuating mechanism, and right- and left-hand doors. The structural sections were riveted and bolted together in a jig fixture. The actuating mechanism was installed, checked for proper functioning, and forwarded to final assembly.

9.1.3.2 Skirt structural assembly.- The skirt structural assembly consisted of longerons, circular ring segments, and skin segments that were fusion welded and then riveted together into an assembly. The assembly was finish-machined as a unit and then forwarded to final assembly.

9.1.3.3 Tower structural assembly.- The tower structural assembly was a fusion-welded titanium tubular structure with fittings at each end. The assembly steps are shown in figure 9-4.

9.1.3.4 Boost protective cover.- The boost protective cover consisted of two major assemblies. The forward assembly (hard cover) provided the structural attachment to the launch escape tower which was necessary to allow the cover to be jettisoned along with the launch escape system. This assembly covered about the forward one-third of the command module. This assembly was fabricated on a tool (form) and consisted of fiberglass facesheets and phenolic-honeycomb-core sandwich construction. A layer of cork thermal protection material was bonded to this and the assembly coated with a temperature resistant paint.

The aft assembly (soft cover) provided the thermal protection needed over the remaining two-thirds of the command module. It consisted of an inner layer of Teflon-coated fiberglass cloth to which was bonded the cork thermal protection material. The assembly was made in seven segments to facilitate shipment and final installation. A plaster-splash process was used to obtain the required fit between the soft cover and the command module. An exact duplication of the command module mold line resulted. A mold line simulator tool was then constructed and used to fit and assembly the soft cover. The operation was performed on each spacecraft because of variations of the command module exterior surfaces.

9.1.3.5 Final assembly.- The elements of the launch escape system were assembled, and a final mechanical fit check with the assigned command module was performed. The assembled unit was then used in support of downstream systems checkout activities.

9.1.4 Spacecraft/Lunar Module Adapter Assembly

The spacecraft/lunar module adapter consisted of a forward and an aft section. Each section consisted of four bonded-aluminum-honeycomb-construction subassemblies. Each subassembly was trimmed and assembled on a major assembly fixture in a pit in the floor which was 28 feet deep

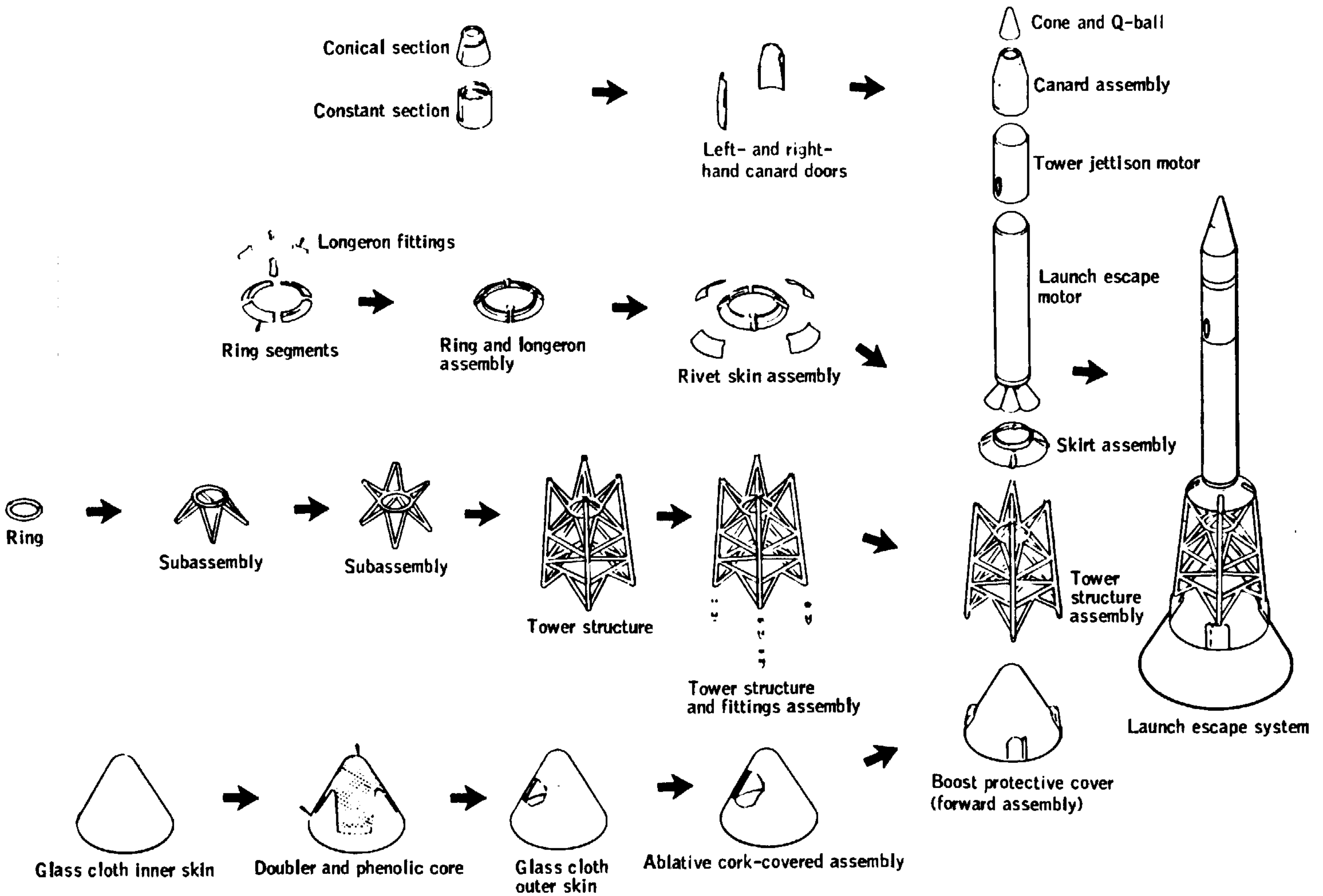


Figure 9-4.- Launch escape system assembly flow.

and 35 feet square (fig. 9-5). This fixture was unique because it was constructed below ground level. The honeycomb panels that made up the subassemblies were prefitted for bonding on assembly jigs, adhesive was applied, and curing was accomplished in one of the largest autoclaves in the United States (fig. 9-6).

Installations of secondary structure and equipment were performed after the assembly was removed from the pit and placed in an above-floor-level workstand. On completion of final assembly, the unit was fitted with a shipping cover and transported to the using site. The first three assemblies were transported by helicopter in approximately 300-mile legs (fig. 9-7). The remaining assemblies were transported by the Super Guppy, a specially modified aircraft.

9.1.5 Systems and Vehicle Checkout

9.1.5.1 Integrated systems checkout.- The integrated systems checkout verified the operation of the electrical, electronic, environmental control, and mechanical systems of the electrically and mechanically mated command and service module. Before power was applied to the spacecraft, a bus continuity check was performed to insure that the power distribution system was wired correctly and that there were no grounded (short-circuited) power circuits. The spacecraft power distribution system was then verified using external power sources and the data systems were checked so that the operational instrumentation systems could be used during systems checkout. Finally, the environmental control system was verified. After completion of the systems testing, the spacecraft was readied for integrated test.

9.1.5.2 Integrated test.- For integrated test, the command module, the service module, and the launch escape tower were electrically mated; electrical simulators were substituted for the spacecraft/lunar module adapter, the launch vehicle, and the spacecraft pyrotechnics; and an inertia simulator was substituted for the service propulsion system nozzle. Ground power was substituted for fuel cell power but batteries with power supply backup were used for the entry batteries.

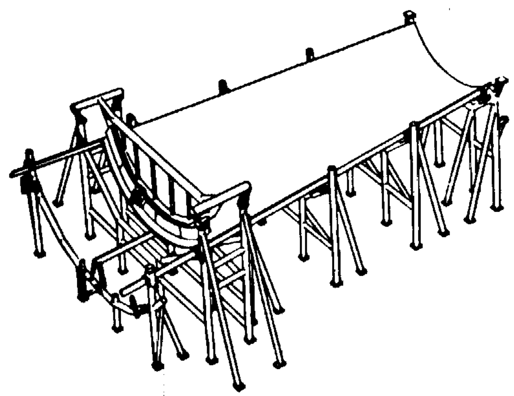
The integrated test was originally performed in two phases: "plugs-in" testing was conducted with the ground checkout equipment connected and "plugs out" testing was conducted with the ground checkout equipment disconnected in an attempt to electrically isolate the spacecraft from the facility grounding system. Beginning with CSM-107 (the Apollo 11 spacecraft), the "plugs-out" phase was abandoned, basically for two reasons. A review of test records revealed that no problems could be identified as resulting specifically from the "plugs-out" configuration and that the vehicle could not, in fact, be electrically isolated.

The integrated test included the abort modes (pad, low-altitude and high-altitude aborts) and the normal mission profile. The normal mission simulation consisted of the following phases: launch profile, orbit insertion, earth orbit, translunar injection and coast, lunar orbit insertion, lunar orbit, transearth injection and coast, entry, and earth landing. The spacecraft systems were exercised as they were expected to be during the various mission phases.

9.1.6 Facilities

The command and service module and the launch escape tower were engineered, designed, assembled, and acceptance tested at the prime contractor facilities at Downey, California. Approximately 400 000 square feet of floor space was used for the Apollo activities. The contractor's facility at Tulsa, Oklahoma, was used to manufacture the spacecraft/lunar module adapter and most of the larger honeycomb subassemblies of the service module.

9.1.6.1 Bonding and test facility.- A 26 000-square-foot building housed the bonding and test facility. Operations performed in this building consisted of honeycomb preparation, metals processing, adhesive preparation, and inspection operations (including ultrasonic). The building contained a temperature- and humidity-controlled room for the adhesive preparation, provisions for overhead handling, complete metal processing facilities, areas for refrigerated storage, mixing equipment, and cutting and spreading tables. Two autoclaves were available for curing the bonded assemblies. One autoclave was especially designed to accommodate the size and shape of the command module. The second autoclave, a standard cylindrical type, was used for smaller panels and subassemblies.


Trimming of the 90° segments prior to assembly

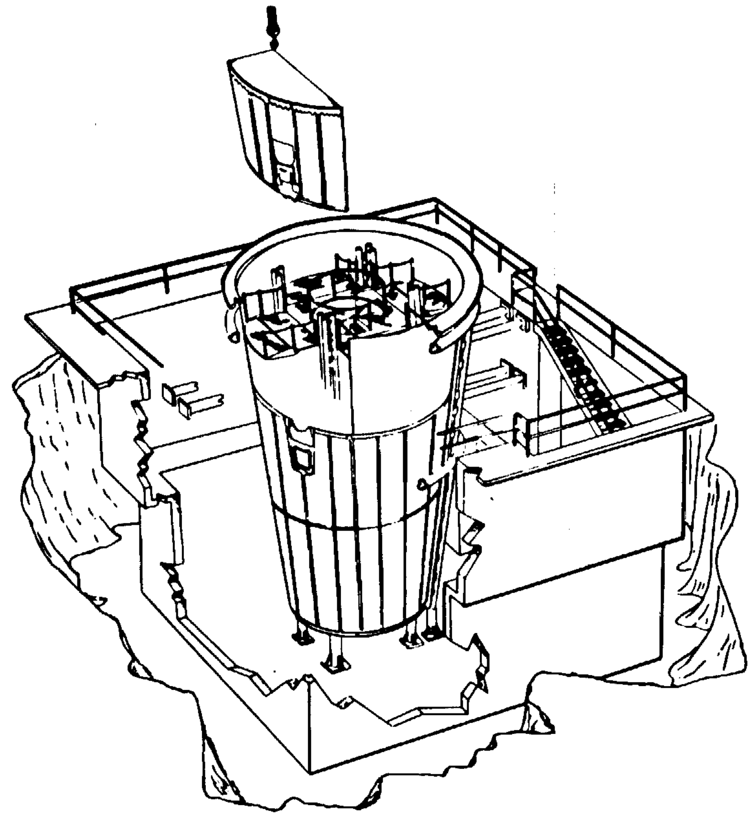

Major assembly fixture and assembly installation

Figure 9-5.- Spacecraft/lunar module adapter mating and assembly.

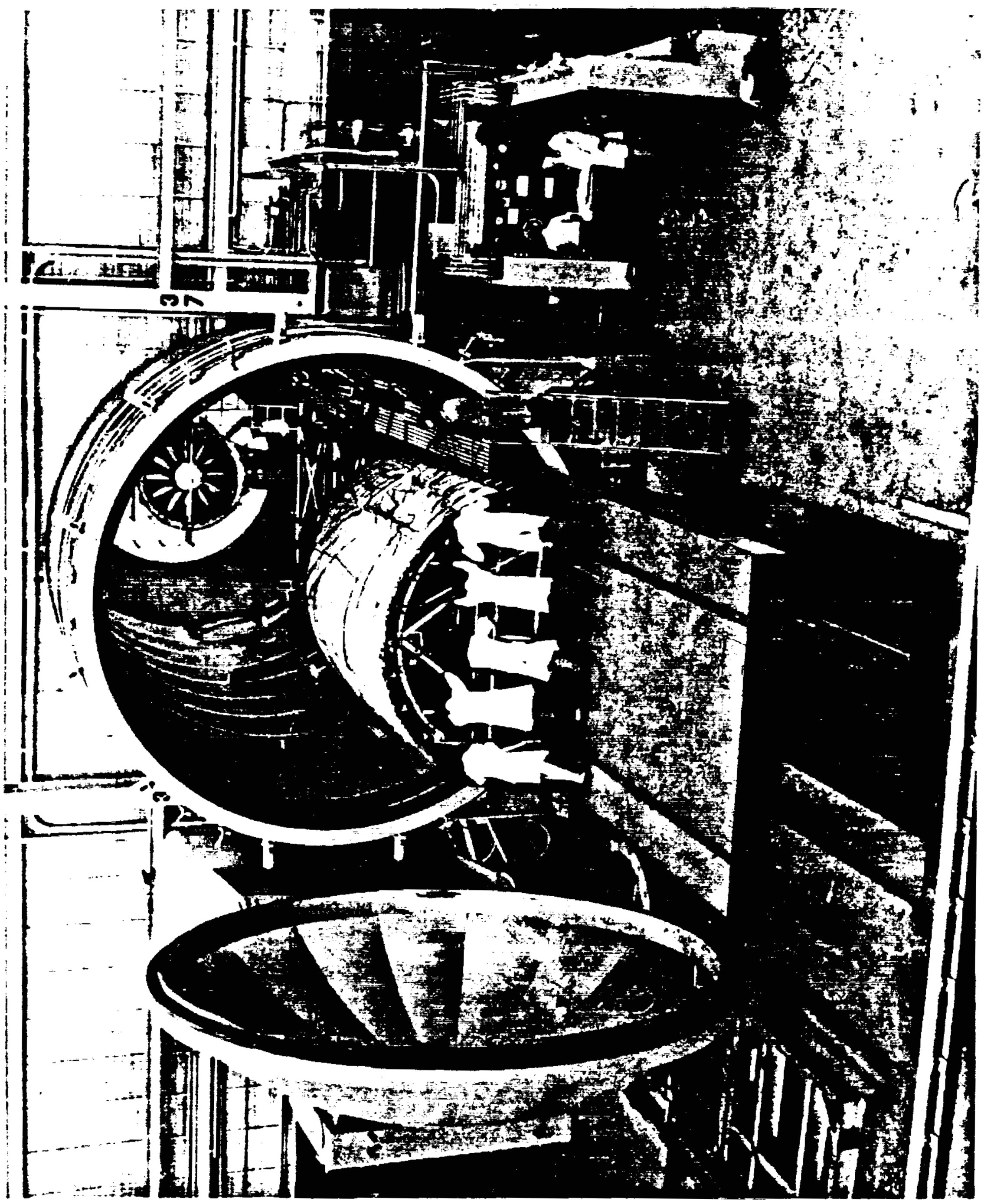


Figure 9-6.- Autoclave at Tulsa facility.

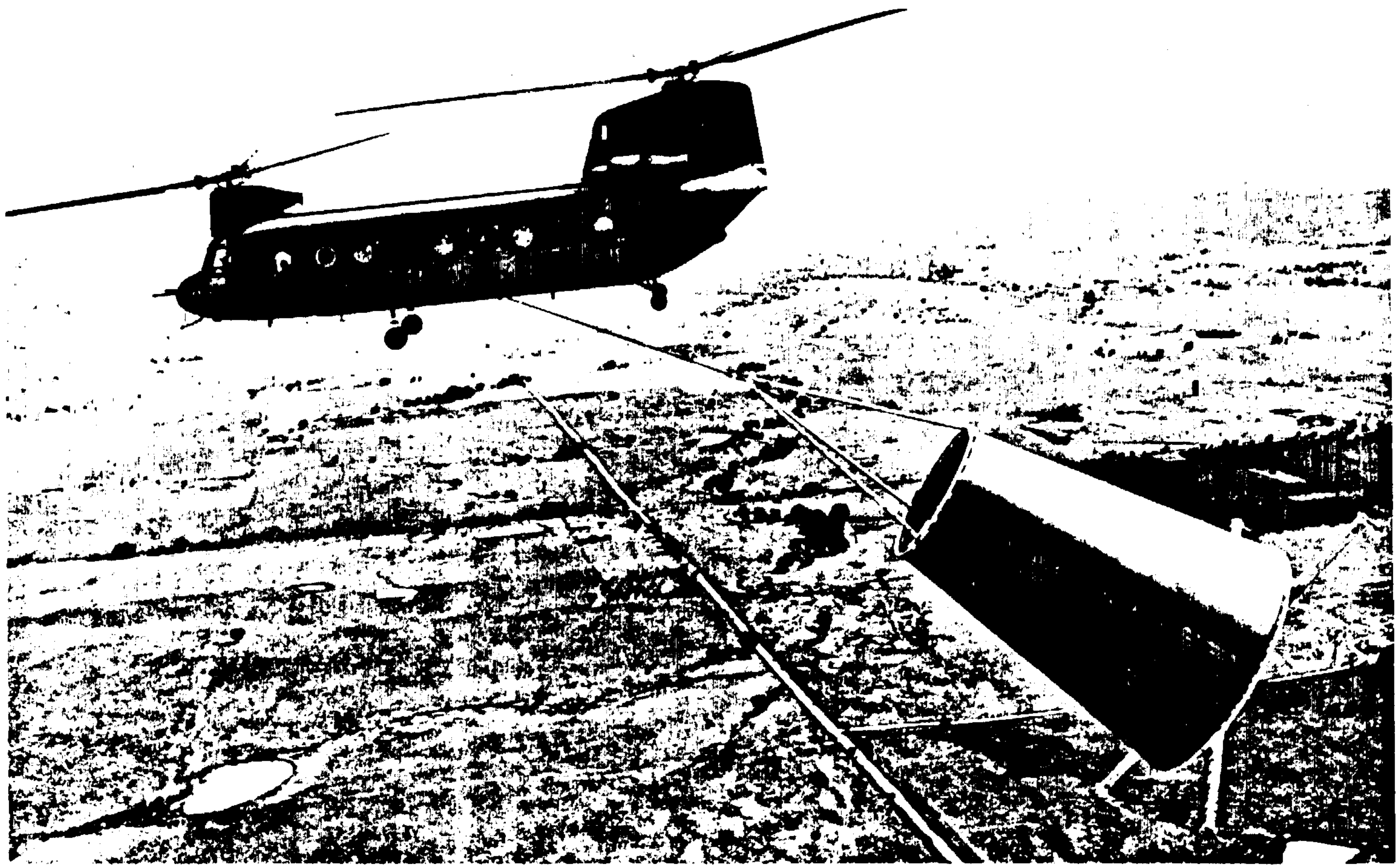


Figure 9-7.- Helicopter transportation of spacecraft/lunar module adapter.

9.1.6.2 Structure fabrication area.- Fabrication of the command and service modules, spacecraft/lunar module adapters, and launch escape towers was performed in approximately 85 000 square feet of high-bay manufacturing area.

Automatic alternating-current and direct-current fusion-welding was used to weld the command module segments. Mechanical equipment was used for trimming and cutting inner and outer panels and holding track-mounted skate heads for all circumferential and longitudinal welding operations.

Protective covers were provided for all spacecraft parts and assemblies to prevent damage to fragile skins, and a special high-lift crane fixture supported tank prefitting and installation operations for the service module.

Manual fusion-welding equipment was used in launch escape tower fabrication operations. Bridge cranes, slings, pickup dollies, and special racks facilitated the handling and transporting of subassemblies and assemblies.

9.1.6.3 Electronic and electromechanical equipment fabrication and checkout area.- An area of approximately 60 000 square feet was provided for the fabrication of electronic and electromechanical equipment. This equipment included deliverable airborne modules, ground support equipment, and systems measuring devices. Operations performed in the production area consisted of wire and sleeving preparation, wire harness and cable assembly fabrication, wiring continuity verification, potting and encapsulation, electronic subassembly fabrication, electronic installation and final assembly, and module and console functional tests.

Standard wire preparation equipment included wire cutters, wire stampers, thermal wire strippers, and small processing ovens. All soldering was performed in an environmentally controlled area that met NASA specifications. This area was air-conditioned; had dust-resistant floors, walls, and ceilings; had 75-foot-candle general illumination and high-level lighting at production work stations; and was equipped with shoe cleaners.

9.1.6.4 Tube fabrication and cleaning facility.- A facility of approximately 12 000 square feet was used for tube fabrication and cleaning. The tube fabrication equipment consisted mainly of cut-off saws, deburring and flaring equipment, and tube bending equipment. Cleaning facilities were provided for the precleaning and final cleaning of stainless steel tubing and for the precleaning, plating, and final cleaning of aluminum tubing. The final cleaning area was environmentally controlled.

9.1.6.5 Pressure testing facilities.- All pressure-testing operations that could not be performed in the final assembly and checkout facility (because of the hazards involved) were performed in special test cells. Hazardous systems and command module tests were performed in a pressure test cell that provided gas pressures and environmental control. Hazardous pressure tests on the service module were performed in an environmentally controlled pit-type test cell that was 25 feet deep, 25 feet long, and 23 feet wide.

9.1.6.6 Systems integration and checkout facility.- An area of approximately 133 000 square feet was provided for spacecraft systems integration and checkout. The interior of the building consisted of four general sections. The sections nearest the east and west walls were of two-story construction to accommodate offices, assembly and maintenance areas, crib control rooms, servicing equipment rooms, and other general supporting areas. The center of the building consisted of a low-bay and a high-bay section. The ceiling of the low-bay section was 42 feet high, and the section had two 10-ton bridge cranes that traveled the full length of the building. This section was used for spacecraft installation, modification, and preparation operations. The ceiling of the high-bay area was 63 feet high, and the section had two 15-ton bridge cranes that also traveled the full length of the building. This area was used for individual systems checkout and integrated systems checkout after module mating.

The primary purpose of this facility was to provide an area in which temperature, humidity, and dust were controlled during installation and checkout operations to assure maximum reliability of the spacecraft integrated systems. Functions performed in this facility included final assembly of systems and subsystems, installation of these components in the spacecraft, individual systems checkout of the command and service module, combined systems checkout of the command and service module, test instrumentation installation, modification and updating to the latest design configuration, integrated test and shipping preparation.

9.1.7 Equipment

The items of manufacturing and test fixtures and equipment used to support the assembly and checkout of the Apollo command and service module were numerous. Some of the more important items are described and listed in table 9-I to provide a generalized concept of overall operations.

9.1.7.1 Automatic circuit analyzer.- The large amount of wiring on the spacecraft required that an automatic circuit analysis test program be instituted for validating interconnecting wiring systems. Time for validating wiring systems was reduced by one-fourth, thus decreasing the overall flow time of the vehicle in manufacturing. Test results were displayed and all anomalies recorded to expedite error location, failure analysis, and the required corrective action. The following were typical tests.

a. Continuity of wiring

b. Noncontinuity of unused pins and connectors

c. Short-circuit detection

d. Leakage detection

e. Insulation resistance

f. Electrical connection bonding resistance

9.1.7.2 Acceptance checkout equipment for spacecraft.- The acceptance checkout equipment was a computerized system that provided centralized, programmed control and monitoring of spacecraft checkout operations. The automatic checkout system, coupled with interface equipment, a digital test command system, and a digital test monitor system, provided manual, semiautomatic, and automatic modes of operation to accommodate system testing, integrated testing, and launch support.

The testing of spacecraft systems was controlled from modules located in system consoles. The modules facilitated the input of the appropriate command selections, computer subroutine selections, or spacecraft guidance computer information to the spacecraft.

Each system console had a variety of test-command capabilities that were necessary for the testing and checkout of a particular system. A console could operate independently simultaneously with other system consoles. The up-link computer interpreted and reacted to the commands initiated from the system console. The signals generated by the acceptance checkout equipment ground station were transmitted by hardlines to the digital test command system. Redundant transmission checks and verification tests were accomplished to ensure maximum confidence in proper command transmissions.

Test data to be down-linked were obtained from sensors in the spacecraft and from the ground support equipment. These data were signal-conditioned in the digital test monitor system and transmitted as serial pulse-code-modulated data to the recording and display equipment that received, recorded, and displayed the spacecraft performance data, as required by the specific test being conducted.

The down-link computer performed the required processing functions such as predetermined limit checks, engineering unit conversions, and data compression. The data were converted to signals displayed as alphanumeric characters on the appropriate system consoles. Displays included unique outputs based on special requirements, the status of automatic test sequences, and the status of specific parameters. Blinking displays indicated that parameter limits were being exceeded.

TABLE 9-I.- COMMAND AND SERVICE MODULE MANUFACTURING FIXTURES AND EQUIPMENT

Fixture/equipment	Purpose
Bonding autoclaves:	Bonding operations.
Cylindrical (12 x 20 ft)	
Clamshell (15-ft diam.)	
Weld fixtures:	
Circumferential skate-type tool	Trim and weld inner shell and ring assembly (crew compartment) to inner aft bulkhead.
Headstock and tailstock positioner	Position, support and rotate crew compartment horizontally during final assembly.
Ferris wheel inner sidewall assembly tool	Assemble, trim and weld inner sidewall components.
Ogive bulkhead tool	Trim and weld bulkhead segments.
Forward inner structure assembly tool	Trim and weld forward inner structure subassembly.
Tumble-and-clean fixture	Dislodge and remove debris resulting from manufacturing operations.
Weight and balance fixture	Determine dry weight and center of of gravity of command module and service module.

9.2 LUNAR MODULE

9.2.1 Ascent Stage Assembly and Checkout

The ascent stage structure consisted of four subassemblies: the front face, the cabin skin, the midsection, and the aft equipment bay. Fabrication of these four subassemblies was accomplished in fixtures; on completion, the subassemblies were placed in an ascent structure main fixture for final assembly and mating operations. The structural assembly was then subjected to a cabin proof and leak test. Optical alignment of the navigation base and secondary structure installation were completed in an ascent structure workstand. The completed structural assembly was then installed in an environmentally controlled ascent stage general fixture for installation of electrical equipment, fluids systems, the reaction control system, the environmental control system module, and other equipment, as shown in figure 9-8.

The ascent stage was then moved to a cold-flow facility for the initial fluids test and checkout operations. Each fluids system was subjected to a set of carefully controlled functional tests that demonstrated proper operation. Testing was conducted to proof the system; test for leaks at joints (both brazed and mechanical); check overall systems leakage, flow rates, pressure regulators, and relief valve functions; and verify orifice configuration to assure proper fluid ratios of oxidizer and fuel for the propulsion system.

From the cold-flow facility, the ascent stage was processed through a rotate-and-clean operation. The cleaned stage was then transferred to an integrated general fixture where the electronic equipment was installed, thermal insulation and thermal shielding were prefitted, the ascent engine was installed, and the primary guidance and navigation system was installed and aligned.

Final test and checkout of the systems (integrated systems tests) were accomplished after the ascent and descent stages had been mated. An entire complex of ground support equipment was interfaced with the assembled stages and, with a carefully controlled set of operational checkout procedures, each system was subjected to controlled stimuli. The responses of the vehicle subsystems were recorded for comparison to the pass/fail criteria required for acceptance. Discrepancies, if found were recorded; troubleshooting was performed to isolate the anomalous condition; corrective action was provided; and retests were conducted to demonstrate satisfactory resolution.

The ascent stage was moved back to the cold-flow facility for final fluids systems test. The ascent stage propulsion and reaction control systems were subjected to procedural tests which demonstrated that the fluid flows, pressures, and functional paths conformed to specifications and could support mission requirements as complete systems. Final verification of the coolant-loop servicing and functional capability was also performed at this time. The ascent stage was then moved back to the integrated general fixture and mated to the descent stage in preparation for the formal engineering acceptance test described in section 9.2.3. On completion of the test, the ascent stage was transferred to a weighing fixture. The stage was weighed, the center of gravity located, and a final inspection made to confirm readiness for shipment. After removal of some of the more fragile equipment such as antennas, which were shipped separately, the ascent stage was packaged for shipment.

9.2.2 Descent Stage Assembly and Checkout

The descent stage structure consisted of machined parts and panel stiffener assemblies that were mechanically joined. The engine compartment was assembled, the tank compartments formed, the upper and lower deck assemblies added, and the machined interstage fittings attached to complete the structural assembly. This assemblage was accomplished in a descent structure main fixture. The stage was then moved to a descent structure workstand where the fluids equipment and wiring was installed. Gross leak checks and harness verification tests were subsequently performed within an environmentally controlled fixture as shown in figure 9-9. Following the equipment installation operations, the stage was moved to the cold-flow facility for testing similar to that described for the ascent stage.

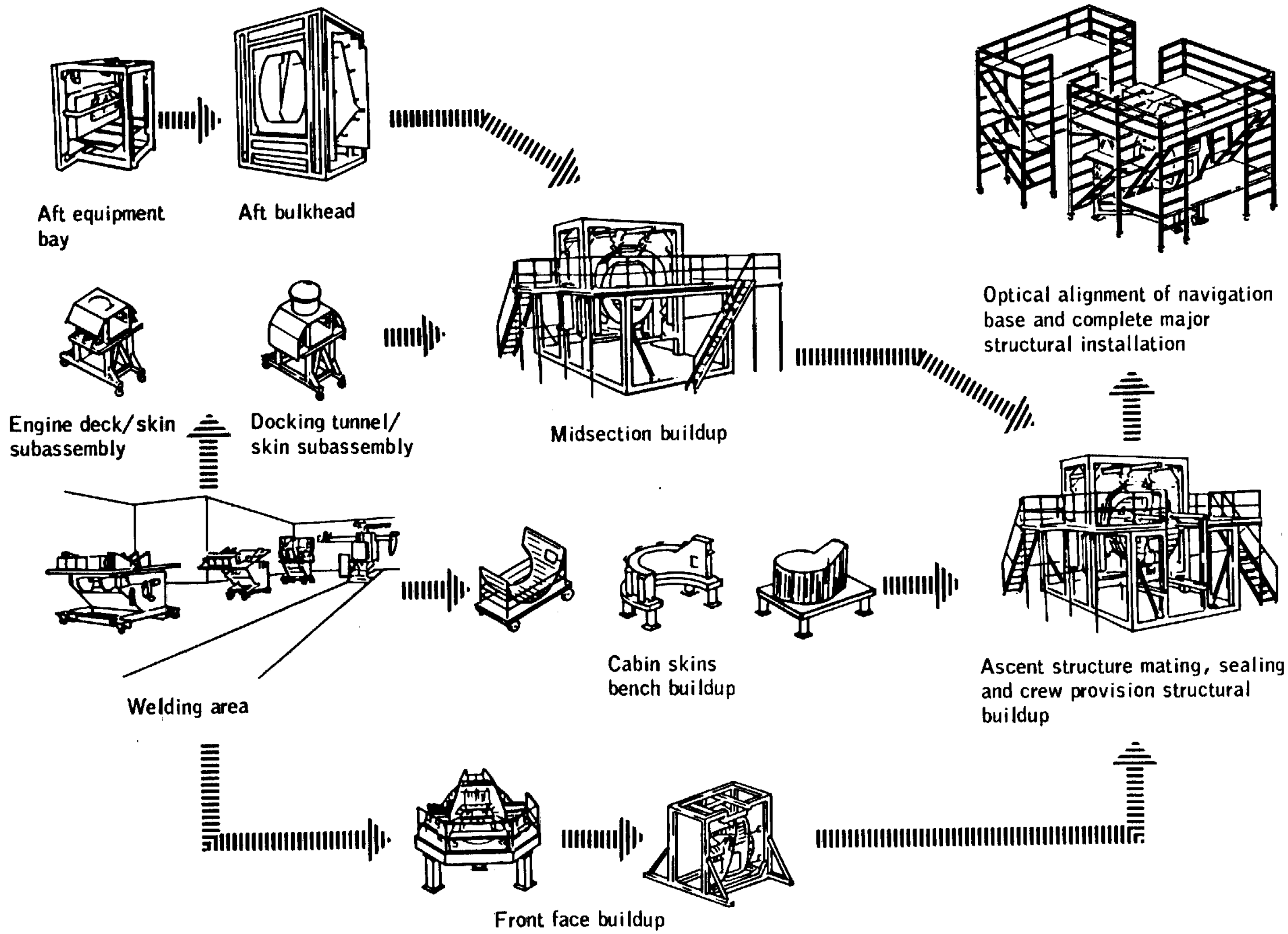


Figure 9-8.- Ascent stage assembly and checkout.

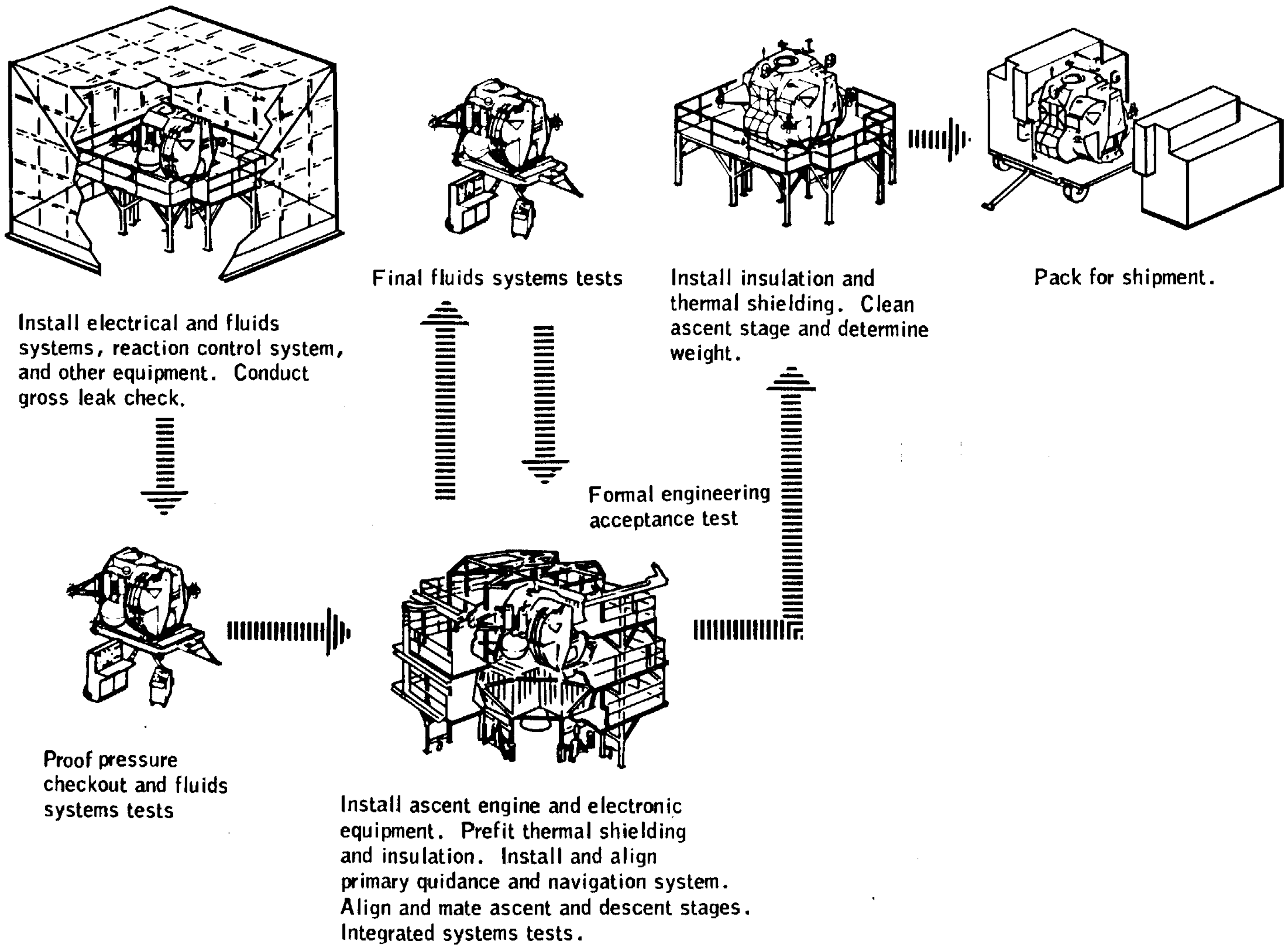


Figure 9-8.- Ascent stage assembly and checkout - Concluded.

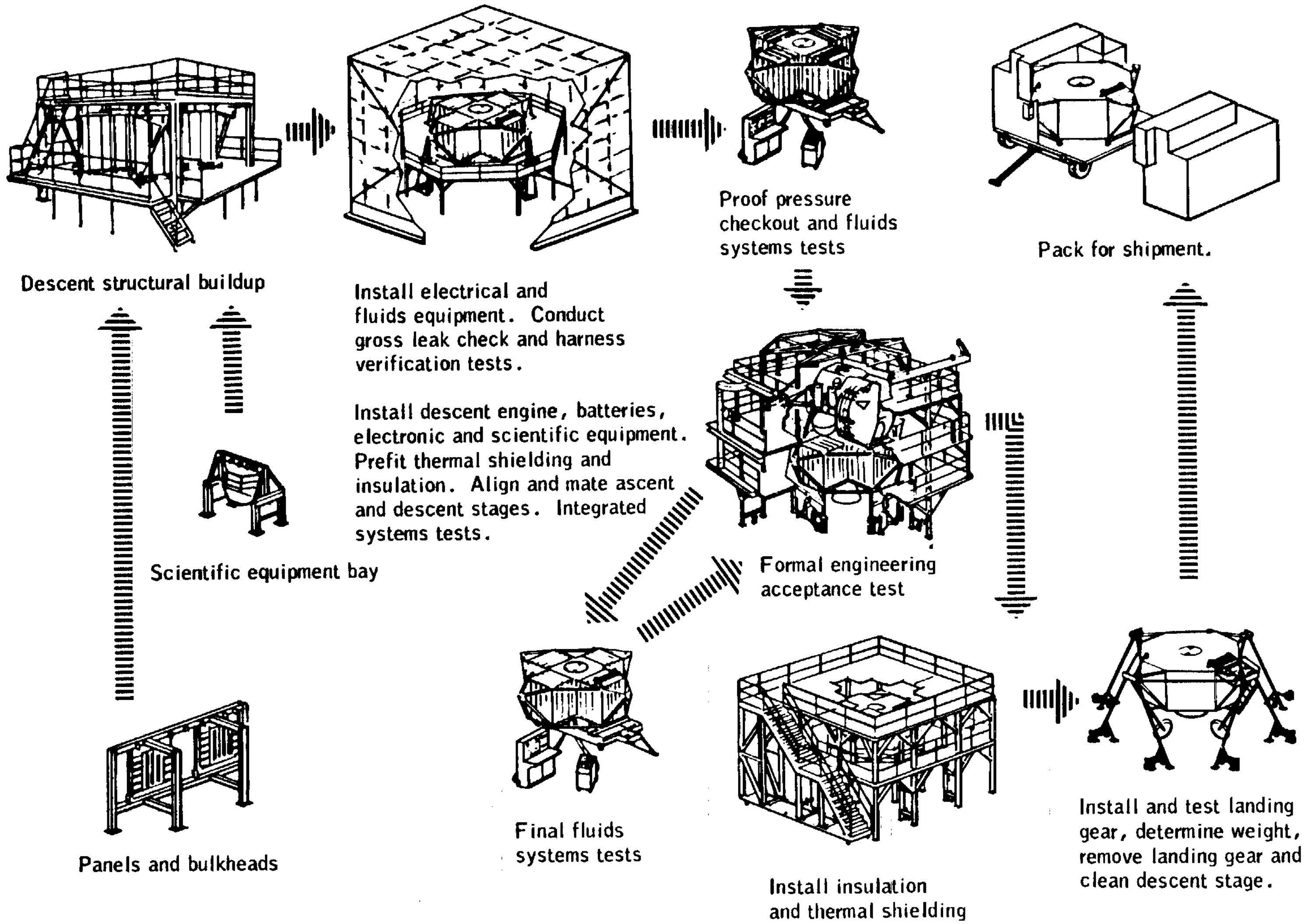


Figure 9-9.- Descent stage assembly and checkout.

From the cold-flow facility, the descent stage was processed through the rotate-and-clean operation. The cleaned descent stage was then moved to the integrated general fixture for installation of electronic and scientific equipment, the descent engine, and for alignment and mating with the ascent stage in preparation for integrated systems tests. On completion of the tests, the descent stage was again moved to the cold-flow facility where final verification was made of the engine installation and the descent propulsion system. When these tests were completed, the descent stage was transferred back to the integrated general fixture and mated to the ascent stage in preparation for the formal engineering acceptance test (sec. 9.2.3). After the test was completed, the landing gear were attached and tested for functional operation, the stage was weighed, the center of gravity was determined, and the landing gear were removed. After a final inspection to confirm readiness for shipment, the descent stage was packed for shipment.

9.2.3 Formal Engineering Acceptance Test

The formal engineering acceptance test was designed to exercise all functional paths of the lunar module vehicle systems. Four ground support equipment/vehicle test configurations were used during the test to provide, as nearly as possible, flight stimuli and response conditions without compromising the vehicle hardware.

The first test configuration consisted of the integrated vehicle with simulated reaction control system thrusters, power supplies instead of batteries, and all the ground support equipment instrumentation associated with the automatic checkout equipment. This test verified the total lunar module systems electromagnetic compatibility performance in typical mission modes. The ascent and descent stages were electrically and mechanically mated for the descent abort and abort staging phases of the mission simulations. The ascent stage was electrically disconnected for the ascent stage simulations.

The second test configuration consisted of the ascent stage and special timing equipment attached to the ground support equipment connectors on the reaction control thruster solenoid circuits. This test was conducted after final wiring of the flight thrusters was completed, and proper timing of the thruster valves and proper primary-to-secondary coil identification were verified.

The third test configuration consisted of the mated descent and ascent stages supported in a fixture that provided motion in the pitch, roll, and yaw axes on command. The end-to-end polarity of the attitude control loop was verified by physically rotating the vehicle and verifying proper response of the rate gyros and the abort sensor gyro assemblies about the vehicle axes.

The fourth test configuration consisted of the mated stages connected to a very minimum of ground support equipment. The vehicle was equipped with flight-type batteries. Each functional phase of a manned lunar mission was performed with switch sequences programmed to duplicate prelaunch checkout, earth-orbit operations, translunar preparation, separation and lunar-orbit insertion, lunar descent and landing, lunar stay, pre-ascent checkout, primary guidance powered ascent, and a demonstration of the abort guidance system abort and rendezvous capability. The test was performed by radio up-link to the lunar module and monitored by radio down-link displays on consoles in an automatic checkout equipment station control room.

9.2.4 Facilities

The lunar module was engineered, designed, manufactured, and acceptance tested at the prime contractor's plant in Bethpage, Long Island, New York, before shipment to the Kennedy Space Center in Florida for launch preparations. The plant consisted of 21 major facilities with more than 5 million square feet of operating space. Since virtually all the prime contractor's manufacturing and testing tasks were to be performed within the Bethpage complex, the facilities selected for lunar module manufacturing and testing were located within a 1-mile radius, thus allowing for an efficient flow of parts, components, and subassemblies to a centralized final assembly and test area.

9.2.4.1 Ascent stage structural/mechanical manufacturing area.- An assembly area of approximately 20 000 square feet was allocated exclusively for the ascent stage structure and mechanical systems installation. An additional 200 000 square feet of facilities and equipment were made available for lunar module use on a time-sharing basis with other programs of the prime contractor. This area was selected because of the complete range of equipment and facilities available for manual or fusion welding, resistance welding, chemical milling, spin forming, honeycomb bonding, heat treating, inspection, shipping, and receiving.

9.2.4.2 Descent stage structural/mechanical manufacturing area.- An assembly area of approximately 15 000 square feet was allocated exclusively for the descent stage structure and subassembly elements. An additional 120 000 square feet of facilities and equipment were available on a time-sharing basis for the manufacture of lunar module detail parts. This area was selected because the descent stage structure, which consisted of machined aluminum beams, chemically milled skin panels, and sheet metal parts, was compatible with the manufacturing techniques used in this area in the production of virtually all sheet metal parts for other programs of the prime contractor.

9.2.4.3 Centralized lunar module assembly, installation, and final acceptance test area.- The overall lunar module support area and facilities required for the final assembly, installation, and test of the lunar module before shipment consisted of approximately 70 000 square feet of space for exclusive lunar module use and an additional 40 000 square feet of facilities and equipment made available on a time-sharing basis with other programs of the prime contractor. The final assembly area was capable of supporting three vehicles in integrated testing at one time besides individual work station areas for two descent stages and three ascent stages. The individual work station areas were used to prepare the vehicle for final acceptance tests and shipment.

9.2.4.4 High-pressure test facility (cold flow).- The high-pressure test facility had special features that permitted remote-controlled static and dynamic testing of high-pressure fluid operating systems. Acceptance and development tests were conducted on lunar module propulsion, environmental control, and reaction control systems. Two control rooms housed the operating consoles and data-acquisition instrumentation equipment. A room for electrical and mechanical support equipment was centrally located so that each test cell could be equipped with the necessary plumbing, wiring, and manifolding for supplying electrical, fluid, and gas requirements.

9.2.5 Equipment

Numerous items of manufacturing and test equipment were used to support the assembly and checkout of a lunar module. Some of the fixtures and equipment used during vehicle assembly and testing are listed in table 9-II.

9.2.6 Specialized Support Laboratories

Many specialized facilities were used to troubleshoot specific problems, check electronic packages, environmentally exercise components for acceptance, or otherwise indirectly support operations. The more important facilities and tasks performed are described.

9.2.6.1 Full-mission engineering simulator.- The lunar module full-mission engineering simulator was a manned simulation facility that provided a means of verifying the actual lunar module flight article capabilities, using an integrated system approach. The simulation profiles consisted of descent from lunar orbit to the surface, ascent to rendezvous, and docking with the command and service module. Simulation also verified the ability to perform various mission aborts. The dynamics of the vehicle were simulated with six degrees of rigid-body freedom using a combination of flight-type and commercial-type equipment.

9.2.6.2 Flight control integration laboratory.- The flight control integration laboratory was used for the integration and verification of the flight abort guidance and flight control systems hardware. The ability to operate and control the entire system in a realistic mission situation was verified before use on a flight vehicle. Preinstallation checkout and system troubleshooting of flight hardware were also performed in this laboratory.

TABLE 9-II.- LUNAR MODULE MANUFACTURING FIXTURES AND EQUIPMENT

Fixture/equipment	Purpose
Ascent stage general fixture	Installation of electrical equipment, fluids systems, reaction control system, environmental control system module, and other equipment.
Descent structure workstand	Installation of electrical equipment and fluid systems.
Integrated general fixture	Installation of ascent and descent engines, electronics equipment, primary guidance and navigation system, antennas and other equipment. Alignment and mating of ascent and descent stages. Acceptance testing.
Rotate-and-clean fixture	Tumbling of either ascent or descent stages to remove debris from manufacturing operations.
Landing gear fixture	Temporary installation of landing gear for functional demonstration of system.
Weight-and-balance fixture	Determine dry weight and center of gravity of ascent stage or mated ascent and descent stages.
Automatic circuit analyzer	See sec. 9.1.7.1.

9.2.6.3 Data reduction facility.- An automated data reduction facility, applicable to all spacecraft programs, was used to process telemetry data in automatic, semiautomatic, or manned control modes. Output devices included strip-chart recorders, oscillographs, event records, an X-Y plotter, a digital printer plotter, and card and tape punch equipment.

9.2.6.4 Primary guidance laboratory.- The primary guidance laboratory was used by associate contractors for preinstallation testing, troubleshooting, and acceptance testing of government-supplied hardware for the navigation system and electronic systems before installation in the vehicle. This unique laboratory was staffed by associate contractor personnel who also supplied the necessary ground support equipment to perform all test requirements.

Additional facilities for specialized support included a laboratory for the development of environmental control systems, a simulator for testing of life support systems, a hydrostatic test laboratory, a drop-test fixture, a thermal-vacuum facility, a facility for conducting heat transport and water management tests, and a laboratory for conducting component tests to verify environmental test requirements.

10.0 LAUNCH SITE FACILITIES, EQUIPMENT, AND PRELAUNCH OPERATIONS

10.1 WHITE SANDS MISSILE RANGE

The Apollo launch escape and earth landing systems were qualified at the White Sands Missile Range by a flight test program conducted from 1963 to 1965. The test program also accomplished significant certification testing of the command and service module structures, batteries, and certain flight instrumentation. Another important task was the first use, including fit and function tests, of the handling and checkout ground support equipment for the command and service module. All the property and equipment assets of the NASA White Sands Missile Range Flight Test Office were dispositioned within 60 days of the last Little Joe II flight test.

10.1.1 Launch Complex

All of the vehicles launched in the course of the flight test program at White Sands were launched from Complex 36. The major facilities are shown in figure 10-1.

As originally constructed, Launch Complex 36 consisted of a blockhouse, service tower, and launch pad designed for firing Redstone missiles. After completion of the Redstone program, the service tower and half of the blockhouse were assigned to the Apollo program for Little Joe II launch vehicle qualification and spacecraft abort tests. The other half of the blockhouse and the launch pad were assigned to another program.

Requirements to support the Little Joe II effort included a new launch pad, permanent tracks on which the service tower could be moved to the new launch pad area, a cable trench between the pad and the blockhouse, a facility transformer station, and a transfer and power room near the launch pad. The transfer and power room, known as the power building, contained junction boxes, regulated power supplies, and monitoring equipment. The service tower (fig. 10-2) required extensive modification to accept the Little Joe II/Apollo vehicle which was larger than the Redstone missile. The service tower was configured such that the spacecraft, when attached to the launch vehicle, was enclosed in a clean room for installation and checkout of components and instrumentation.

10.1.2 Vehicle Assembly Building

A vehicle assembly building (fig. 10-1) was constructed approximately 1 mile from the launch area. The building included a high bay area, electromechanical laboratories, storage facilities, and solid propellant rocket motor checkout areas. The little Joe II launch vehicles were unloaded at this building on arrival and, occasionally, the building was used to store an Algol rocket motor overnight. Later, a portable clean room was added in the building to permit final installation of the reaction control and hydraulic actuation systems under a controlled environment.

Permanent office space for operations personnel was not constructed because of the relatively short duration of the program. Instead, 15 mobile office trailers were provided for use during vehicle assembly and checkout activities. Trailers in the launch pad area were moved to a safe site just before initiation of the final systems checks before each launch and were returned after launch.

10.1.3 Little Joe II Control System Test Facility

The control system test facility was located at an isolated site (fig. 10-1) and contained all the equipment required to test and service the reaction control system and the hydraulic-powered aerodynamic control system. The facility included a concrete test pad and a prefabricated steel building that was environmentally controlled to a temperature of 70° ±5° F. The pad and building were separated by a distance of 45 feet for operator safety. The building was

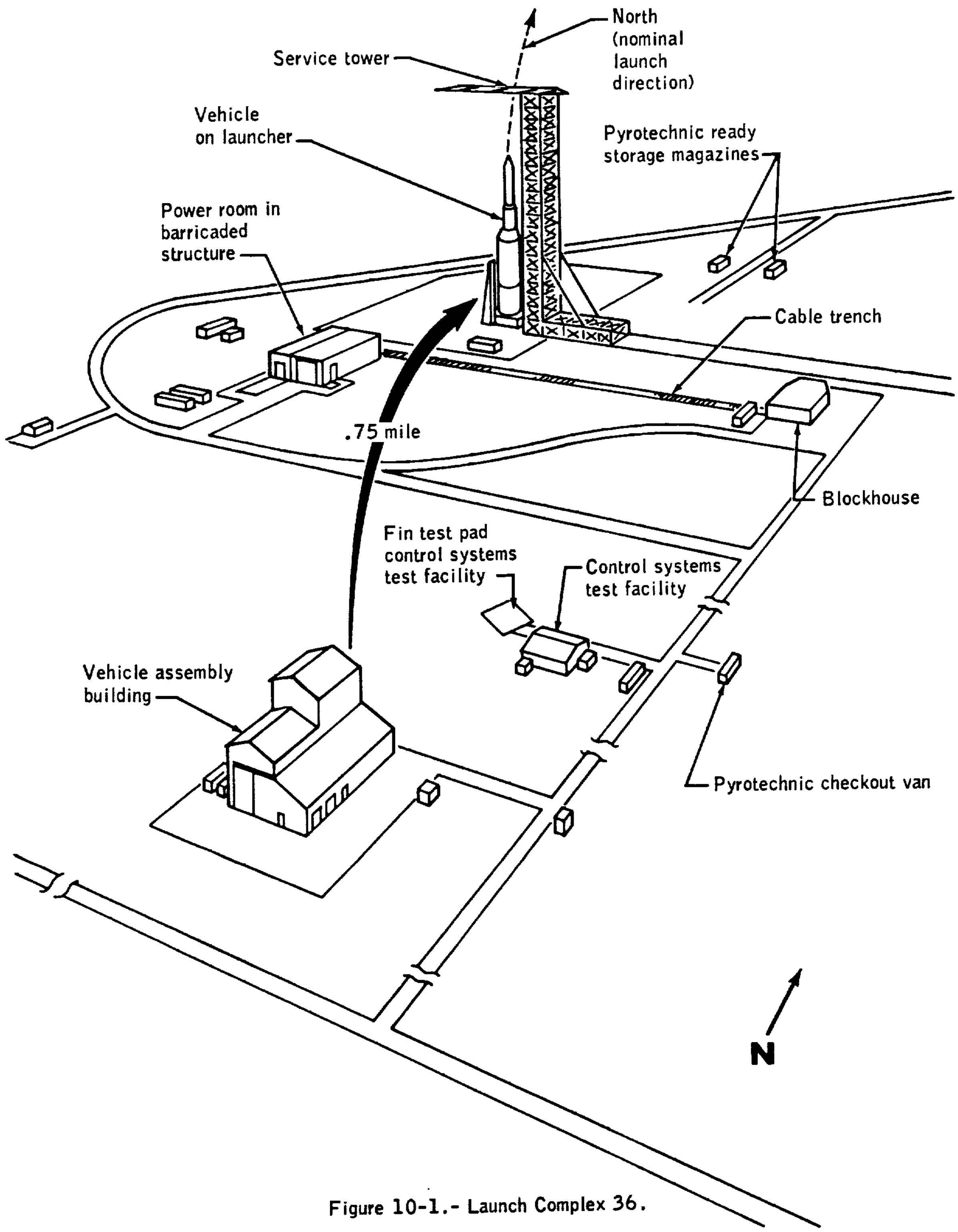


Figure 10-1.- Launch Complex 36.

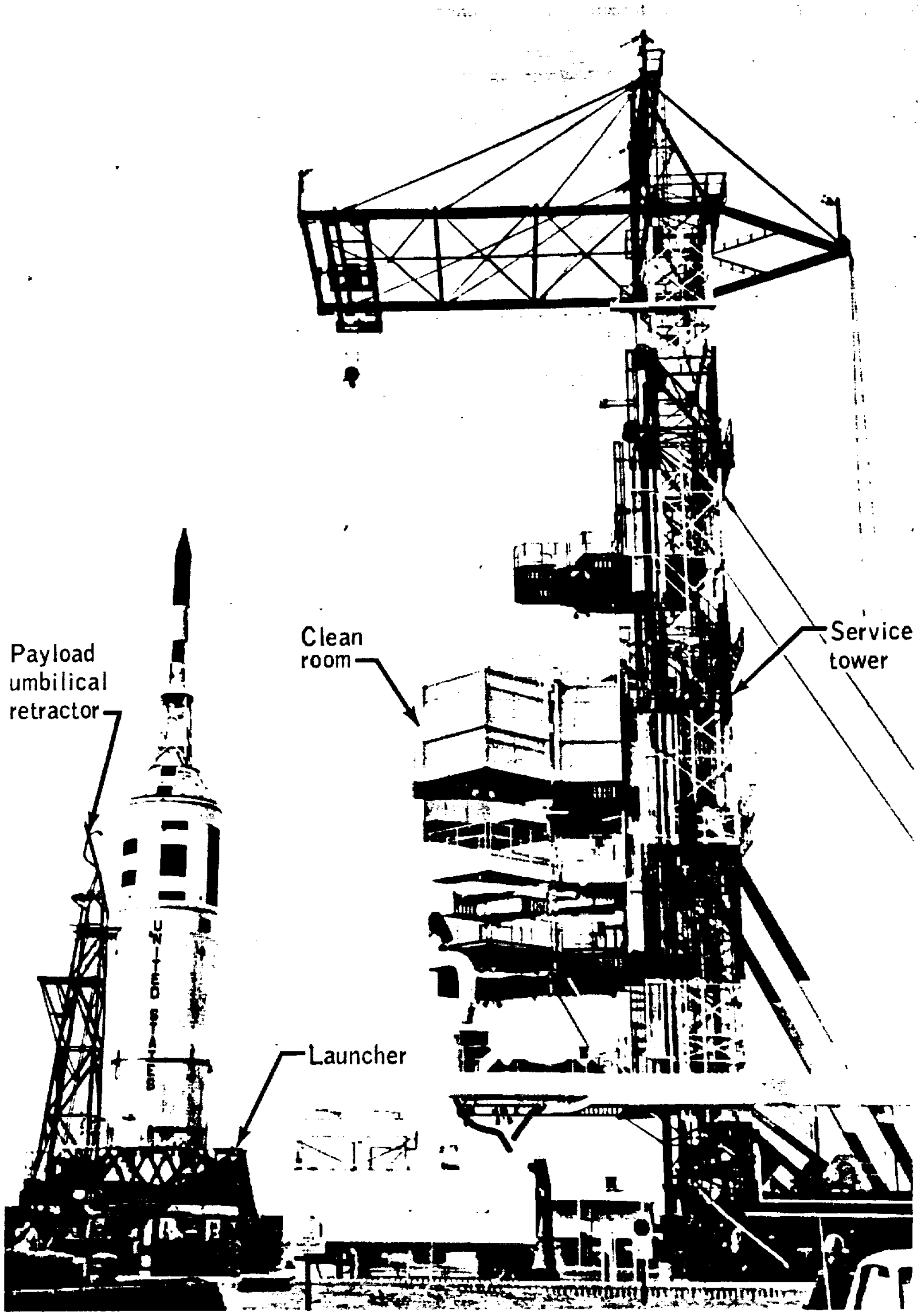


Figure 10-2.- Prelaunch operations at Launch Complex 36.

designed to withstand an overpressure of 42 pounds per square foot, equivalent to the simultaneous explosion of all four reaction control system tanks. The pad included floodlights for night operations, showers and water flushing for hydrogen peroxide safety, tiedowns for the fin stand, and electrical power outlets. The ground-support equipment used for fin servicing was placed on a paved area of the facility. A hydrogen peroxide servicing trailer could be placed inside the building for hydrogen peroxide surveillance. An attitude control fin test control was used to control and monitor fin testing, and portable recording equipment was used to monitor system performance.

10.1.4 Little Joe II Launcher

The launcher (fig. 10-2) was a mechanical structure used for the final assembly and launching of the Little Joe II/Apollo vehicles. Heavy steel I-beams formed the major structure so that a minimum amount of refurbishment was required between launches. The launcher mast, attached to the support platform, supported the payload umbilical retracting assembly and provided the base for two support arms that stabilized the vehicle during thrust buildup and lift-off. The launcher was swiveled on electric-motor-driven crane-type trucks for azimuth positioning. The support platform was pivoted by means of electric-motor-driven screw jacks for elevation positioning. The positioning controls and indicators were located in the blockhouse. In addition, a control panel in the blockhouse contained valve and pressure controls and indicators for the pneumatic systems which operated the vehicle support arms and the payload umbilical retracting assembly.

Changes made to the launcher during the program included (1) redesign of the payload umbilical system for the A-003 mission to accommodate repositioning of the umbilical on boilerplate spacecraft 22, and (2) incorporation of an extension on the mast for the A-004 mission because of the more forward location of the umbilical on spacecraft 002.

The launcher performed as designed for all five Little Joe II launches. All mechanisms performed smoothly before and after each launch, and refurbishment was held to a minimum. Actual launcher positioning was within 6 minutes of the desired angle in azimuth and 1.5 minutes of the desired angle in elevation.

10.1.5 Ground Support Equipment

10.1.5.1 Little Joe II.- The major ground support equipment items for the Little Joe II launch vehicles were consoles and equipment racks used for system control; air conditioning for maintaining motor grain temperature; reaction control system and attitude control system testing and servicing equipment; an environmental tent; handling equipment; and miscellaneous items generally used for test and checkout. There were 248 items of ground support equipment. Of this total, approximately 70 were commercial standard items purchased by NASA, and 50 were commercial standard items purchased by the contractor. The remaining items were manufactured specifically for the Little Joe II program. The launch vehicle manufacturer furnished slings and dollies for handling the vehicle airframes and all components except Algol rocket motors; the rocket motor subcontractor furnished all handling equipment for these motors.

Vehicle systems varied from mission to mission; therefore, continuous surveillance of ground support equipment was conducted. Every effort was made to use available equipment. In general, the ground support equipment performed well.

10.1.5.2 Command and service module.- The command and service module contractor furnished handling, checkout and servicing ground support equipment. The handling equipment (45 units) consisted of support stands, workstands, lifting slings and beams, weight and balance equipment, and transport dollies. The checkout equipment (22 units) included the launch escape and earth landing systems checkout and test equipment, test conductor consoles in the launch control center, and miscellaneous smaller articles for operations such as battery checkout and wire harness continuity checks. Servicing equipment (9 units) included a battery charger, test pressure units, and related equipment. In addition, the contractor furnished miscellaneous auxiliary equipment (28 units) such as tool kits and shipping covers.

10.2 EASTERN TEST RANGE/KENNEDY SPACE CENTER

10.2.1 Saturn IB Launch and Checkout Facilities

AS-101 and AS-102 were missions in which Apollo boilerplate spacecraft were launched from the U.S. Air Force Eastern Test Range in support of spacecraft development objectives. The facility requirements for these launches were minimal in that the Saturn IB development was already well underway and Launch Complex 37 (fig. 10-3) had been in use for a considerable length of time prior to the AS-100 series of flights. Pre-mate checkout of boilerplate spacecraft 13 and 15 was accomplished in Air Force hangar AF, which was also used for the launch vehicle S-IV stage premate checkout. Spacecraft ground support equipment was provided to check the sequential, pyrotechnic, telecommunications, and environmental control systems. Flight development instrumentation was provided as government furnished equipment and existing FM/FM ground stations at hangars S and D were available for telecommunications reception.

During the period following the boilerplate flights, new facilities were constructed and activated for the AS-200 series of unmanned flights to qualify all spacecraft and launch vehicle systems for manned flights. Initial concepts required specific facilities for individual checkout of the various spacecraft systems. Checkout included static firing of the reaction control and main propulsion systems, with an eventual mating of modules and a final test in altitude chambers prior to stacking on the launch vehicle. Figure 10-4 is an artist's conception of the industrial area facilities. The following facilities were constructed: a solid-propellant storage facility, a pyrotechnics and parachute installation building, two cryogenic test buildings, two hypergolic test buildings consisting of two test cells each, a fluid test support laboratories building, an environmental control system test building consisting of two test cells, an ordnance test facility, an operations and checkout building equipped with two altitude chambers and numerous integrated test stands, and a parachute packing building. Also provided were warehouses, repair and maintenance facilities, office space, and a flight crew training building which housed various simulators and trainers for the flight crew. Living quarters and medical and recreational facilities were provided for the flight crews in the operations and checkout building. Sites and the basic industrial needs (e.g., water and power) were planned for a main propulsion static firing facility; however, final construction of the complex was not accomplished. Instead, Air Force Launch Complex 16, an obsolete Titan I launch pad, was equipped to provide static firing and hypergolic ground support equipment maintenance capability at a considerable program cost savings. A surplus water tank was used for environmental protection for the service modules and ground support equipment during hydrostatic testing of replaced service propulsion system tanks and for a static firing of the Apollo 7 service propulsion system before launch.

10.2.2 Saturn V Launch and Checkout Facilities

A procedure in which the space vehicle was assembled and checked out at the launch pad was entirely satisfactory for the Saturn IB flights. However, the size and complexity of the Saturn V vehicle and the scheduled frequency of flights dictated the use of a new mobile launch concept wherein the vehicle was assembled and checked out in a protected environment, and the flight-ready vehicle was transported to the launch site for final servicing and propellant loading. Launch Complex 39 (fig. 10-3) was constructed to carry out the mobile launch concept. The complex was located approximately 5 miles north of the Kennedy Space Center industrial area.

10.2.2.1 Vehicle assembly building.- The Apollo/Saturn V space vehicles were assembled in the vehicle assembly building (fig. 10-5). The building contains a high bay area 525 feet high and a low bay area 210 feet high. With a length of 716 feet and a width of 518 feet, the building has 343 500 square feet of floor space. By volume, it is one of the largest buildings in existence, containing 129 482 000 cubic feet of space.

A cutaway view of the interior of the vehicle assembly buidling, as configured for the Apollo program, is shown in figure 10-6. The high and low bay areas, serviced by a transfer aisle for movement of vehicle stages, formed two distinct operational elements of the building. The high bay area contained four separate bays for the assembly and checkout of the Saturn V stages, instrument unit, and Apollo spacecraft. Access to the space vehicle was provided by work platforms in each high bay. Each platform was constructed in two parts. The parts could

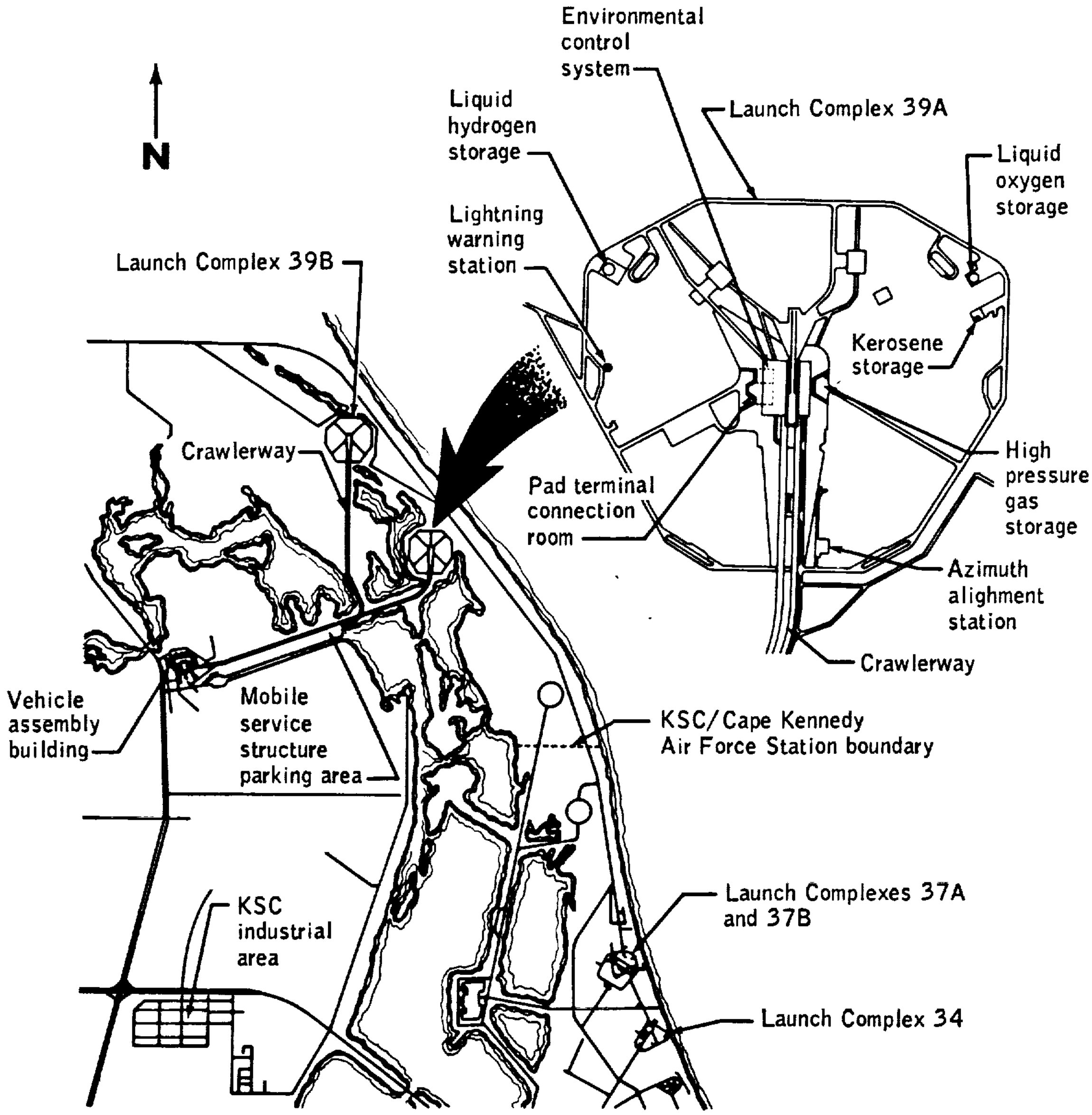


Figure 10-3.- Kennedy Space Center/Cape Kennedy Air Force Station facilities.

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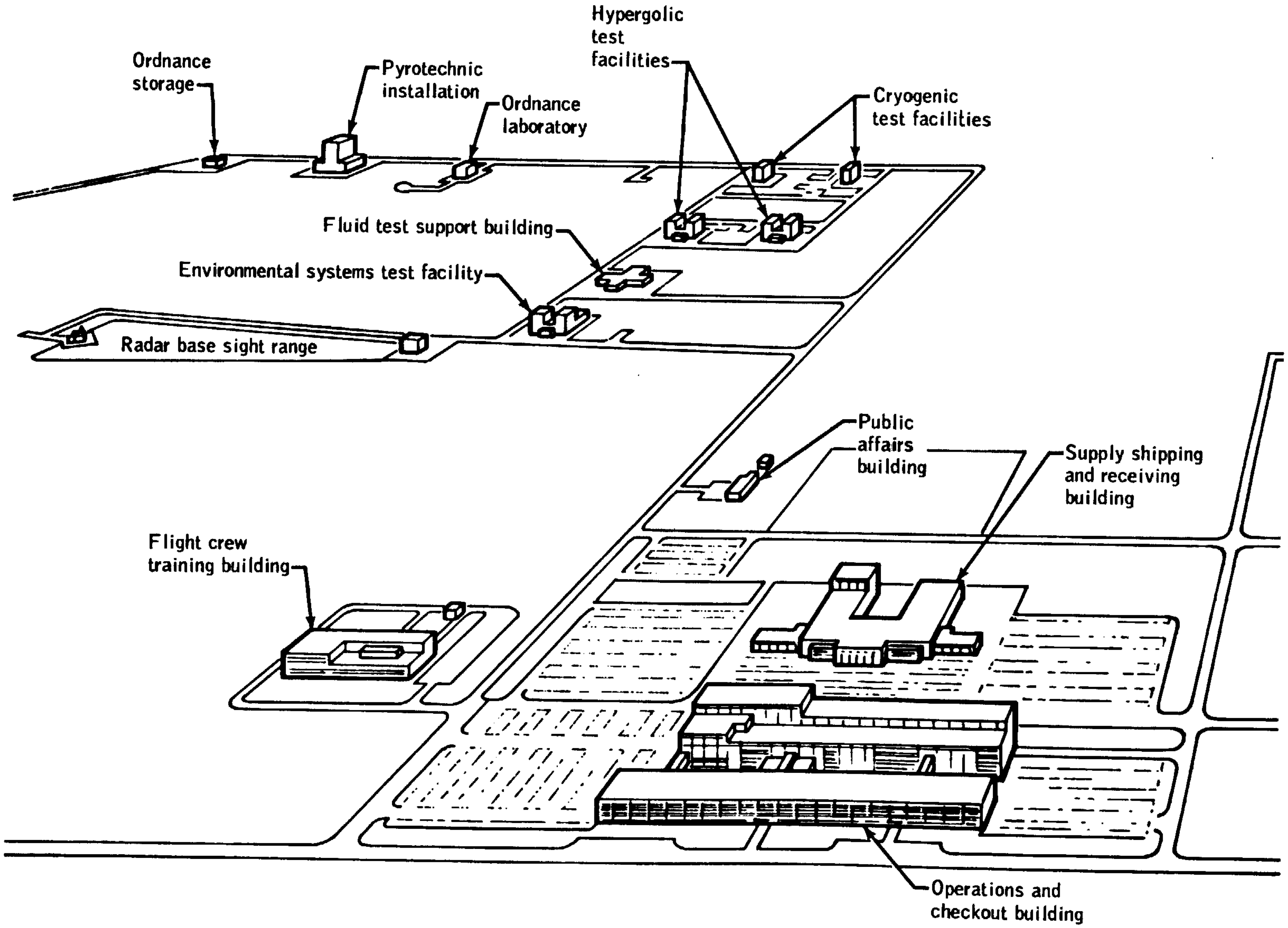

Figure 10-4.- Artist's concept of Kennedy Space Center industrial facilities.

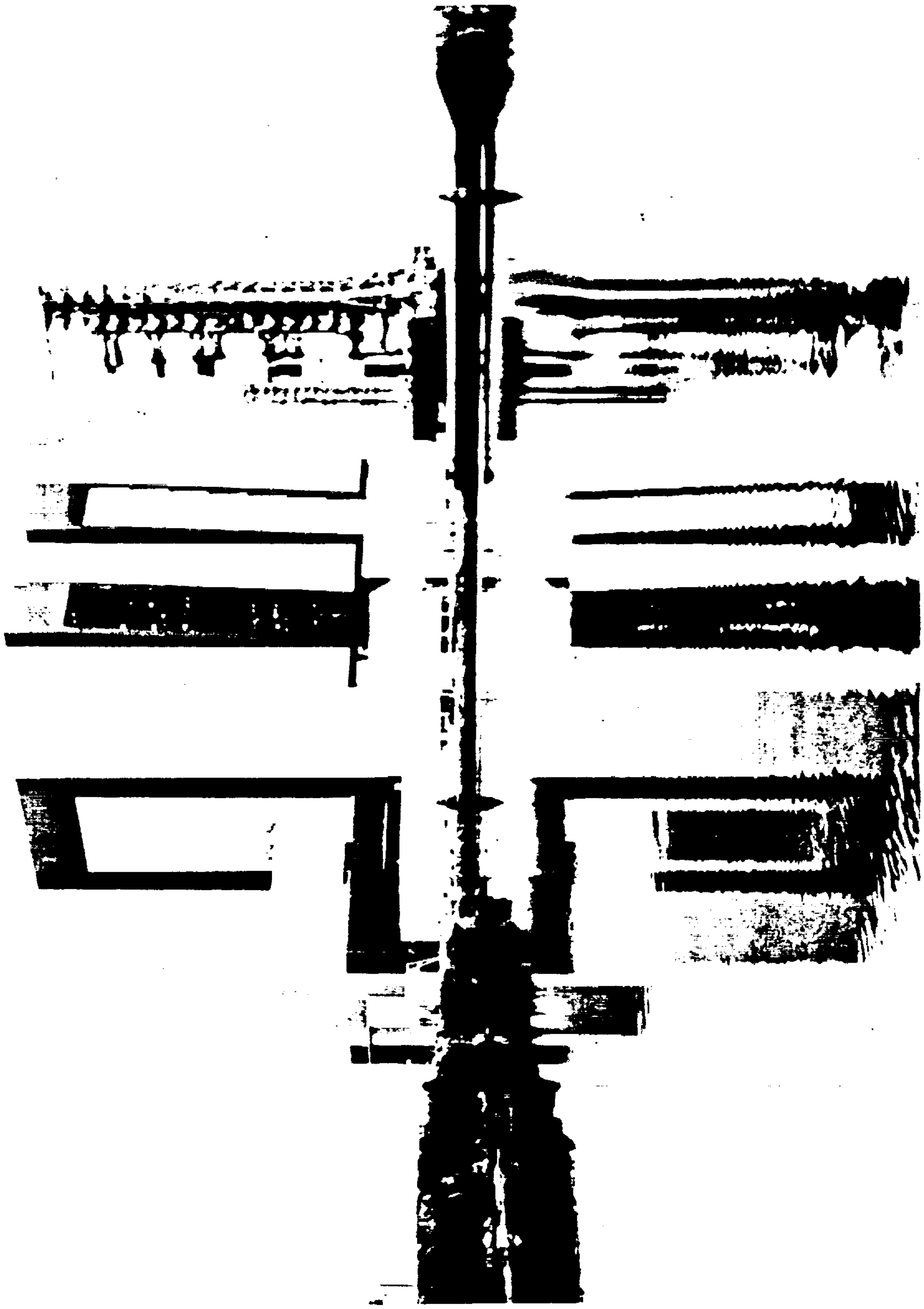

Figure 10-5.- Vehicle assembly building.

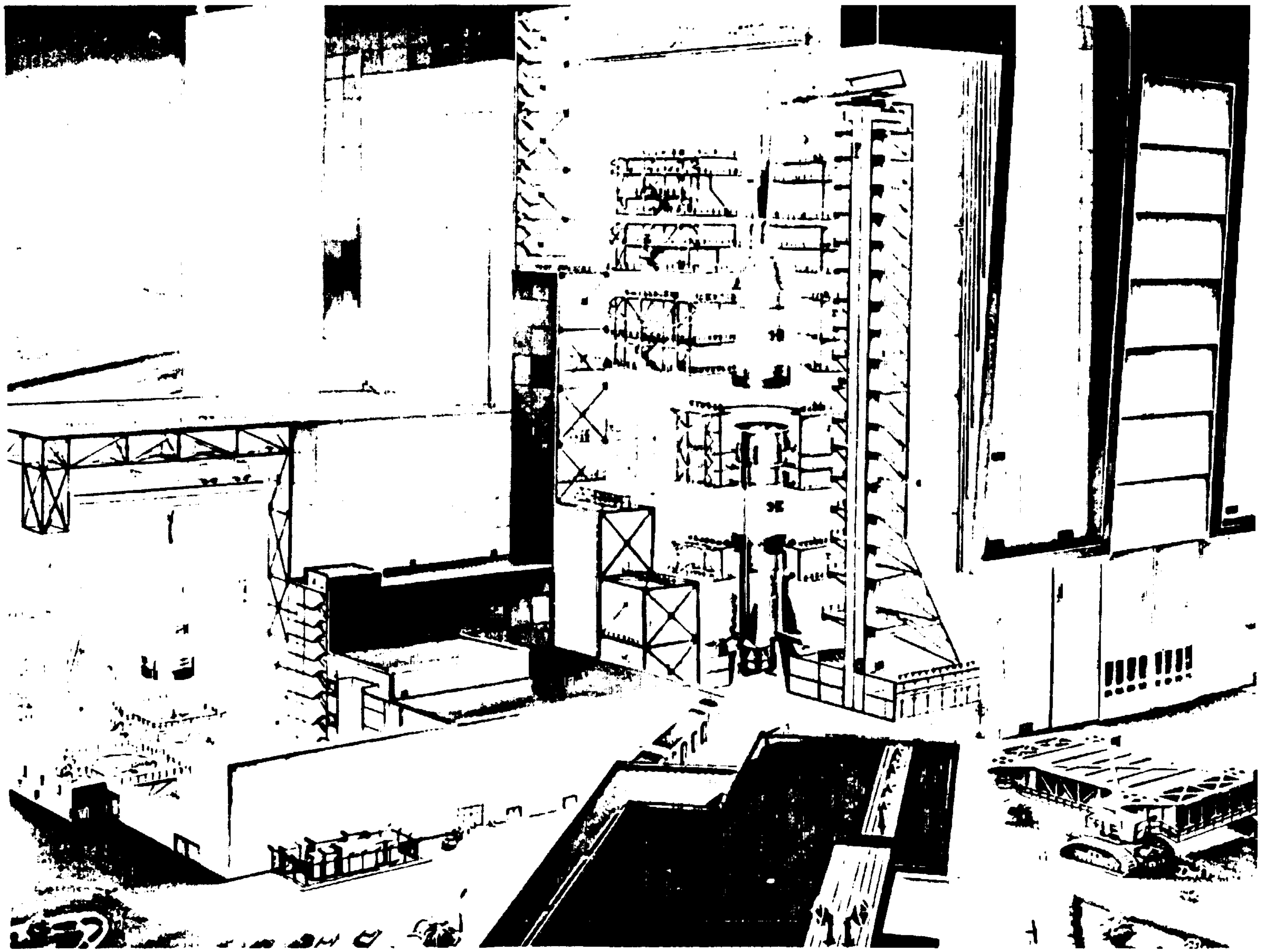

Figure 10-6.- Cutaway of vehicle assembly building.

be moved together and mated, affording 360° access to the vehicle. The low bay area, approximately 442 feet by 274 feet, contained eight stage preparation and checkout cells as well as quarters for flight crews and support personnel who were required to remain nearby during critical periods of assembly and checkout. Additional areas were used for office space and storage.

Control rooms for automatic spacecraft checkout operations were located in the operations and checkout building, with stimuli and response signals carried by hardline to the vehicle assembly building and launch pads.

10.2.2.2 Mobile launchers.- Each space vehicle undergoing assembly inside the vehicle assembly building was supported by a mobile launcher (fig. 10-7). The 18 000-square-foot base of the launcher later served as the launch platform. The base contained holddown arms and masts for servicing the first stage of the vehicle. The base also housed computer systems, digitally controlled equipment for propellant and pneumatic lines, and electrical power and water systems. A 45-foot square opening was built into the base for rocket exhaust at lift-off.

Permanently positioned on the base of the mobile launcher was a 380-foot-high launch umbilical tower that provided support for nine swing arms for direct access to the vehicle. The tower also contained 17 work platforms and distribution equipment for propellant, pneumatic, electrical and instrumentation systems. Two high-speed elevators afforded access to the work platforms. Mounted on top of the tower was a 25-ton-capacity crane. The height of the combined base and umbilical tower was 445 feet.

10.2.2.3 Launch sites.- Two launch pads were constructed at Launch Complex 39. The facilities that comprised pad A are shown in figure 10-8. The mobile launcher, with the flight-ready space vehicle mounted on it, was secured to six mounting mechanisms located on the concrete surface of the pad. Other fixed components to service and effect launch of the space vehicle included liquid oxygen and hydrogen service towers, a fuel system service tower, and an electrical power pedestal.

A steel-reinforced concrete enclosure, covered with as much as 20 feet of earth fill, housed electronic equipment which was part of the communications link between the mobile launcher and the launch control center. Similar enclosures housed a terminal connection room, an environmental control systems room, a high pressure gas storage room and an emergency egress room. Located near the perimeter of the pads were kerosene, liquid oxygen, and liquid hydrogen storage facilities, and a remote air intake facility. Holding ponds for retention of fuel spill and waste water and a burn pond for disposal of hydrogen gas boiloff were also located within the launch site area.

A flame trench partially bisected each pad. Prior to launch a 700-ton wedge-shaped flame deflector, was moved by rail into the flame trench and positioned directly beneath the space vehicle so that it would deflect the flames and channel the exhaust along the flame trench. To dissipate flames and minimize damage to the pad, a water deluge system was available which could pump 40 000 gallons of water a minute into the flame trench.

10.2.2.4 Mobile service structure.- The mobile service structure (fig. 10-9) was a steel trussed tower that was positioned adjacent to the space vehicle on the launch pad to provide access for connecting certain ordnance items, performing checkout functions, servicing spacecraft systems, and fueling the spacecraft. The structure had five work platforms which closed around the space vehicle. Two platforms were self-powered for positioning at the desired levels; the remaining three could be repositioned but were not self-powered. Two elevators provided access to the work platforms. Located in the base portion of the structure were a mechanical equipment room, an operations support room, and areas for equipment storage. The structure weighed 10 500 000 pounds and was 410 feet in height.

10.2.2.5 Transporter.- Two transporter units were manufactured to move the mobile launchers and the mobile service structures. First, a transporter moved a mobile launcher into the vehicle assembly building. On completion of vehicle assembly, a transporter was again used to move the mobile launcher and vehicle (a load of more than 11 million pounds) approximately 3 1/2 miles over a specially constructed crawlerway to one of the launch sites (fig. 10-7). During the trip, the load was maintained within 10 minutes of arc from vertical, even while the transporter

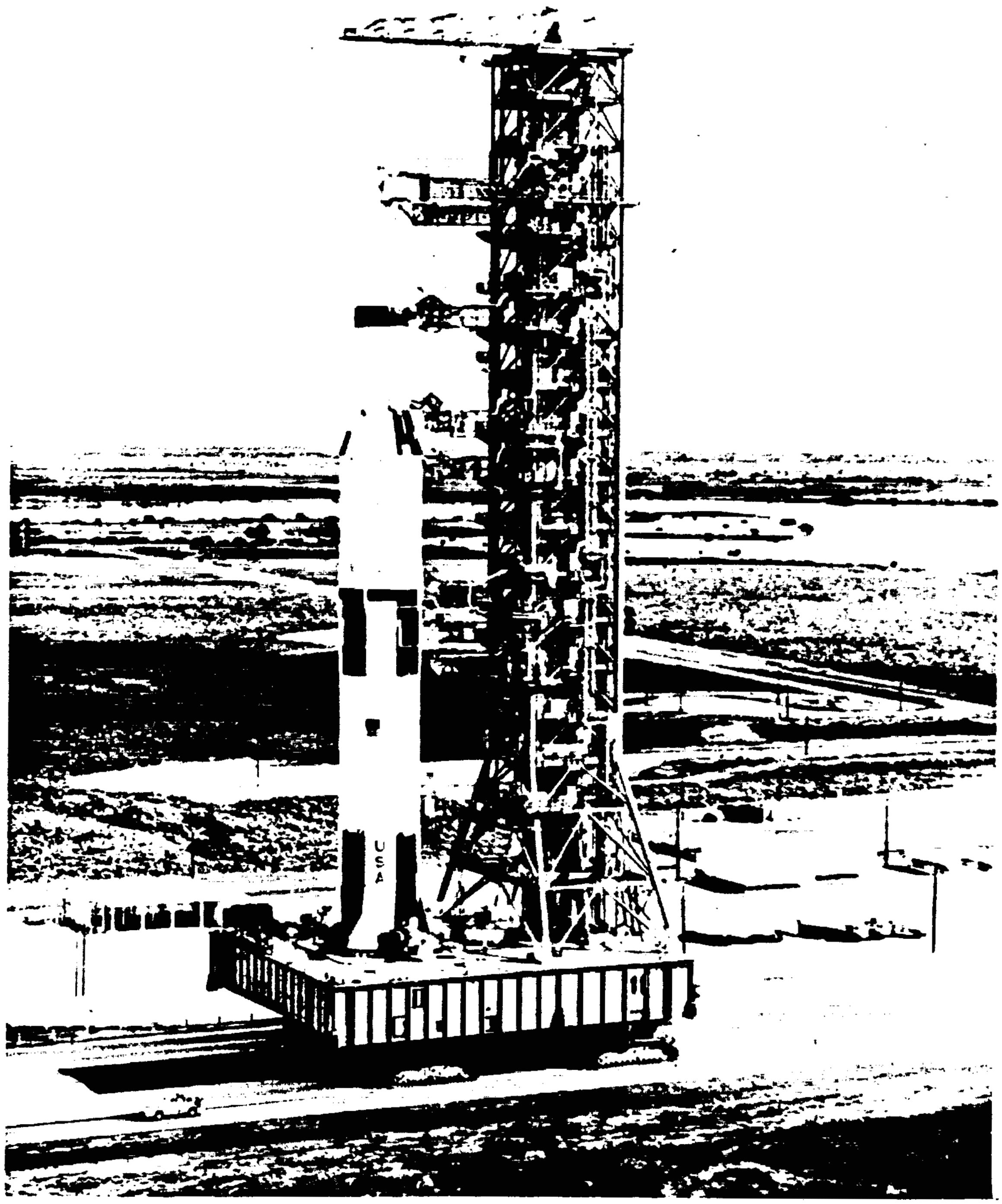

Figure 10-7.- Mobile launcher and space vehicle being transported to launch pad.

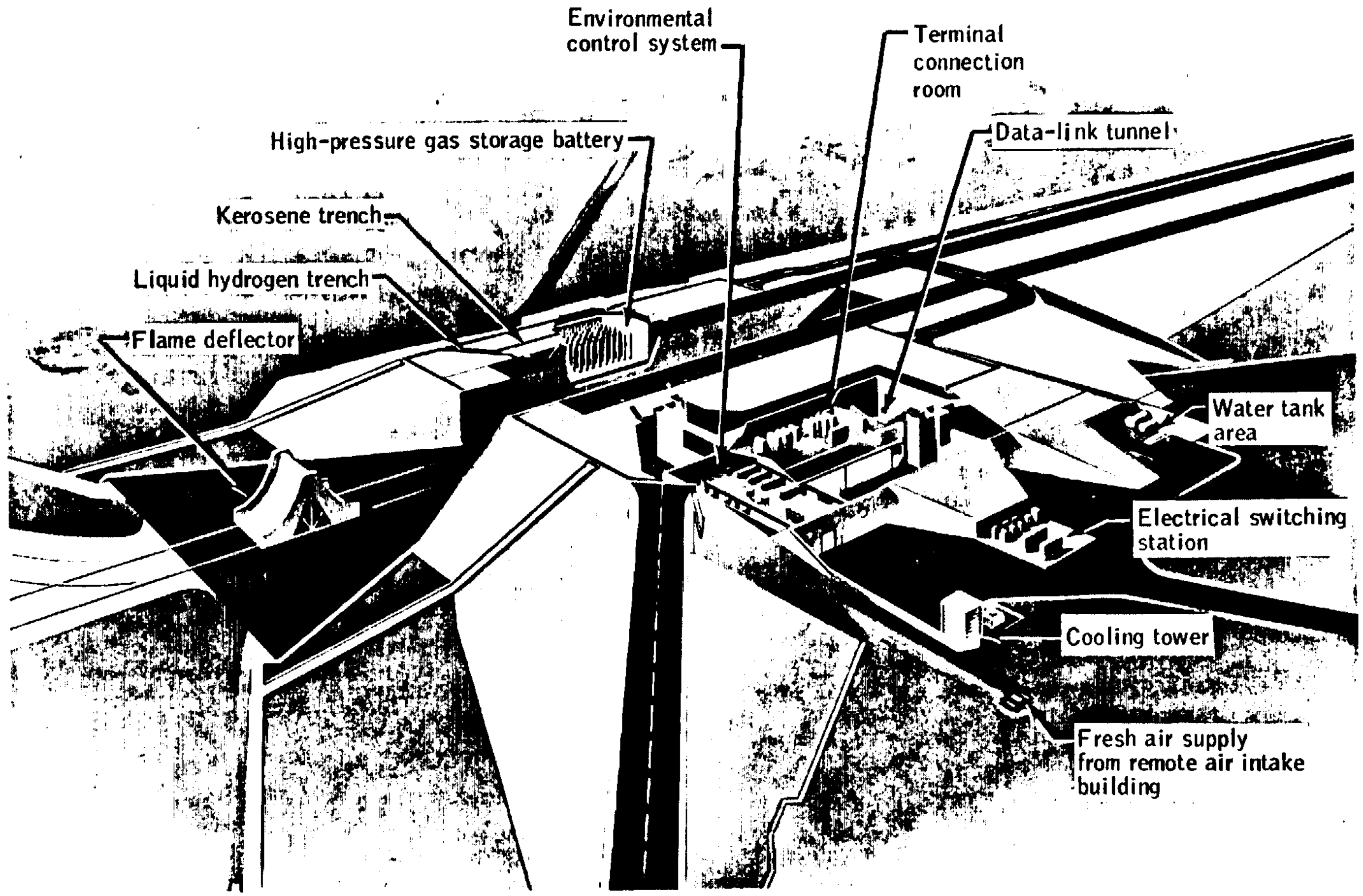

Figure 10-8.- Cutaway view of Pad A, Launch Complex 39.

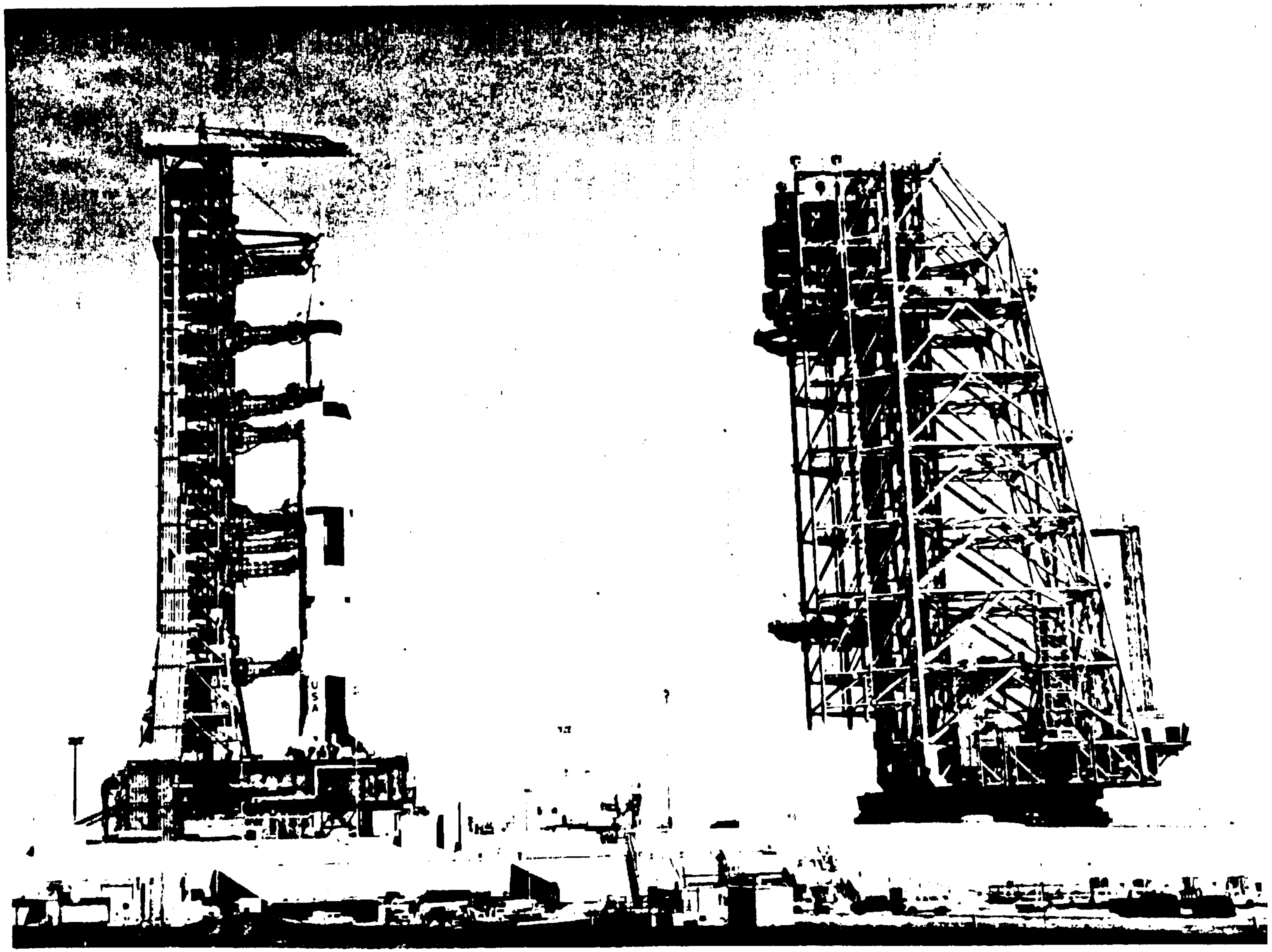

Figure 10-9.- Mobile launcher and mobile service structure being positioned on launch pad.

climbed a 5 percent grade to the launch pad. In order to accomplish this, the transporter was equipped with both automatic and manual leveling devices. After depositing the mobile launcher and space vehicle on the pad, the transporter moved the mobile service structure from its parking area to the launch pad. Finally, the transporter returned the service structure to the parking area before launch.

The transporter was 131 feet long, 114 feet wide, and weighed 6 million pounds. It had a load capacity of 12 million pounds and, when loaded, had a maximum speed of 1 mile per hour. The vehicle moved on four double-tracked crawlers, each 10 feet high and 40 feet long. Each shoe on a crawler track weighed approximately 2000 pounds.

Motive power was provided by two 1750-horsepower deisel engines that drove four 1000-kilowatt generators. The generators, in turn, powered 16 traction motors. Power for steering, ventilation and electrical systems was provided by two 1065-horsepower deisel engines that drive two 750-kilowatt generators. The smaller engines also powered a hydraulic jacking system that raised and lowered the load.

10.2.2.6 Launch control center.- Final countdown and launch were controlled from a four-story building located just east of the vehicle assembly building. The launch control center was also used in conducting many of the checkout and test operations required during space vehicle assembly. Facilities for various service and support functions are located on the ground floor. The second floor contains telemetry, radio, tracking, instrumentation, data reduction and evaluation equipment. The third floor has four firing rooms which contain monitors and control consoles. One of these rooms is shown in figure 10-10. The fourth floor has projection screens for display of launch site information and conference rooms.

10.2.3 Vehicle Checkout Operations

Prelaunch checkout of the Apollo spacecraft and launch vehicles at the Kennedy Space Center underwent a number of variations from the relatively simple flow of operations for the boilerplate flights to the more complex flow for the sophisticated J-missions. The following description applies to the final missions. The flows for the launch vehicle, the lunar module, and the command and service module are described separately up to the point where the vehicles were mated and moved to the launch pad. The description of the launch pad operations pertains to the entire stack.

10.2.3.1 Launch vehicle.- The initial assembly and checkout activities of the launch vehicle were accomplished in two major areas of the vehicle assembly building, the high bay area and the low bay area. The low bay area activities included receipt and inspection of the S-II stage, S-IVB stage and the instrument unit, and the assembly and checkout of the S-II and S-IVB stages. An insulation leak check, J-2 engine leak check and propellant level probe electrical checks were performed on the S-II stage. A fuel tank inspection, engine leak test, hydraulic systems test, and propellant level sensor electrical checks were made on the S-IVB stage.

In the high bay area, the S-IC stage was positioned and secured to the mobile launcher, access platforms were installed and umbilicals were secured. Electrical continuity checks were then made followed by pneumatic, fuel, and engine leak checks, and instrumentation and range safety system checks. The S-II stage was then mated to the S-IC stage, and the S-IVB stage and instrument unit were added. As each stage was mated, electrical continuity and system tests were performed. Following completion of the stage systems tests, launch vehicle integrated tests were accomplished. Vehicle separation, flight commands, sequence malfunction, and emergency detection system checks were made. The spacecraft was then mated and the space vehicle was ready to move to the launch pad.

10.2.3.2 Lunar module.- The lunar module was received at the Kennedy Space Center in two major subassemblies, the ascent stage and the descent stage. The stages were inspected for damage on arrival. In parallel, the landing gear, explosive devices, batteries, rendezvous radar, and abort sensor assembly were received and inspected. The rendezvous radar was then sent to the radio-frequency test facility for checkout, and the abort sensor assembly was sent to the stability and control laboratory for calibration.

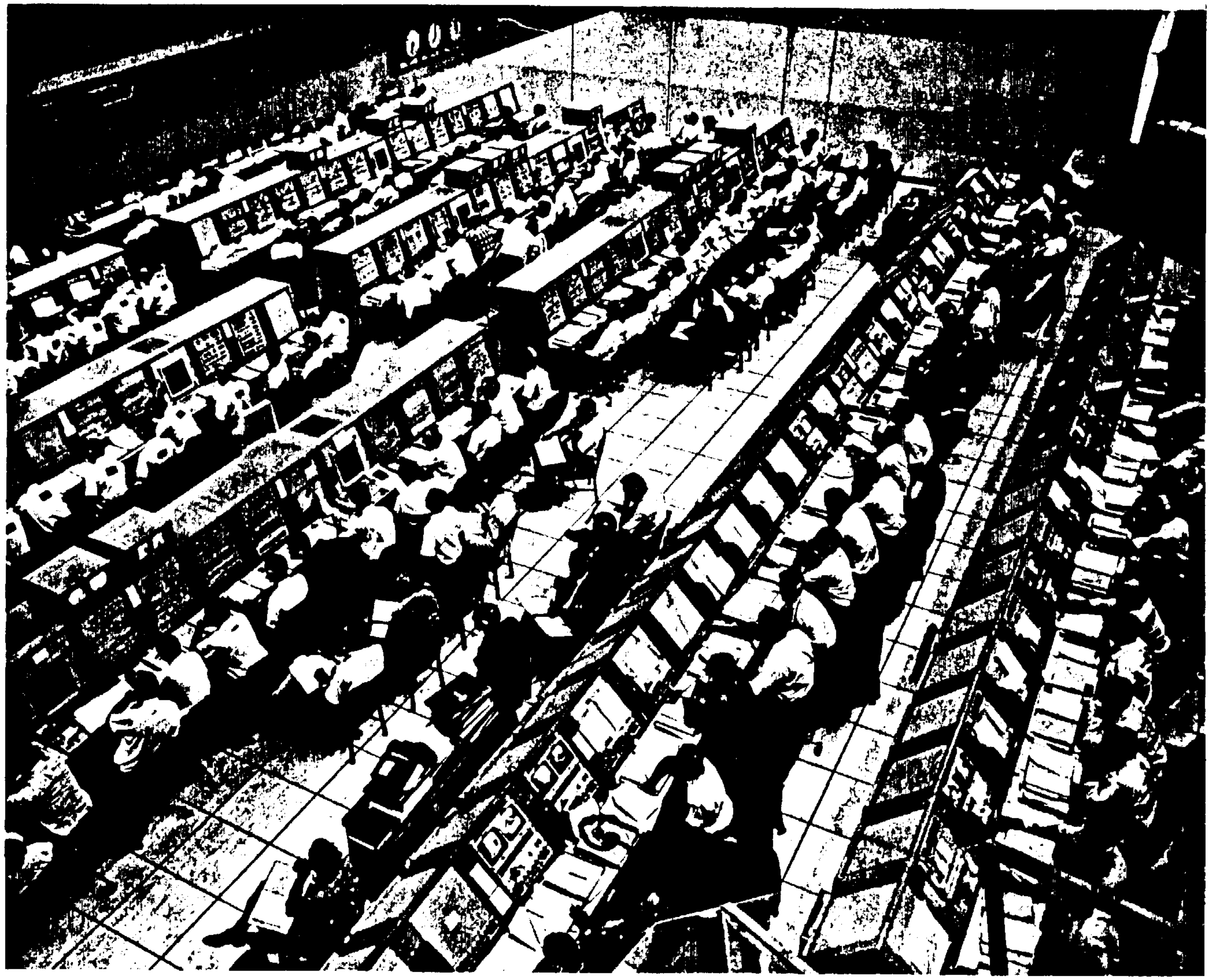

Figure 10-10.- Launch control center firing room.

The ascent stage was positioned on the ascent stage work stand and, similarly, the descent stage was positioned on the descent stage work stand. Propulsion and reaction control system gas leak and functional tests were then performed on the two stages. Upon completion of these tests, the descent stage was placed in the altitude chamber and the ascent stage underwent an S-band steerable antenna functional test. The ascent stage was then inverted for a mechanical docking test conducted in conjunction with the command and service module. The ascent and descent stages were then mated in the altitude chamber in preparation for combined systems tests at sea-level pressure and altitude tests. Following combined systems tests, the abort sensor assembly was installed in the spacecraft, after which crew provisions stowage checks were conducted on both the ascent and descent stages. Environmental control system functional tests were then performed at sea-level pressure, the gaseous oxygen and water management system tanks were serviced, and systems to be operated during the altitude tests were verified.

A simulated altitude test run was conducted with a fully stowed cabin using both the prime and backup crews. An unmanned altitude test (run 1) was conducted to verify cabin integrity and environmental control system functions. Two manned altitude tests (runs 2 and 3) were then conducted with the prime and backup crews. After altitude chamber deservicing, an additional chamber run (run 4) was made for systems drying. Following the altitude tests, all descent stage crew provisions, the lunar roving vehicle, and experiment items were stowed and deployed by the flight crew. The lunar roving vehicle was then installed for flight and the lunar module was moved to the landing gear fixture for landing gear installation and testing. The mated lunar module with the landing gear retracted was then installed in the lower section of the spacecraft/ lunar module adapter.

10.2.3.3 Command and service module.- The command and service module was received at KSC in four major subassemblies: the launch escape system, the spacecraft/lunar module adapter, the service module, and the command module. The subassemblies underwent the following operations:

a. Launch escape system. The launch escape system components were inspected and taken to the pyrotechnics installation building for assembly, weight and balance measurements, and thrust vector alignment. The subassembly was then transferred to the vehicle assembly building and mated to the command module just prior to moving the space vehicle to the launch pad.

b. Spacecraft/lunar module adapter. The adapter was inspected and delivered to the operations and checkout building integrated test stand where the upper section of the adapter was removed in preparation for installation of the lunar module. After the installation of the landing gear (sec. 10.2.3.2), the lunar module was installed in the lower section of the adapter and alignment was optically verified. The upper section of the adapter was then reinstalled and interior work platforms were added for later operations.

c. Command and service modules. Upon delivery of the command and service modules to the operations and checkout building, the command module heat shield was inspected, and the two spacecraft modules were moved to the altitude chamber and mated. A receiving inspection and side hatch functional test were then performed, umbilical buildup was accomplished, the environmental control system was connected and checked for leaks, and the command and service modules were electrically mated. A cabin leak test was conducted followed by alignment of the crew optical alignment sight and the lunar module active docking target. The lunar module ascent stage was then inverted over the top of the mated command and service modules (sec. 10.2.3.2) and a mechanical docking test was performed. This was followed by a leak test and functional test of the scientific instrument module door thruster system. The scientific experiments were then installed and a combined systems test was performed during which the experiments were functionally verified and selected spacecraft interfaces and systems were checked out.

A simulated altitude test was performed in preparation for manned altitude testing. The command and service modules were then serviced and an unmanned and two manned altitude tests were performed (one with the prime crew and one with the backup crew). Operations following the manned altitude testing included transferring inertial measurement unit power to ground support equipment, draining and drying the environmental control system water system, performing an open-loop communications test, performing a service propulsion system ball valve leak test, removing stowed equipment, performing a post-egress inspection, and powering down the spacecraft. The mated command and service modules were then transferred to a work stand for installation and leak check of the service propulsion system engine nozzle extension, and installation and checkout of the high gain antenna. After antenna checkout, the command and service modules were moved to the integrated test stand and mated to the spacecraft/lunar module adapter. Ordnance items (except for detonators) were then installed. Upon completion of the ordnance installation, the work platforms were removed and the assembled spacecraft was transferred to the vehicle assembly building. While at the vehicle assembly building, the spacecraft was mechanically mated to the launch vehicle and the launch escape system and hard boost protective cover were installed. The complete space vehicle and mobile launcher were then transported to the launch pad.

10.2.3.4 Launch pad operations.- Upon arrival of the space vehicle and mobile launcher at the launch pad, the mobile service structure was positioned adjacent to the space vehicle, ground support equipment was connected, and the white room was positioned around the command module. An integrated systems test was performed using a launch vehicle simulator to validate command and service module systems and verify ground support equipment interfaces. In parallel, a combined systems test was performed on the lunar module to functionally verify the electronic systems, and leak and functional tests of the gas subsystems were accomplished. Following these tests, a systems interface test was performed to verify the electrical interface between the command and service module and the lunar module. The spacecraft was then electrically mated to the launch vehicle and two space vehicle overall tests were performed. A "plugs out" test was made to verify radio frequency, ordnance, pressurization, propulsion, guidance and control, propellant, and emergency detection systems. A "plugs in" test was performed to verify proper operation of all systems during an automatic firing and flight sequences.

A flight readiness test with simulated aborts and normal mission sequences was performed followed by crew emergency egress practice and a cabin leak test. A test was then conducted to verify hypergolic propellant systems readiness, and hypergolics were loaded in preparation for a countdown demonstration test. The countdown demonstration test verified that the space vehicle and the ground support equipment were in launch status. The test was performed in two stages, wet and dry. In the wet portion of the test, the launch vehicle propellants were on board, the spacecraft was unmanned, and the vehicle was counted down to T minus zero. After recycling the space vehicle to a dry condition (propellants drained), the last hours of countdown were simulated with the crew on board.

Following the countdown demonstration test, preparations were started for the actual countdown. The countdown began approximately 4 days before the launch readiness day, and the final space vehicle checkout and servicing operations were performed. The final phase of the countdown started approximately 9 hours prior to lift-off. During the final phase, the cryogenics were loaded, conditioned, and pressurized; final checks were made on all systems; the propulsion systems were serviced and prepared for launch; and the crew manned the command module. Automatic sequencing started at T minus 187 seconds. The S-IC stage ignition command was given at T minus 8.9 seconds and, at T minus zero, the launch commit was given which caused the holddown arms to retract hydraulically. The holddown arms restrained the launch vehicle until a satisfactory thrust level was achieved, after which the controlled release assemblies provided for gradual release of the vehicle during lift-off.

11.0 LUNAR RECEIVING LABORATORY

11.1 INTRODUCTION

The Lunar Receiving Laboratory was originally conceived and constructed to provide rigid quarantine conditions for members of the Apollo flight crews, Apollo command modules, and returned lunar samples. The facility was operated in this capacity for the Apollo 11, 12, and 14 missions. Although the quarantine requirement was subsequently relaxed, the facility continued to operate in full support of the returned sample program. This effort, which formed the bulk of the laboratory activities, involved the processing, examination, preliminary analysis, and distribution of lunar material. The laboratory was occupied in 1967 and was certified as ready for quarantine support in June 1969. In the following month, the Lunar Receiving Laboratory commenced operations in support of the Apollo 11 mission.

11.2 ORIGINAL CONCEPT

A special subcommittee of the Space Sciences Board, National Academy of Sciences, was convened in 1964 to consider the potential ramifications of working with material, personnel, and equipment returned from the lunar surface. The subcommittee recommended that a facility be constructed for the following purposes:

a. Quarantining returning Apollo crewmembers, equipment, and lunar samples for a specified period

b. Conducting specific biomedical evaluations of lunar samples while isolated to determine whether any lunar sample contained hazardously replicating micro-organisms

c. Conducting time-critical physical science investigations of lunar samples while isolated during the quarantine period

d. Controlling, processing, and preparing lunar samples and distributing samples to designated principal investigators for scientific analysis

e. Providing a repository and curatorial facility for all retained lunar samples

The Lunar Receiving Laboratory was designed and constructed in response to this recommendation.

11.3 FACILITIES

The Lunar Receiving Laboratory was designed to provide the functional areas illustrated in figure 11-1. The administrative and nonisolated support areas were separated from the isolated operations areas by a biological barrier that was activated during specified quarantine periods. Each operational unit behind this barrier, as shown in the figure, represented a unique part of the facility.

11.3.1 Crew Reception Area

The returning crewmen who had been exposed to lunar material and also to potentially hazardous lunar biological elements were quarantined for a period of approximately 21 days, beginning at departure from the moon. The crew reception area not only provided the facilities for sustenance and comfort of the flight crews and support personnel during the quarantine period, but also provided the capability to house other personnel who might have become exposed to hazardous biological elements in the sample laboratory. The area contained complete living facilities, a recreational area, a medical facility, and an isolated interview room. This entire system was separated from other areas of the laboratory complex and the ambient environment by primary and secondary biological barriers. Since the interior of the command module could also have been contaminated, the spacecraft was sealed and stored in the crew reception area for the duration of the quarantine period.

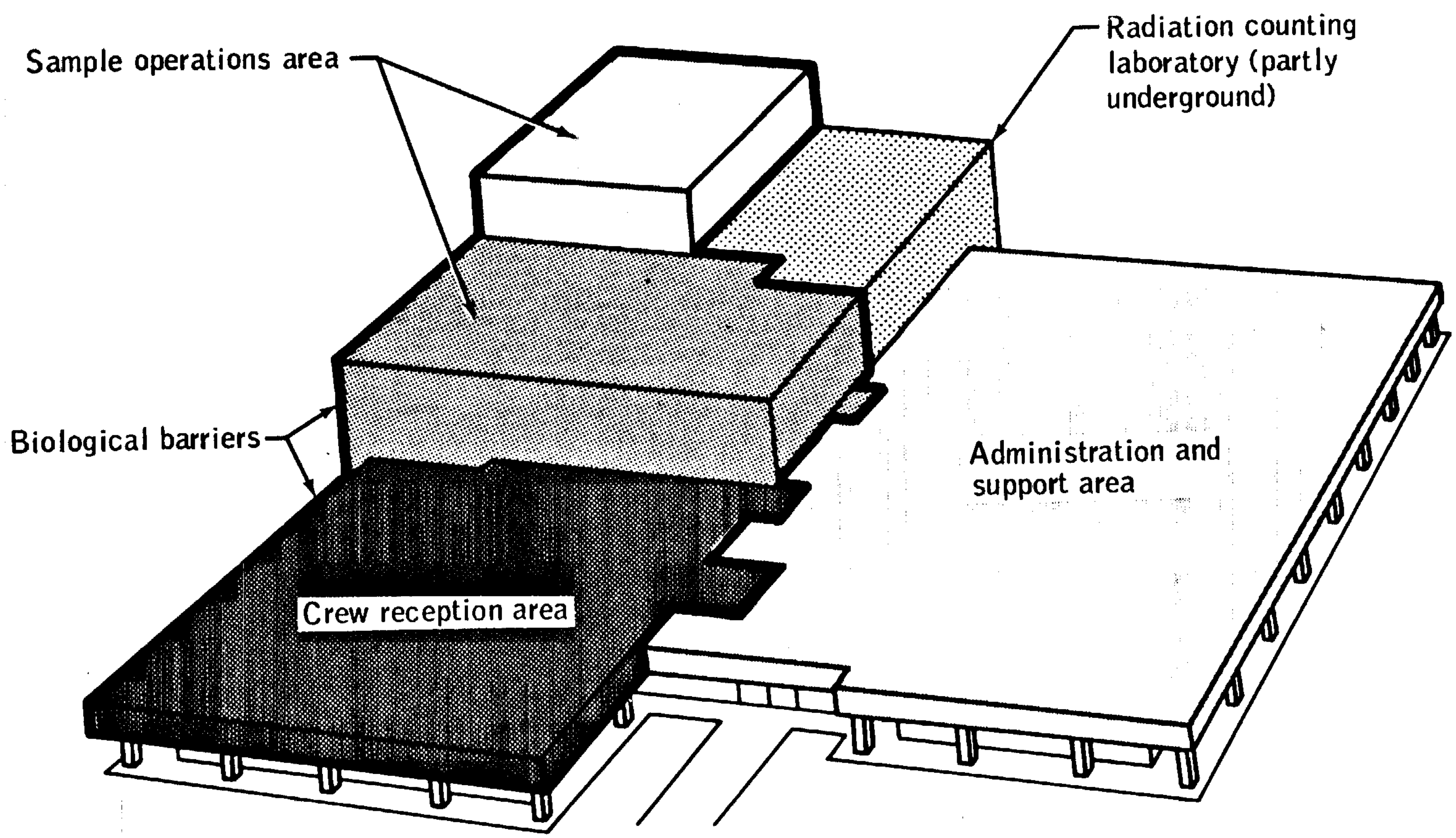

Figure 11-1.- Lunar Receiving Laboratory functional areas.

11.3.2 Sample Operations Area

The lunar sample containers were opened and sample examinations were conducted behind a two-way biological barrier system composed of gas-tight glove cabinets and vacuum chambers. This handling and containment system was unique in that conventional containment units are designed to prevent contamination in only one direction. The two-way system was designed to protect laboratory scientists and technicians from contact with lunar material while protecting the samples from terrestrial contamination.

The immediate operations performed on returned lunar samples in the sample operations area included sterilization of the exterior of sample containers, opening and unpacking of the containers in a near vacuum, sampling of effluent gases, visual examination and photography of the samples, division of samples, and preparation of portions of the samples for detailed physical-chemical and biological examinations. The requirement for a vacuum system was later withdrawn, after which a dry nitrogen system was used.

The physical-chemical examination included tests for reactions with atmospheric gases and water vapor, and preliminary examination of the mineralogy, petrography, and chemistry of the lunar samples. Examinations of this kind and of a biological nature were performed in greater detail by other laboratories after the quarantine period.

Lunar samples were used for the following kinds of biological examinations: aerobic and anaerobic culturing; inoculation of plants, eggs, tissue cultures, invertebrates, and vertebrates (normal and germ free); and biochemical analysis.

11.3.3 Radiation Counting Laboratory

A radiation counting laboratory (fig. 11-2) was included in the Lunar Receiving Laboratory because some of the induced radioactivity of lunar samples would decay in less time than the quarantine period.

11.3.4 Thin Section Laboratory

A thin section laboratory was included in the Lunar Receiving Laboratory to facilitate production of petrographic thin sections of lunar soil and rock fragments. This provided the capability to study in detail the crystal structures of many samples in a timely manner.

11.4 OPERATIONS

11.4.1 Preliminary Processing and Examination

Closely guarded quarantine control procedures were used for the preliminary processing and examination of the lunar material returned during the Apollo 11, 12, and 14 missions. Figure 11-3 illustrates lunar sample processing for these missions. Included are operations that were accomplished under quarantine conditions and the investigations that came after quarantine was lifted. Quarantine was not required for the Apollo 15, 16, and 17 missions because examination of samples during the early missions had shown a complete absence of pathogenic substances.

The sample laboratory and the vacuum laboratory, located in the sample operations area, were the primary locations for initial sample processing. The vacuum system was used only during the processing of the Apollo 11 and 12 samples. After Apollo 14, the samples were initially processed in two sterilized cabinet systems. The vacuum system and, later, the other cabinet system served primarily as a receiving point from which the lunar samples were distributed to other portions of the Lunar Receiving Laboratory and eventually to the scientific community. All of the initial processing occurred in the same two cabinet systems on Apollo missions 15, 16 and 17 without sterilization of the cabinets.

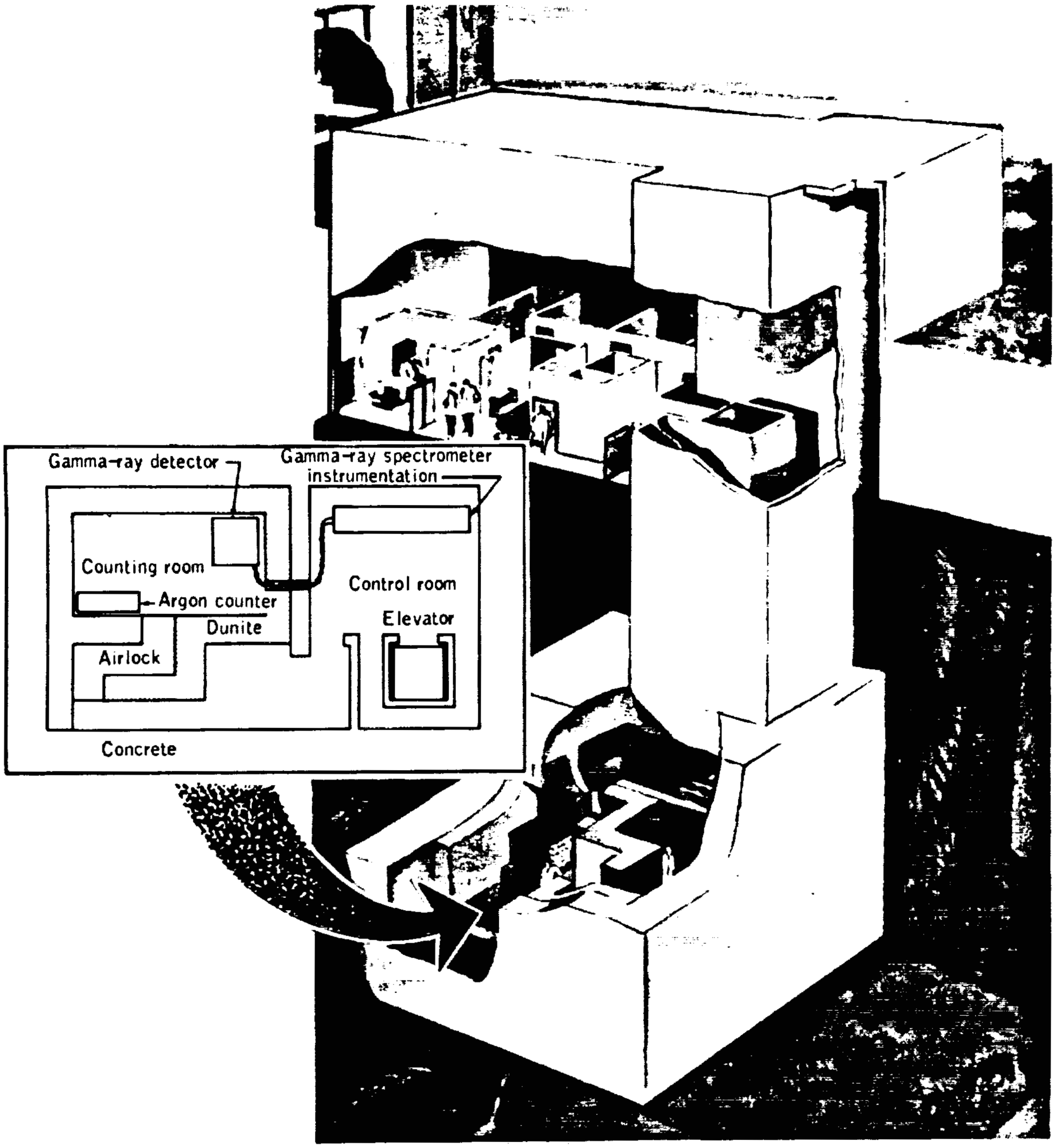

Figure 11-2.- Radiation counting laboratory.

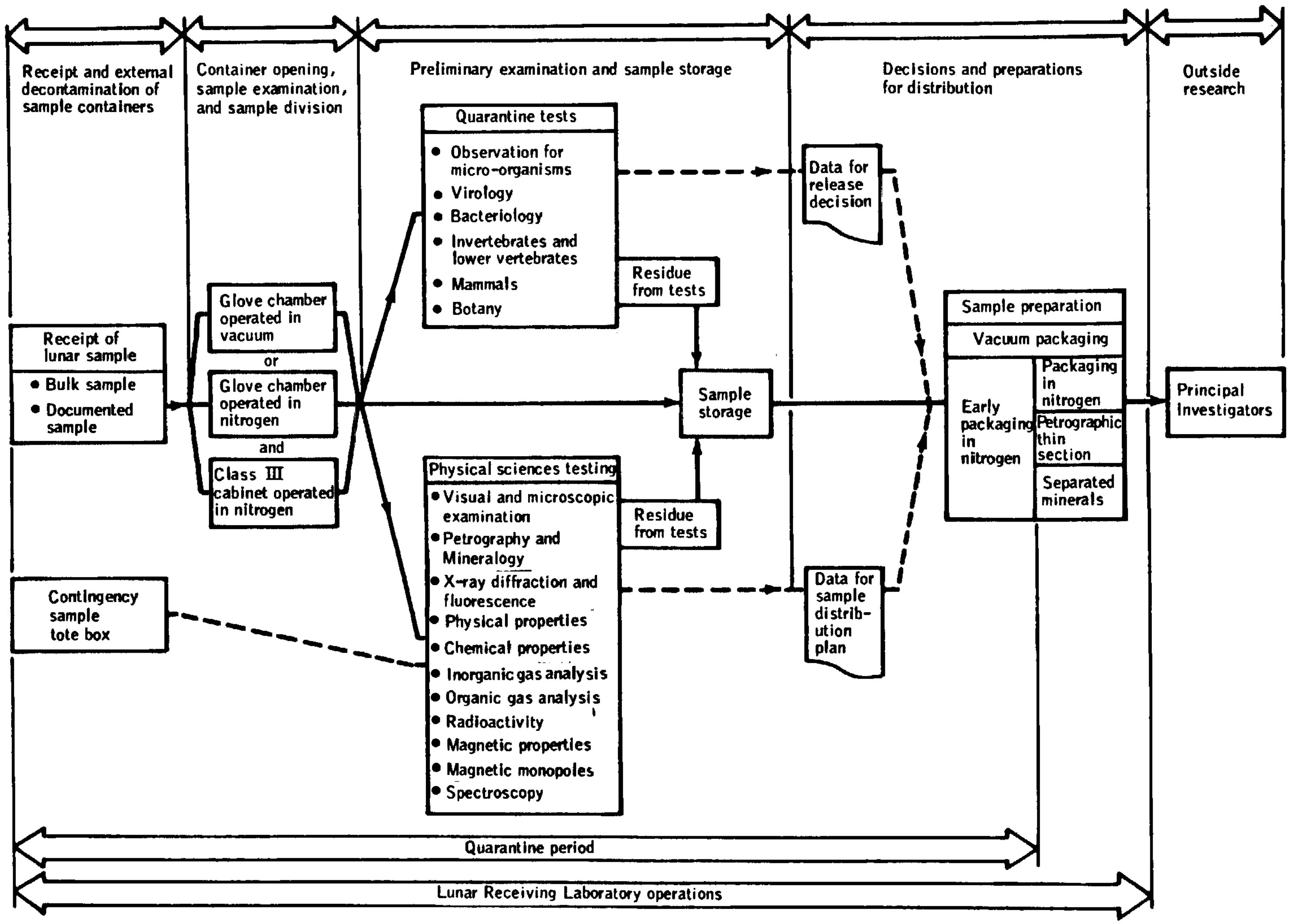

Figure 11-3.- Lunar sample flow diagram.

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The processing which occurred in these systems included:

a. Unpacking samples from the return containers

b. Weighing

c. Photography (orthogonal and stereoscopic)

d. Sieving fines

e. Dusting rocks

f. Microscopic examination

g. Modeling (rocks)

h. Determining lunar orientation

i. Initial allocation, including some chipping.

When the quarantine requirements were discontinued after Apollo 14, the complexity of laboratory operations decreased considerably. Although no lunar-derived biological contaminants had been found, certain tests were continued as a safeguard. All subsequent sample processing operations were conducted in nitrogen cabinetry instead of the vacuum system since only the exposure of the lunar material to terrestrial contaminants was of primary interest.

11.4.2 Sample Processing

Although lunar samples were cataloged, photographed, and described in the preliminary operations phase, such activity was only the beginning of the scientific work. A portion of the samples from each mission was selected by a Lunar Sample Analysis Planning Team composed of eminent members of the scientific community. This team transmitted an allocation plan to the lunar sample curator, who then implemented the sectioning and packaging of samples. To illustrate the work required, reference is made to sample 12021, which is sample 21 from Apollo 12. Figure 11-4 shows sample 12021 on the slab saw in the beginning stages of sectioning. Before this operation, a detailed cutting plan was prepared with reference to specified allocation requirements. The cutting plan began with the instruction, "Separate from large end, by chipping, all pieces which can be removed by taking advantage of the numerous existing fractures ... make the initial cut with a circular saw such that the thickness of the resulting slice is about 1.5 centimeters." Figure 11-5 illustrates the two "daughter" samples produced. Figure 11-6 illustrates the precise documentation detail which follows the sectioning of a lunar rock. Such drawings, together with laboratory test results, formed data packages that were individually prepared for the samples distributed to selected scientists. These principal investigators were allocated the minimum amount of sample consistent with their intended research, and the detailed drawings were necessary to identify precisely the particular portion of rock allocated for their study.

A Preliminary Examination Team, consisting of between 20 and 40 scientists, was assigned the responsibility of describing the returned lunar samples. The team was made up of NASA scientists and visitors who represented the scientific community. The visitors represented both universities and agencies. The descriptions of the samples are documented in reports published in the periodical Science, in the Preliminary Science Reports (NASA SP series), and in an informal publication of the lunar sample curator's office.

11.4.3 Gas Analysis

The functions of the gas analysis laboratory, located in the sample operations area, are broadly grouped into mission-support and mission-related activities. Figure 11-7 is a schematic representation of this laboratory as it existed during the Apollo program.

Figure 11-4.- Lunar sample 12021 undergoing sectioning.

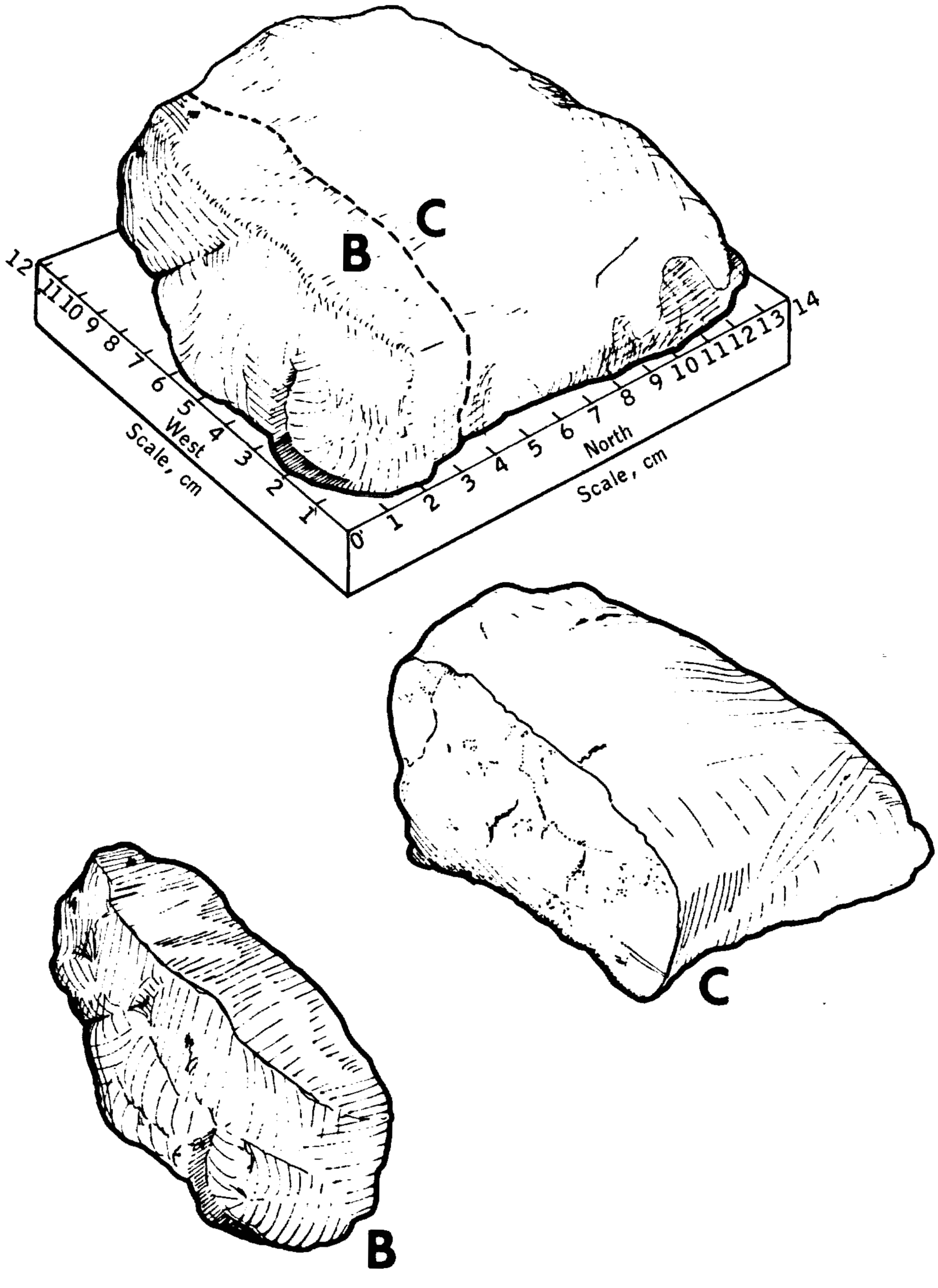

Figure 11-5.- Plan for cutting lunar sample 12021.

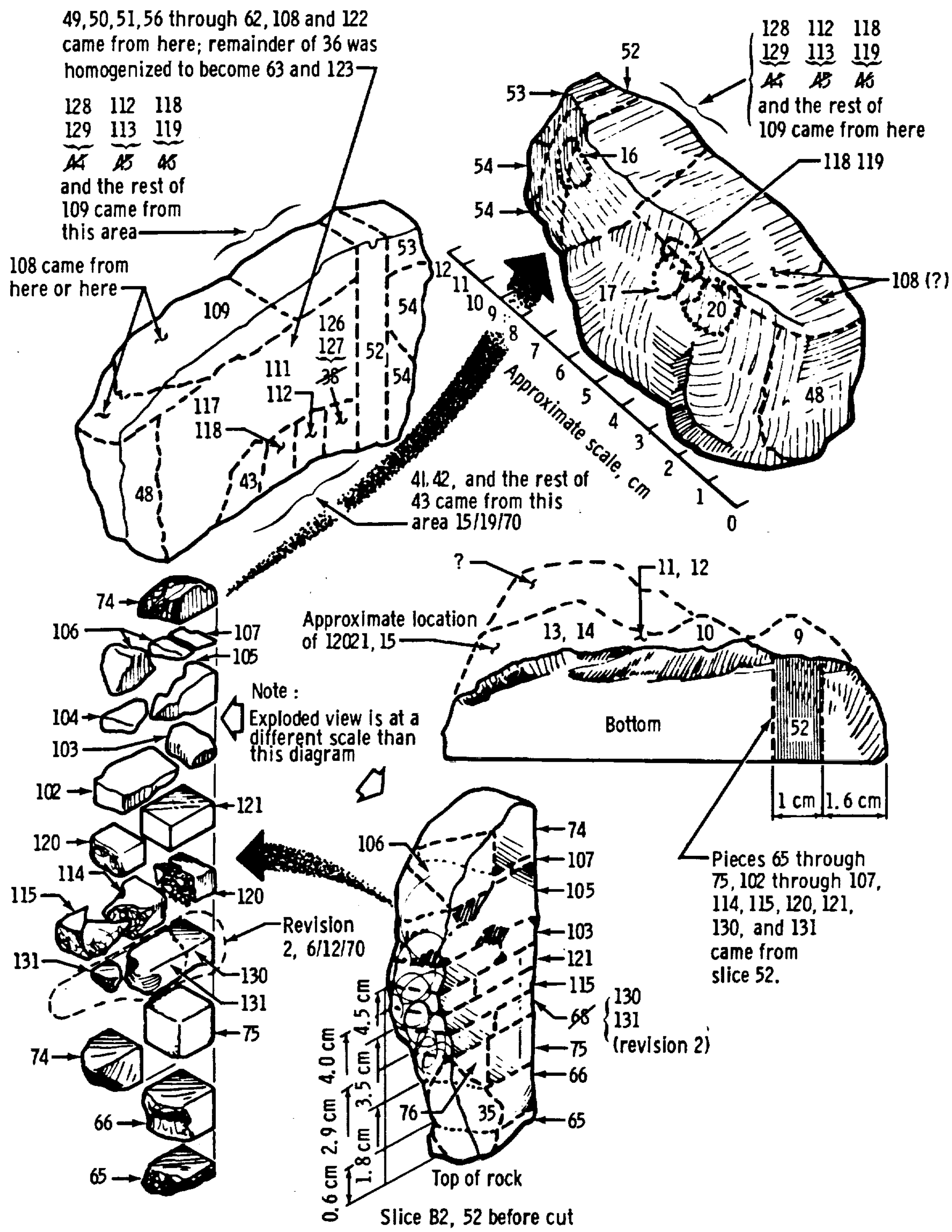

Figure 11-6.- Documentation of slice B, lunar sample 12021, after cutting.

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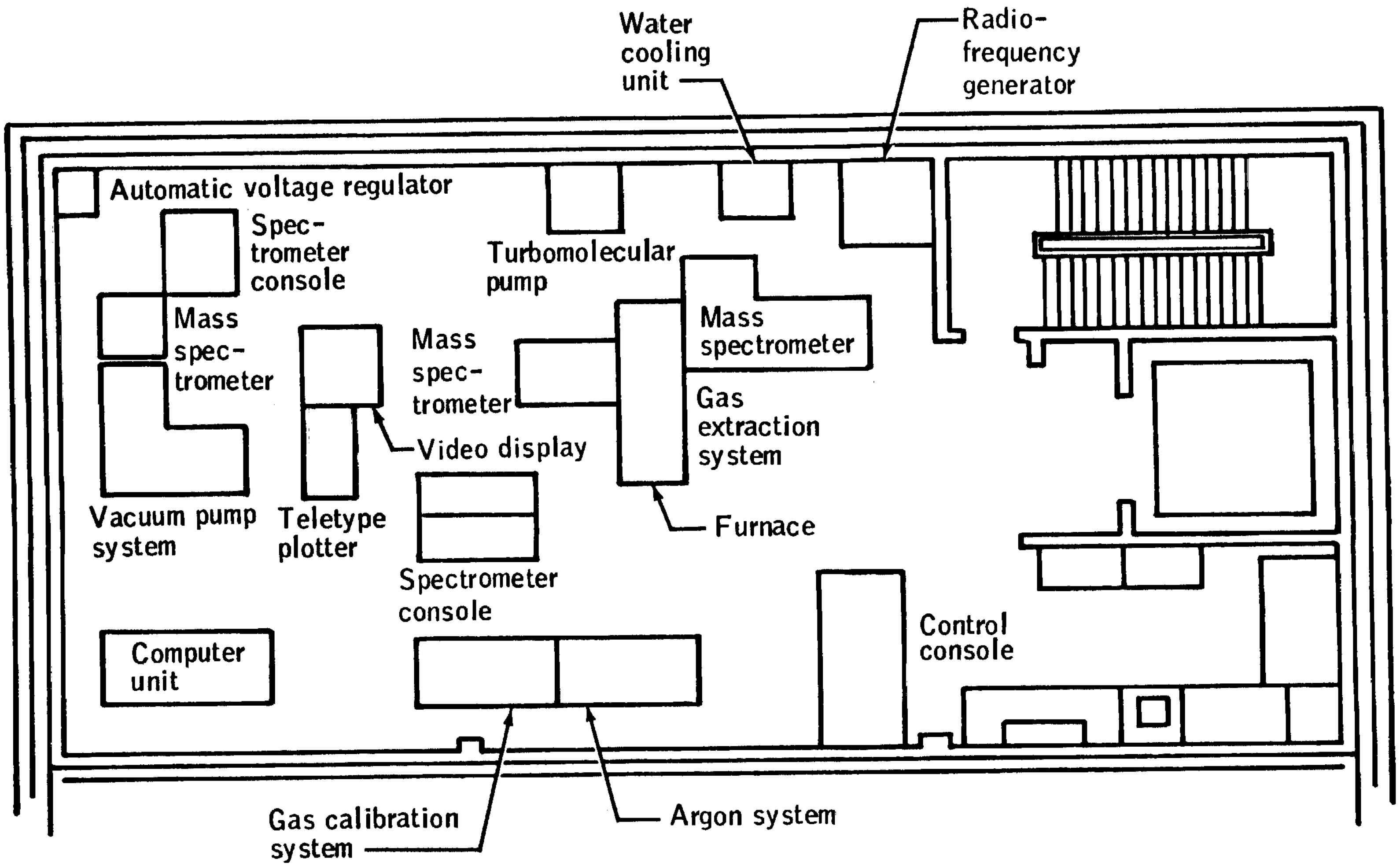

Figure 11-7.- Gas analysis laboratory floor plan.

Mission-support activities were those operations carried out during the preliminary examination phase of the program and included:

a. Organic contamination monitoring

b. Inorganic trace-gas contamination monitoring

c. Preliminary analyses of organic materials in lunar samples

d. Preliminary analyses of total carbon content of lunar samples

e. Analyses of trace gases and radioactive gases in sealed-sample containers

f. Preliminary analyses of noble gases in lunar samples

g. Determination of radioactive gases in lunar samples in conjunction with radiation counting activities

11.4.4 Radiation Counting

The radiation counting laboratory was used to measure the emitted radiation from lunar samples through gamma-ray spectrometry. This facility provided the Lunar Receiving Laboratory with the capability to perform nondestructive analysis of lunar samples during the quarantine period and before the short-lived nuclides could significantly decay. The lunar samples selected for radiation counting were packaged in stainless steel vacuum-tight containers. Several samples that weighed between 200 and 2000 grams were counted in this laboratory during the preliminary examination. The samples selected for analysis were purposely varied so that all, or most, geological types were represented.

11.4.5 Biological Testing

Portions of the returned lunar samples were distributed to the biological test laboratories located in the sample operations area. The personnel in these laboratories, under quarantine conditions and using extensive test procedures, determined whether the returned samples contained detrimental alien life-forms. All biological testing was performed within special biological cabinetry designed to contain extremely hazardous pathogenic material. The Lunar Receiving Laboratory is the only facility in the world capable of handling a large variety of plant and animal test subjects under such containment conditions. Details of the biological tests conducted during the program are given in section 8.7.

11.5 AFTER APOLLO

The Lunar Receiving Laboratory was closed to lunar sample handling when the Apollo 17 preliminary examination phase was concluded. Only a small portion of the material returned from each lunar landing mission was allocated for research. Most of the lunar material is being conserved intact, under nitrogen storage conditions, for future studies when scientific measurement technology is expected to far surpass present capabilities. All sample distribution, storage, and packaging activities have been transferred to the office of the lunar sample curator. Although priorities change with science and technology, the Lunar Receiving Laboratory will remain in history as the first facility designed solely for the containment of extraterrestrial material.

APPENDIX A - APOLLO FLIGHT DATA

TABLE A-I.- UNMANNED SATURN LAUNCH VEHICLE AND APOLLO SPACECRAFT DEVELOPMENT FLIGHTS

Mission	Type	Launch			Vehicle configuration		Additional data
		Complex (a)	Date	Time, G.m.t., hr:min:sec	Launch vehicle	Payload	
SA-1	Launch vehicle development, suborbital	34	Oct. 27, 1961	15:00:06	Saturn I with dummy second stage and Jupiter nose cone		Vehicle achieved altitude of 84.6 miles and range of 206 miles
SA-2	Launch vehicle development, suborbital	34	Apr. 25, 1962	14:00:34	Saturn I with dummy second stage and Jupiter nose cone	22 900 gallons of water for Project Highwater 1	Water container was detonated at altitude of 65.2 miles after 162.6 seconds of flight
SA-3	Launch vehicle development, suborbital	34	Nov. 16, 1962	17:45:02	Saturn I with dummy second stage and Jupiter nose cone	22 900 gallons of water for Project Highwater 2	Water container was detonated at altitude of 103.7 miles after 292 seconds of flight
SA-4	Launch vehicle development, suborbital	34	Mar. 28, 1963	20:11:55	Saturn I with dummy second stage and Jupiter nose cone		
SA-5	Launch vehicle development, earth orbital	37B	Jan. 29, 1964	16:25:01	Saturn I	Jupiter nose cone containing sand ballast to simulate Apollo spacecraft mass	First Saturn I launch vehicle with live second stage
A-101	Launch vehicle and spacecraft development, earth orbital	37B	May 28, 1964	17:07:00	Saturn I (SA-6)	Boilerplate command and service module, adapter, and launch escape system (BP-13)	Spacecraft and S-IV stage disintegrated during entry into earth atmosphere over Pacific Ocean during 54th revolution
A-102	Launch vehicle and spacecraft development, earth orbital	37B	Sep. 18, 1964	16:22:43	Saturn I (SA-7)	Boilerplate command and service module, adapter, and launch escape system (BP-15)	Spacecraft S-IV stage disintegrated during entry into earth atmosphere over Indian Ocean during 59th revolution
A-103	Micrometeoroid experiment, earth orbital	37B	Feb. 16, 1965	14:37:03	Saturn I (SA-9)	Boilerplate command and service module, adapter, and launch escape system (BP-16). Pegasus A satellite enclosed by service module until orbital insertion	Initial "operational" launch vehicle in Saturn I series. Satellite was commanded off August 29, 1968
A-104	Micrometeoroid experiment and spacecraft development, earth orbital	37B	May 25, 1965	07:35:01	Saturn I (SA-8)	Boilerplate command and service module, adapter and launch escape system (BP-26). Pegasus B satellite enclosed by service module until orbital insertion	Satellite was commanded off August 29, 1968
A-105	Micrometeoroid experiment, earth orbital	37B	July 30, 1965	13:00:00	Saturn I (SA-10)	Boilerplate command and service module, adapter, and launch escape system (BP-9A). Pegasus C satellite enclosed by service module until orbital insertion	Satellite was commanded off August 29, 1968, and disintegrated during entry into earth atmosphere August 4, 1969

[a]All vehicles were launched from the U.S. Air Force Eastern Test Range, Cape Kennedy, Florida.