SPACE POWER CHAMBERS
(Microwave System Lab—Building 7)
NASA Glenn Research Center at Lewis Field
Cleveland
Cuyahoga County
Ohio

Historical and Architectural Information
Space Power Chambers 1959–75

WRITTEN HISTORICAL AND DESCRIPTIVE DATA
PHOTOGRAPHS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
Great Lakes Support Office
1709 Jackson St.
Omaha, Nebraska 68102

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This document (HAER No. OH-133) is one of three HABS–HAER reports regarding a single test facility at the NASA Glenn Research Center. The facility was originally built as the Altitude Wind Tunnel (AWT) but was converted into the Space Power Chambers (SPC) in the early 1960s, as described in the first two reports—HAER No. OH-132 (AWT) and HAER No. OH-133 (SPC). The third report (HAER No. OH-134) describes the support buildings required to support the operations.

Contents

1.0 Overview of Space Power Chambers

Location:	National Aeronautics and Space Administration (NASA) John H. Glenn Research Center at Lewis Field 21000 Brookpark Road, Cleveland, Cuyahoga County, Ohio The Space Power Chambers (SPC) facility was located in the wedge-shaped block of Ames, Moffett, Durand, and Taylor roads near the center of what is now the NASA Glenn Research Center. The facility faced north on Ames Road with SPC No. 1 to the east and SPC No. 2 wrapping from the northwest corner past the southwest corner and through the south leg.
Elevations:	SPC No. 1's southeast corner was at 754'-0" and its northeast corner was at 755'-0". SPC No. 2's southwest corner was at 751'-0", its south leg was at 755'-0", and its northwest corner was at 751.5'-0". The Shop and Office Building was at 754'-0", the Refrigeration Building was at 754'-0", Cooling Tower No. 1 was at 752', the Air Dryer Building was at 753'-0", Substation B was at 757'-0", and the Steam Plant was at 759'-0".[1]
UTM Coordinates:	17 427938E 4585154N (NAD83) Latitude: 41.41471 Longitude: –81.86227 Quadrangle: Lakewood, Ohio
Present Owner:	NASA John H. Glenn Research Center at Lewis Field.
Present Use:	The SPC's two test chambers were demolished in 2009. The SPC was last used for its original function in 1975, but the former wind tunnel test section had recently been used by the Communications Division to store large pieces of equipment. The surrounding room had been littered with excess equipment and supplies. The former Shop and Office Building, presently named the Microwave Systems Laboratory (MSL), was not part of the demolition. The shop and high-bay areas currently house the near-field and far-field test facilities. These test ranges are used by the Communications Division for antenna testing and vehicle and equipment storage. The former SPC No. 1 control room in the balance chamber below the test section is now used as the Far-Field Antenna Test Facility. The overhead crane remains in working condition and is used by the MSL. The office portion of the building is used primarily as office space by the Educational Programs Office.
Historian:	Robert S. Arrighi Wyle Information Systems, Inc. NASA Glenn History Program Cleveland, Ohio 44135

2.0 Historical Information

2.1 Physical History

Figures 1 and 2 show aerial views of the SPC.

2.1.1 Location Maps

Figure 3 locates the SPC in the U.S. Geological Survey (USGS) Lakewood, Ohio, quadrangle.

2.1.2 Original Plans

As the Altitude Wind Tunnel (AWT), the facility served as an altitude simulating engine research wind tunnel from 1944 to 1958. The AWT was the first and largest wind tunnel at the National Advisory Committee for Aeronautics' (NACA's) Aircraft Engine Research Laboratory (AERL). The addition of large supersonic wind tunnels and altitude simulating engine test stands at the lab between 1948 and 1955, however, reduced the need for the tunnel.

During the rush of the early space era, the tunnel was used for several small rocket engine tests. In 1959 and 1960, the interior of the tunnel was used for a series of Project Mercury tests. Two sets of turning vanes, the cooling coils, and makeup air valves were removed at that time, ending the facility's days as a wind tunnel.

Between 1961 and 1963, the facility was converted into two large test chambers, and on September 12, 1962, it was renamed the SPC (Figs. 4 to 7). The drive fan, exhaust scoop, and turning vanes were removed from the east end of the tunnel and bulkheads were inserted to create the two chambers. The high-vacuum chamber, SPC No. 1, was located in the eastern leg of the former wind tunnel. A dome with a removable lid was added near the southeast corner. A high-altitude chamber, SPC No. 2, occupied the entire south leg, the west leg, and the throat section of the former tunnel. The SPC was used for various tests of the Centaur second-stage rocket until the mid-1970s.

The Shop and Office Building (Bldg. 7, currently the MSL) is a T-shaped structure facing north on Ames Road. The Shop and Office Building contained the former tunnel test chamber and the SPC control rooms in its south extension, two floors of offices in the east wing, a shop area in the west wing, and a high-bay area with an overhead crane running north and south down the middle of the building to transport articles into the test section. The test chamber room in the rear was an open two-story space with the tunnel sunken in the floor.

The Exhauster Building (Bldg. 8—served as the Visitor Center until 2010; is currently the NASA Glenn Briefing Center) is a two-story rectangular structure located immediately to the east of the wind tunnel. A section of the building was used as a clean room during the 1960s and was renamed the Solar Power Laboratory. The Refrigeration Building (Bldg. 9), a rectangular structure, was located to the immediate west of the tunnel. It contained cooling equipment for the AWT and Icing Research Tunnel (IRT). Other related buildings include Cooling Tower No. 1 (Bldg. 10), the Vacuum Pump House, and the Circulating Water Pump House (Bldg. 78, which was renamed the Solar Power Laboratory Annex).

2.1.3 Project Information

This report was part of a wider effort to document the AWT/SPC facility prior to its demolition. Documentation was formally begun in May 2005 after Statement of Work 6.31 for the NASA Glenn History Program was finalized. The project included the gathering of records, images, films, and oral histories; and researching the facility, its tests, and significance. The resulting information is being disseminated via a book, a website, a multimedia disk (CD–ROM), a documentary video, and this report. This report was revised in the fall of 2013.

In 2005, NASA Glenn proposed to remove the entire wind tunnel circuit except for the test section within the high bay of Building 7 (Fig. 8). Building 7 and most of the other support buildings were not included in the demolition. Although the AWT/SPC facility was unique on the basis of size alone, the maintenance costs for the facility became so high as to be justified only by the largest of research programs. Although mostly idle since the mid-1970s, this facility had had a rich history and had played an important role in NASA and aerospace history. For this reason, NASA Glenn decided to document the facility as thoroughly as possible before its demolition and to share the information with the public and within the Agency.

2.1.4 Construction Data Sheet

Dates of Construction:	1942–44, and 1961–63
	Excavations for the facility's foundations began in May 1942 and were completed by late December. The frame of the Shop and Office Building was in place by September 1942, and the building was largely complete by September 1943. Construction of the tunnel shell began in late 1942 and was completed in January 1944. The Refrigeration Building and the Exhauster Building were completed in the fall of 1943.[2–7]
	The internal components of the tunnel's western leg were removed in late 1959. The official construction of the SPC began in July 1961 and was completed in September 1962. The addition of the dome was begun in early 1963 and completed that September.
Engineers:	The original engineers included Alfred Young, Louis Monroe, Larry Marcus, Harold Friedman, Carl Bioletti, Walter Vincenti, John Macomber, and Manfred Massa of the NACA.[8] SPC engineers included Robert Myer, who designed the bulkheads.
Contractors:	The contractors were the Sam W. Emerson Company, Pittsburgh-Des Moines Steel Company, the Carrier Corporation, Collier Construction Company, General Electric Company (GE), the York Corporation, the Arthur E. Magher Company,[9] Armstrong Cork Company, Norris Brothers, and Robert M. Pelkey, Inc.
Owner:	The facility was originally constructed as a wind tunnel for the AERL.

The laboratory's name was changed to the NACA Flight Propulsion Laboratory in April 1947. The name was changed to the NACA Lewis Flight Propulsion Laboratory in 1948 in honor of the recently deceased George Lewis, the NACA's Director of Aeronautical Research. After the NACA's integration into the new NASA space agency on October 1, 1958, the name was modified to be the NASA Lewis Research Center. In March 1999, the name was changed again to the NASA John H. Glenn Research Center at Lewis Field.

Significance: The AWT had served as the first wind tunnel in the United States for studying full-size aircraft engines in atmospheric conditions similar to those encountered during flight. In the late 1950s, though, the facility shifted its focus to space and its interior was used as a large altitude chamber. The chamber was involved in several important tests for the Project Mercury Program. These included the guidance system for the Big Joe launch, posigrade and retrorockets, and the escape tower rockets. In addition, the seven Mercury astronauts and several test pilots came to the facility to train in a unique rotational test rig.

SPC No. 1, which was added to the facility between 1961 and 1963, was among the first large vacuum chambers in the country that could simulate the environment of outer space. The SPC No. 1 vacuum tank was rivaled in size only by the smaller Mark I tank at the Arnold Engineering Development Center (AEDC).[10]

The SPC's significance is directly linked to the success of the Centaur second-stage rocket (Fig. 9). The Centaur's original mission was to carry the Surveyor spacecraft to soft-land on the Moon and photograph the lunar surface in preparation for the Apollo Program. The SPC was directly involved with ten Centaur missions, but its testing influenced just about every subsequent mission. SPC No. 1 was used to conduct a series of long-term systems tests on a full-scale Centaur and nose-cone separation tests for multiple Surveyor missions. SPC No. 2 could simulate the conditions experienced in the upper levels of the atmosphere. Some of this chamber's investigations included Atlas/Centaur (AC) separation tests, shroud jettison studies for the Orbiting Astronomical Observatory (OAO) missions, and a number of liquid-hydrogen propellant management studies. Centaur remained a successful workhorse, carrying Pioneer, Viking, Voyager, the OAOs, Cassini, and many other spacecraft.

2.1.5 Topography

The SPC was located on a portion of the original 200 acres acquired by the NACA from the Cleveland Municipal Airport in late 1940 for an engine research laboratory (the current location of NASA Glenn). The site had previously been used by the airport for parking and grandstands for the National Air Races.[11] The airport borders the laboratory on the east. The rest of the border loosely follows the Rocky River which bows to the northwest around the main campus. The river valley is densely forested, but the main portion of the property is flat and featureless.

The SPC was built on a flat, featureless area at an elevation ranging from 751'-0" to 755'-0" above sea level. The nearby area contained several other laboratory buildings, including the Engine Research Building (Bldg. 5, ERB), the IRT (Bldg. 11), and several small support buildings for the IRT. These original buildings had similar designs and finishes, giving the area a unified appearance (Fig. 10).

2.1.6 Original Construction

The original design for the tunnel began in 1940 at the NACA Langley Memorial Laboratory and NACA Ames Aeronautical Laboratory. The tunnel's distinctive shell, test section, and electrical drive system were designed at NACA Ames by Carl Bioletti, Walter Vincenti, John Macomber, and Manfred Massa. Most of the other components were engineered at NACA Langley by Al Young, Larry Marcus, Harold Friedman, and others.[12]

The Sam W. Emerson Company was the prime contractor for the general construction work. They commenced the excavations for the facility in the spring of 1942 (Fig. 11) and completed the task by late December.[13] The construction of the Office and Shop Building was completed in September 1943. This was followed closely by the completion of Refrigeration and Exhauster buildings.[14–19] The Pittsburgh-Des Moines Steel Company fabricated and constructed the shell.[20]

Planning for the refrigeration system started at NACA Langley in April 1942, but it was soon taken over by the Carrier Corporation. Carrier's cooling system for the AWT was the largest refrigeration system in the world. Carrier provided all the system's equipment and was then contracted to install the system.[21] The original control room, test section, and tunnel were completed in January 1944, and the facility ran its first test on February 4, 1944.[22–27]

After fifteen years of wind tunnel use, center management decided that the facility would not be used for its airflow generation but for its large internal space and altitude simulating capabilities. Although the decision to create the SPC would not be made for another two years, the first unofficial steps began between September 1959 and April 1960. The cooling coils, makeup air pipe, and turning vanes had been removed from the west end of the tunnel (Fig. 12). An elevated walkway and banks of lights were erected along the western wall. A catwalk was erected along the ceiling of the western leg. In addition, the tunnel's interior was cleaned and repainted. Various fittings were installed on the floor and walls as part of several temporary test stands and setups.

Over about one year beginning in April 1959, a gimballing system (the Multiple Axis Space Test Inertia Facility, MASTIF) was installed at the base of the tunnel's throat section (Fig. 13). This was a three-axis rig with a pilot's chair mounted in the center surrounded by three 21'-0"-diameter cages. A two-level steel platform, used to enter and view the rig, was constructed around the rig. The top level of the platform was even in height with the test section and the lower level was approximately 3' above the tunnel floor.

Starting in 1961, a number of steps were taken to convert the wind tunnel into two large test chambers (Figs. 14 to 17). This included separating the chambers from each other, resealing the outer shell, adding a removable dome, and upgrading the exhaust system for space simulation. In addition, the existing drive shaft, fan, turning vanes, and exhaust scoop were removed from the east end of the tunnel.

Three bulkheads were installed inside the tunnel to create the two chambers. The largest was the 31'-0"-diameter seal between structural ribs No. 70 and 69 near the southeast corner of the southern leg where the wind tunnel fan was located.[28] A section of the upper half of the tunnel near the southeast corner was cut out and removed with a crane. The crane was then used to install the large red bulkhead, one half at a time, in the opening. Another seal was created at the east end of the former test section, which completed sealing off the entire eastern leg of the tunnel for SPC No. 1.

During the conversion process, the outer skin of the tunnel was removed to check the inner shell for leaks (Fig. 18). Structural tests revealed that the entire SPC No. 1 chamber area had to be rewelded. Some of those involved with the conversion felt that this was due to the original hurried wartime construction. The rewelding slowed down the conversion progress and drove up costs.[29] The insulation and outer shell were not reinstalled. Since the larger SPC No. 2 chamber would be used for upper atmospheric tests, it did not have to be rewelded, and the insulation and outer shell remained in place.

The interior of the 30'-0"-diameter, 100'-0"-long SPC No. 1 was sandblasted and repainted with a double-coat of aluminum paint that would not outgas in a high vacuum.[30] The AWT's exhaust system was replaced by a new oil-diffusion-based system that could create a vacuum to 10^{-6} mm of mercury.[31] A new Vacuum Pump House was constructed underneath SPC No. 1 to house this new vacuum system (Fig. 19). The ten diffusion pumps were connected from below to the chamber floor.

The Centaur rocket program was transferred to NASA Lewis in October 1962, just as the SPC was nearing completion. Center management decided that the new vacuum chamber would be an ideal place to study the behavior of the rocket's systems in a space environment. At this time, the SPC's most distinguishing trait, a 22.5'-0"-diameter cylindrical extension with a detachable dome (Fig. 20), was created near the southeast corner. The extension was created in the ceiling of the chamber so that the full-size Centaur could be vertically positioned inside the chamber. The extension was capped with a removable dome so that the Centaur could be lowered inside by a crane.[32]

Another 20'-0"-diameter bulkhead was inserted on the western end of the test section (Fig. 21) before the throat section. This, along with the 32′-0" seal in the southeast corner, created another test chamber—SPC No. 2—in the remainder of the tunnel.[33] This large, J-shaped chamber was used for a number of Centaur shroud separation and propellant behavior tests. Previous test equipment, including the gimbal spin rig, was removed from the tunnel. Although the wind tunnel internals were removed and the walls were painted for the Project Mercury tests, the area was cleaned up and repainted for the new SPC chamber. The existing tunnel exhausters were sufficient for simulating the altitudes of the upper atmosphere at which shrouds would be jettisoned.[34]

The clamshell lid for the former tunnel test section was removed, and a metal bridge and stairway into the tunnel were built at the east end of the test section. Steel-grated flooring was installed in the bottom of the test section. An overhead rail crane was mounted in the northeast leg to transfer articles from the test section in the high bay into SPC No. 1.

A new control room for SPC No. 1, which sought to replicate the launch control room at Cape Canaveral, was created underneath the former tunnel test section (Fig. 22). Instrumentation cables traveled from the east wall directly up to the dome. The existing wind tunnel control room was modified to run the tests in SPC No. 2. This primarily involved rewiring and altering the control panels.

Although the SPC was completed in September 1962, the modifications and setup for the Centaur Program pushed back the first tests for over a year. The first separation tests in SPC No. 2 began in October 10, 1963. The Centaur rocket was placed in SPC No. 1 on March 19, 1964, and environmental testing began that December. Surveyor separation tests began in SPC No. 1 during the interim in July 1964.

2.1.7 Alterations

The SPC facility did not undergo any major alterations during its operational period from 1963 to 1975. Various platforms, hooks, braces, and other temporary items were added to the interior for test setups. Some of these additions were left in place afterwards, but most were cut off near their bases.

SPC No. 2 included an oval platform elevator (Fig. 23) that could be raised the entire height of the chamber on two vertical steel girders. The elevator's 11'-0"-diameter interior opening allowed it to be placed around the payload shrouds to assist in separation test preparations.[35]

In an effort to test deceleration pellets for the new Zero Gravity Research Facility, a penetration was installed in the top of SPC No. 2 in late 1965. A 5'-0"-diameter, over 20'-0"-tall deceleration stand was mounted to the chamber floor. A temporary shacklike enclosure was built on the top of the tunnel to protect the accelerator apparatus. A tubular device extended to the deceleration bucket on the chamber floor.[36]

The SPC control room and its Shop and Office Building were transformed into the MSL in the early 1980s. This included the repurposing of the SPC No. 1 control room and sealing of the high-bay area.

2.2 Events History

2.2.1 Project Mercury

In response to the Soviet Union's launch of the Sputnik I and II satellites in 1957, President Eisenhower pushed for the creation of a civilian space agency. NACA Lewis, which had been working on rocket propulsion and high-energy fuels for years, was influential in the decision to base the new agency on the existing NACA laboratories. NASA officially came into being on October 1, 1958, and the NACA Lewis Flight Propulsion Laboratory became the NASA Lewis Research Center. The center underwent a major reorganization and for the next ten years concentrated its efforts almost exclusively on the space program.

NASA's first step would be Project Mercury—a series of twenty-one unmanned and seven single-person orbital flights. On October 15, 1959, the team coordinating Project Mercury, the Space Task Group (STG), met to allocate the testing assignments among the NASA centers. The AWT would be used extensively, but not as a wind tunnel. The tunnel's interior and altitude simulation would be utilized to test the Mercury/Atlas separation system, calibrate retrorockets, and test the attitude control system. The facility also was selected to study the escape tower rocket plume and to train astronauts how to bring a spinning capsule under control.[37]

The first attempt to launch a capsule on a full-size Atlas booster was dubbed Big Joe. Big Joe was a single mockup Mercury capsule without an escape tower, life support, or other systems. The flight was designed to simulate the reentry of the capsule without actually placing it in orbit and to test the launch and recovery processes.[38] NASA Lewis was asked to assemble the capsule and design the electronic instrumentation and automatic stabilization system.[39]

The STG decided to forgo their original plans to use balloons and to instead employ the AWT to qualify the capsule and all its systems at high altitudes before launch.[40] The MASTIF was created inside the AWT to simulate the various motions the capsule would be subjected to. During the early summer of 1959 qualifications, the attitude control and retrorockets were fired, and the capsule was exposed to simulated altitudes up to 80,000' for long periods of time.[41] On September 9, 1959, Big Joe MA–1 was successfully launched on an Atlas D missile, and the mission objectives were achieved.[42]

The Mercury capsule had six rockets on a "retro-package" affixed to the bottom of the capsule. Three of these were posigrade rockets used to separate the capsule from the booster, and three were retrograde rockets used to slow the capsule for reentry into Earth's atmosphere. There were several problems while the posigrade and retrograde rockets were being qualified, and there was no backup system if the retrograde braking system failed. The STG assigned the task of resolving the issue to NASA Lewis and NASA Ames.[43]

Full-scale separation tests using mockups of both the Redstone and Atlas boosters were conducted in the AWT at altitudes comparable to the upper atmosphere (Fig. 24). The capsule's posigrade rockets were fired, and the capsule jettisoned forward on a tether. The AWT tests in January and February 1960 determined that a gas buildup in the Redstone ballast section actually accelerated the separation process.[44] Mercury/Atlas separation tests in mid-April ensured that the firing of the posigrade rockets did not injure any other components and determined the actual boost level of the posigrades.[45]

Three Mercury retrorocket qualifications tests were also begun in April 1960 in the AWT (Fig. 25). A retrograde thrust stand was erected in the southwest corner of the tunnel. The studies showed that a previous problem of delays in igniting the propellant had been resolved. Follow-up test runs verified reliability of the coated igniter's attachment to the propellant grain.[46] In addition, the capsule's retrorockets were calibrated so that they would not alter the capsule's position when fired.[47]

During late spring 1960, the AWT was used to determine whether the plume from the Mercury capsule escape tower rocket would engulf the capsule during an emergency separation from the booster. The escape tower was a 10'-0" steel rig and rocket attached to the nose of the Mercury capsule. The tower had its own propulsion system, which could be used to jettison the capsule to safety in the event of launch vehicle malfunction on the launch pad or at any point prior to separation from the booster.[48] The tunnel was evacuated to an altitude of approximately 100,000', and the escape tower was mounted to the tunnel wall with a mockup Mercury capsule at the end. Three different escape tower motors were successfully fired.[49]

One of the highest profile tests ever conducted in the AWT was the MASTIF (Fig. 26), informally referred to as the “gimbal rig.” The MASTIF was a three-axis rig designed the previous year to test the Big Joe guidance system. Modified with a pilot’s chair mounted in the center, a control stick, and a mock control panel, the MASTIF was used during February and March 1960 to train the Mercury 7 astronauts on how to rein in a tumbling spacecraft. It was also used to study the effects of rapid rotation on the pilots’ eyesight. The rig was set up in the northwest corner of the tunnel. The pilot was strapped in on a foam couch in the center of the rig with only the arms free to operate communications and panic buttons and a stick that controlled the small nitrogen jets that ran the movement of the MASTIF.[50]

2.2.2 Centaur Program

Between 1958 and 1960, NASA Lewis refocused its efforts almost completely on the space program. NASA Lewis built or reassigned nineteen space-related facilities during the Apollo Program and mothballed numerous aeronautics facilities.[51] With 4700 employees, Lewis had become the second largest NASA center by 1964.[52]

It was during this rich period of growth that the Centaur second-stage rocket program, NASA Lewis’s most important contribution to the space program, was transferred to Cleveland. Although it was designed solely for the Surveyor missions to explore the Moon’s surface, Centaur went on to perform scores of missions. These included Pioneer, Viking, the Lunar Orbiter, OAOs, Cassini, and others. The AWT played a key role in resolving early problems with the Centaur.

The Centaur Program was created by the Department of Defense in 1958, but it shifted to the NASA Marshall Space Flight Center on November 8, 1959.[53] The first launch on May 8, 1962, failed shortly after lift-off because of a Centaur malfunction, and the program was on the verge of cancellation. NASA Marshall engineers had never felt comfortable with Centaur’s nontraditional design or liquid-hydrogen propellant. NASA Lewis had been performing work with hydrogen and other nontraditional fuels for years and was confident in its safety and the advantages. In October 1962, the program was transferred to NASA Lewis.

NASA Lewis was steadily building up space-related test facilities in Cleveland and at its satellite Plum Brook Station. Among these were the two new large test chambers recently created inside the former AWT. One chamber could replicate an outer space environment and the other that of Earth’s upper atmosphere. The new facility was officially renamed the SPC on September 12, 1962.[54]

NASA Lewis’s nuclear propulsion and power programs also were gearing up at this time, and SPC No. 1, the space tank, had actually been built to study the Systems Nuclear Auxiliary Power Program (SNAP–8) nuclear power generator.[55] Plans for the chamber were changed with the transfer of the Centaur Program. Another year of construction was needed to add an extension and domed lid to SPC No. 1 to accommodate an upright Centaur (Fig. 27).

2.2.3 Surveyor Nose Cone Tests

The first studies in the new facility, however, were a series of AC separations (Fig. 28) conducted in SPC No. 2 during the fall of 1963. The simulated AC vehicle was hung horizontally in the large chamber. When the retrorockets fired, the Atlas model, which was on wheels, was jettisoned into a net. Researchers found that the firing of the eight retrorockets was inconsistent. Follow-up studies with standard and alternate versions of the rocket igniters firing at pressure altitudes up to 98,000' revealed the causes of the unpredictability. The lighters were redesigned by the manufacturer and requalified in the SPC.[56] In addition, the rockets were configured in such a way that the misfiring of one rocket would not mar the separation.[57] A new method of loading the propellant also was derived from these studies. The increased impulse significantly reduced the separation time, which reduced the danger of collision between the two stages during separation.[58]

After successful launches of the Lewis-led AC–2 and AC–3, NASA Lewis researchers conducted a series of nose fairing tests in anticipation of the next Centaur launch scheduled for late 1964, which would attempt to place a mockup Surveyor spacecraft into orbit. Although ambient atmosphere separation tests prior to AC–3 were successful, the separation during the AC–3 launch had difficulties that nearly caused a mission failure. NASA engineers felt that the low pressure of space affected the bottle used to activate the explosive bolts. SPC No. 1's space simulation could determine any design faults in the AC–3 fairing and flight-qualify the AC–4 shroud components (Figs. 29 and 30).[59]

The tests of the fairing were conducted in the northeast corner of SPC No. 1 from July 31 to November 24, 1964, with many high-speed cameras installed. After numerous modifications and adjustments, NASA Lewis researchers determined that internal jet expansion separation devices could successfully jettison the fairing without damaging the payload. It was also determined that these separation tests must be conducted in a vacuum environment.[60] All modifications implemented between the AC–3 and AC–4 missions were verified in the SPC. As a result, AC–4 was the first Centaur mission to have an error-free shroud jettison.[61]

Despite the fact that the fiery failure of AC–5 was caused by the booster engines, modifications had been made to the Centaur and the nose cone that required requalification of the shroud. This flight qualification of the new shroud was conducted from May to July 1965 in SPC No. 1. These studies tested the nose cone design, determined the impact on the payload envelope, and studied the shroud's effect on the new, thinner Centaur fuel tanks.[62] Although the payload envelope had to be altered, NASA Lewis researchers approved the entire nose fairing design and load limits for flight.[63] The successful mission of AC–6 (Fig. 31) on August 11, 1965, restored NASA's confidence in the Centaur's capabilities.

2.2.4 Centaur Environmental Testing

During the buildup to the Surveyor flights, NASA Lewis researchers wanted to determine how the Centaur's auxiliary propulsion, hydraulic, pneumatic, and electrical systems behaved in a space environment. Of particular concern was the effect of the heat from the electronics on the cryogenic liquid-hydrogen propellant. A Centaur 6A rocket was flown to Cleveland on a C–130 aircraft and transported via flatbed truck to the SPC shop area in October 1963 (Fig. 32). For several months, General Dynamics personnel worked with NASA Lewis researchers as they studied and began reassembling the rocket in shop area. The 6A model had to be reharnessed electronically and updated to properly replicate the Centaur that would be performing the AC–4 mission.[64] On March 19, 1964, the Centaur was rolled out of the shop. A 100'-0" crane lifted the lid off the dome, then lifted the rocket into the air and lowered it into a test stand inside the chamber (Fig. 33).

SPC No. 1 sought to replicate all aspects of outer space except microgravity and meteor impingements. The new oil diffusion pumps pulled the vacuum down to a pressure level of 10^{-5} mm of mercury.[65] The cold temperature was supplied by a nitrogen-filled cold wall erected around the Centaur (Fig. 34). The radiation of space was created using banks of quartz lamps. In addition, a pneumatic system rotated the rocket's RL–10 engines as they would be during flight.[66]

After the proper vacuum was achieved in the tank, the rocket was brought to launch temperature, the electrical system was turned on, and the test commenced. The first three minutes of the test were the Atlas booster phase. The Centaur systems were activated immediately afterward the simulated separation. This involved prestarting the Centaur's RL–10 engines, engine ignition and cutoff, coasting for approximately twenty-five minutes, a second engine firing and cutoff, payload separation, Centaur course reversal, and finally the shutdown of all Centaur systems by ground-based operators.[67]

After the AC–4 tests, the rocket was reharnessed in the AC–8 configuration. In all, there were twenty to thirty test runs conducted over several years. Every aspect of the test was intended to be identical to actual flight, down to minutiae like the ink used to mark wires.[68]

These studies verified the trustworthiness of Centaur's basic design and proved that the electrical system could perform during a two-burn flight in a space environment. The few design problems that were discovered, such as the electrical inverter and C-band transponder, were rectified before the Surveyor flights.[69] Among these was the recommendation not to use pressurized electronics canisters, and avoiding overheating by maintaining the minimal necessary power level.[70]

2.2.5 Propellant Management Studies

The SPC also was utilized for several liquid-hydrogen management tests such as the Weightlessness Analysis Sounding Probe (WASP) and Centaur hydrogen vent studies. The WASP was a two-stage sounding rocket designed by the NASA Lewis Spacecraft Technology Division to examine the control of liquid-hydrogen propellant during the periods between rocket firing, as on the two-burn Centaur flights. The WASP rocket would carry a transparent fuel tank and television cameras to film the behavior of the propellant during flight.[71]

The WASP's shroud underwent testing in the SPC in August 1964 and April 1966 (Fig. 35). On June 7, 1966, the WASP rocket was successfully launched off of Wallops Island with intentional sloshing of the liquid hydrogen.[72] The almost seven minutes of microgravity during freefall from 250,000' provided researchers enough data to launch AS–203 in July 1966.[73]

The December 1964 AC–4 and April 1966 AC–8 missions were designed as propellant management studies. When the first engine burn ended on AC–4, the liquid hydrogen sloshed forward, resulting in the venting of some of the hydrogen in liquid rather than gas. The propellant's motion and resulting inability to maintain the vehicle's balance while gases were being vented off skewed the Centaur's trajectory, causing additional liquid venting and tumbling. Approximately ninety percent of the liquid hydrogen was lost, and the engines could not be restarted—resulting in a failed mission. The failed AC–4 mission demonstrated that engine shutoff, coasting, and restarting forces influenced the propellant's behavior.[74,75]

Although research programs like Aerobee had previously studied the behavior of liquid hydrogen on scaled models, the AC–4 flight revealed the unique issues created by the forces associated with full-size propellant systems.[76] NASA Lewis researchers undertook a series of propellant management studies (Fig. 36) that resulted in several modifications for the AC–8 flight. These included a baffle in the hydrogen tank to prevent sloshing, energy dissipaters, and a redesign of the vent system. The new system underwent extensive qualification and vent valve performance tests in SPC No. 2.[77] On the AC–8 mission, the propellant was successfully managed and off-gasses were expelled without altering the rocket's trajectory.[78]

2.2.6 Larger Shroud Testing

The SPC also was used for a series of Centaur and Agena nose-cone separation tests for the OAO missions. The OAO satellites were designed by the NASA Goddard Space Flight Center to study and retrieve ultraviolet data on specific stars and galaxies that Earth-bound and even atmospheric telescopes could not view because of ozone absorption.[79] The OAO satellites were direct predecessors of the Hubble Telescope.[80]

The instrumentation and payload were covered by a nose cone as the rocket traveled through the atmosphere. The nose cone was then ejected once the vehicle was in space. SPC No. 2 was used because it was not necessary to simulate space since the nose cone separation occurred in the upper atmosphere. The existing exhausters were strong enough to reach that level.[81] In addition, the nose fairing was larger than the Surveyor fairings, and the extra room in SPC No. 2 was needed.

A steel base, 10'-0" in diameter, was installed on the floor at the center of the chamber. A metal spacer was attached to the base, and a mock Centaur forward bulkhead was attached to the spacer. The fairing and payload were then mounted to the forward bulkhead. A 50'-0" x 30'-0" nylon net was horizontally secured 11'-0" above the chamber floor to catch the fairing halves after they were jettisoned.[82]

The first OAO satellite with its four experiments would be the heaviest payload yet carried by the Atlas/Agena D.[83] During the summer of 1965, the shroud was tested three times in SPC No. 2 at altitudes of twenty miles. Accelerometers on the model and shroud provided researchers with data that could verify a successful separation during the actual launch.[84] The April 8, 1966, OAO–1 launch and separation went smoothly, but a battery failure caused the mission to fail within ninety minutes.[85]

After the failed first Agena-OAO mission, NASA management decided to replace the Agena with the more powerful Centaur rocket; however, the basic Agena separation system and nose cone were retained. The 40'-0"-long modified nose fairing for the OAO–2 mission was 18'-0" longer than the AC Surveyor nose fairing, and it was jettisoned by a mechanical spring rather than by a gas thruster system.[86]

In April 1968, three OAO nose fairing setups were successfully jettisoned in SPC No. 2 at a simulated altitude of 90,000' (Fig. 37).[87] OAO–2 was launched on AC–16 on December 7, 1968, and after only a month, it obtained over twenty times the amount of ultraviolet data from stars than from all of the sounding rocket studies over the previous fifteen years combined.[88]

The next OAO mission, OAO–B, failed on November 30, 1970, when the nose fairing did not separate properly.[89] Although not used to test the shroud before the launch, the SPC was a principle element of the failure investigation. Tests in SPC No. 2 during April 1971 led to a redesigned single-piece fairing.[90] In April and May 1972, a full-scale version of this new OAO nose cone underwent a series of successful jettison tests in SPC No. 2 (Fig. 38). OAO–C, or Copernicus, launched by AC–22 on August 21, 1972, remained an active observatory for eight years.[91]

2.3 Contemporary Vacuum Chamber Facilities

2.3.1 Vacuum Chamber Development

As humans began flying aircraft at greater elevations, there were an increasing number of attempts to create ground-based facilities to test the behavior of both humans and aircraft components in altitude conditions. In general, altitude conditions were simulated with vacuum chambers, which reduce the air pressure inside the tank. These chambers are containers that achieve low pressure or vacuum by using exhausters or pumps to remove the air and other gases. For basic altitude simulation, air pressure and temperature have to be controlled, but humidity and air density may also be factors.

There are many different types and sizes of vacuum chambers used for a variety of different purposes. In the aerospace test facility field, there are two basic variations. The first are smaller test cells used for altitude engine testing, such as the Propulsion Systems Laboratory (PSL) at NASA Glenn or the T cells at the AEDC. The second are the large vacuum chambers used to study flight hardware in a space environment, such as NASA Glenn's Space Power Facility (SPF) and NASA Marshall's Space Environment Simulation Laboratory (SESL). The AWT falls into the former category, and the SPC falls into the latter.

The first controlled demonstration of a vacuum dates back to Italy in 1643. After inverting a sealed mercury tube and lowering it into a pool of mercury, Evangelista Torricelli became the first person to maintain a vacuum. By observing that the mercury in the tube did not run out, he surmised that air in the tube had a weight and its exertion of pressure on the mercury in the pool kept the mercury in the tube elevated. This demonstration led to a series of bell jar vacuum experiments in the 1660s.[92]

With the advent of aircraft in the early twentieth century, manufacturers sought ways to test the engines in altitude conditions. The first altitude test beds in the 1910s were built at high elevations. Frequent inclement weather and the relatively low altitudes dampened the effect of these facilities. The Zeppelin Works created at Friedrichshafen in south Germany may be the first vacuum chamber designed specifically to test aircraft engines. It was used for the engines for the Zeppelin airships.

Almost simultaneously, the National Bureau of Standards (NBS) created an altitude chamber for engines in the United States. Hobart Cutler Dickinson was instrumental in the design of the Liberty aircraft engine at the onset of World War I and became head of the NBS aeronautical powerplant section. In this role, Dickinson designed and operated the nation's first altitude chamber for testing full-scale aircraft engines. The simulated 35,000' chamber was constructed by the NBS at the request of the NACA.[93] It made its first test run on December 26, 1917, with a Liberty 8 engine.[94]

In the 1930s, the Italian city of Guidonia added a test bed that could simulate altitudes up to 16,000'. In 1933, the Germans created a similar test facility capable of partially simulating altitudes of 62,000'. A second facility at Rechlin also controlled the inlet temperature down to –60 °C and a pressure altitude of 59,000'. The first real German altitude chamber was the Herbitus facility built in Munich during 1941. It was an actual tank in which refrigerated air was ducted to the engine inlet, the exhaust gas was cooled, and the tank was evacuated to a pressure altitude of 36,000'. At the end of the war, the facility was seized by American troops. The Herbitus was considered the first altitude test bed for jet engines. It was dismantled and reassembled at the AEDC.

2.3.2 NACA Altitude Chambers

The NACA's AERL in Cleveland, Ohio, used the vacuum concept to lower the air pressure to simulate high altitudes in the AWT in 1944. The wind tunnel used exhausters to create a vacuumlike atmosphere and remove combustion gases. The AWT could operate full-scale engines in conditions that replicated the speed, altitude, and temperature of actual flight.

Two altitude test cells were built inside the AERL's ERB during the mid-1940s to alleviate the AWT's workload. This facility, referred to as the Four Burner Area, contained two static chambers into which full-size engines could be installed and run at altitudes up to 50,000' and temperatures ranging from 200 to minus seventy degrees Fahrenheit. An even larger pair of test chambers, the PSL, was added in 1952. Similar facilities, such as the Ordnance Aerophysics Laboratory in Texas, were built in the 1950s.

The late 1950s brought not only increasingly larger and faster engines, but more importantly the advent of the space age. Initial missions in the late 1950s revealed that the behavior of engines, flight systems, and hardware was affected by the conditions encountered in space. The AWT's altitude simulation was used during 1959 and 1960 for a number of Project Mercury tests at pressure altitudes up 100,000'. These did not use the tunnel's airflow, just its 51'-0" diameter and its 163'-long western leg and the exhauster pumps.

In 1960, McDonnell created a 30'-0"-diameter vacuum chamber at its St. Louis location. The effort, referred to as Project Orbit, subjected the Mercury capsule to simulated missions in the chamber altitudes up to 40,000'. Soon afterward, a more powerful altitude test chamber was constructed in Hanger S at Cape Canaveral. When completed, altitude pressure would simulate 225,000'. The chamber, a vertical cylinder with domed ends, was 12'-0" in diameter and 14'-0" high. The chamber was designed to allow a partial spacecraft functional check in a near-vacuum environment. Construction was completed in April 1960. The first simulated orbital mission, with the Mercury spacecraft in the altitude chamber, was conducted on April 1961.[95] These were useful tools but were limited by their size.

In 1960, it was decided to increase the AWT's vacuum capabilities and to permanently construct two test chambers within the tunnel shell—one capable of simulating the altitudes of outer space, the other of Earth's upper atmosphere. The facility was renamed the SPC. It was originally intended to study a full-scale SNAP–8 nuclear space power conversion system.

At the time, there were no tanks of that size that could produce such a deep vacuum in the United States. By the end of 1962, when the SPC was completed, there were nine large vacuum chambers. Many others would emerge by 1965. Although larger chambers capable of deeper vacuums would later be constructed, the rapid conversion of the AWT into a space tank allowed the 31'-0"-diameter, 100'-0"-long tank to play a vital role in the early years of the space program.

There were two major tanks that became operational in 1965: the Aerospace Environmental Chamber known as Mark I at the AEDC and the two chambers in the SESL at what is today the NASA Johnson Space Center. The 35'-0"-diameter, 65'-0"-long Mark I tank was slightly wider than the SPC but not as long. The 65'-0"-diameter, 120'-0"-tall Chamber A at the SESL was built specifically to test the Apollo capsule. It was significantly larger than the SPC and could create high altitudes. Like Mark I, the SESL's Chamber B was wider than the SPC but not as long.[96]

At NASA Lewis in the 1960s, Director Abe Silverstein continued to seek better facilities to test flight hardware and propulsion systems in space environments. An auxiliary site called Plum Brook Station was used to build a test reactor and a number of large space test facilities. The two most impressive were the B–2 Space Propulsion Facility (now a National Historic Landmark) and the massive SPF. The SPF remains the world's largest thermal vacuum chamber, measuring 100'-0" in diameter and 122'-0" high (Fig. 39). It has been used extensively to test rocket payload fairings, various systems for the International Space Station, and planetary landing systems, such as those developed for the Mars Exploration Rovers. In March 2007, NASA announced that the SPF would be used to perform integrated environmental testing of the *Orion* crew exploration vehicle. The tests will simulate environmental conditions such as those the *Orion* will experience during launch, in-orbit operations, and reentry.[97]

In 1998, Hughes Space and Communications Company added a 63,000-cubic-foot, dual-capacity thermal vacuum chamber to its massive Integrated Satellite Factory in Los Angeles. The facility can conduct four thermal vacuum tests at space altitudes, five near-field antenna tests, and two thermal stress tests.[98]

3.0 Architectural Information

The SPC contained NASA Lewis's first and only large vacuum chamber for testing flight hardware from 1963 until it was superseded by the SPF at Plum Brook Station in 1969. The SPC was located inside the former AWT (Fig. 40), which was among the first group of structures built at the NACA AERL in the 1940s. The SPC contained two altitude test chambers within the tunnel shell.

The SPC's supporting infrastructure included the Shop and Office Building, the Vacuum Pump House, the Refrigeration Building, and Cooling Tower No. 1. All of these structures were built in the immediate vicinity of the SPC. The SPC's central location allowed it to easily work in conjunction with several other facilities and buildings, including the hangar, the ERB, and the PSL.

The tunnel, which contained the two chambers, was a massive rectangular structure 263'-0" long on the north and south legs, and 121'-0" long on the east and west sides. The 20'-0"-diameter former tunnel test section, which served as the main entranceway to the two test chambers, was contained in the rear test chamber room of the Shop and Office Building. The courtyard inside the tunnel loop was approximately 40' wide at the east end, 18' at the west end, and 168' long.[99]

3.1 SPC No. 1

The high-vacuum SPC No. 1 (Fig. 41), which was created in the east leg of the tunnel, had an internal volume of 70,000 cubic feet and a length of 100'-0". The chamber was 31'-0" in diameter at the southeast end and 27'-0" in diameter at the northeast end.[100] A 22.5'-0"-diameter cylindrical extension with a removable dome was inserted in the ceiling to create 45'-0" of vertical space within the chamber (Figs. 42 and 43).[101]

SPC No. 1 could create the conditions found at an altitude of 100 miles so that researchers could study how spacecraft would behave in outer space. The chamber was connected to the center's central air system, which could evacuate the chamber to an altitude of 100,000'. Two piston pumps further thinned the air, and the final vacuum was brought down by ten oil diffusion pumps located below the chamber.

The complex setup in the chamber could replicate all aspects of space except microgravity and meteors. A nitrogen-filled cold wall, which enveloped the spacecraft, supplied the cryogenic temperatures of space, and six banks of quartz lamps simulated solar radiation. In addition, a hydraulic system caused the rocket's RL–10 engines to rotate as they would during flight. A tanking system was used to keep the balloonlike fuel tanks partially filled, and a wide array of telemetry was installed. The tests were operated and monitored in a control room that resembled the actual launch pad controls.

Unlike the vacuum tank in SPC No. 1, SPC No. 2 did not require a major overhaul for it to be used as a high-altitude test chamber. The existing AWT exhauster and refrigeration systems were powerful enough to achieve the desired altitudes up to 100,000'.

3.1.1 Shell

The original tunnel was composed of a 1"-thick inner steel shell with fiberglass insulation over it and a thinner outer steel covering. The outer covering and insulation were permanently removed during the creation of SPC No. 1. The inner steel alloy shell was rewelded and sealed to withstand the decreased pressures that the chamber would be subjected to. The two large corner rings and thirty-one tunnel support rings jutted out from the shell.

The sealing of SPC No. 1 was particularly important to creating a vacuum comparable to that found in space. One of the most pressing problems during the creation of the tank was the poor welds that were made during the hurried World War II construction of the tunnel. Small plastic bags were placed over each weld and filled with helium, and a helium leak detector was used to analyze how much helium leaked through each of the welds and penetrations.[102] The entire SPC No. 1 shell was rewelded at a considerable expense.

Coating of the tunnel with a protective gray paint appears to have ceased in the mid-1990s. SPC No. 1's shell appears to have suffered less rust damage than the thin protective steel covering the rest of the facility (Fig. 44).

3.1.2 Dome and Extension

The dome, installed between the 78th and 83rd ring on the eastern leg of the tunnel, provided a 45'-0"-high area inside the chamber.[103] The top of the dome was elevated 17'-6.125" from the tunnel shell. The dome sat atop a vertical base that extended from the top of the tunnel (Fig. 45). This steel base had steel fins radiating from its perimeter that corresponded to the tunnel's support rings. Around the top of the base was a steel support band.[104]

The exterior sides of the dome contained nine 32"-diameter circular portals that extended 1.5'-0" outside of the dome.[105] Two of the dome's ports permitted electrical connections to heater panels inside the chamber.[106] The lower panels were powered through ports near the bottom of the chamber. The wires from the dome were guided through the chamber and into the SPC No. 1 control room in the Shop and Office Building by two cable trays.

An elevated catwalk erected around the dome allowed access to the instrumentation portals and cable trays. From this catwalk, a small ladder and a stairway of four metal steps was built to allow access from the dome base to the top of the cap. A small fixed ladder connected the catwalk to a grated footbridge running northwest. This bridge joined the existing walkway along the top of the tunnel's northeast leg. A series of light fixtures were placed along the catwalk and pathway. The walkway that originally ran along this portion of the tunnel was removed during the conversion to the vacuum chamber.

The dome was capped by a 22.5'-0"-diameter lid that was approximately 4.5' high (Figs. 46 to 48).[107] The lid had a flat circular top area with a vent pipe and a sealed stove pipe in the center. There also were three eyehooks to secure cables used for lifting. This top area was surrounded by metal handrails, and there were four grated steps with handrails leading from the edge of the lid to its top.[108]

When the lid was in place, a 0.25" ring around the lid was welded to a 0.25" ring around the chamber opening. This permitted both a solid seal and the ability to break the seal when the cap had to be removed.[109]

3.1.3 Interior Walls

The interior walls were primarily smooth with few obstructions or penetrations besides the dome in the ceiling and the ten vents in the floor for the diffusion pumps. The corner rings were flat surfaces that were relatively flush with the walls. There were a series of flood light fixtures mounted along the upper portions of the walls with cable trays just below (Fig. 49). The floor had a large number of fixed eyehooks and other fittings that were used for various test setups in the 1960s. There was a monorail crane track down the middle of the ceiling. The former wind tunnel drive shaft penetration that had been sealed in 1961 was almost flush with the eastern wall.

During the conversion process from wind tunnel to altitude chamber, rust, scale, and engine exhaust pollutants were sandblasted from the interior of the tunnel. The new chamber was then sealed with a double-coat of aluminum paint.[110]

In 2005, the walls and ceiling showed some signs of rust but were in fairly good condition (Fig. 50). The floor, however, had suffered a great deal of rust and water damage (Fig. 51), especially underneath the dome. This had been caused by rain entering through the unsealed access portals around the dome.

3.1.4 Bulkheads

SPC No. 1 was sealed from the rest of the tunnel by bulkheads at the southwest and northwest portions of the chamber. The larger, 31'-0"-diameter convex bulkhead at the southwest consisted of a circular metal plate at its center with twelve triangular pieces of steel radiating from it (Fig. 52). A 24"diameter viewing port was located several feet below the center plate.[111]

The 27'-0"-diameter bulkhead at the north end of the chamber contained three access ports on each side and a 15'-0"-diameter door (Figs. 53 and 54) in the middle. The door was braced by two horizontal metal beams across its upper portion, and it had dual O-ring seals.[112] An overhead pulley with a thick steel chain was used to open and shut the door. Nitrogen inlet and outlet connections were installed on chevron baffle chambers.[113]

The access ports were aligned vertically on each side of the door. The north side had three 18" instrumentation ports (Fig. 55) with aluminum face plates. The south side had two of the same and an 18"-diameter viewing port with a polished plate glass face. The plates were buried between 12" and 27" into the bulkhead away from the chamber.[114]

3.1.5 Crane

An overhead 4000-pound rail crane (Fig. 56) was installed in SPC No. 1. It ran west a short distance in the northwest corner, then curved and ran southward along the chamber ceiling to the southwest corner.[115]

Because of the 15'-0"-diameter access door in the northern bulkhead, a platform with steps had to be constructed inside the chamber (Fig. 57). This platform was approximately 5'-0" above the floor and stretched the entire width of the bulkhead. The stairs had dual handrails, and the platform had posts across the front with chain as a railing.

3.2 Vacuum

3.2.1 Vacuum System

The vacuum system was the primary element in SPC No. 1's ability to simulate a space environment. During the conversion of the tunnel to a space tank, the existing pumping system was replaced by a new oil-diffusion-based system. Ten diffusion pumps (Fig. 58) and several roughing pumps were installed in the new Vacuum Pump House building underneath SPC No. 1 (Fig. 59). The empty chamber could be evacuated to 10^{-6} mm of mercury.

The vacuum was brought down slowly in several phases to prevent excessive airflow over the pumps. The center's central exhauster system could evacuate the tank to 100,000'-0" pressure altitude in about fifteen minutes. The two piston pumps would simultaneously remove 12.5 cubic feet per second of air during the roughing stage.[116] A rotary positive displacement pump would then remove air at 500 cubic feet per second. The final vacuum was pulled down by the ten 32"-diameter oil diffusion pumps (Fig. 60), which could remove 17,650 cubic feet per second of air. The entire process took about twenty-four hours, but the chamber could be returned to sea level almost instantly using a gaseous nitrogen system.[117]

3.2.2 Vacuum Pump House

The new pumps were housed in the 12'-0"-high, 46'-0.875"-long, and 20'-1"-wide structure built directly underneath SPC No. 1 (Figs. 61 to 65). The main portion of the Vacuum Pump House actually used the bottom of the chamber as its roof. The front north side had a sloping roof 9'-0" high at its lower edge. The east side of the building had a pedestrian door near the center and ventilation louvers further northward. The west side had identical louvers. The north side had a single pedestrian door and rectangular louvers. The south end had a double set of pedestrian doors. A hood connected the sides of the main structure to the bottom of the wind tunnel.[118]

The pump house had ten 32"-diameter oil-diffusion pumps lined in pairs that were capable of pumping 50,000 cubic meters per second. An 18"-diameter pipe joined the pumps and connected them to a Roots-Connersville vacuum blower pump in the northwest corner that were capable of pumping 850 cubic meters per minute and to two Stokes 3/2 H mechanical vacuum pumps in the northeast corner.[119]

Since the chambers have been idle, this structure had been used for storage by the Educational Services Division. It was demolished during the demolition of the tunnel in 2009.

3.3 Centaur Systems Test Setup

Besides the addition of the dome and extension to the SPC No. 1 vacuum tank, there were several other modifications made specifically for the environmental testing of the full-sized Centaur rocket. These included components to simulate the temperatures of space, general setup and work equipment, and infrastructure to power and operate the spacecraft.

3.3.1 Centaur 6A Rocket

The Centaur that was used for the SPC No. 1 tests was an early 6A model with thinner fuel tanks than later versions (Fig. 66). This Centaur was used for static engine tests in Sycamore Canyon, California, and launch site integration tests at Cape Kennedy. It was originally intended to be used for the follow-up to the AC–2 flight, but a renovation of the launch pad delayed the launch.[120] The Centaur was removed and transported to Cleveland, and another Centaur was eventually launched.

The 28.5'-0"-long, 10'-0"-diameter Centaur 6A had two Pratt & Whitney RL–10 15,000-pound-thrust engines that rotated to steer the rocket. During the coast periods, hydrogen peroxide engines on the aft side maneuvered the rocket.[121] The Centaur had two balloon-type propellant tanks. The electronics and control systems were at the forward section of the rocket, and the mechanical and propulsion systems were near the rear. The electronics package was located just below the payload and above the Centaur's forward bulkhead. A fiberglass fairing shielded the electronics and payload during the launch. The cryogenic propellant tank was shielded by insulation panels until the spacecraft exited the atmosphere.

3.3.2 Platform

The Centaur rested in an approximately 9'-tall triangular stand (Fig. 67) that sat on the chamber floor below the dome. The stand had a circular metal band approximately 18" wide in the middle into which the rocket was inserted. This band was supported at its edges by steel beams arranged in two triangular shapes. This entire structure was elevated approximately 6' by three struts. Two stretch towers inside the chamber supported the Centaur vertically and kept the spacecraft from collapsing on itself.

A large moveable platform was constructed along the floor of SPC No. 1 that allowed technicians access to the Centaur setup. The circular platform was 5'-9" in diameter and surrounded the vertically standing Centaur.[122] The platform ran along the east and west walls of the chamber on 30"-high metal rails.[123]

3.3.3 Cold Wall

A large liquid-nitrogen-cooled copper baffle was erected around the entire Centaur setup to simulate the cold temperatures of outer space (Figs. 68 and 69). The radiant heat absorption device was designed specifically for these tests. The canisterlike cold wall was 20'-0" in diameter and rose 42'-0" high into the dome. The dome lid actually contained the top of the baffle. The baffle had liquid-nitrogen-filled ribs, or bottles, that ran vertically the length of the Centaur and was painted black on the interior to attract heat.[124] These bottles had to be welded together using the new heliarc technique, which involved welding on copper. The success of this process was crucial because any nitrogen leaks would break the desired vacuum level.[125]

A thermal siphon was used to draw cryogenic liquid nitrogen into the vertical ribs. The liquid nitrogen was stored in three 7000-gallon tanks stored outside of the chamber and pumped into the baffle through penetrations in the dome and near the rocket's base. The pressurization was remotely managed from the control room. The nitrogen flowed through a separation tank, which contained a float switch that automatically kept the cold wall filled. A basin was placed underneath the cold wall to trap any cryogenic fuels that leaked from the wall or engines.[126]

3.3.4 Heater Panels

A radiant heater system was designed specifically for these Centaur tests to simulate the effect of the Sun's heat on the rocket systems. Certain lamps could be turned on at different times to recreate the changing areas where the rocket would be exposed to sunlight during a mission. Six sectors of 500-W tungsten-iodine lamps (Fig. 70) were arranged around the Centaur to simulate solar radiation. Four of these arrays were on the upper end of the Centaur—one contained twenty-three lamps at the payload adapter and three contained ninety-one lamps that surrounded the entire forward portion of the vehicle. Two arrays with 145 lamps were located near the RL–10 engines.[127]

3.3.5 Telemetry

The Centaur telemetry in SPC No. 1 comprised six subsystems (Fig. 71). These included a strong system for powered flight and a lower power system for coast periods. Camera and data transmission systems were installed to view the liquid-hydrogen tank. Ground support equipment controlled and monitored the Centaur.[128]

Extensive instrumentation, including 200 transducers and eighteen landlines, were used to record the data in the offsite receiving station. The recorded data were edited down at a later date. A number of K-logger chart-recording systems were used to record up to forty different parameters. A television camera, which was controlled and viewed in the SPC control room, was mounted near the lower section of the Centaur.[129]

A cable rack ran vertically next to the Centaur inside the chamber and exited through a portal in the dome. This rack carried the vehicle's thermocouple lines and other wiring to the control room below the former wind tunnel test section.[130]

3.3.6 Pneumatic System

The Centaur had thin fuel tanks that required pressurization to retain their proper form. If the pressure difference between the upper section of the vehicle and the lower portion with the fuel tanks changed, the vehicle would likely collapse. A pneumatic system was installed in SPC No. 1 to maintain this pressure differential at all times. The oxidant pressure was maintained at eight to ten pounds per square inch above the internal fuel tank pressure, which was kept at four to six pounds per square inch higher than the chamber pressure.[131]

3.3.7 Hydraulic System

The Centaur's RL–10 engines were hydraulically rotated as they would be during a flight but were not fired for the SPC tests. Their boost pump rotors were secured, and the propellant lines were sealed.[132] All fluid and air lines were hooked up to quick disconnects, and all the vents and valves were ducted outside of the chamber. Redundant, parallel electric systems were installed to ensure continuity during the tests.[133]

3.3.8 Liquid-Hydrogen Supply

The Centaur used liquid oxygen as an oxidizer and liquid hydrogen as a propellant. Since the Centaur's engines were not fired during the SPC No. 1 tests, it was not necessary to use liquid oxygen. Instead, the oxidizer tank was filled with liquid nitrogen. Because of its density in comparison to hydrogen, the tank was only filled ten percent with the nitrogen.[134]

Liquid hydrogen was supplied to SPC No. 1 through a pumping system that penetrated the lower south wall of the chamber. A large liquid-hydrogen dewar was stored on railroad ties beneath the chamber, and additional dewars could be added using tanker trucks.[135] Figure 72 shows the control panel used to control this system.

3.4 SPC No. 2

Not including the area used for SPC No. 1 or the former tunnel test section, the remainder of the tunnel was converted into a larger, but less powerful, vacuum chamber. This J-shaped chamber ran from the southeast corner, through the south leg, through the west leg, and through the throat section; it stopped just to the west of the test section (Fig. 73). The diameter of the longer section in the south leg was approximately 33' at its east end and 51' at the west. The diameter of the throat section in the north leg narrowed from 51'-0" at the west to 20'-0" at the east. The widest section was the 121'-0"-long, 51'-0"-diameter west leg.[136]

3.4.1 Shell

The shell for SPC No. 2 was the original wind tunnel shell built in the 1940s. A 1"-thick steel alloy similar to the current ASTM 710 Grade A3 steel plate was used to endure the low temperatures of the high-altitude environment. This alloy was covered with fiberglass insulation and a second, thinner steel shell to protect against the weather.[137]

Coating of the facility with a protective gray paint appears to have ceased in the mid-1990s. Rust began to appear on the exterior of the tunnel by 1999 and was *extensive* by 2005. In recent years, the outer shell on the top of the tunnel would bow under human weight.

3.4.2 Top of the Tunnel

A series of stairs, ladders, and platforms were installed on the top of the tunnel in the 1940s to allow access (Fig. 74). These had steel handrails that were approximately 3' high and segmented by a horizontal bar.[138]

3.4.3 Interior Walls

Although sections of the area that would be SPC No. 2 had been cleaned and repainted a few years prior for the Project Mercury tests, the area was cleaned and repainted again during the conversion to the SPC. The corner rings were flat surfaces that were relatively flush with the walls. These were 42" across at their midpoints and widened to 48" at the floor. The walls were smooth but did contain a number of obtrusions, particularly in the large western leg where the majority of the SPC No. 2 tests took place. In later years, a 15" x 74" rectangular hole was cut into the lower western wall.

The 51'-0"-diameter western leg (Figs. 75 and 76) had a number of former cooling lines and two large makeup air lines that were capped on its western wall in 1958 to 1959. This area also had many fittings and modifications because of the Project Mercury tests and the tests performed in SPC No. 2.

One metal work platform with handrails was mounted to the lower interior wall, and another was mounted to the center of the exterior wall. These work areas were added or removed depending on the test being conducted. However, several small “toe stairs” that had been created in the tunnel wall leading up to the platform areas remained. Other sets of this type of stairs were added on the interior northwest corner ring (Fig. 77) and on the exterior western wall leading up to longer elevated catwalk along the wall.

The steel-grated catwalk ran virtually the entire length of the section at the chamber’s approximate vertical midpoint. Banks of floodlights were installed on the wall over the catwalk. Access was provided near the northwest corner by the set of seven toe steps that led to a small steel platform. From this platform, a fixed ladder led up to the catwalk.[139]

There were a number of fittings welded to the floor in the western leg. These included four 4"-diameter cuplike fittings 54" apart from one another that were arranged in a square pattern in the center of the area. Fourteen 10"-long, 3.5"-diameter tubular fittings were welded to the floor. Ten of these ran in a row north and south, one was on the south end, and three more were on the north end. These were used to tighten the nets for the shroud separation tests.

Large test articles were brought through a removable bulkhead at the junction of the tunnel's throat section and test section. A new "squirrel hole" access portal (Fig. 78) was created in the northern leg near the northwest corner of the tunnel in early 1959 to allow personnel into the chamber for the MASTIF tests. In recent years, this provided the only entrance into the chamber.

The squirrel hole entrance was a 8'-8"-long, 48"-diameter tube that ramped from the exterior of the tunnel into the wide section. The interior opening was 58" wide, 82" high, and surrounded by a slight concrete collar. The exterior opening had a steel lip with bolt holes around it. The tube had a hand rail and steel floor treads. A short set of metal stairs provided access to this entrance from the exterior (Fig. 79).[140]

The former tunnel throat section, which narrowed the tunnel's diameter from 51'-0" to 20'-0", had a 20-step metal stairway from the chamber floor to a platform level with the test section. An industrial private automatic exchange (PAX) telephone was mounted on a 35.5" pole at the base of these steps for the MASTIF tests. A small metal platform was mounted to the inner wall at the top of the stairs.

A 16-step stairway led to a small platform along the northern wall. A steel ladder rose from this platform to a catwalk (Fig. 80) that ran overhead through the western leg for the Project Mercury tests. This catwalk was shortened during the creation SPC No. 2. Several steel-grated platforms were mounted to the curved walls of the interior wall of the throat section (Figs. 81 and 82).[141] These were installed or removed depending on the test being conducted. The northern steps, catwalk, and platforms were permanently removed years ago.

The interior of the south leg (Figs. 83 and 84) of SPC No. 2 had few obtrusions except several eyehooks welded to the lower walls near the west corner. In recent years, several rectangular holes had been cut into the lower half of the tunnel walls; these revealed the insulation, mesh, and outer shell. There were two T-bars set up near the bulkhead in the southeast corner with the cross bar being approximately 36" high. Figure 85 shows a hoist box installed on the inner wall.

In 2007, the overall condition of the interior of the chamber was fairly good considering it had not been maintained in over thirty years. The walls did have some rusting, particularly near the southeast corner and along the seams. The welds at the support ring seams had been numbered with spray paint in recent years.

3.4.4 Bulkheads

SPC No. 2 was sealed off from SPC No. 1 by a 31'-0" bulkhead (Fig. 86) near the southeast corner. This bulkhead was painted red on the SPC No. 2 side and bowed into the chamber. A 24"-diameter viewing port approximately 24" from the chamber floor allowed researchers to look into SPC No. 1.[142]

SPC No. 2 was sealed off on the other end by a 20'-0"-diameter bulkhead (Fig. 87) between the throat section and the former wind tunnel test section. This concave bulkhead had an approximately 3'-deep lip around it that expanded into the throat section and a flat 20'-0"-diameter plate.

3.4.5 Elevator

SPC No. 2 included an oval platform elevator on vertical steel girders that could be raised the entire height of the chamber (Fig. 88). The elevator's 11'-0" interior diameter allowed the structure to be placed around payload shrouds to assist in separation test preparations.[143] The steel girders were mounted to the chamber floor and secured to the ceiling. Pulleys at the top of the shafts were attached to weights at the bottom. Cameras were set up on top of each post to film the separations, and an enclosed metal ladder ran the length of the southern post.[144]

3.4.6 Cranes

SPC No. 2 had two overhead monorail cranes. The first was a westward-sloping crane (Fig. 89) installed in the throat section for the Project Mercury tests. It was suspended from the chamber ceiling by six pairs of struts and a cross beam. Within the throat section, this crane had a second track that veered to the south, providing access to areas near the inner wall. The second crane (Fig. 90) ran along the SPC No. 2 ceiling the length of the western leg, then curved and traveled several feet into the south leg. This crane had a handheld control box that hung from the track.

Figures 91 and 92 show tie downs and a net for a shroud separation test in SPC No. 2 and equipment mounted on an interior wall, respectively.

3.5 Space Power Chambers Building

The former Shop and Office Building, renamed the Space Power Chambers Building in 1963, contained offices, a high bay, a shop area, two control rooms, and other support for the work being conducted in the SPC. The building was originally constructed in the 1940s to support the wind tunnel, but many of its functions were transferred to the SPC in the early 1960s.

3.5.1 Control Room for SPC No. 1

A new control room to operate SPC No. 1 was constructed in the balance chamber underneath the former tunnel test section. Efforts were made to make this control room as much like the Centaur launch controls at Cape Canaveral as possible.[145] The 23'-7.25"-wide, 20'-11.75"-long room went through the bulkhead that separated the tunnel's balance chamber from the rest of the building.[146] Access was provided through the mezzanine level of the SPC Building.

The arrangements of the control panels (Fig. 93) made the room's interior appear octagonal. The eastern section (Fig. 94) had the vehicle pressure and tanking controls (Fig. 95); hydrogen peroxide, hydraulic, stretch, pneumatic, and canister purge systems; the baffle and vacuum systems; and a solar simulator temperature monitor. The northern section consisted of temperature and pressure monitors, electrical power controls and monitor, signal conditioning, and a solar simulator temperature monitor.

The western wall contained the guidance system, C band system, Azusa radar interferometer tracking system, nose cone, and vent valve monitors. The southern section had data and event recorders (Fig. 96), and radiofrequency and range safety monitors.

The center of the room had two racks of control panels running parallel north and south. The eastern rack contained the test conductor controls, ground programmer, vehicle power monitor and flight control, and engine controls. The western rack contained data recorders manufactured by Brush Instruments. The exterior of the octagonal setup was a walkway with minor pieces of equipment, including telephones, air conditioners, and gas detectors.[147]

The original air lock into the test section on the second floor was removed in 1995.[148] At this time, this section of the building went under a major renovation. The stairs were bolstered, walls were repainted, a suspended acoustical ceiling was installed, and office areas were modernized. The SPC No. 1 control room was remodeled and used as the Far-Field Antenna Test Facility.[149] The control room area is now used as a small laboratory for antenna testing. It was not affected by the demolition of the tunnel in 2009.

3.5.2 SPC No. 2 Control Room

The former wind tunnel control room was converted into the control room for the tests in the SPC No. 2 altitude chamber (Figs. 97 to 99). This primarily involved rewiring the telemetry and updating the control panels. The tunnel's floor-mounted pneumatic engine controls were removed. The panels ran east and west along the south wall of the room. The original acoustic tiles on the walls and ceiling remained, as did the overhead fluorescent light fixtures.

The eastern panel controlled the exhaust flow from SPC No. 2, SPC No. 1, the PSL, the ERB, and the cooler. These areas were laid out schematically on the panel with toggle switches and indicator lights. The next panel operated the liquid-nitrogen system. It consisted of thirteen clock-faced dials and many tank pressurization controls. The panel at the west end contained a large number of controls for cameras inside SPC No. 2.

4.0 Index of Space Power Chambers Photographs

Many C-numbered photographs are available from NASA's or NASA Glenn's image archives:

NASA Image eXchange (NIX, http://nix.nasa.gov/) GRC ImageNet http://grcimagenet.grc.nasa.gov/home/scr_main.cfm).

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Appendix—Figures and Images

Figure 1.—SPC with SPC No. 1 to the left and SPC No. 2 occupying the rest of the tunnel, 2005 (OH_Cuyahoga_Space-Power-Chambers_001).

Figure 2.—NASA Lewis Research Center with the SPC left of center (viewed from the northwest), 1963 (OH_Cuyahoga_Space-Power-Chambers_002).

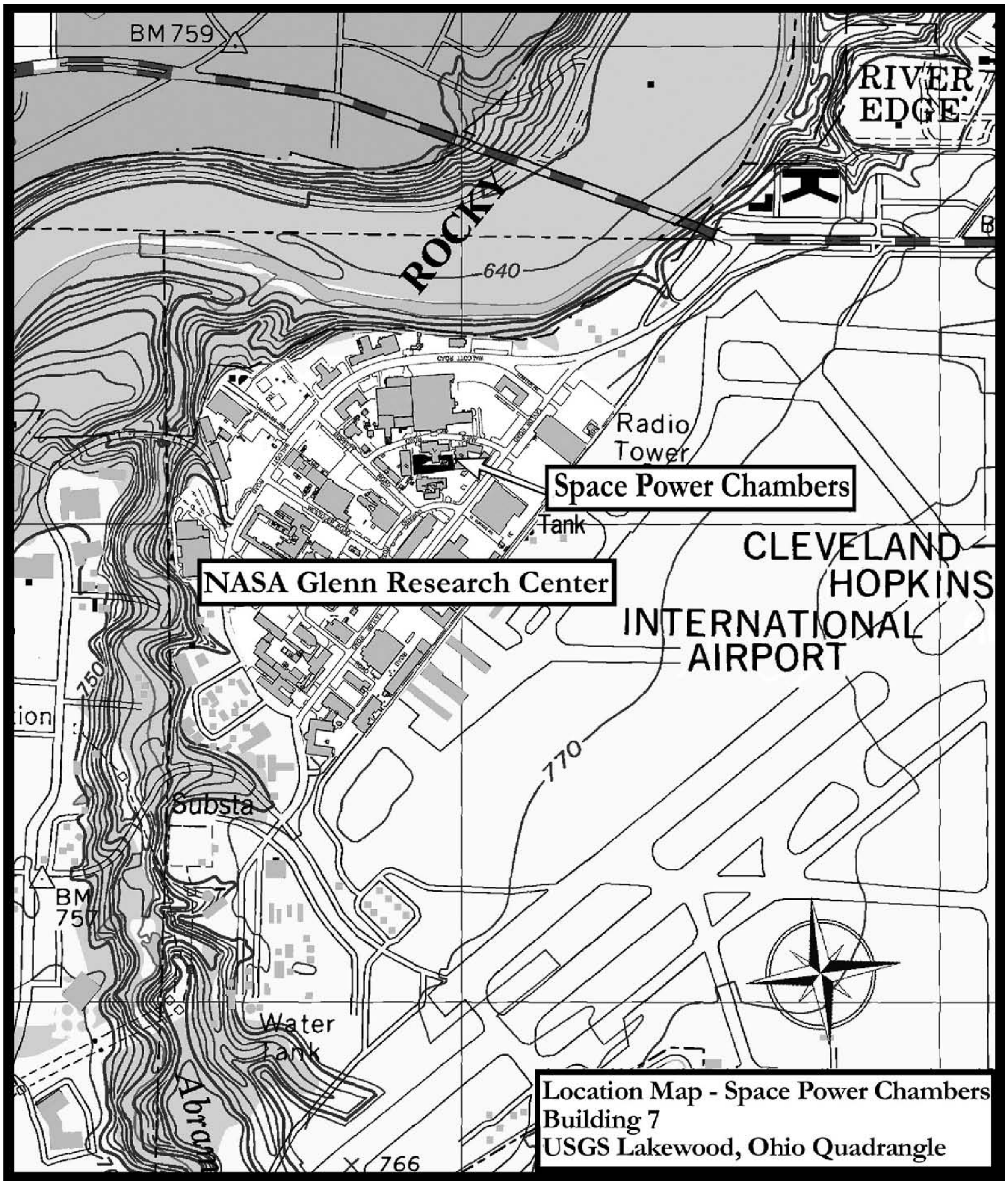


Figure 3.—Location map for the SPC (Bldg. 7), 2009 (OH_Cuyahoga_Space-Power-Chambers_003).

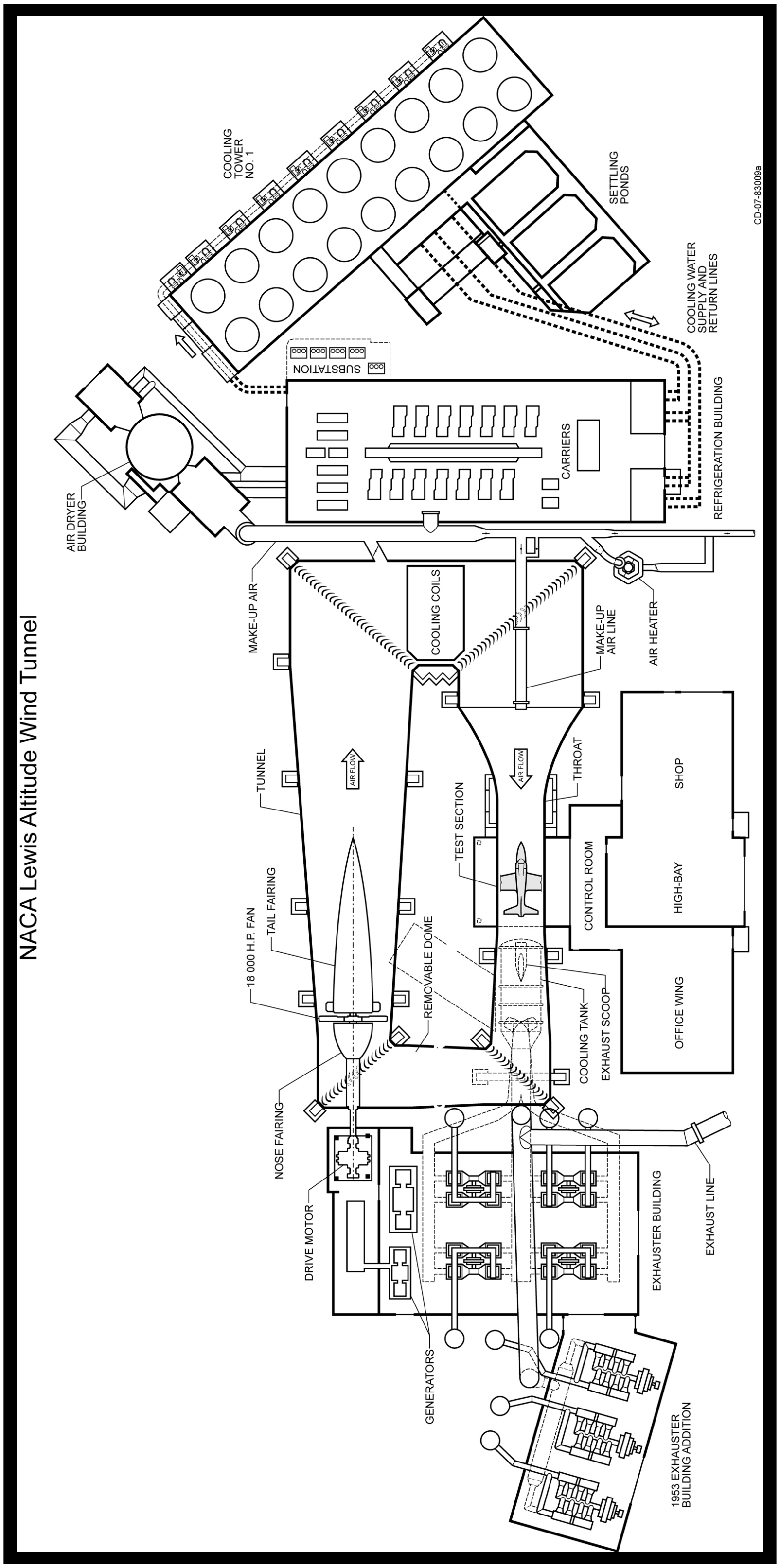


Figure 4.—SPC complex, showing SPC No. 1 (left) and SPC No. 2 (right), 1964 (OH_Cuyahoga_Space-Power-Chambers_004).

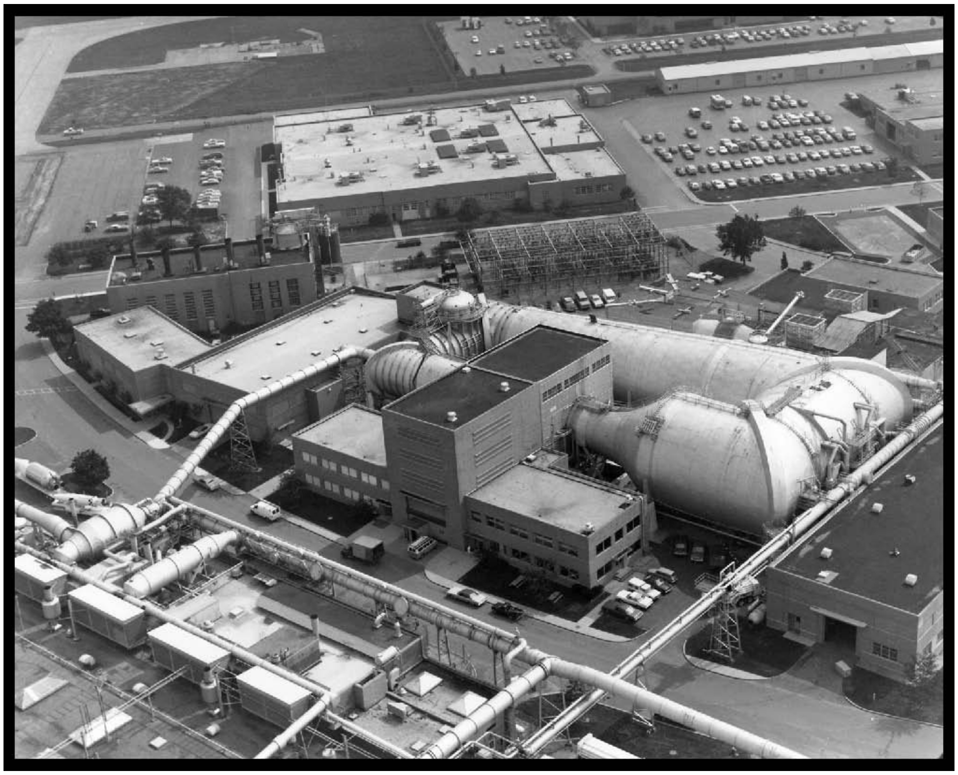


Figure 5.—SPC with Solar Power Laboratory (left), Shop and Office Building (center), and Refrigeration Building (right), 1979 (OH_Cuyahoga_Space-Power-Chambers_005).

Figure 6.—Interior of SPC No. 1, 2005 (OH_Cuyahoga_Space-Power-Chambers_006).

National Aeronautics and Space Administration

Centaur Environmental Test—Space Power Chamber No. 1

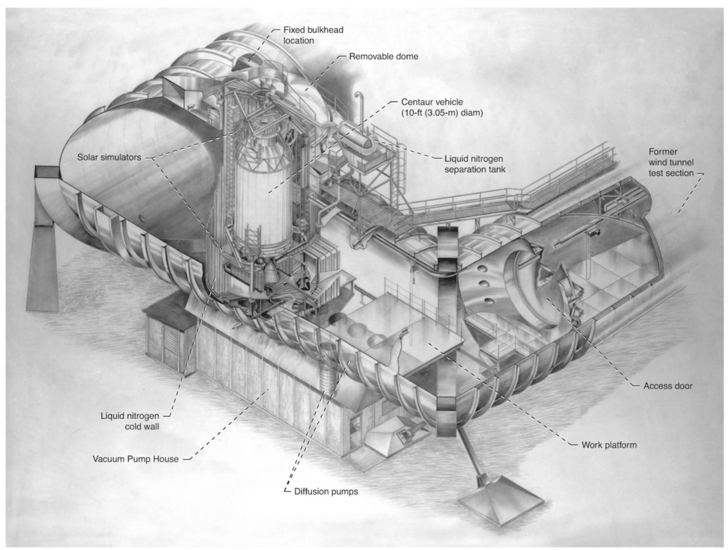
The Space Power Chambers (SPC) was among the first wave of large vacuum chambers built in the early 1960s to test space flight hardware in simulated space environments. The facility, built during 1961 and 1962 in the former Altitude Wind Tunnel (AWT), contained a vacuum chamber, SPC No. 1, in the eastern end and a high-altitude chamber, SPC No. 2, in the larger western end.

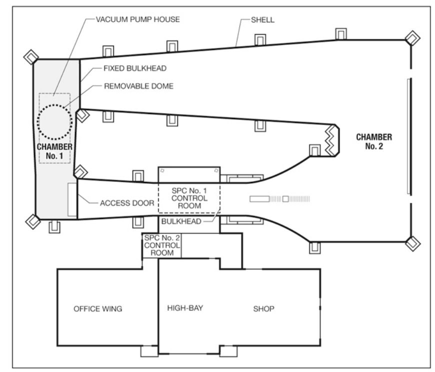
SPC No. 1 was 100 feet long, 31 feet in diameter at one end, and 27 feet in diameter at the other. An extension, removable dome, and other components were added in 1963 in order to accommodate the Centaur second-stage rocket. The Centaur program, acquired by NASA Lewis in October 1962, was intended to carry the Surveyor spacecrafts to the Moon ahead of the Apollo Program. As part of an intensive effort to improve the rocket, a full-scale Centaur was installed inside the SPC vacuum chamber for a series of qualification tests in a space environment.

The SPC No. 1 had a massive exhauster system in a pump house below the chamber that was tied into other exhauster systems at the Center. After the initial air was removed from the chamber, two piston pumps simultaneously removed 12.5 cubic feet of air per second during the roughing stage. A rotary positive displacement pump pulled additional air at 500 cubic feet per second. The final vacuum is pulled down by the ten 32-inch-diameter oil diffusion pumps, which could remove 17,650 cubic feet of air per second.

In addition to the vacuum, SPC No. 1 could simulate the low temperatures and solar radiation of space. A large copper cold wall with its interior coated with heat-absorbing black paint was created specifically for these tests and assembled around the Centaur. The 42-foot-high wall had vertical ribs filled with liquid nitrogen, which produced the low temperatures. Six panels of 500-watt tungsten-iodine lamps were arranged around the Centaur to simulate the effect of the Sun's heat on the rocket performance. Four of these arrays were on the upper end of the Centaur, and two were located near the RL–10 engines. Certain lamps could be turned on at different times to recreate the changing areas of the rocket exposed sunlight during a mission.

Centaur's autopilot, guidance, main propulsion, hydraulic, hydrogen peroxide supply, boost-pump attitude control, telemetry, tracking, range safety, and pneumatic systems were studied. These studies proved that the Centaur's electrical system could perform during a two-burn flight in a space environment. The few problems that were identified were rectified before the Surveyor flights. The researches also discovered the electronics did not create or absorb heat and that the pressurization of instrument packages was not needed and actually caused performance problems.





An open area in SPC No. 1 away from the cold wall was used to conduct separation tests of the Centaur/Surveyor nose fairing in 1964. A malfunction during the separation on the previous launch almost caused the mission to fail. The SPC investigations found that internal jet expansion separation devices could successfully jettison the fairing without damaging the payload. It was also determined that all separation tests must be conducted in a vacuum environment.

The larger SPC No. 2 chamber could simulate the conditions experienced in the upper levels of the atmosphere. Some of this chamber's investigations included Atlas/Centaur separation tests, shroud jettison studies for Centaur's Orbiting Astronomical Observatory (OAO) missions, and a number of liquid hydrogen propellant management studies. These included qualifying an Agena shroud converted for the Atlas/Centaur-6 mission, and redesigning the OAO shroud after a failure in 1968.

As launch vehicles and payloads became larger, the SPC became too small to continue shroud separation tests. Many of these studies were conducted in the massive Space Power Facility at Plum Brook, which began operating in 1969. SPC No. 1 had been dormant since the late 1960s and SPC No. 2 since 1975. The AWT/SPC facility has played a significant role in the progression of the nation's aerospace progress—from the World War II reciprocating engine to the first turbojet models to more advanced jets of the 1950s through Project Mercury, the Apollo Program, and ensuing Centaur interplanetary flights.

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Delineated by the NASA Glenn Research Center, 2009

NASA Space Power Chambers Recording Project
Historic American Engineering Record
National Park Service
United States Department of the Interior

CLEVELAND

Space Power Chambers
National Aeronautics and Space Administration—Glenn Research Center
Cuyahoga County

OHIO

Historic American Engineer Record
OH-133

Figure 7.—Centaur environmental test setup, 1964 (OH_Cuyahoga_Space-Power-Chambers_007).

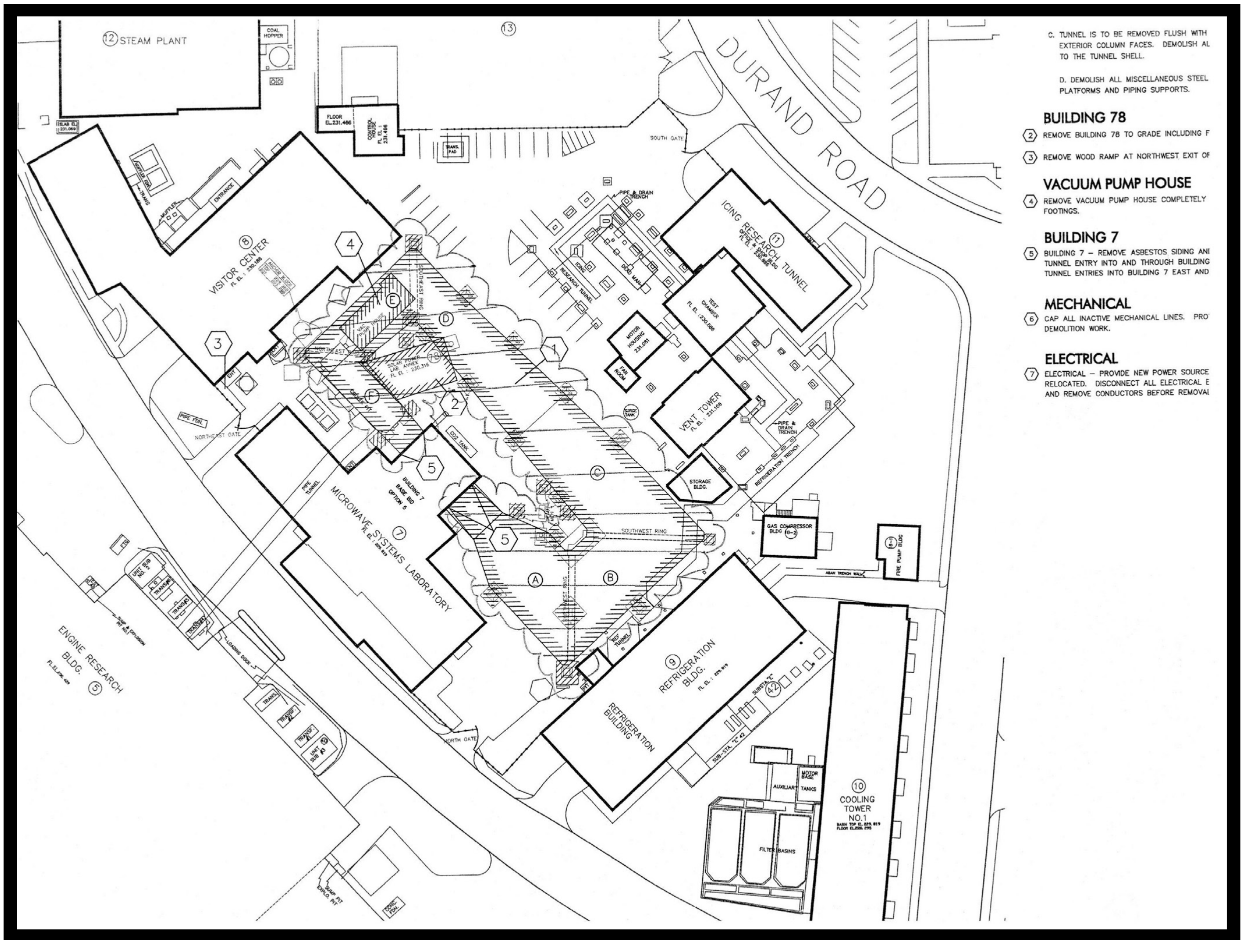

Figure 8.—Demolition plan for the AWT. Areas of the SPC that were demolished are indicated by hash marks, 2005 (OH_Cuyahoga_Space-Power-Chambers_008).

Figure 9.—NASA Lewis researcher being interviewed in the SPC shop area in front of the Centaur rocket, 1963 (OH_Cuyahoga_Space-Power-Chambers_009).

Figure 10.—NASA Lewis, showing the Cleveland Municipal Airport (left), the Rocky River valley (right), and the city of North Olmsted (background) (viewed from the northeast), 1963 (OH_Cuyahoga_Space-Power-Chambers_010).

Figure 11.—Original construction of the east leg of the AWT and future SPC No. 1, 1943 (OH_Cuyahoga_Space-Power-Chambers_011).

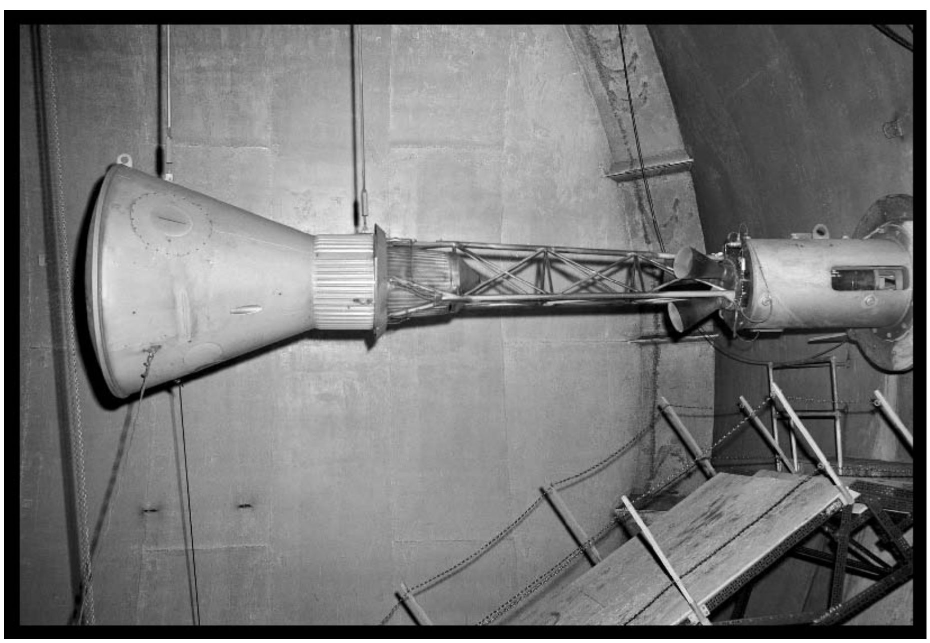

Figure 12.—Project Mercury escape tower rocket test in the AWT after the vanes and cooling coils were removed, 1960 (OH_Cuyahoga_Space-Power-Chambers_012).

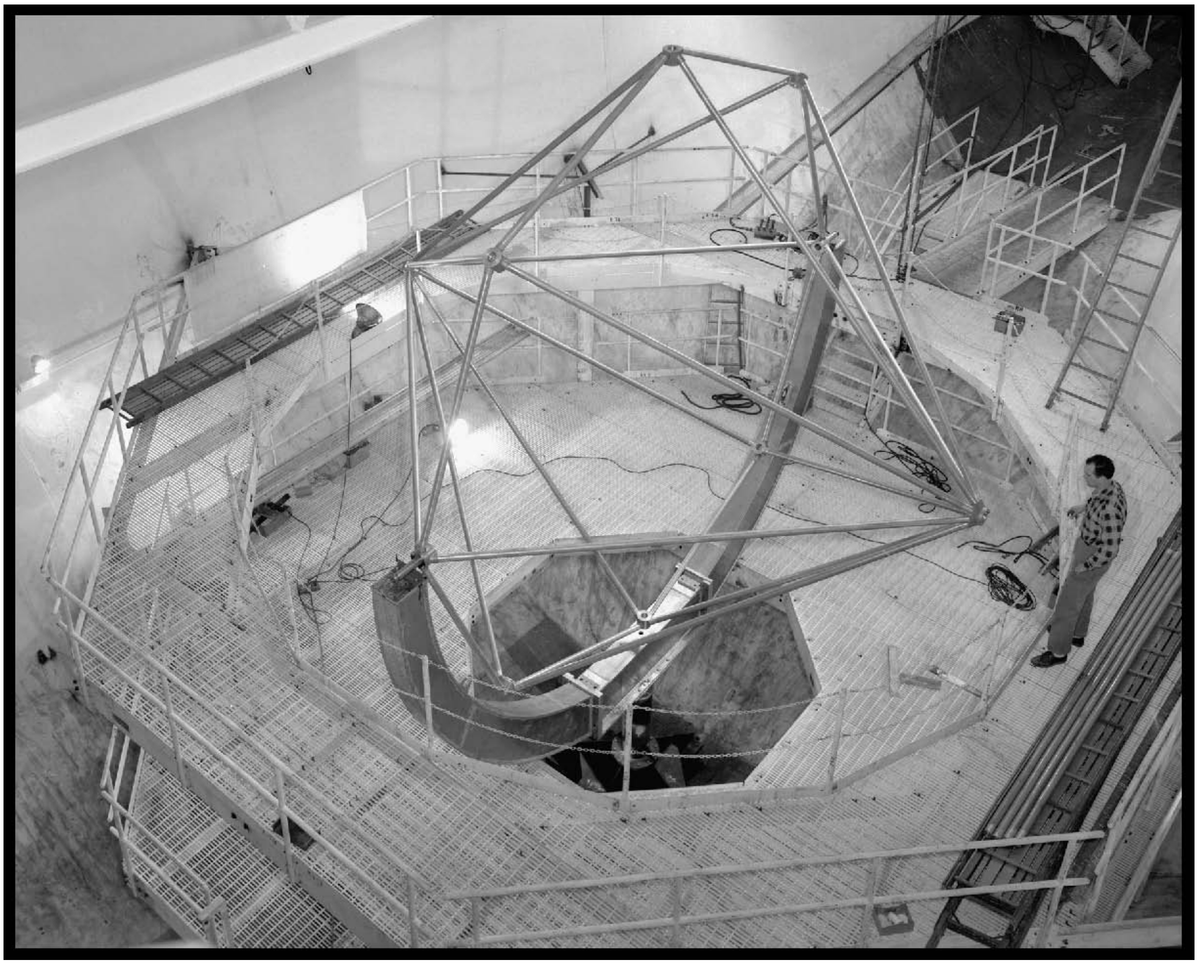

Figure 13.—Installation of the gimbal rig near the AWT throat section with the vanes and makeup air nozzle removed, 1959 (OH_Cuyahoga_Space-Power-Chambers_013).

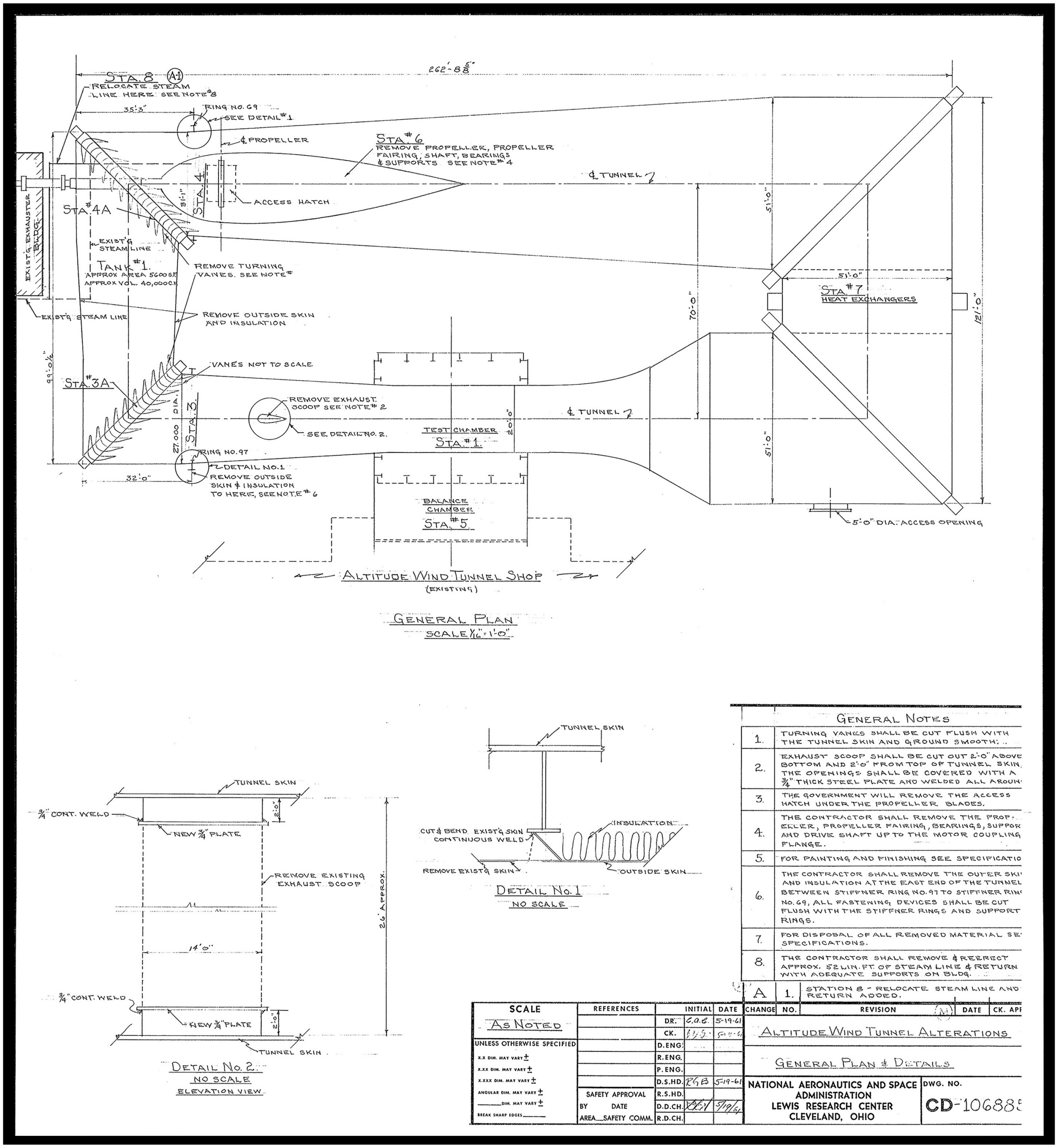

Figure 14.—Plans for removal of the AWT fan, air scoop, and turning vanes for the SPC, 1961 (OH_Cuyahoga_Space-Power-Chambers_014).

Figure 15.—Bulkhead section being lifted into the opening cut in the southeast corner of the tunnel, 1961 (OH_Cuyahoga_Space-Power-Chambers_015).

Figure 16.—Bulkhead installed in the southeast corner of the tunnel (viewed from the west), 1962 (OH_Cuyahoga_Space-Power-Chambers_016).

Figure 17.—Outer steel layer of the wind tunnel being removed so that the inner layer could be rewelded to create a higher vacuum seal, 1961 (OH_Cuyahoga_Space-Power-Chambers_017).

Figure 18.—Interior of SPC No. 1 prior to the addition of the dome, showing diffusion pump portals in the floor, 1962 (OH_Cuyahoga_Space-Power-Chambers_018).

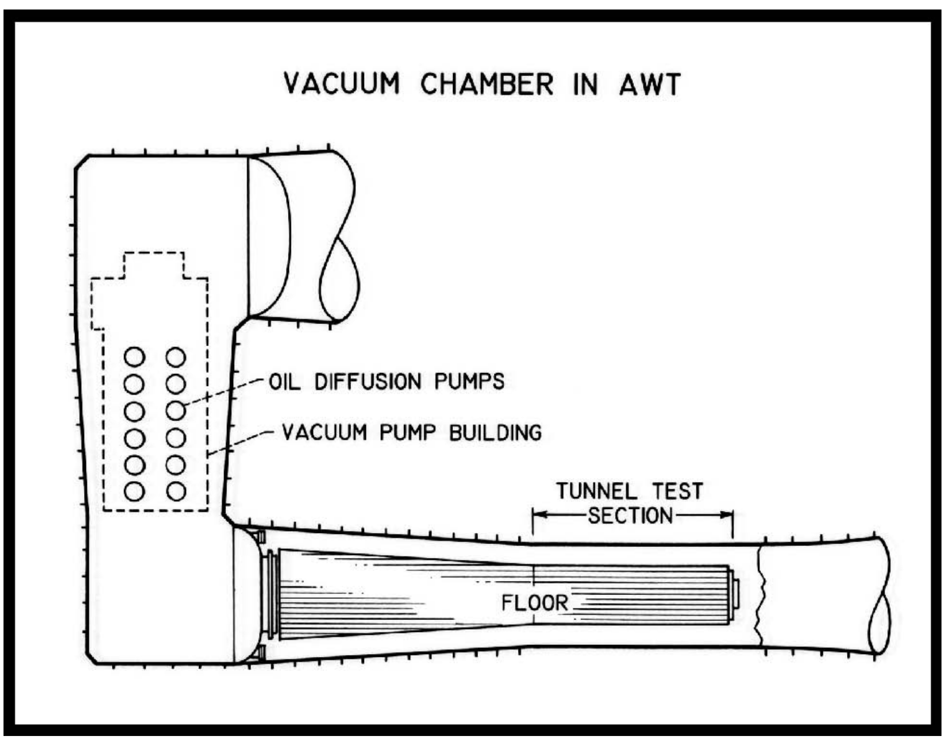

Figure 19.—SPC No. 1, showing the Vacuum Pump House, bulkheads, and flooring in the former tunnel test section, 1961 (OH_Cuyahoga_Space-Power-Chambers_019).

Figure 20.—Extension and dome created near the southeast corner of SPC No. 1 (viewed from the west), 1963 (OH_Cuyahoga_Space-Power-Chambers_020).

Figure 21.—Southwest corner of SPC No. 2 being renovated after the Project Mercury tests, 1961 (OH_Cuyahoga_Space-Power-Chambers_021).

Figure 22.—Construction of the control room for the SPC underneath the former wind tunnel test section, 1961 (OH_Cuyahoga_Space-Power-Chambers_022).

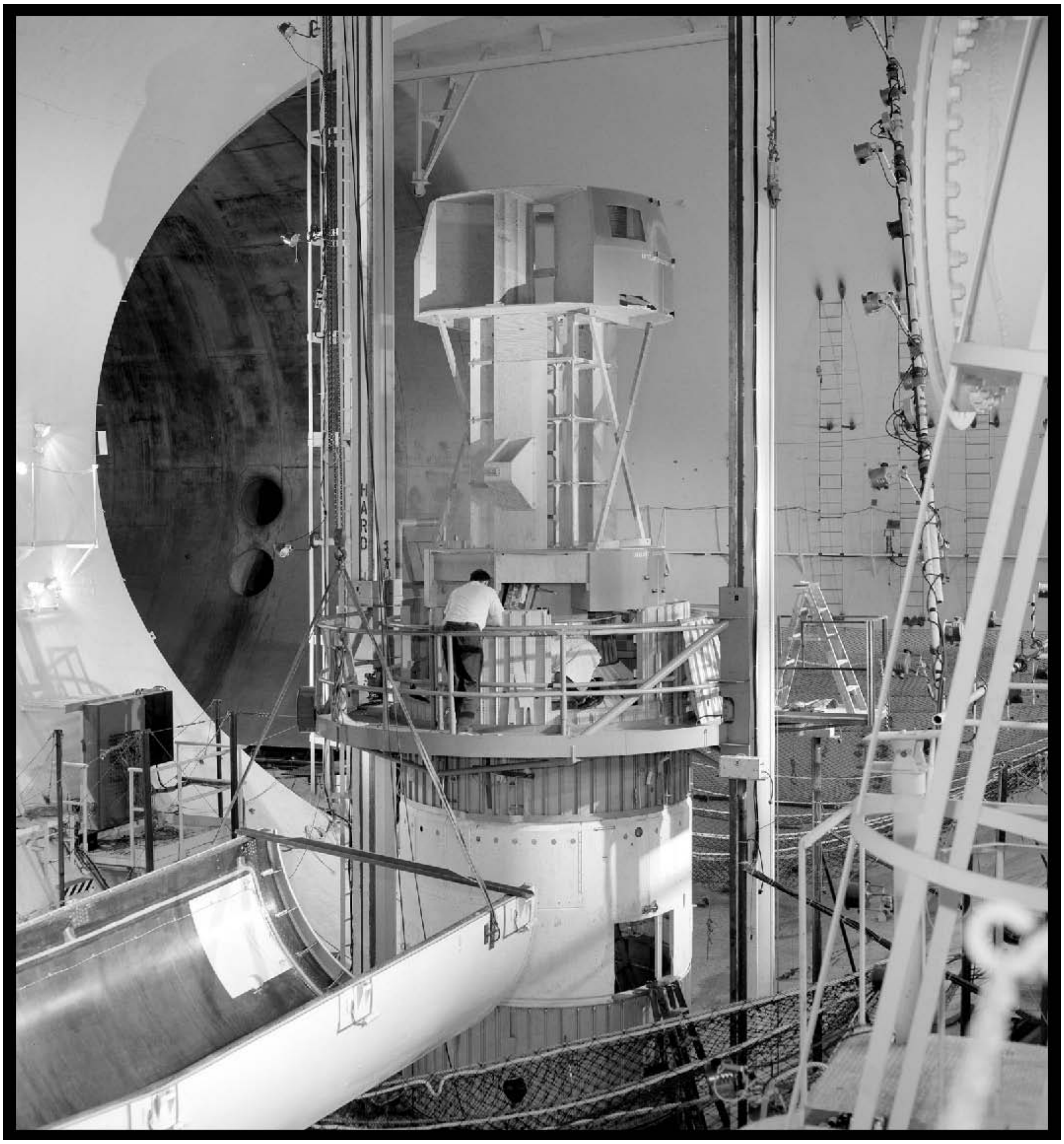

Figure 23.—Platform elevator around the Centaur payload inside SPC No. 2, 1972 (OH_Cuyahoga_Space-Power-Chambers_023).

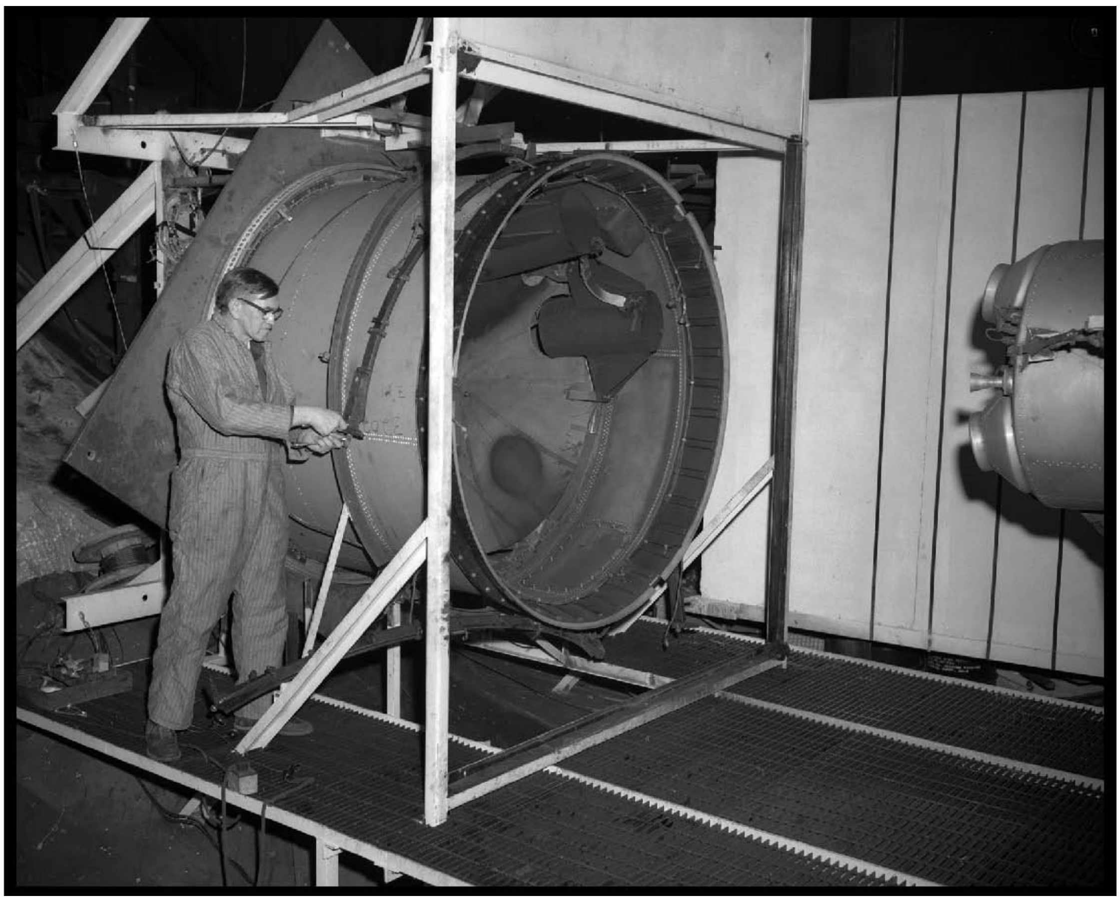

Figure 24.—Mercury capsule/Redstone booster separation test inside the AWT, 1960 (OH_Cuyahoga_Space-Power-Chambers_024).

Figure 25.—Mercury capsule retrorocket test setup inside the AWT, 1960
(OH_Cuyahoga_Space-Power-Chambers_025).

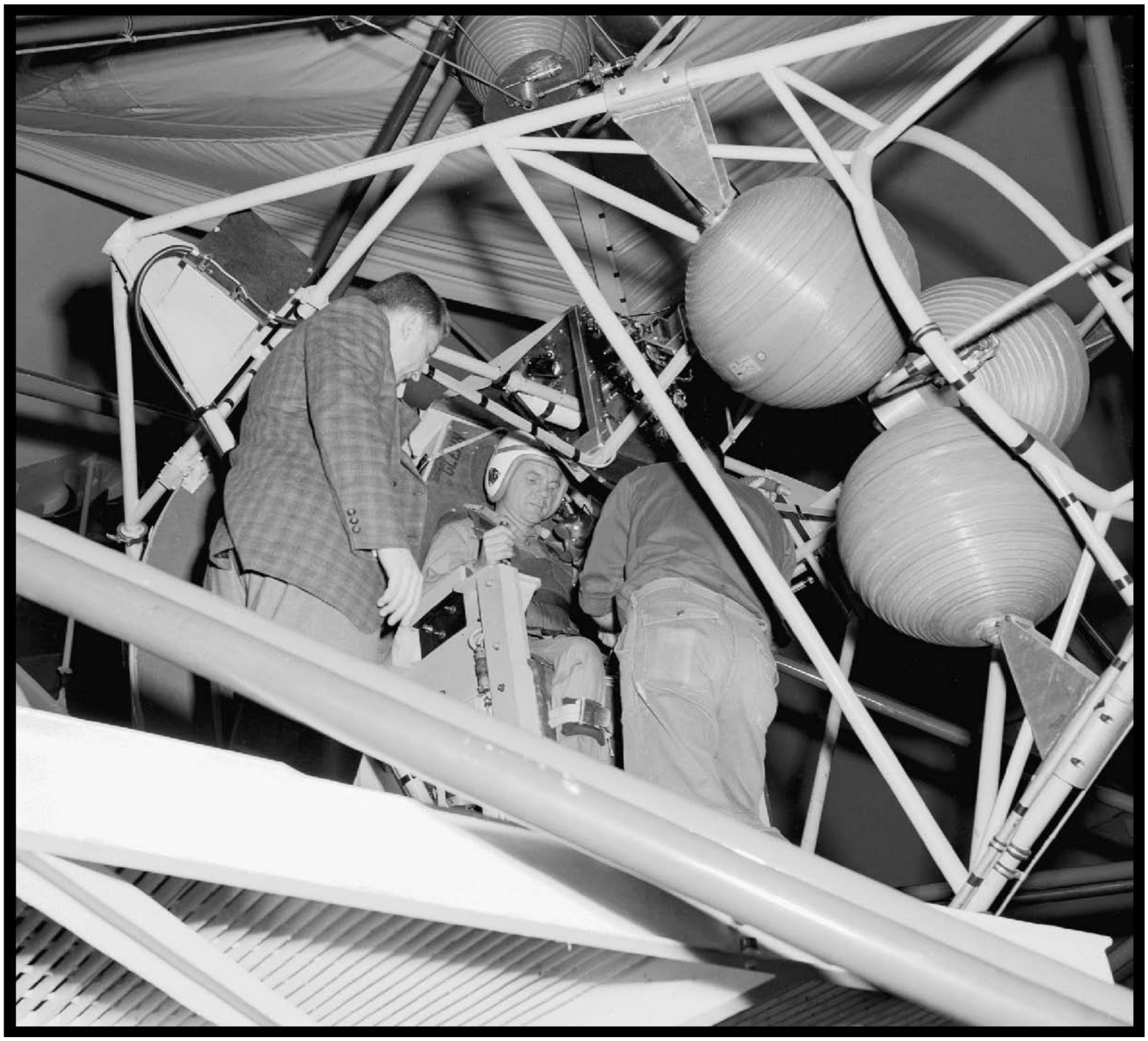

Figure 26.—John Glenn prepares for a test in the Multiple Axis Space Test Inertia Facility (MASTIF) inside of the AWT, 1960 (OH_Cuyahoga_Space-Power-Chambers_026).

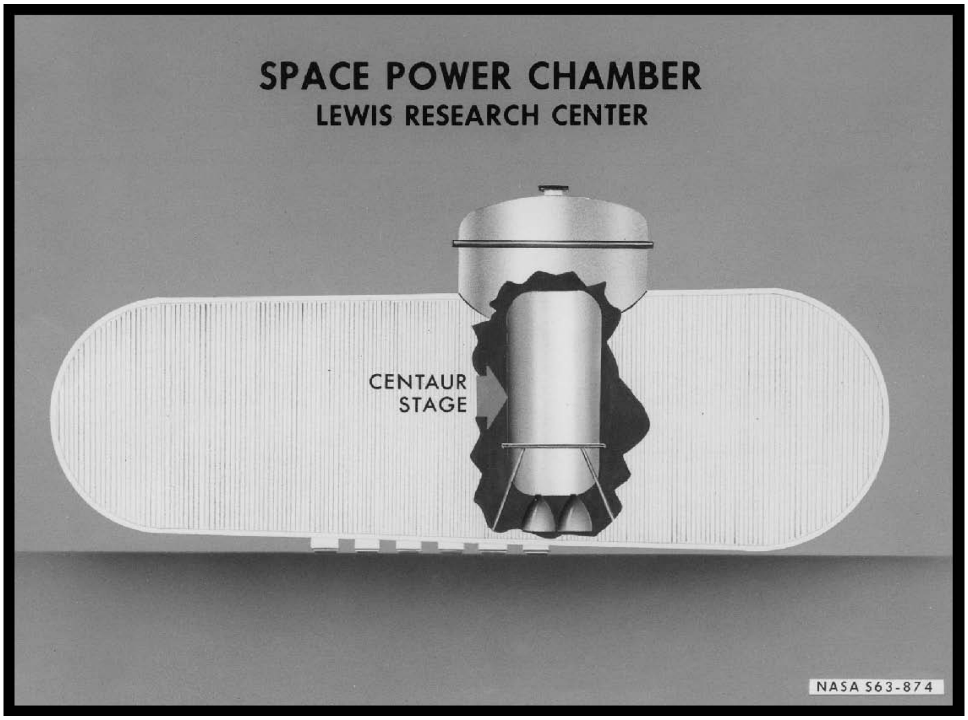

Figure 27.—SPC No. 1 with extension and dome for the Centaur rocket, 1964
(OH_Cuyahoga_Space-Power-Chambers_027).

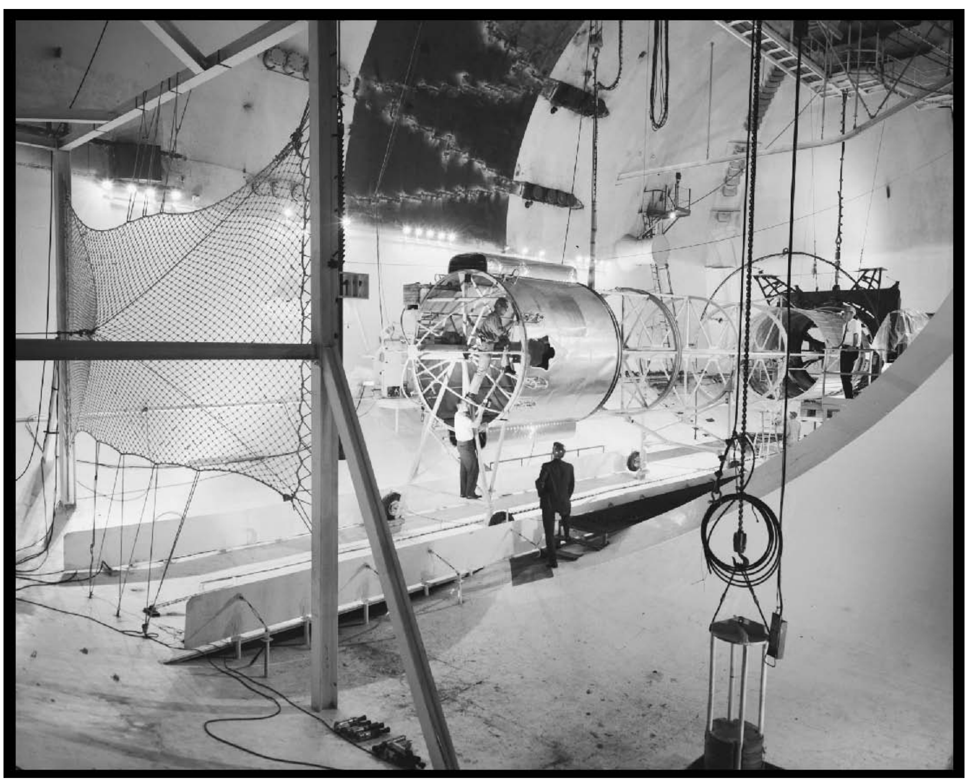

Figure 28.—The first tests in the SPC were a series of AC separation studies
in SPC No. 2, 1963 (OH_Cuyahoga_Space-Power-Chambers_028).

Figure 29.—Surveyor nose cone during tests in the northeast corner of SPC No. 1 for the AC–4 mission, 1964 (OH_Cuyahoga_Space-Power-Chambers_029).

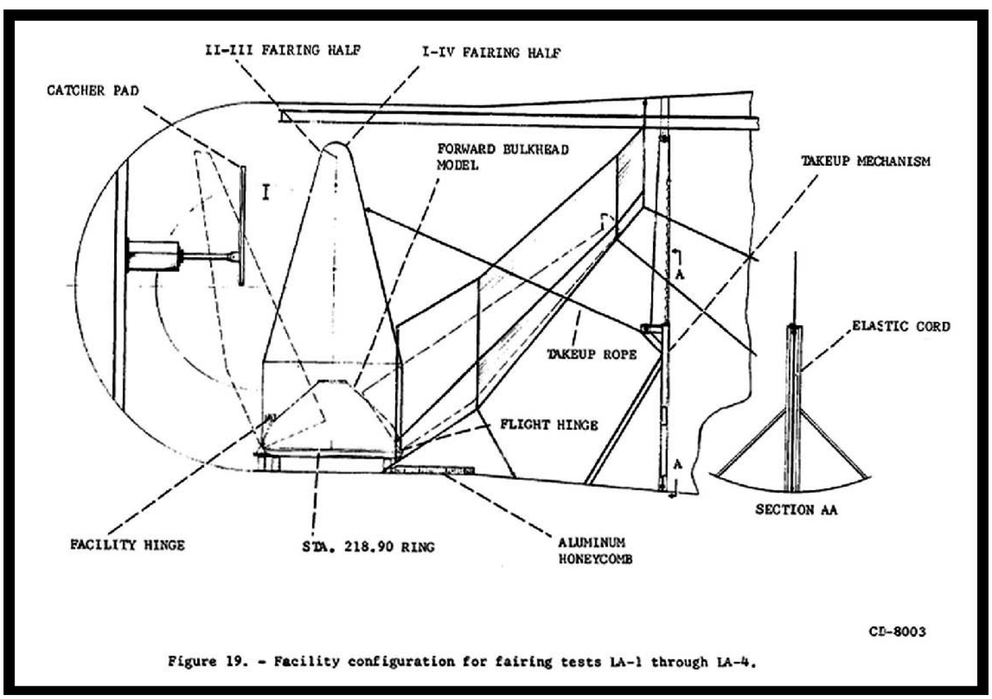

Figure 30.—SPC No. 1 setup for Surveyor nose cone separation tests, 1967 (OH_Cuyahoga_Space-Power-Chambers_030).

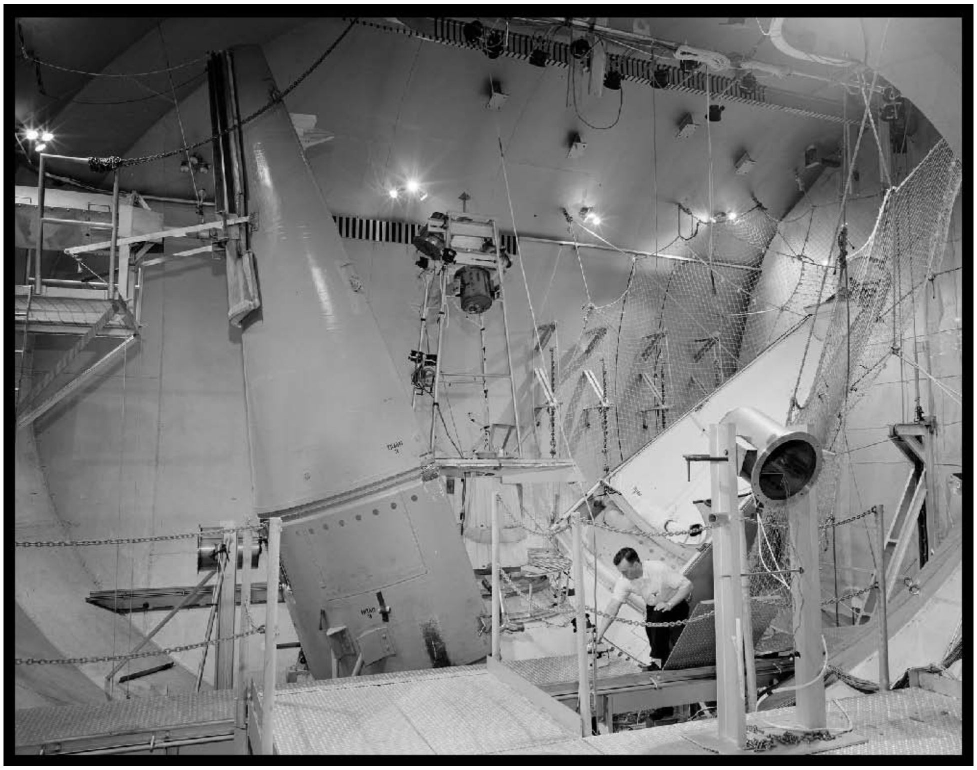

Figure 31.—Surveyor shroud qualification for the AC–6 mission in the northeast corner of SPC No. 1, 1965 (OH_Cuyahoga_Space-Power-Chambers_031).

Figure 32.—Centaur 6A being inspected in the SPC shop area prior to insertion into the chamber, 1963 (OH_Cuyahoga_Space-Power-Chambers_032).

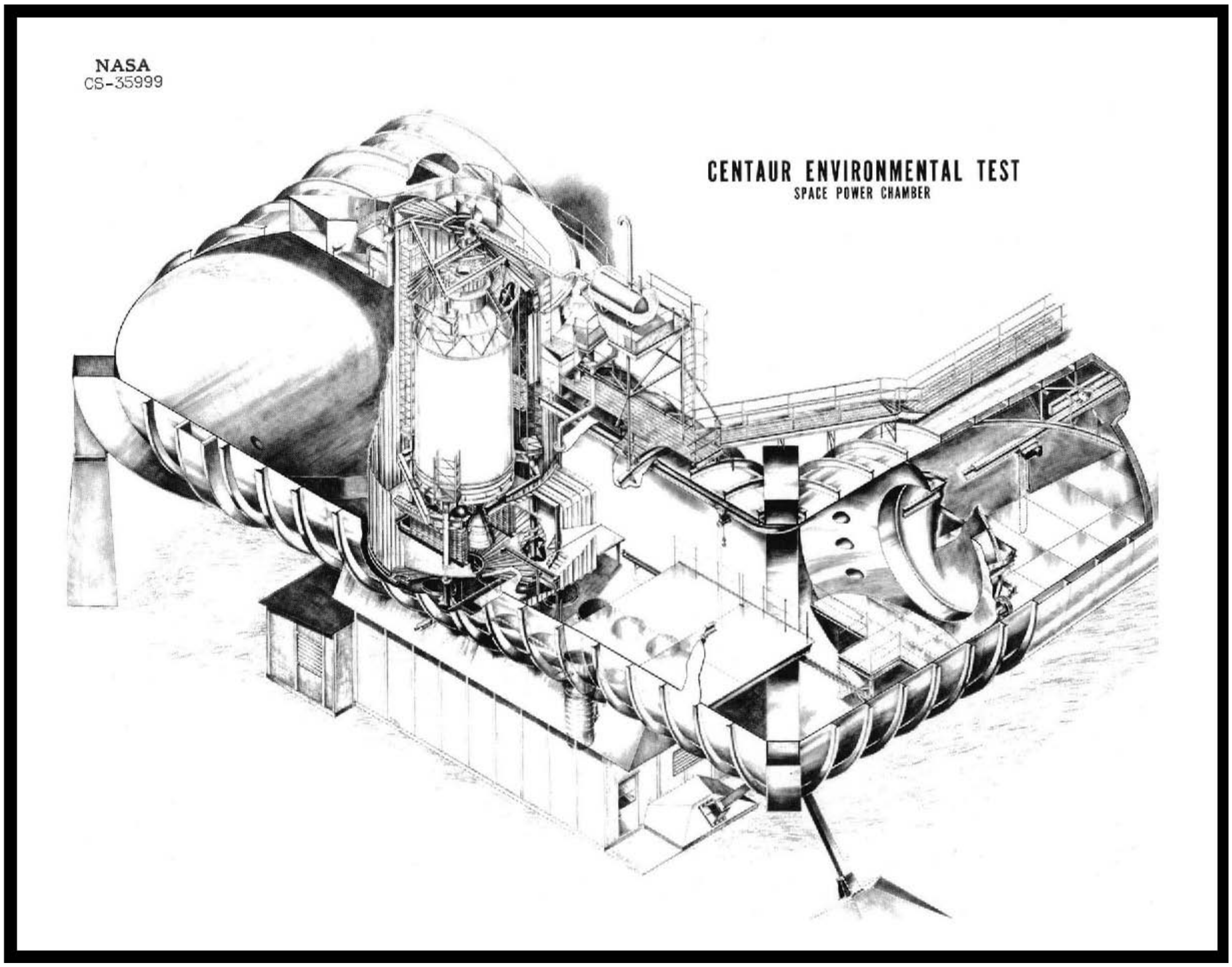

Figure 33.—Cutaway of SPC No. 1 showing the installation of the Centaur rocket, 1965 (OH_Cuyahoga_Space-Power-Chambers_033).

Figure 34.—Nitrogen-filled cold wall (40'-0" high and 20'-0" in diameter) assembled around the Centaur in SPC No. 1, 1963 (OH_Cuyahoga_Space-Power-Chambers_034).

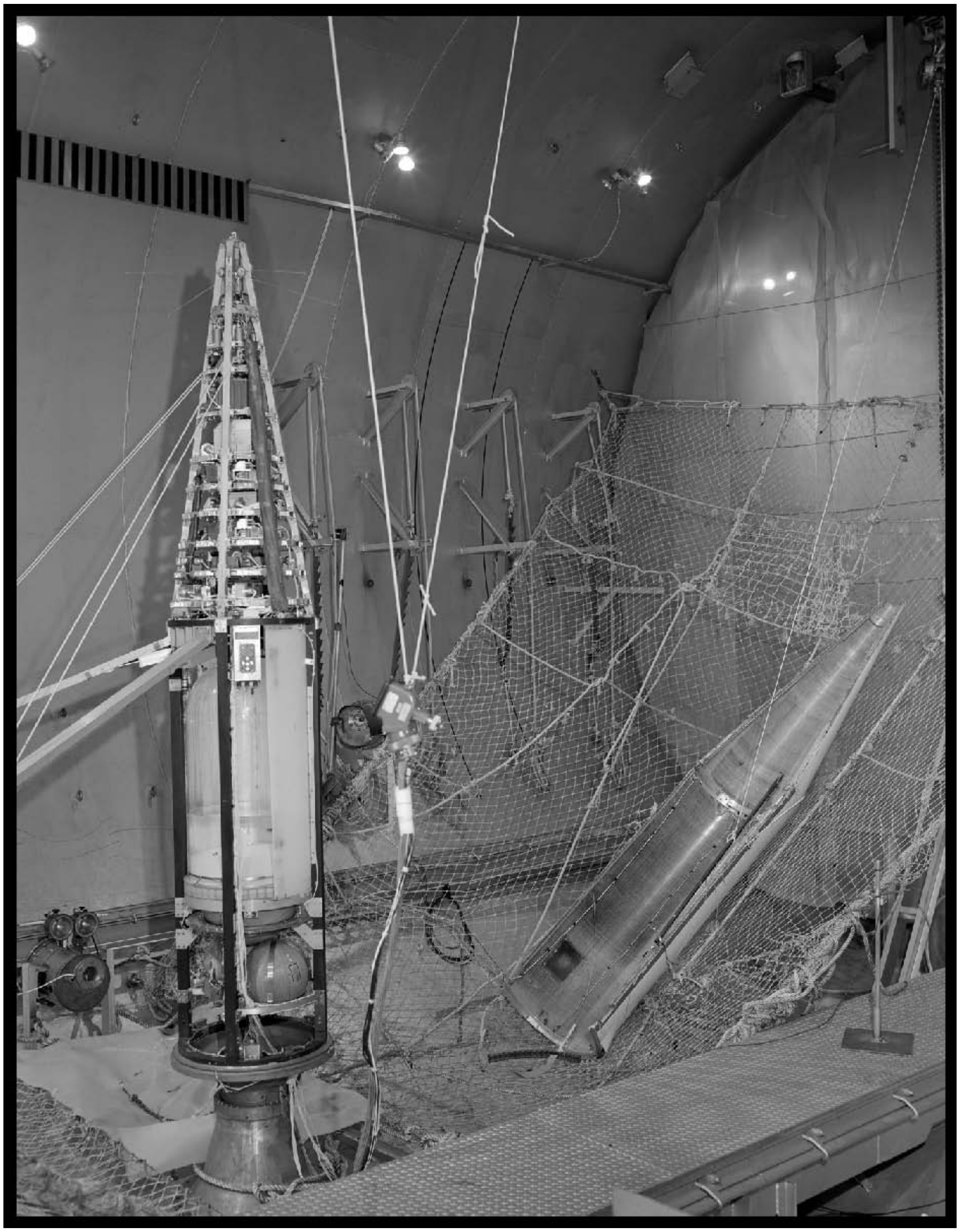

Figure 35.—WASP shroud jettison test setup in the northeast corner of SPC No. 1, 1966 (OH_Cuyahoga_Space-Power-Chambers_035).

Figure 36.—Hydrogen vent rig installed in SPC No. 2 following the failure of the AC–4 flight because of sloshing, 1965 (OH_Cuyahoga_Space-Power-Chambers_036).

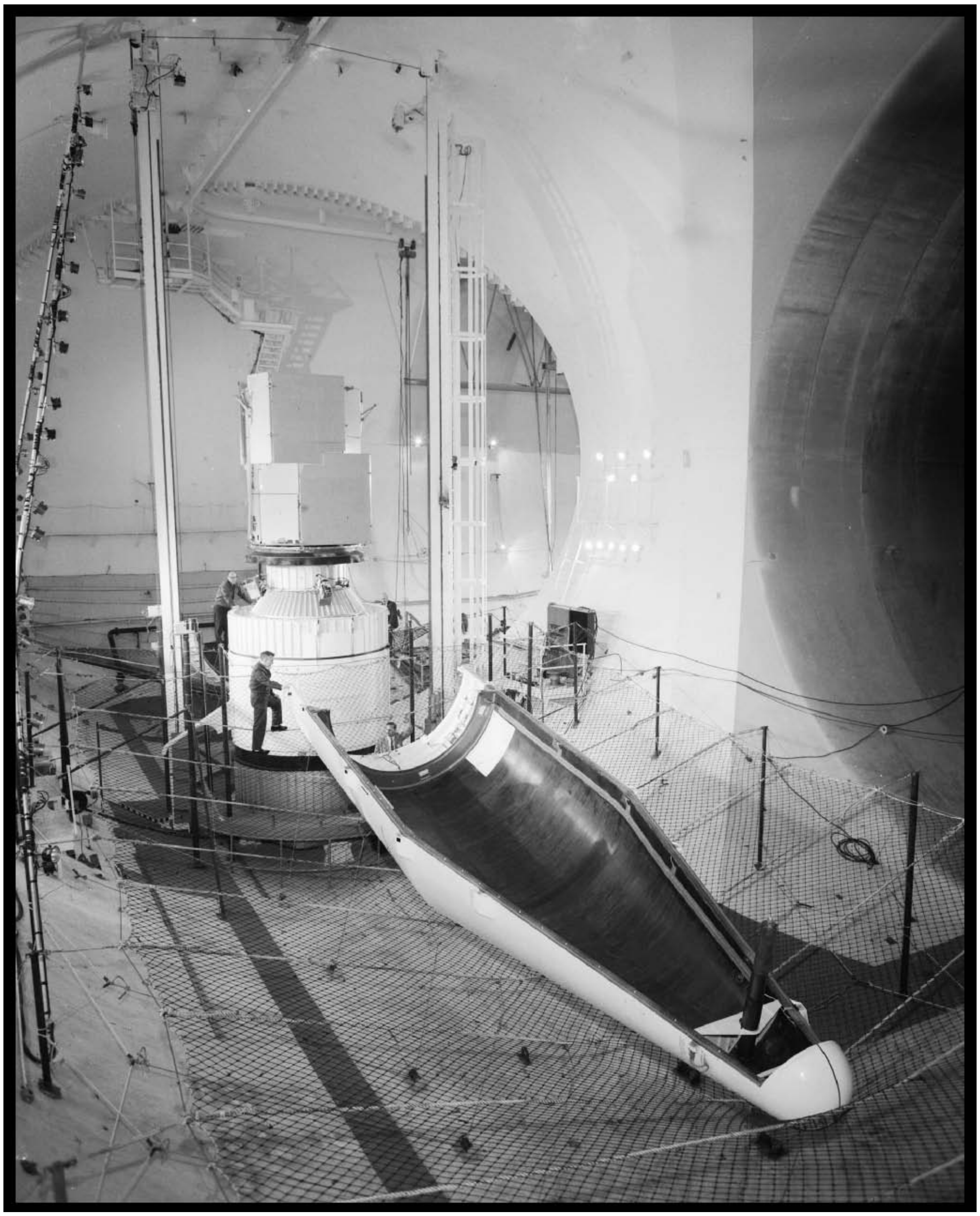

Figure 37.—Modified Agena shroud being tested with a Centaur model in SPC No. 2 for OAO–2, 1968 (OH_Cuyahoga_Space-Power-Chambers_037).

Figure 38.—Redesigned single-piece shroud being tested in SPC No. 2 for use on the OAO–C mission, 1972 (OH_Cuyahoga_Space-Power-Chambers_038).

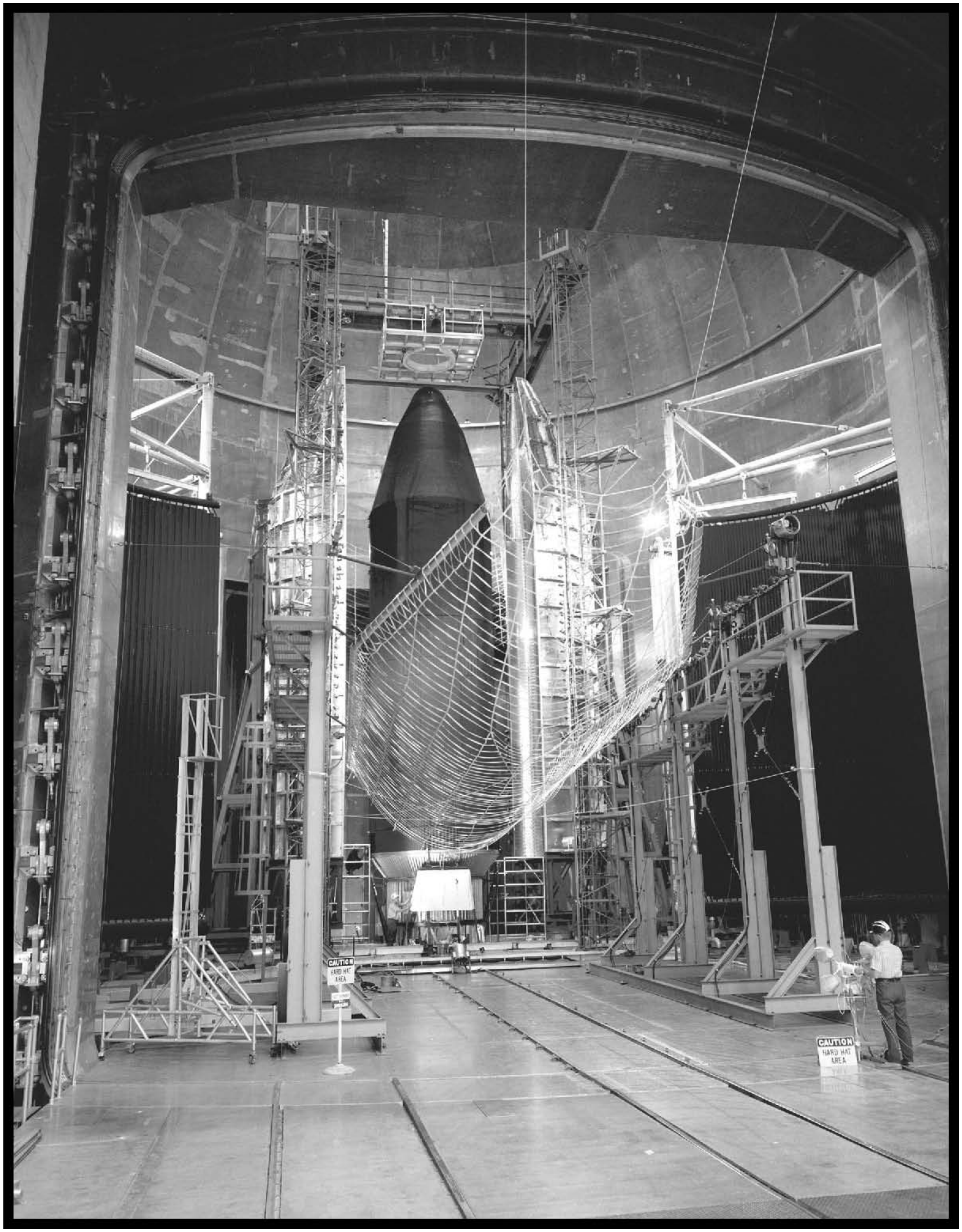

Figure 39.—Inside the SPF at NASA Glenn's auxiliary Plum Brook Station, 1973 (OH_Cuyahoga_Space-Power-Chambers_039).

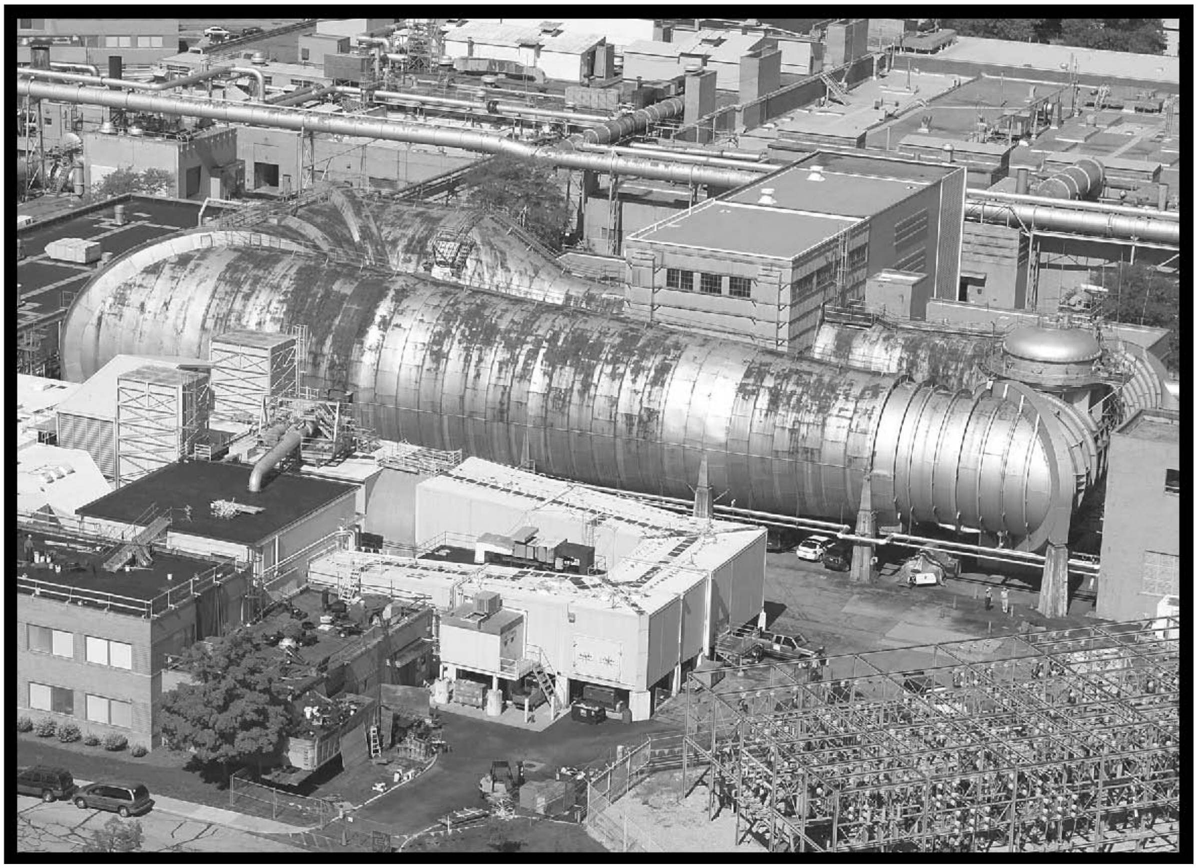

Figure 40.—SPC complex in the former AWT (viewed from the south), 2005
(OH_Cuyahoga_Space-Power-Chambers_040).

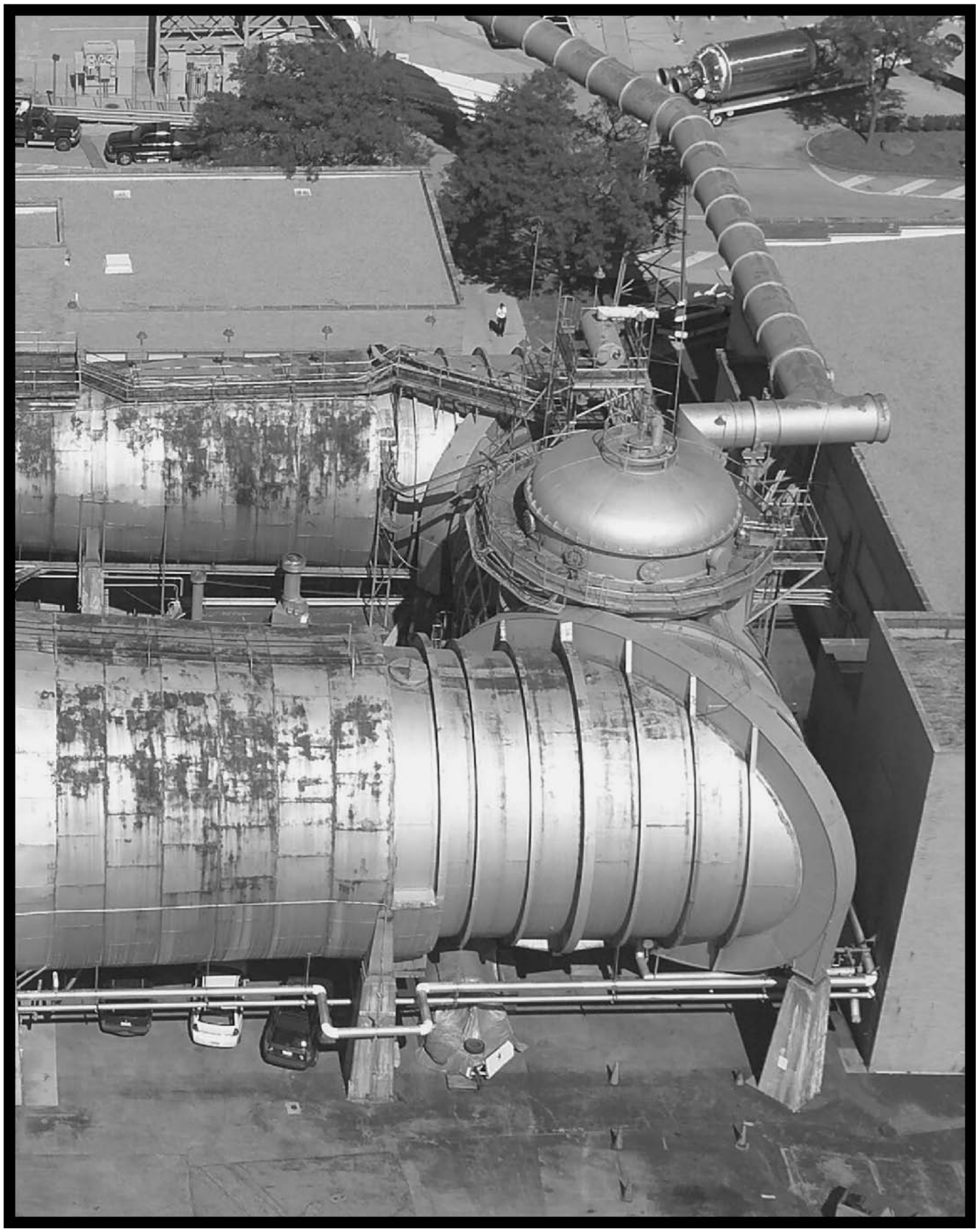

Figure 41.—SPC No. 1 in the east leg of the former AWT (viewed from the south), 2005 (OH_Cuyahoga_Space-Power-Chambers_041).

Figure 42.—SPC No. 1 extension and dome (viewed from the west), 2005
(OH_Cuyahoga_Space-Power-Chambers_042).

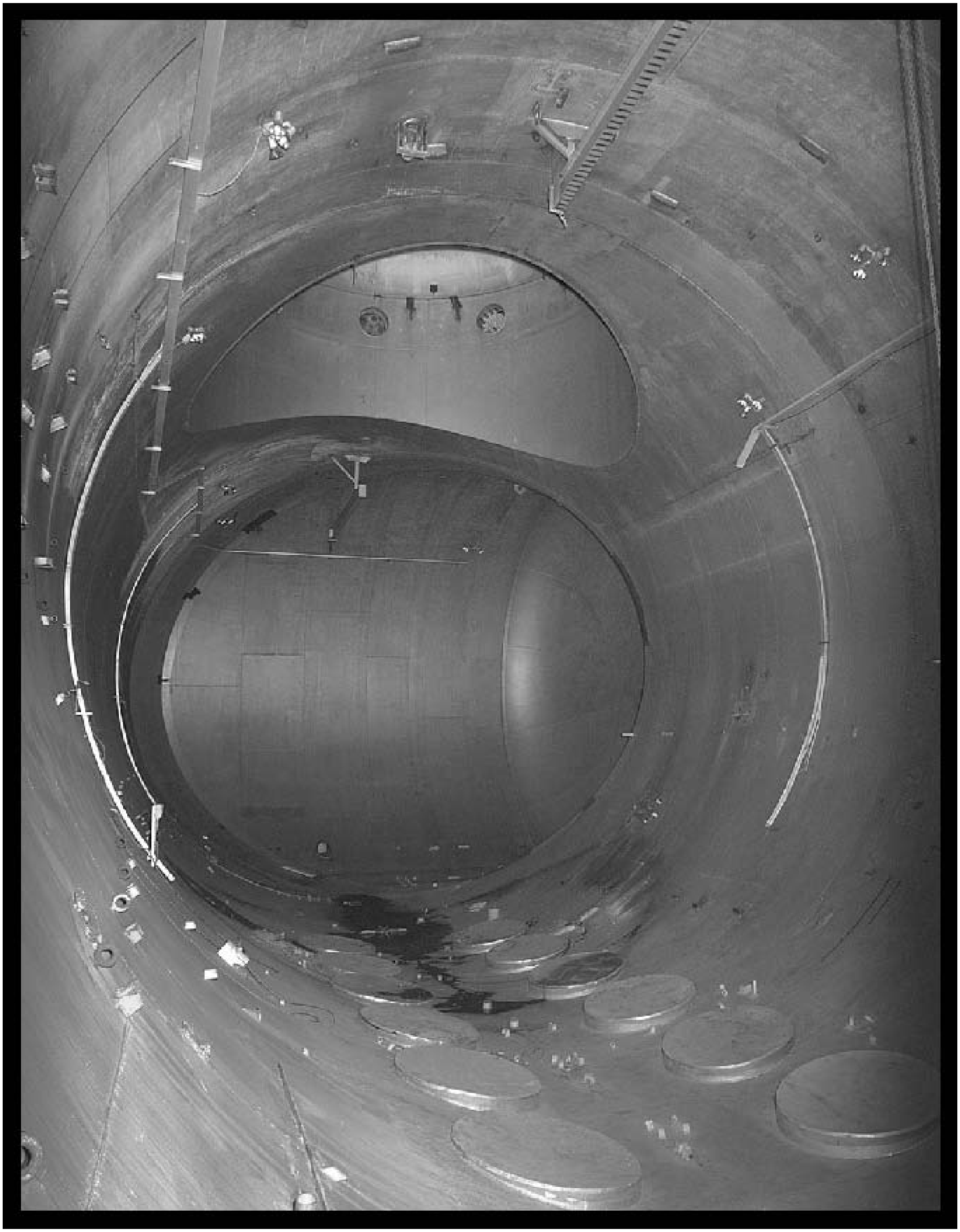

Figure 43.—Interior of SPC No. 1 with an opening for the dome at the top and pump penetrations on the floor (viewed from the north), 2005 (OH_Cuyahoga_Space-Power-Chambers_043).

Figure 44.—SPC No. 1 shell to the right with the original tunnel outer shell to the left showing heavy rust damage, 2005 (OH_Cuyahoga_Space-Power-Chambers_044).

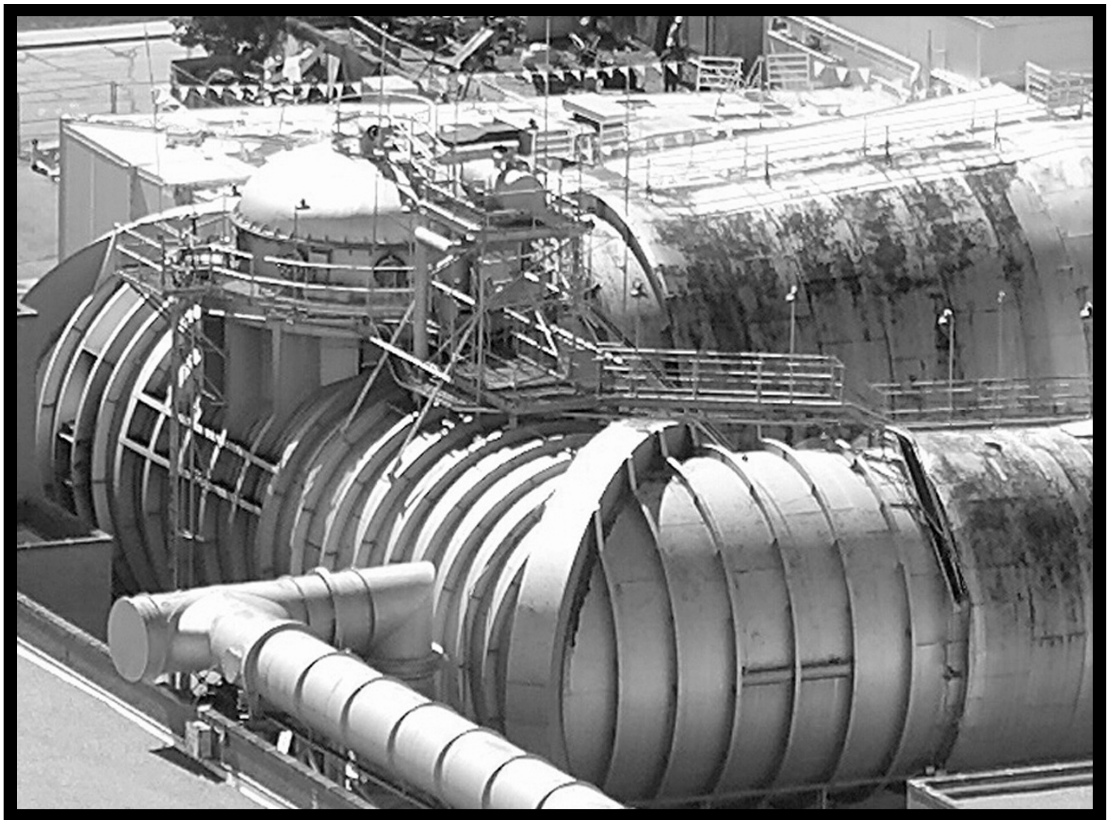

Figure 45.—SPC No. 1 with its extension, dome, and surrounding walkways (viewed from the northeast), 2005 (OH_Cuyahoga_Space-Power-Chambers_045).

Figure 46.—SPC No. 1 dome showing its base, instrumentation portals, and lid (viewed from the north), 1963 (OH_Cuyahoga_Space-Power-Chambers_046).

Figure 47.—Crane removing the lid from the SPC No. 1 dome (viewed from the east), 1964 (OH_Cuyahoga_Space-Power-Chambers_047).

Figure 48.—SPC No. 1 lid being lowered to the ground by a crane, 1964 (OH_Cuyahoga_Space-Power-Chambers_048).

Figure 49.—SPC No. 1 interior with the extension and dome at the top and the cable tray along the wall (viewed from the north), 2005 (OH_Cuyahoga_Space-Power-Chambers_049).

Figure 50.—SPC No. 1 dome and lid (viewed from inside the chamber), 2005 (OH_Cuyahoga_Space-Power-Chambers_050).

Figure 51.—SPC No. 1 floor showing water damage and numerous fittings from tests (viewed from the south), 2005 (OH_Cuyahoga_Space-Power-Chambers_051).

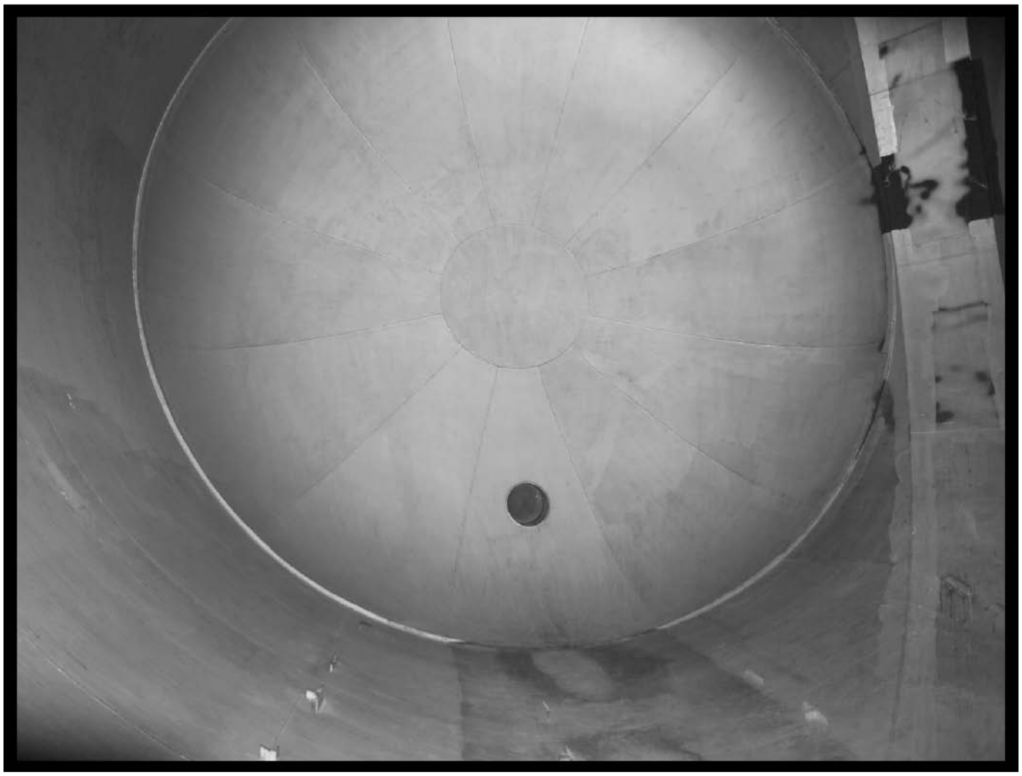

Figure 52.—31'-0"-diameter bulkhead at the south end of SPC No. 1
(viewed from the east), 2005 (OH_Cuyahoga_Space-Power-Chambers_052).

Figure 53.—Inside SPC No. 1 bulkhead with a swinging door in the center and ports on the sides (viewed from the east), 1962 (OH_Cuyahoga_Space-Power-Chambers_053).

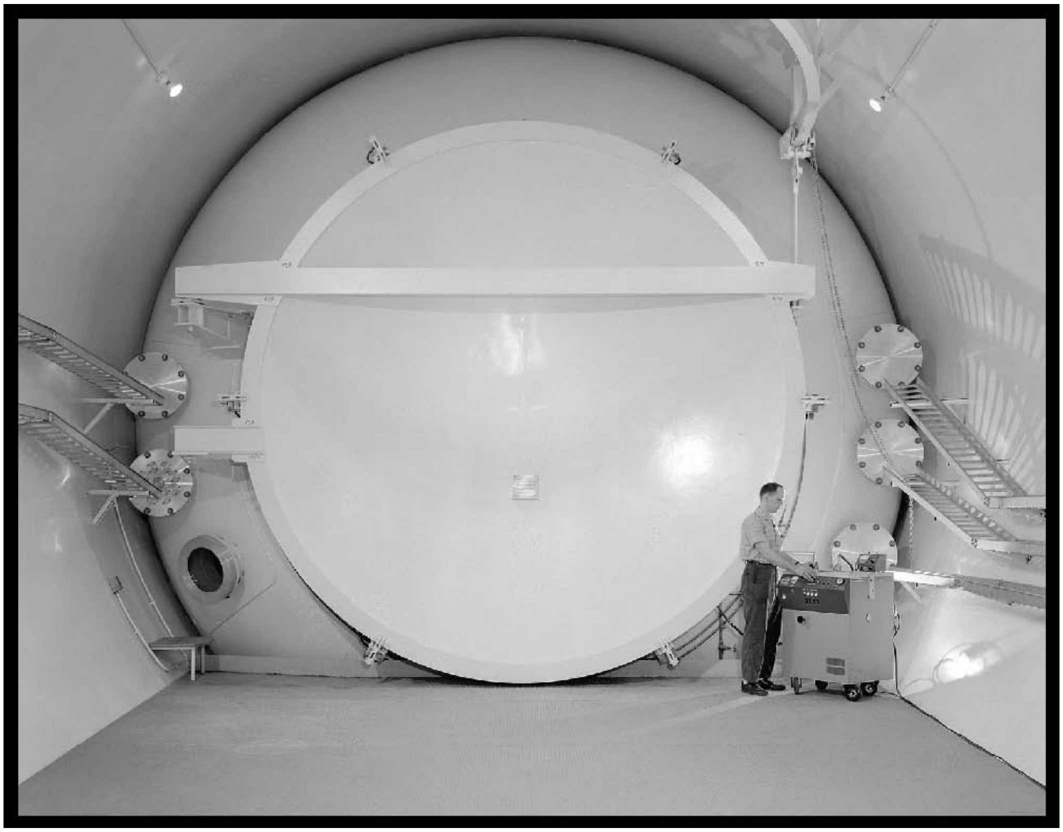

Figure 54.—Former test section of SPC No. 1 bulkhead with its door closed (viewed from the west), 1962 (OH_Cuyahoga_Space-Power-Chambers_054).

Figure 55.—Close-up of one of the instrumentation ports in the north SPC No. 1 bulkhead, 2005 (OH_Cuyahoga_Space-Power-Chambers_055).

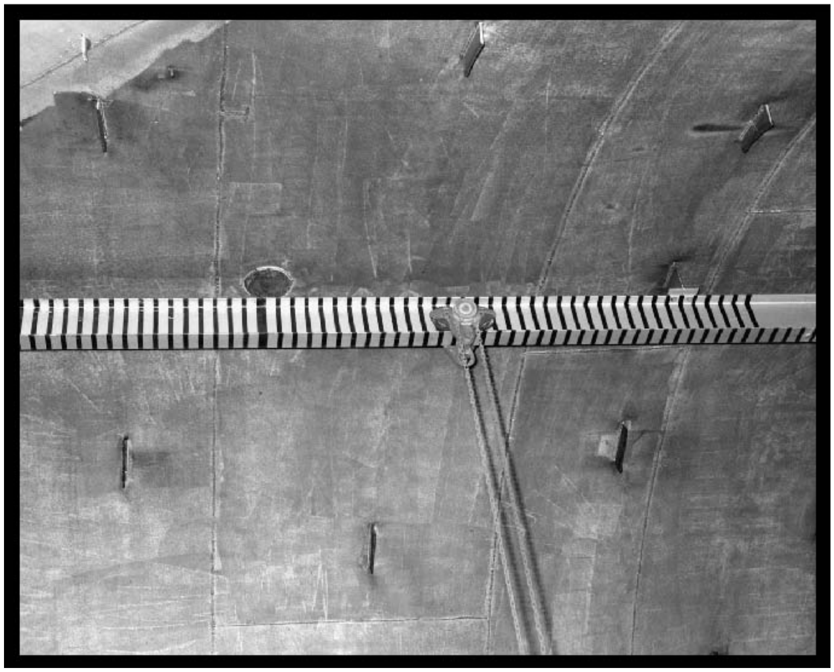

Figure 56.—4000-pound monorail crane along the center of the SPC No. 1 ceiling, 2005 (OH_Cuyahoga_Space-Power-Chambers_056).

Figure 57.—Platform inside SPC No. 1 that provided access to the doorway in the bulkhead, 2005 (OH_Cuyahoga_Space-Power-Chambers_057).

Figure 58.—Close-up of one of ten diffusion pump openings in the floor of SPC No. 1, 1962 (OH_Cuyahoga_Space-Power-Chambers_058).

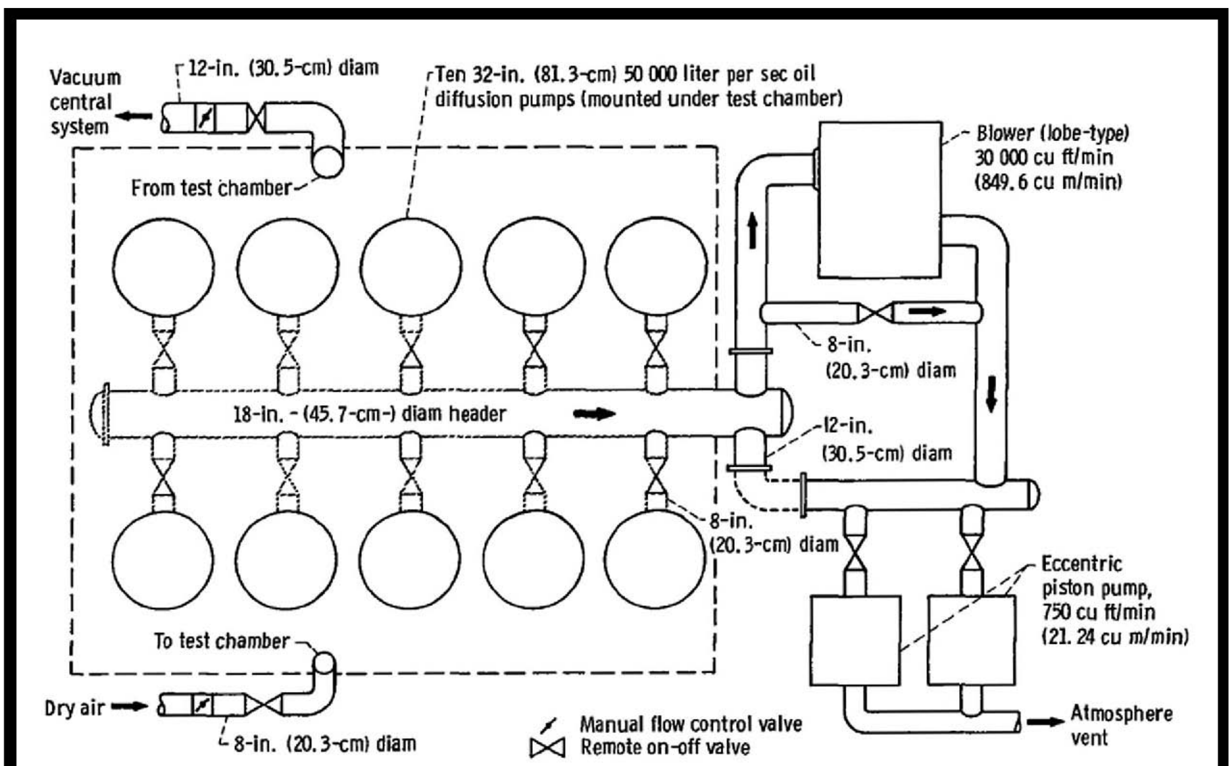

Figure 20. - Test chamber vacuum system and dry air bleed system.

Figure 59.—Test chamber vacuum system and dry air bleed system, 1970 (OH_Cuyahoga_Space-Power-Chambers_059).

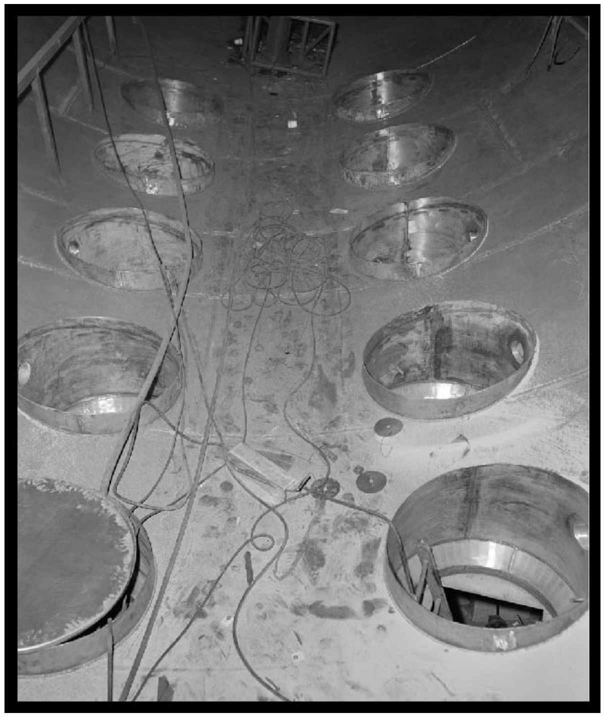

Figure 60.—Diffusion pump openings in SPC No. 1 during its conversion to a vacuum tank, 1961 (OH_Cuyahoga_Space-Power-Chambers_060).

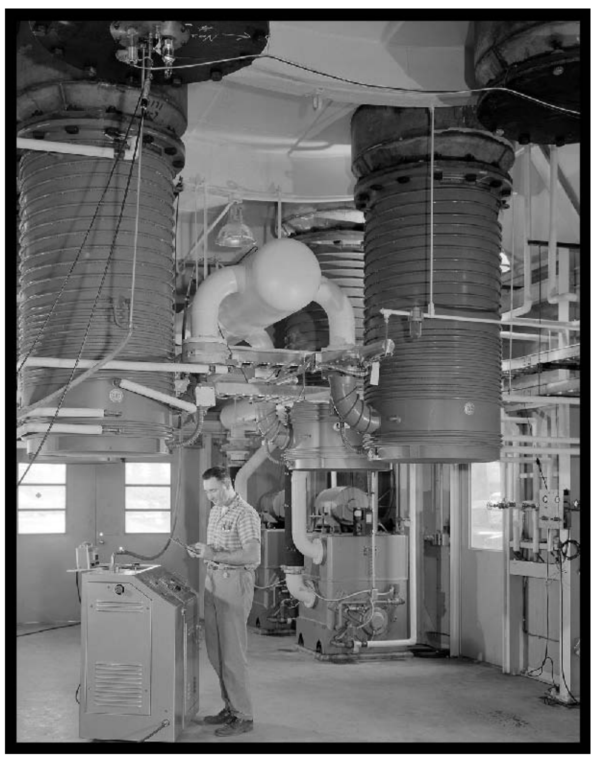

Figure 61.—Interior of Vacuum Pump House and its diffusion pumps below SPC No. 1 (viewed from the north), 1962 (OH_Cuyahoga_Space-Power-Chambers_061).

Figure 62.—Rear of Vacuum Pump House beneath SPC No. 1 (viewed from the southeast), 2007 (OH_Cuyahoga_Space-Power-Chambers_062).

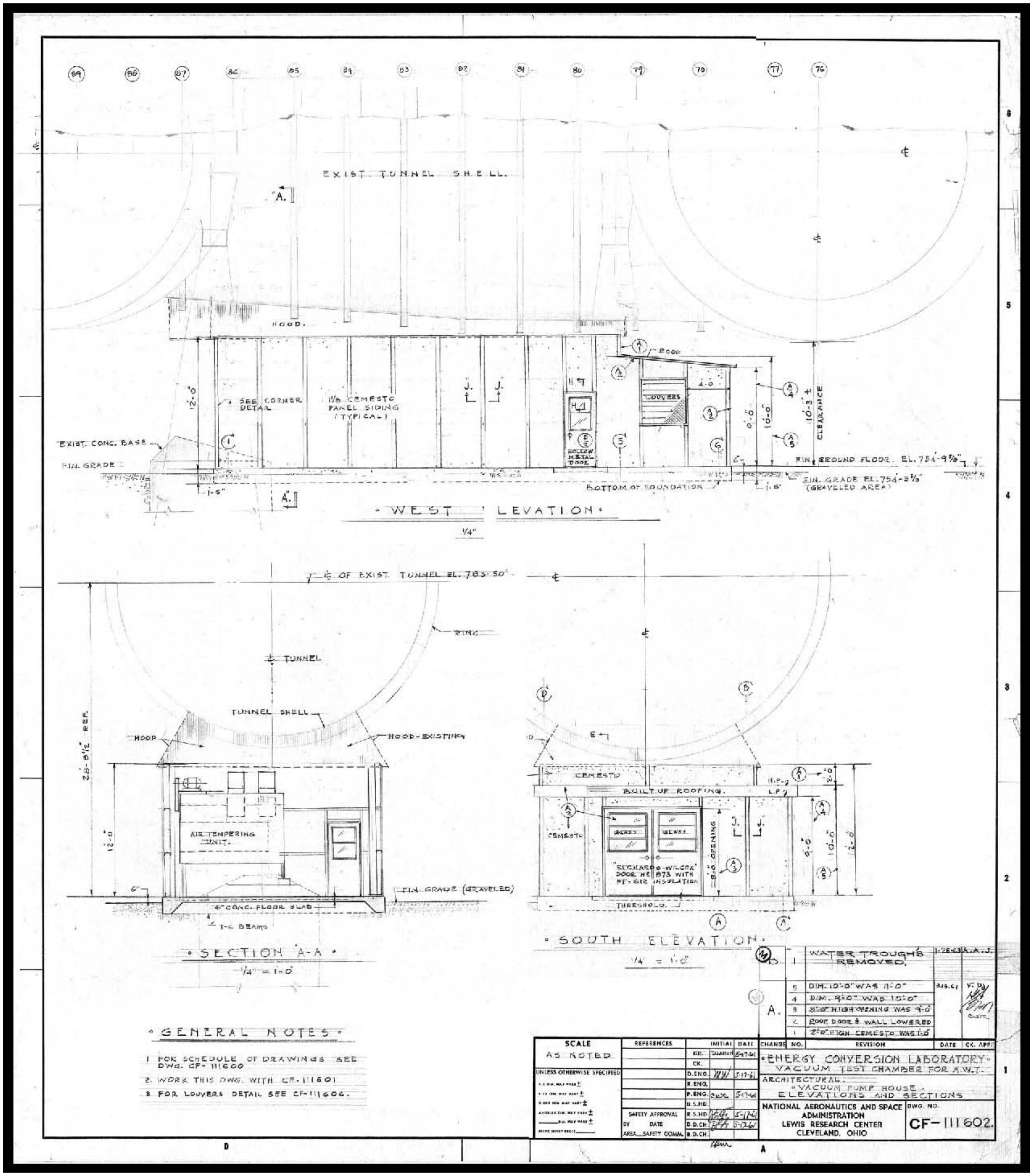

Figure 63.—Vacuum Pump House elevations and sections drawings, 1961
(OH_Cuyahoga_Space-Power-Chambers_063).

Figure 64.—Construction of Vacuum Pump House beneath SPC No. 1, 1961 (OH_Cuyahoga_Space-Power-Chambers_064).

Figure 65.—Exterior of the Vacuum Pump House under SPC No. 1 (viewed from the northeast), 2007 (OH_Cuyahoga_Space-Power-Chambers_065).

Figure 66.—Centaur 6A rocket readied in SPC shop before testing in SPC No. 1, 1963
(OH_Cuyahoga_Space-Power-Chambers_066).

Figure 67.—Stand that supported the Centaur rocket being lifted into SPC No. 1, 1964
(OH_Cuyahoga_Space-Power-Chambers_067).

Figure 68.—The nitrogen separation tank setup to left of the dome supplied the cold wall inside with coolant, 1967 (OH_Cuyahoga_Space-Power-Chambers_068).

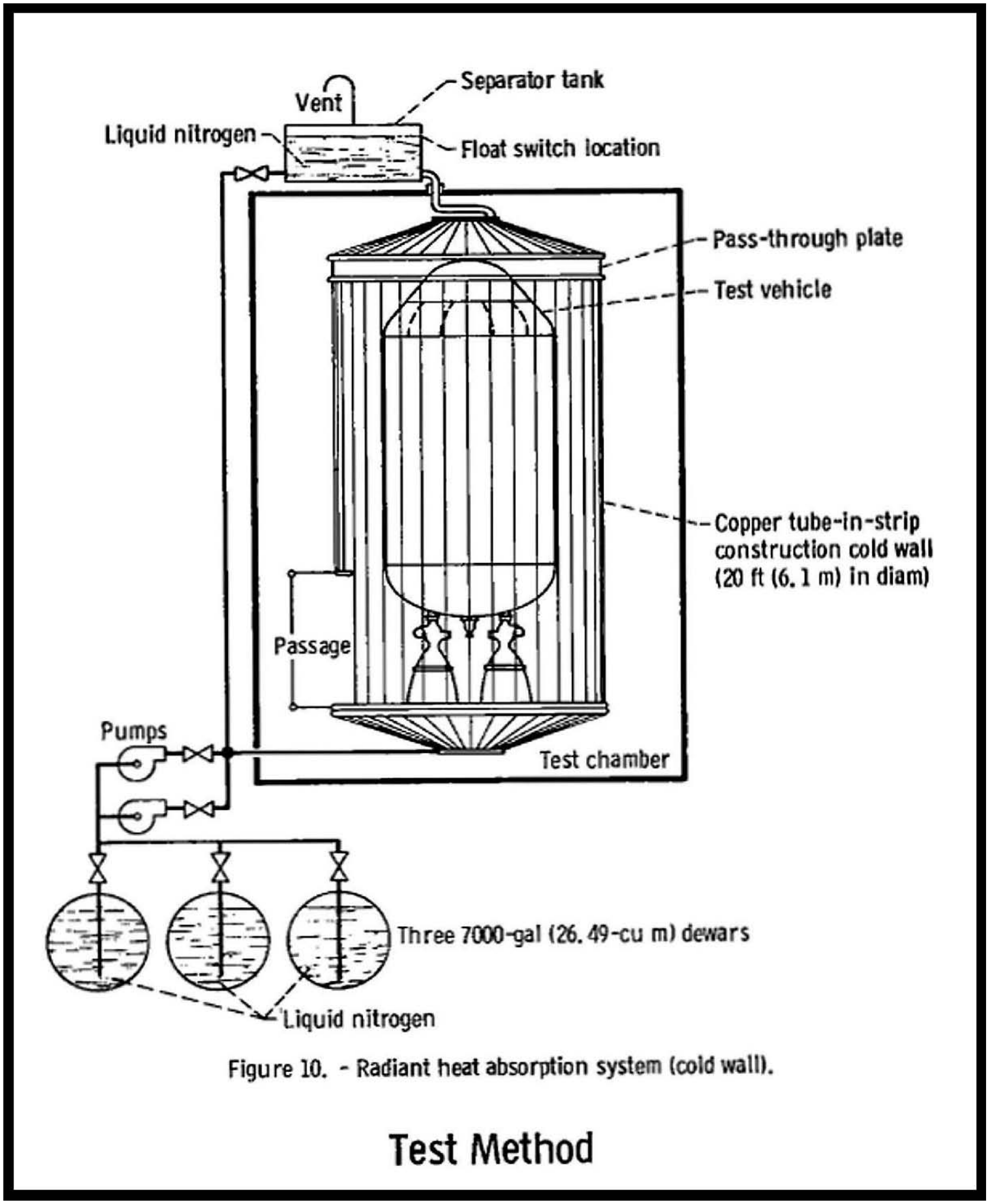

Figure 69.—Nitrogen cold wall placed around the Centaur that absorbed radiant heat to create cryogenic temperatures, 1970 (OH_Cuyahoga_Space-Power-Chambers_069).

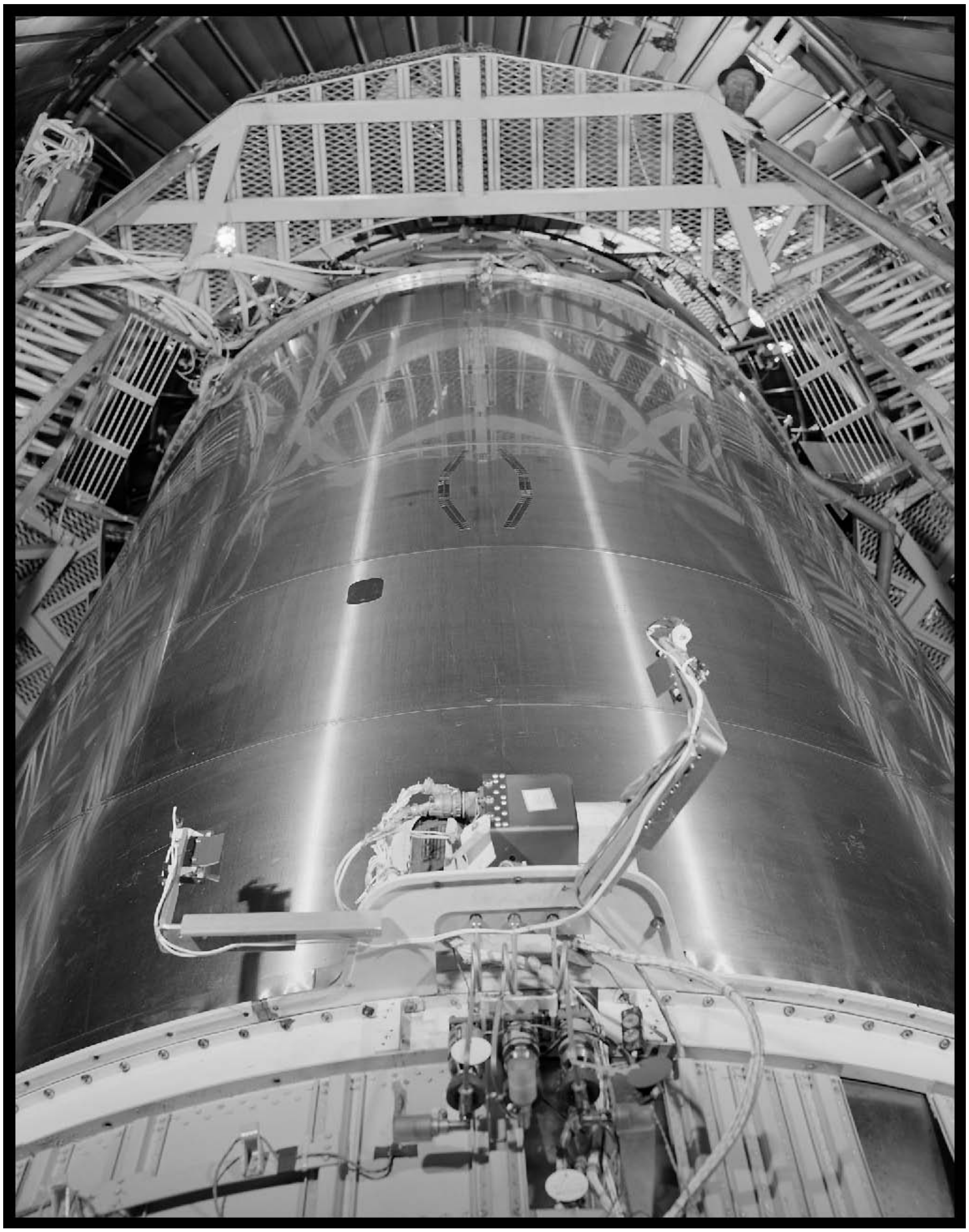

Figure 70.—View up the side of the Centaur showing a group of tungsten lamps in the foreground, 1967 (OH_Cuyahoga_Space-Power-Chambers_070).

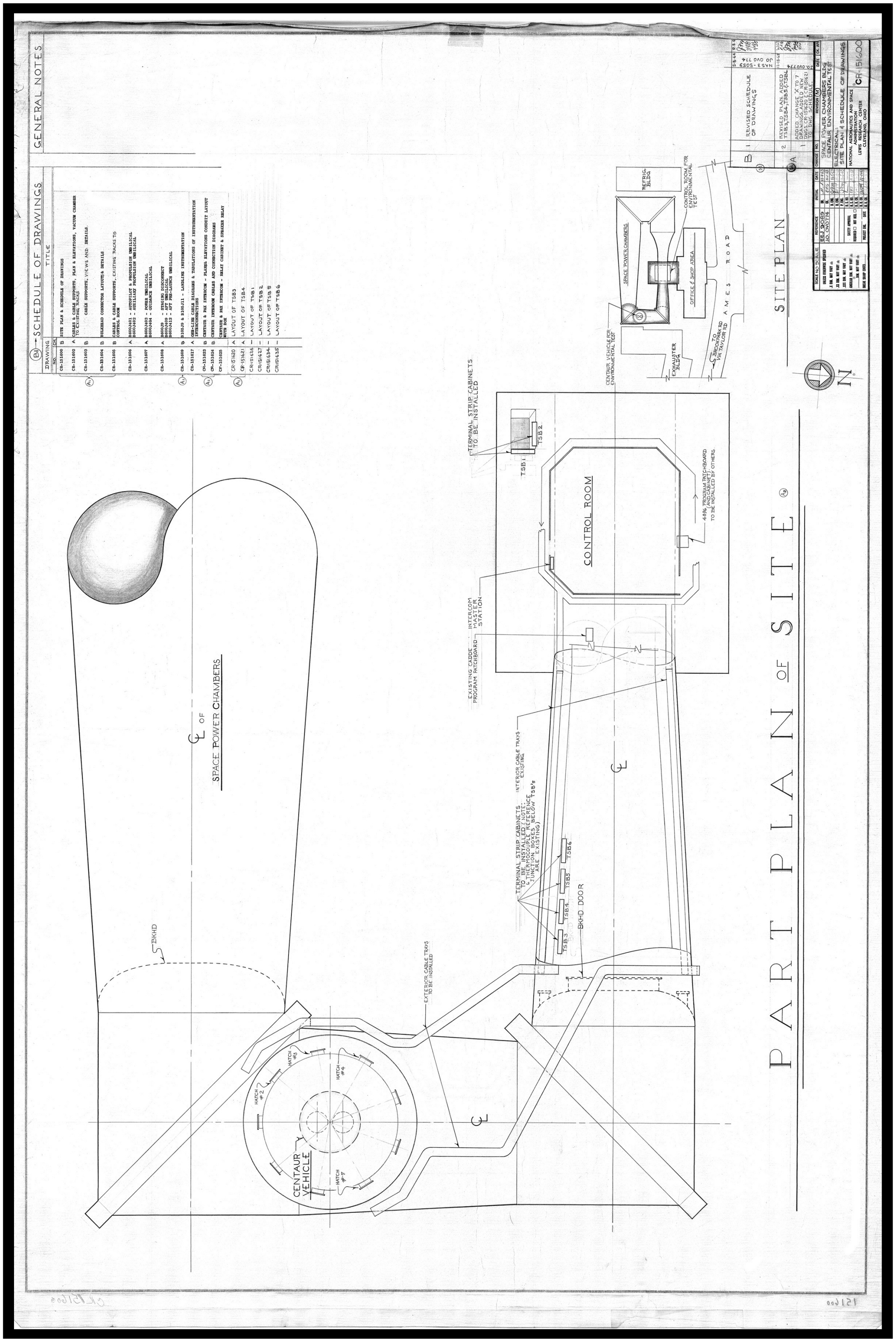

Figure 71.—Telemetry connections between SPC No. 1 and the control room, 1963 (OH_Cuyahoga_Space-Power-Chambers_071).

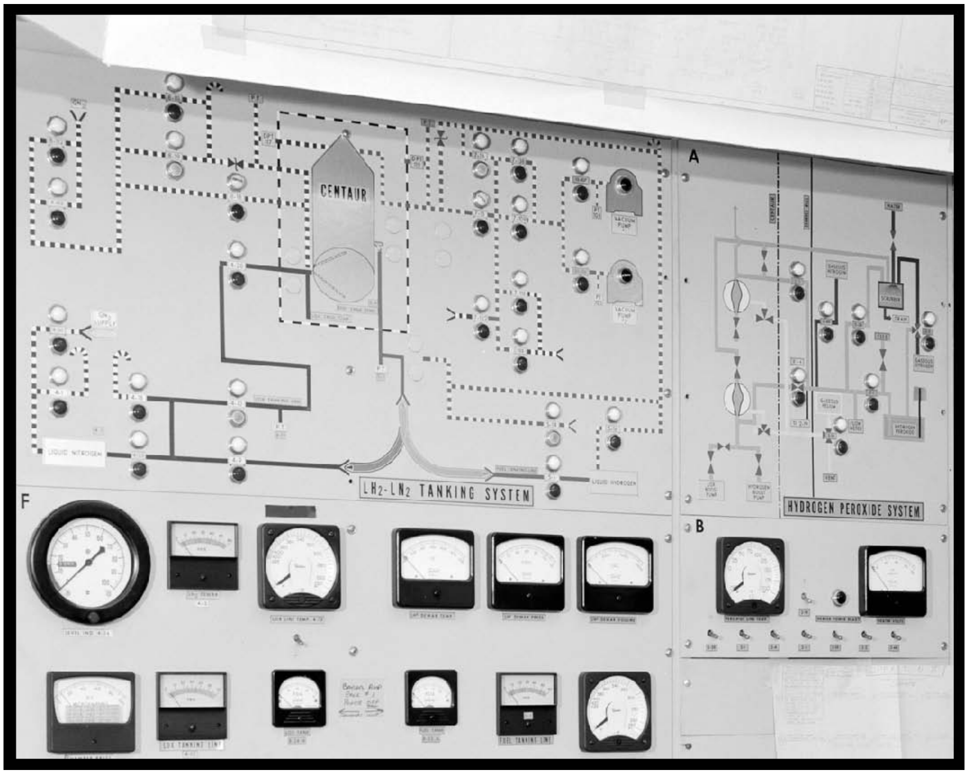

Figure 72.—Control panel in SPC control room for the liquid-hydrogen/liquid-nitrogen tanking system, 1967 (OH_Cuyahoga_Space-Power-Chambers_072).

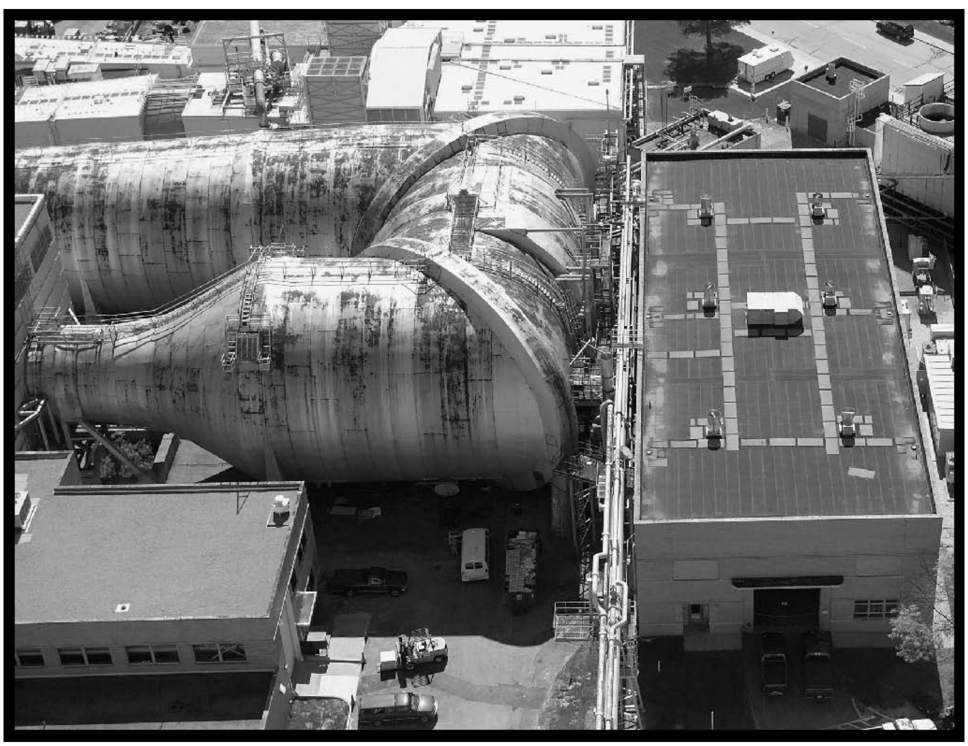

Figure 73.—Exterior of SPC No. 2 (aerial view from the north), 2005 (OH_Cuyahoga_Space-Power-Chambers_073).

Figure 74.—South leg of SPC No. 2 with walkway on top (viewed from the south), 2005 (OH_Cuyahoga_Space-Power-Chambers_074).

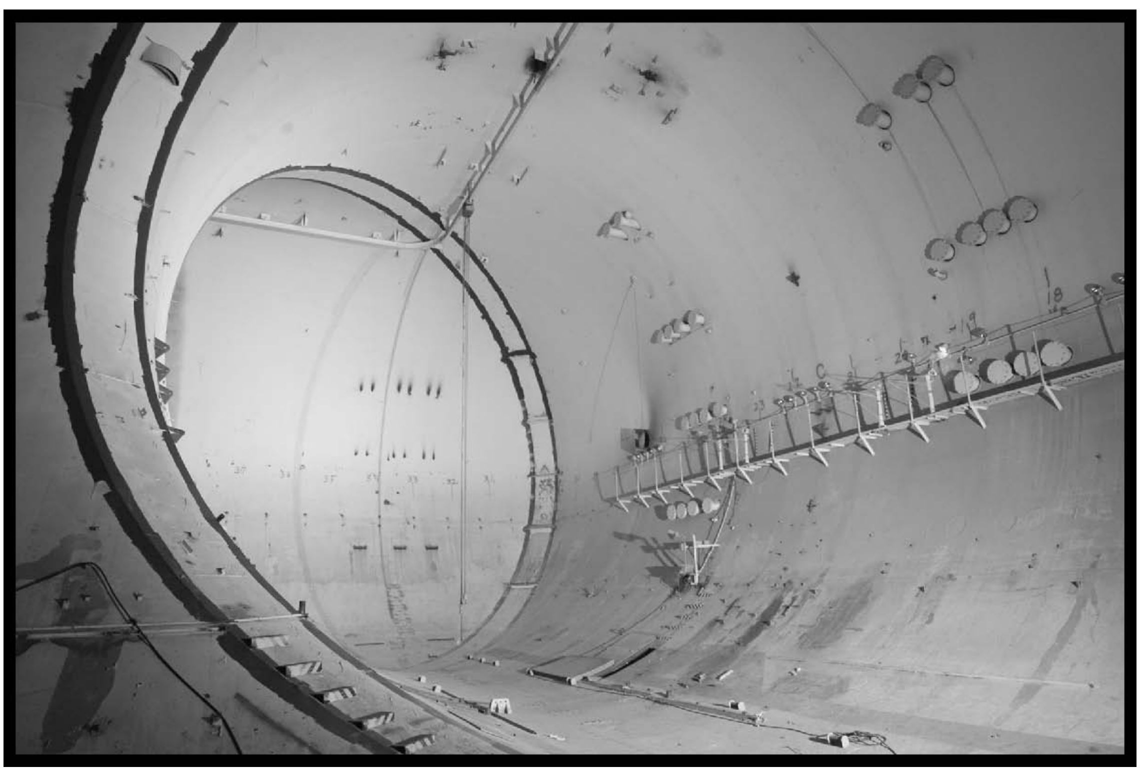

Figure 75.—51'-0"-diameter western leg of SPC No. 2 with a catwalk along the outer wall (viewed from the north), 2007 (OH_Cuyahoga_Space-Power-Chambers_075).

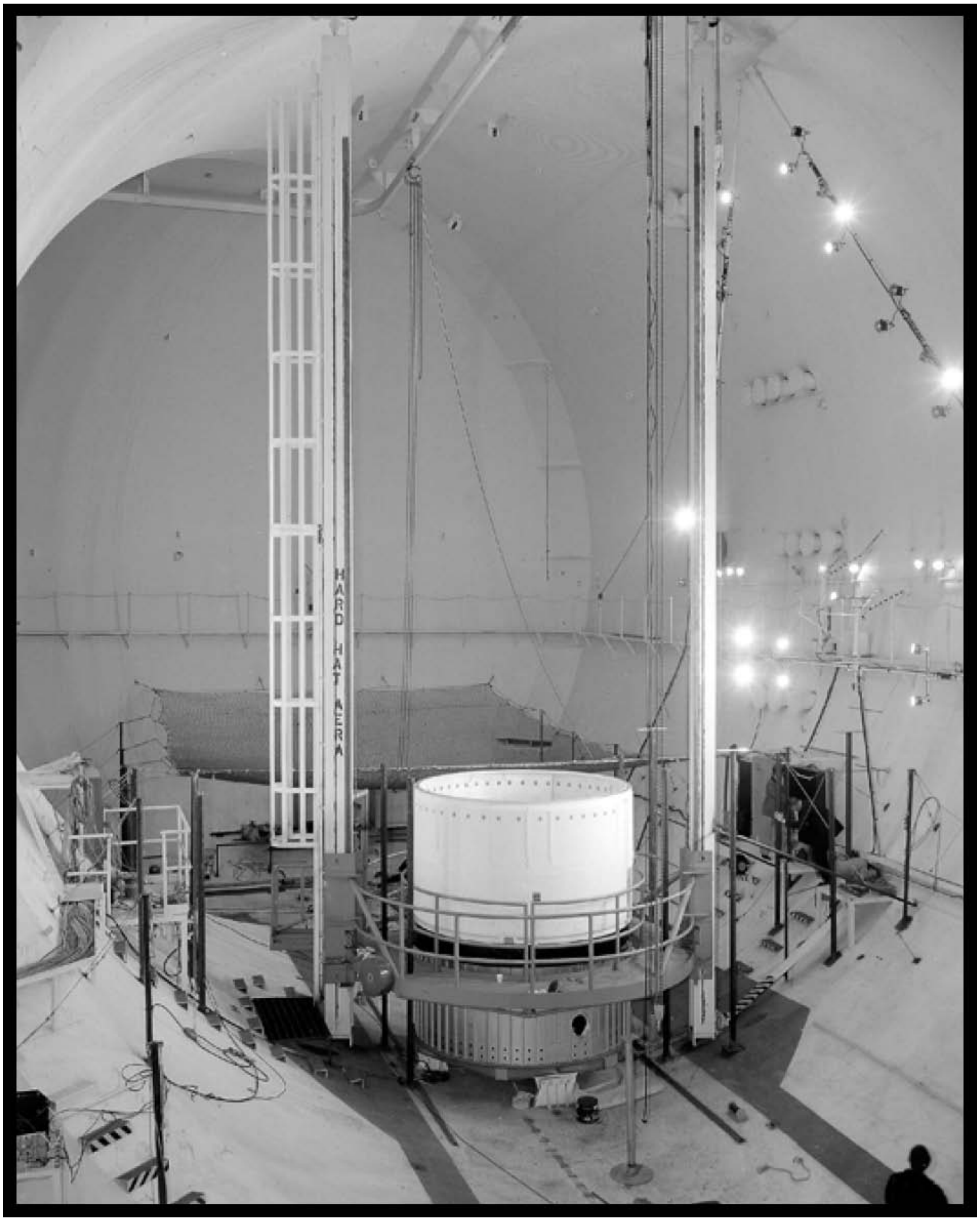

Figure 76.—Western leg of SPC No. 2 with crane, elevator stands, and platforms against the walls (viewed from the south), 1965 (OH_Cuyahoga_Space-Power-Chambers_076).

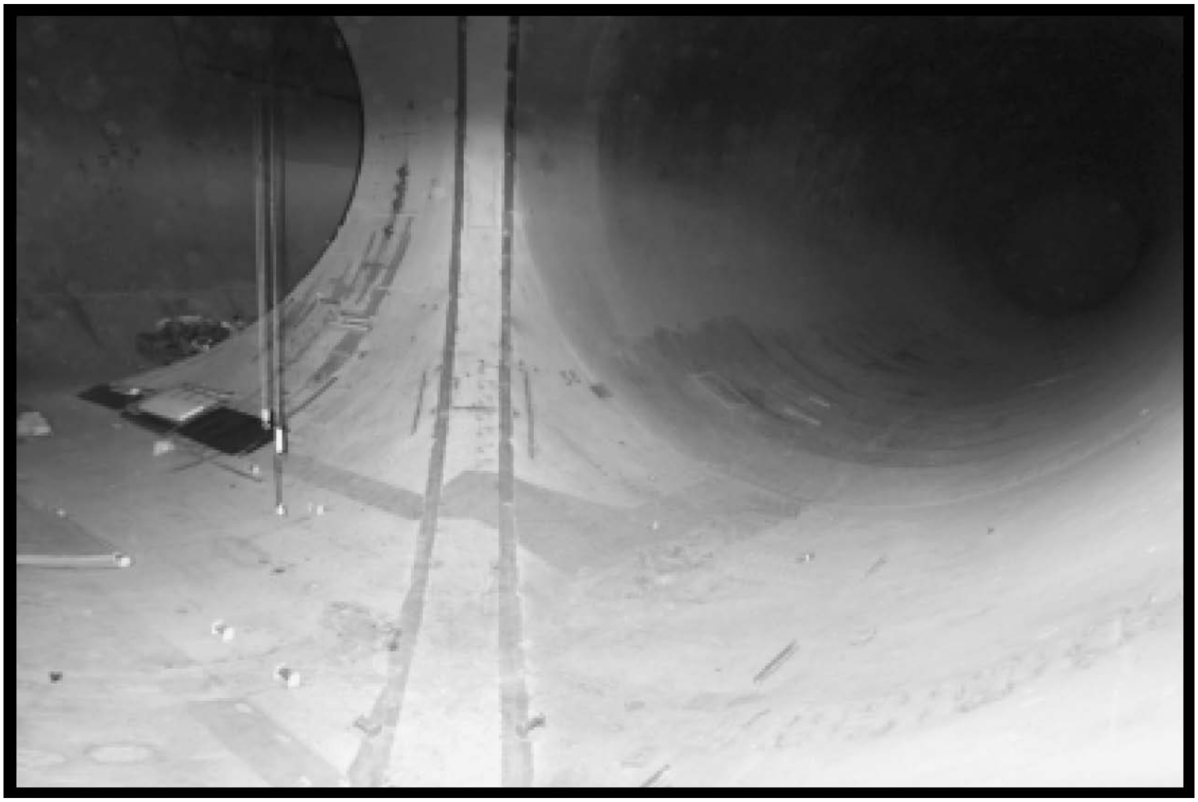

Figure 77.—Corner ring with the western leg of SPC No. 2 in the foreground (viewed from the southwest), 2005 (OH_Cuyahoga_Space-Power-Chambers_077).

Figure 78.—Interior view of squirrel hole entrance into SPC No. 2, 2005 (OH_Cuyahoga_Space-Power-Chambers_078).

Figure 79.—Interior and exterior of the access door built into the north wall of SPC No. 2, 2005 (OH_Cuyahoga_Space-Power-Chambers_079).

Figure 80.—Throat section of SPC No. 2 showing overhead crane and catwalk (viewed from the east), 1963 (OH_Cuyahoga_Space-Power-Chambers_080).

Figure 81.—Throat section of SPC No. 2 with the bulkhead at the far end
(viewed from the west), 2007 (OH_Cuyahoga_Space-Power-Chambers_081).

Figure 82.—Throat section of SPC No. 2, showing steps and a telephone in the foreground
(viewed from the west), 2007 (OH_Cuyahoga_Space-Power-Chambers_082).

Figure 83.—South leg of SPC No. 2 (viewed from the east), 2007
(OH_Cuyahoga_Space-Power-Chambers_083).

Figure 84.—South leg of SPC No. 2 (viewed from the west), 2007
(OH_Cuyahoga_Space-Power-Chambers_084).

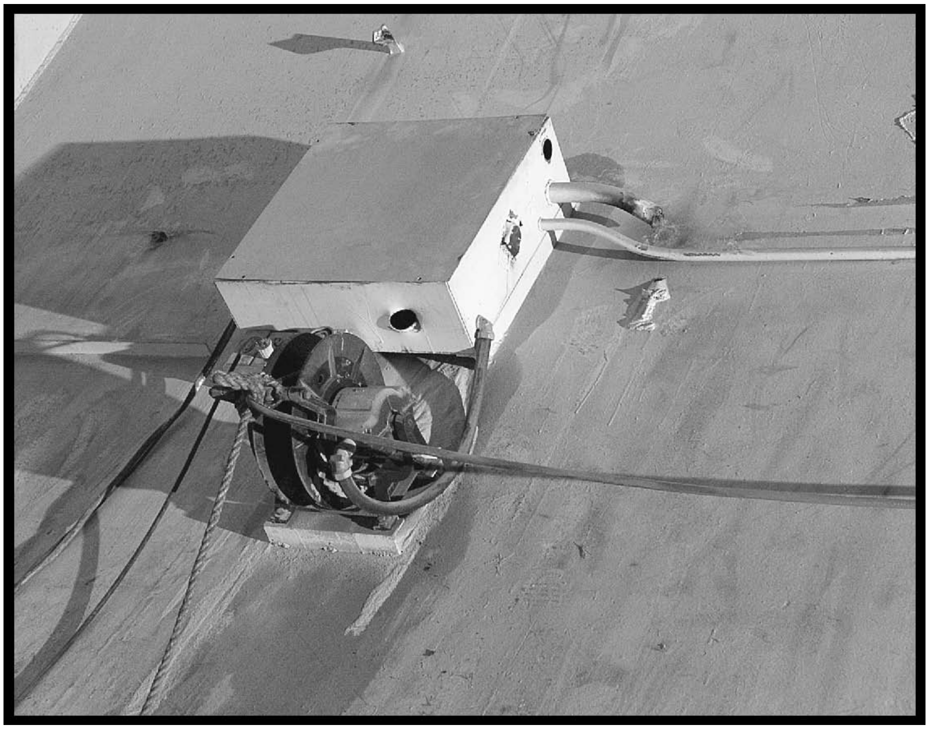

Figure 85.—Hoist box installed on the inner wall just prior to the throat section, 2007
(OH_Cuyahoga_Space-Power-Chambers_085).

Figure 86.—31'-0"-diameter bulkhead near the southeast corner of
SPC No. 2 (viewed from west of SPC No. 2), 2007
(OH_Cuyahoga_Space-Power-Chambers_086).

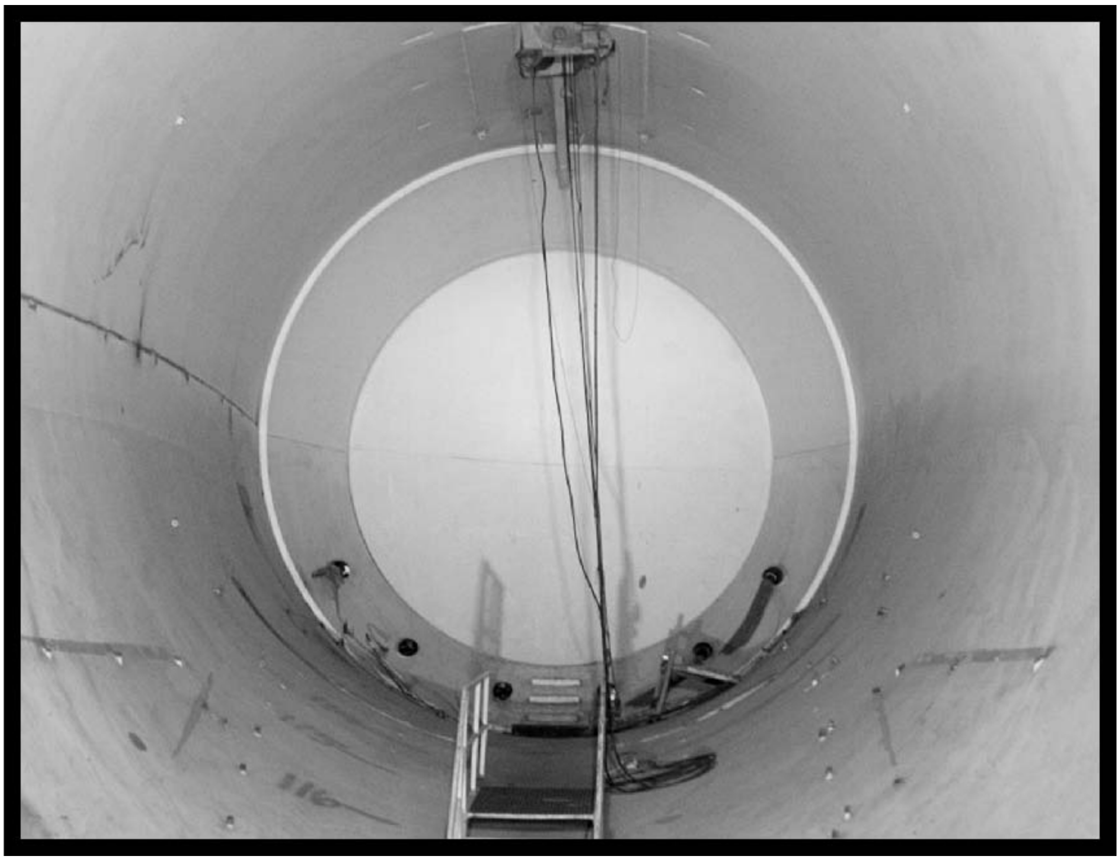

Figure 87.—20'-0"-diameter bulkhead near the west end of the former test section (viewed from west of SPC No. 2), 2007 (OH_Cuyahoga_Space-Power-Chambers_087).

Figure 88.—Platform elevator in SPC No. 2 lifted above Centaur model (viewed from the north), 1968 (OH_Cuyahoga_Space-Power-Chambers_088).

Figure 89.—Overhead crane and its two rails (viewed from east of the throat section), 2007 (OH_Cuyahoga_Space-Power-Chambers_089).

Figure 90.—Crane in western leg of SPC No. 2 near the southwest corner (viewed looking up), 2005 (OH_Cuyahoga_Space-Power-Chambers_090).

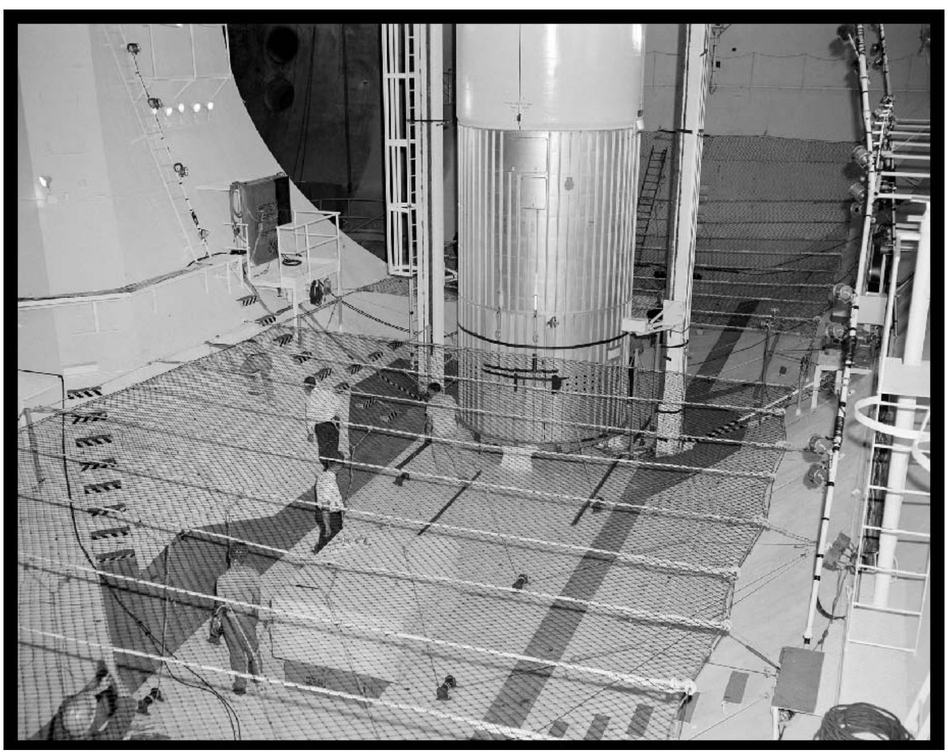

Figure 91.—Tie downs and net strung across SPC No. 2 to catch the shroud during the separation test, 1965 (OH_Cuyahoga_Space-Power-Chambers_091).

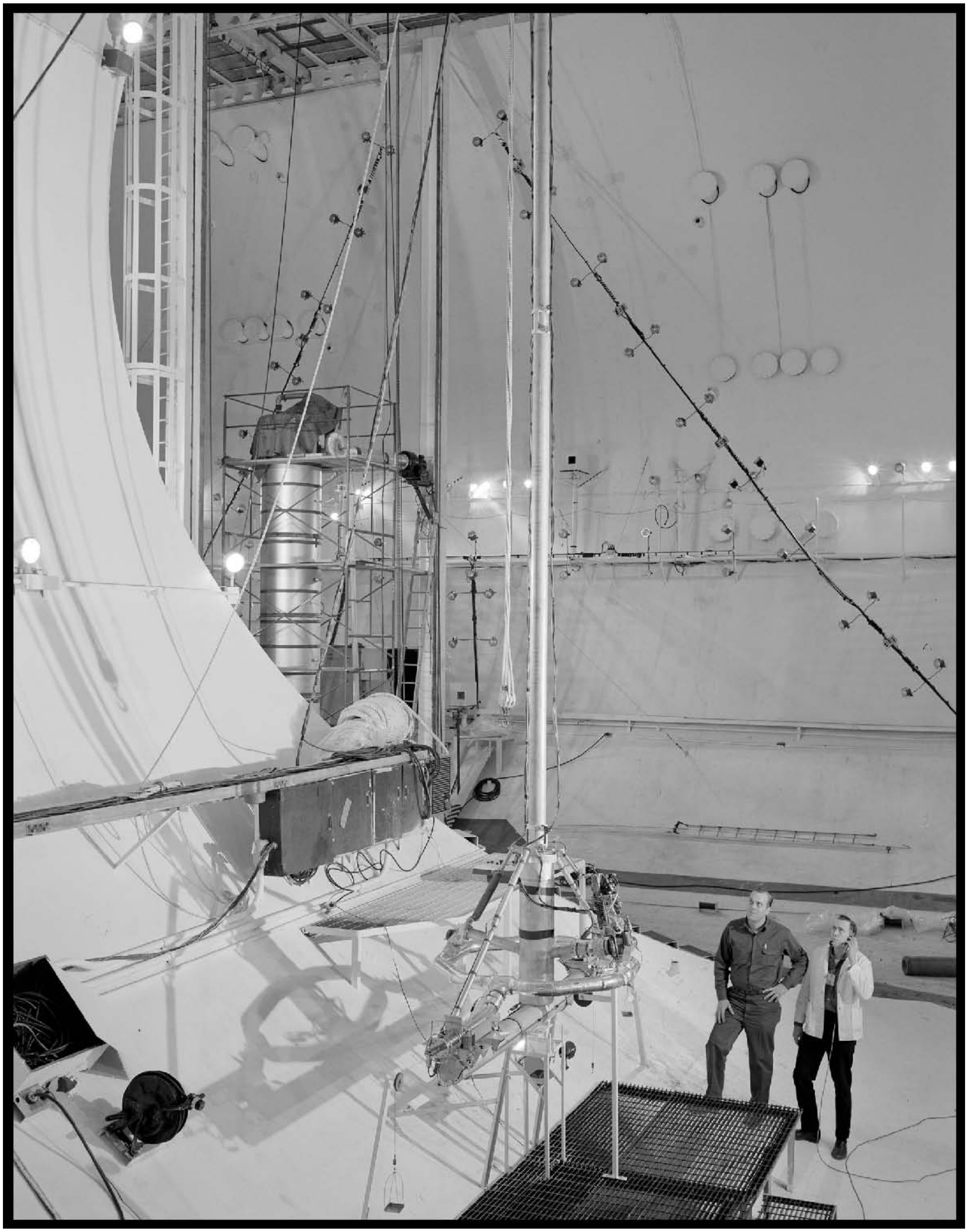

Figure 92.—Equipment mounted to the interior wall near the throat section, 1965 (OH_Cuyahoga_Space-Power-Chambers_092).

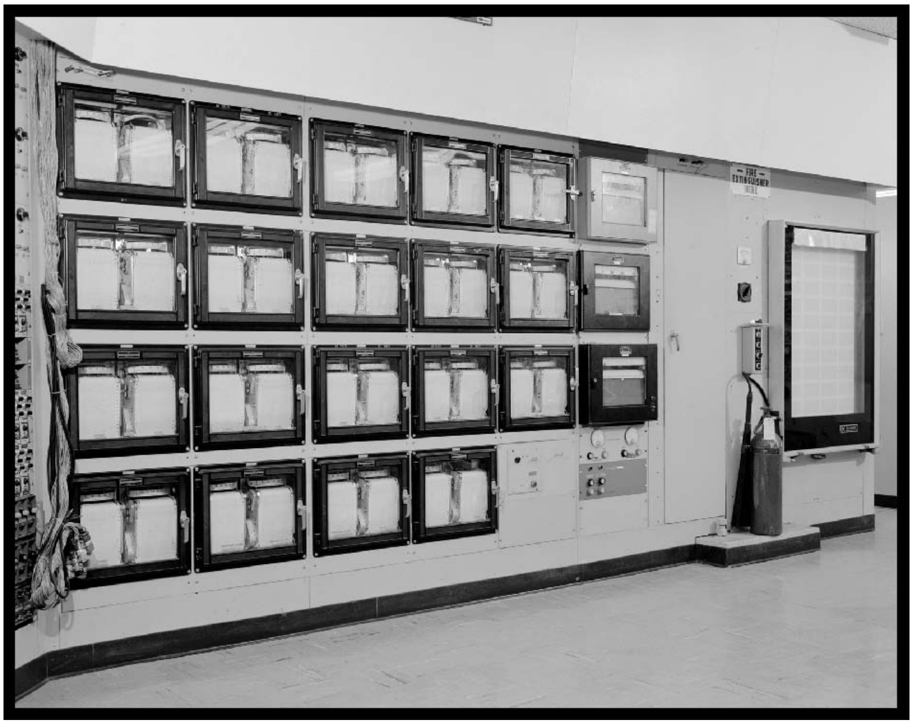

Figure 93.—Southern wall in SPC No. 1 control room with various event monitors, 1967 (OH_Cuyahoga_Space-Power-Chambers_093).

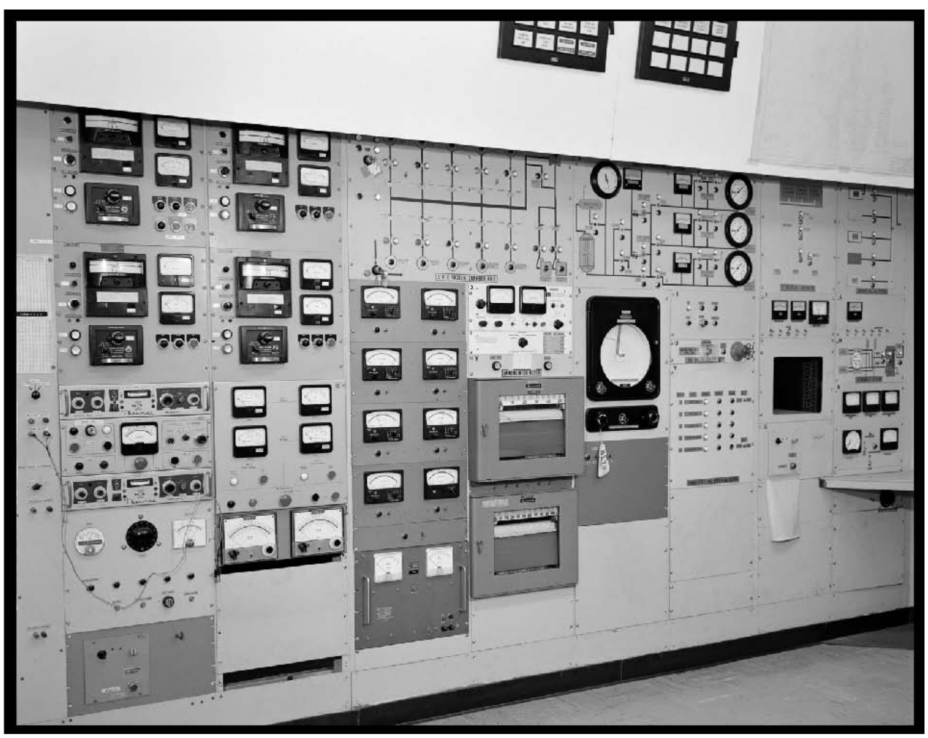

Figure 94.—Control panels on the east wall of the SPC No. 1 control room, 1967 (OH_Cuyahoga_Space-Power-Chambers_094).

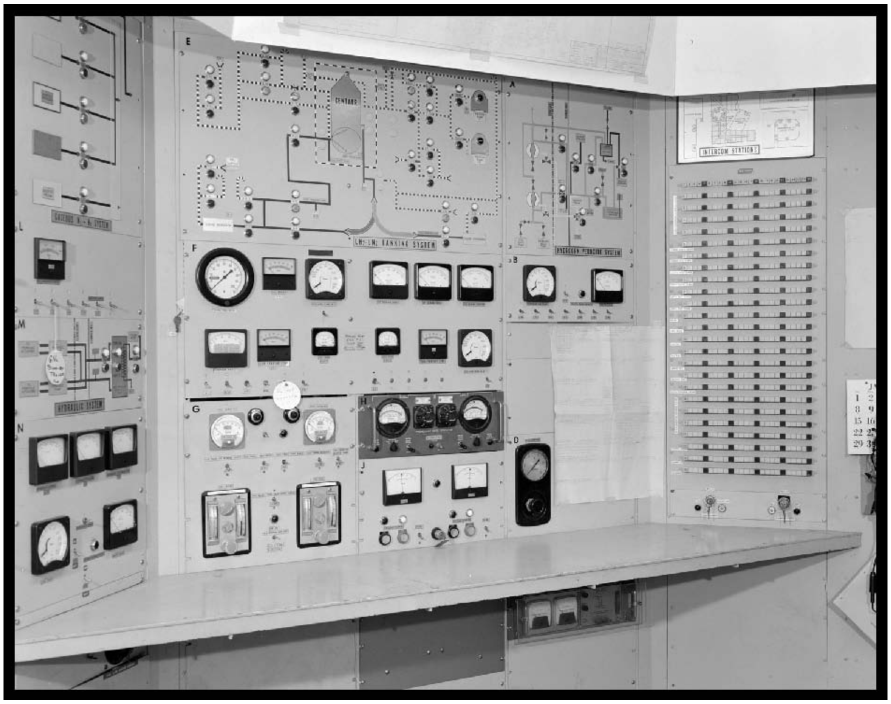

Figure 95.—Panels for the Centaur tanking system in the southeast corner of the SPC No. 1 control room, 1967 (OH_Cuyahoga_Space-Power-Chambers_095).

Figure 96.—Data recorders in the western rack in the center of the SPC No. 1 control room, 1967 (OH_Cuyahoga_Space-Power-Chambers_096).

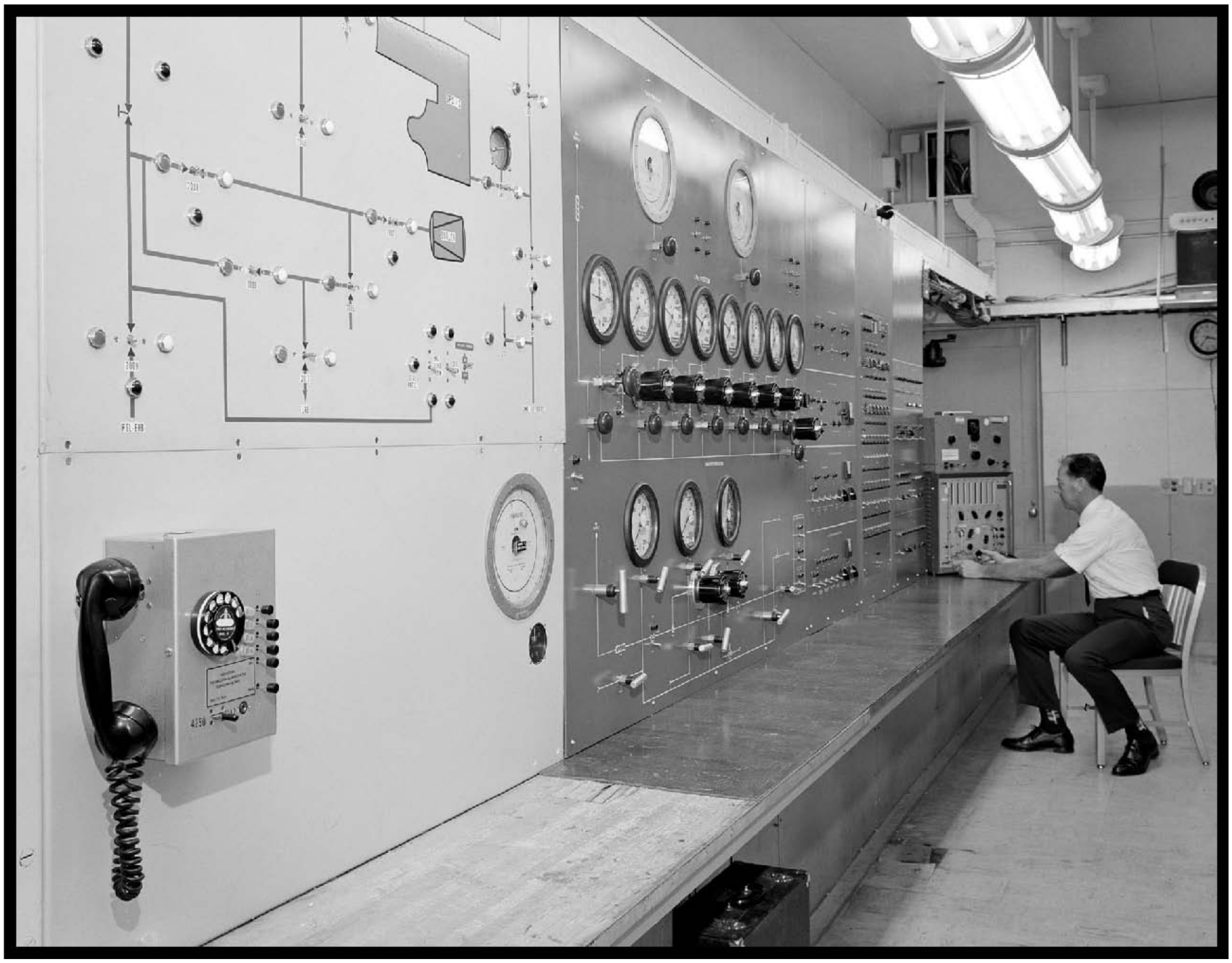

Figure 97.—SPC No. 2 control room with the airflow control panel in foreground (viewed from the east), 1963 (OH_Cuyahoga_Space-Power-Chambers_097).

Figure 98.—Interior of SPC No. 2 control room with the control panel on the left (viewed from the east), 1963 (OH_Cuyahoga_Space-Power-Chambers_098).

Figure 99.—SPC No. 2 control room (viewed from the west), 1963 (OH_Cuyahoga_Space-Power-Chambers_099).