ROCKET ENGINE TEST FACILITY – GRC BUILDING No. 202 HAER No. OH-124-A
(Rocket Propulsion Test Facility-Rocket Test Cell Building 202)
NASA Glenn Research Center
Cleveland
Cuyahoga County
Ohio

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF MEASURED DRAWINGS

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

February 27, 2003

HISTORIC AMERICAN ENGINEERING RECORD

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(Rocket Propulsion Test Facility – Rocket Test Cell Building 202)

HAER No. OH-124-A

Location: NASA Glenn Research Center
Cleveland
Cuyahoga County
Ohio
UTM: 17.427520.4584000
Quadrangle: Lakewood, Ohio 1:24,000

Date of Construction: 1955-57

Engineers: H. K. Ferguson Company

Present Owner: National Aeronautics and Space Administration – Glenn Research Center

Present Use: Vacant/Not in use.

Significance: The Rocket Engine Test Facility Complex is a National Historic Landmark, and Building 202 is included in the description of the complex on the National Historic Landmark nomination form. Building 202 is located 1,600' south of Building 100, which housed the Rocket Operations and Control Room. Engineers designed Building 202 as an industrial-style facility intended for testing experimental rocket engine designs and evaluating propulsion reactants. The building's significance lies not in its architecture but in the research conducted at the site, which contributed to the success of America's space program. Building 202 was built for engine systems research using high-energy propellants for missiles and later NASA upper-stage launch vehicles. The facility was unique in its ability to test rocket engines fueled with high-energy propellants such as liquid hydrogen with either liquid oxygen or fluorine oxidizers. The facility was also unique for its silencing equipment, which muffled the rockets' roar, and for the exhaust-gas scrubbers, which were designed to remove hydrogen fluoride and other contaminants from the exhaust, based on data provided by previous National Advisory Committee on Aeronautics (NACA) research and testing in smaller rocket test cells.[1] The successful development of the Centaur rocket and the upper stages of the Saturn V can be largely credited to the research completed by the National Aeronautics and Space Administration (NASA) at the Rocket Engine Test Facility and other test cells and

[1] John Sloop, *Liquid Hydrogen as a Propulsion Fuel* (Washington, D.C.: NASA Special Publication No. 4404, 1978), 80.

facilities at Lewis Research Center. Facility personnel designed most of the equipment in Building 202 that monitored engines under test and that recorded useful test data. NASA personnel developed highly innovative technology to solve design and operational problems. Building 202 was part of the original 1955-57 Rocket Engine Test Facility construction phase.

Project Information: This documentation was initiated on May 15, 2002, in accordance with a Memorandum of Agreement among the Federal Aviation Administration, NASA, The Ohio State Historic Preservation Officer, and the Advisory Council on Historic Preservation. The City of Cleveland plans to expand the Cleveland Hopkins International Airport. The NASA Glenn Research Center Rocket Engine Test Facility, located adjacent to the airport, must be removed before this expansion can be realized. To mitigate the removal of this registered National Historic Landmark, the National Park Service has stipulated that the Rocket Engine Test Facility be documented to Level I standards of the Historic American Engineering Record (HAER). This project was initiated to fulfill that requirement.

Historians: Robert C. Stewart Historical Technologies, West Suffield, Connecticut
Dr. Virginia P. Dawson History Enterprises, Cleveland, Ohio

Introduction:

Building 202 is located on land that was formerly part of the Cleveland Municipal Airport. NASA currently owns this property. From 1930-40, the airport expanded to cover more than 1,000 acres. During this period the airport was home to the National Air Races, and the western portion of the airport served as a parking area during these events. In 1940 the National Advisory Committee on Aeronautics (NACA) decided to build its Aircraft Engine Research Laboratory on 200 acres of the airport site. This location included the National Air Races parking lots and an adjacent strip of land that belonged to the Cleveland Metropolitan Park. In April 1947, the Aircraft Engine Research Laboratory was renamed the Flight Propulsion Research Laboratory to reflect its role in propulsion research. The name changed again in 1948 to the Lewis Flight Propulsion Laboratory, in honor of George William Lewis.[2] In 1958, the name was modified once again, to the Lewis Research Center. This name change reflected the facility's role in the new NASA, which had developed around a core of NACA facilities. Lewis

[2]George Lewis served as Director of Aeronautical Research for the National Advisory Committee for Aeronautics (NACA) from 1923-47. Under his leadership, NACA's Langley Research Laboratory established its reputation for outstanding contributions to aeronautical knowledge, which included both basic engineering research and testing. Lewis was responsible for obtaining funding for NACA's many unique test facilities. During World War II he oversaw the building of two additional national aeronautical research laboratories. The Lewis Flight Propulsion Laboratory was named after Lewis because of his important role in NACA.

Research Center continued its role as a NASA research facility throughout the 1980s and 1990s, and in March 1999, the center was officially renamed the NASA John H. Glenn Research Center at Lewis Field. Today, the Glenn Research Center at Lewis Field occupies more than 350 acres west of Cleveland Hopkins International Airport.[3] A map in the graphics section of this report shows the location of this research facility.

A request authorizing construction of a test facility for evaluating high-energy propellants and rocket engines was approved in 1952. As built, the facility consisted of a test cell and ancillary buildings dedicated to the testing of full-scale rocket engines. The complex was located on ten aces of a 40-acre tract known locally as the "South 40" and situated at the south end of NASA's Glenn Research Center. The new Rocket Engine Test Facility was designed to permit up to three minutes of rocket engine operation at a thrust of eighty-nine kilonewtons. Upon its completion in the fall 1957, this facility was the largest high-energy rocket engine test facility in the United States. Built at a cost of $2.5 million, the complex originally encompassed two major components: a control center housed in Building 100, and a test cell at Building 202. Other components included an observation blockhouse constructed as part of the original construction phase, and Buildings 205 and 206, built in the 1960s to accommodate liquid fuel and oxidizer vaporization facilities.

Building 202 included a test cell, a propellant supply system, and a distinctive system for scrubbing exhaust gases to remove waste products generated during combustion. The scrubber also silenced the noise of rocket firing. There was a small shop adjacent to the test cell where personnel assembled engines and installed instruments to measure test data. Also adjacent to the test cell was a tank farm of high-pressure helium bottles. Storage areas for some fuels, liquid oxygen, and water were located on the hillside east of Building 202. From this elevated storage location, hydrocarbon fuels, ammonia, and hydrazine were transported by gravity to the test cell below. Propellant pressure tanks were filled with fluorine or liquid hydrogen transported to the facility on trailers. Water for the scrubber was supplied using a gravity-fed system from a tank with a capacity of 500,000 gallons.

It must be emphasized that the Rocket Engine Test Facility was classified as a research facility. As such, the staff focused on a mission to test new designs and concepts, analyze successes and failures, re-design, and re-evaluate. The environment fostered creative and innovative solutions in a field of study that was new and in which there were many unknown factors. While major aerospace companies were conducting corporate research in rocket engine development, the Rocket Engine Test Facility was able to evaluate novel concepts and transfer viable ones to other research facilities for scale-up and possible production. The type of research that was completed produced data cost-effectively by testing model and sub-scale engines. Sub-scale testing also produced useful design data with minimal use of expensive fuels and oxidizers. Typically these test engines had 4.8" chambers with 2.62" throats, or 10" chambers with 7.6"

[3] National Aeronautics and Space Administration, "Lands of the Lewis Research Center" (Cleveland: National Aeronautics and Space Administration, 1978), 13-14.

throats. Using high-pressure reactant feeds, an engine with a 4.8" throat could produce thrusts of 75 kilonewtons (17,000 pounds).

The complex had the high-pressure capabilities and facilities for testing a comprehensive variety of rocket fuels and oxidants. An addition that was constructed in 1984, and which was known as Test Stand B, equipped Building 202 for the testing of large area ratio rocket nozzles under conditions that simulated those in space.[4] Building 202 played a pivotal role in the development of hydrogen rocket fuel technologies. Research conducted by NASA personnel at this test facility contributed to the successful development of the Centaur rocket and the upper stages of the Saturn V rocket. The research completed at Building 202 was therefore central to the success of the Apollo moon exploration program in the late 1960s and 1970s.

Site Description:

The Rocket Engine Test Facility complex is located on a ten-acre site within a forty-acre area at the southern end of NASA's Glenn Research Center. This location is locally known as the "South 40." Building 202, the Rocket Engine Test Facility Rocket Test Cell Building, is located on the side of a small, steep gorge. The gorge drains an arm of Abram Creek, which is a tributary of the Rocky River. The east side of the gorge was contoured during construction to create a uniform slope, and two service roads were provided for the facility. Both service roads paralleled the hillside contours and permitted relatively level access up the steep hillside. The lower service road led to the test cell, while the upper road serviced Building 205, Building 206, and the water reservoir. The general Rocket Engine Test Facility site is accessible from the Lower South Road at NASA Glenn Research Center. South Road begins at the intersection of Walcott Road and Cedar Point Road in the Glenn Research Center complex at Lewis Field.

The elevation of Building 202 at the test cell floor is 735.25' above sea level. The surface of Abram Creek is approximately 50' below the test cell floor. Several ancillary structures stand in the immediate vicinity of Building 202. Two of these are Building 205, the South Area Propellant Transfer and Storage Area, and Building 206, the Cryogenic Vaporizer Facility. Other support structures in the immediate area include the 500,000-gallon water storage reservoir, which was built on the hillside at an elevation of 760' above sea level. The hillside site and the placement of the water storage tank at an elevation above Building 202 allowed water to be gravity-fed to the scrubber/silencer. The reservoir water was used to scrub exhaust gases produced by the rocket engines being tested. The final support facility is a small observation blockhouse positioned approximately 260' north of the test cell. All of these support structures are functional industrial buildings devoid of architectural or aesthetic features. They are representative examples of form dictated by function.

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[4] Harry Butowsky, "Rocket Engine Test Facility, National Register of Historic Places Nomination" (Washington, D.C.: United States Department of the Interior, National Park Service, 1984).

Description of Building 202:

General:

Building 202 was built on an L-shaped plan. The longer leg was constructed using I-beam uprights and lighter structural steel forms, and the building exterior was sheathed with vertically corrugated, insulated metal wall panels. The facility contained an observation room, an office, a tool crib, and a locker room with toilets and a shower. A utility bay housed a boiler and an electrical distribution cabinet. A small substation room housed a transformer and switchgear. The facility's welding booth occupied the southwest corner of the building. The central area of this wing provided space where technicians could service engines and prepare them for a test. The southern part of the building that fronts on Lower South Road had an overhead garage door that opened into the central service area. Two overhead monorail cranes lifted engines from trucks or trailers and carried them to the service area or welding booth. A stairway led to a small basement below the service area, where a compressor tank and heat exchanger were stored. The base of the L-shaped plan housed the fuel and oxidant pits, test cell, scrubber/silencer, valve house, and pump house. Wastewater treatment facilities were located north of the scrubber/silencer.

The Fuel and Oxidant Pits:

The fuel pit, oxidant pit, and observation room were constructed of reinforced concrete. The floor level of both pits was 26' below the test cell floor. The fuel and oxidant pits were separated from the test cell and observation room by a 2'-thick reinforced concrete wall.[5] This heavy construction could withstand an explosion or fire in the test cell. JP-4 was transferred from a tanker to a cylindrical tank vessel suspended from a frame in the fuel pit. The frame was equipped with a Baldwin load cell that transmitted analog data regarding the weight of the fuel and vessel to the control room.[6] The oxidant pit was similarly equipped with liquid oxygen tanks. An outer jacket containing liquid nitrogen enveloped the oxygen tanks.[7] Liquid oxygen was transferred from a mobile tanker-trailer into a double-walled, vacuum-insulated tank called a "Dewar," which was located on the hillside west of Building 202.[8] Oxygen flowed to the tanks in the oxidizer pit through a pipe that was jacketed with a liquid nitrogen bath. The liquid oxygen was forced from the tanks and into the test engine by pressurized helium gas, which displaced the oxygen. The fuel and oxidant pits were both equipped with sprinkler systems for

[5] Drawing CE-101310 Test Cell Building Foundation Plan.

[6] Drawing CE-101634 Fuel Tank ─ General Assembly.

[7] Liquid nitrogen boils at –195.8ºC, while liquid oxygen boils at –183ºC. As a result, the liquid nitrogen maintained the liquid oxygen below its boiling point and prevented significant evaporative loss. It also guaranteed greater accuracy in determining actual oxidant usage.

[8] Sir James Dewar invented the Dewar flask in 1892. It insulated against the transfer of heat by conduction, convection, or radiation. It was commercialized in 1904 as the "Thermos" flask.

fire suppression. During experiments with fluorine, the liquid nitrogen bath served to liquefy any vaporized fluorine that leaked from the tank. This was a safety feature that minimized the possibility of atmospheric fluorine release.

The termination or observation room was designed to protect test observers and the electronic equipment used to transmit data to the control room in Building 100. Using a periscope-like window and mirror system, engineers in the observation room directly observed rocket engine tests from a safe location. The test engineer in the observation room could also press an "abort" button that would immediately shut down a test through a programmable logic controller.

The Test Cell:[9]

The vertical test stand located at the center of the test cell was built to accommodate rocket engines firing with a maximum thrust of 20,000 pounds. This limit was imposed by the weight of mountings, plumbing, controls, and instrumentation. The facility's scrubber/silencer and foundations were designed, however, to handle engines exerting up to 100,000 pounds of thrust. The supporting frame for the engine was instrumented with strain gauges, pressure sensors, load cells, and thermocouples that measured the engine thrust and other data. These data were sent to the adjacent observation room for relay to the control room.

The cell measured 43'-8" wide and 30'-8" deep, and enclosed a usable floor area of 1,325 square feet. The shed roof of the test cell was 25' high on the west side and 35' high to the east. The test cell enclosure consisted primarily of upright steel I-beams, which were the major structural members, while lighter steel channel and angle beams fastened between the I-beams produced a modular framed structure. The walls and roof of the structural frame were sheathed in corrugated cement asbestos sheets, also known as "Transite" or "Carrystone." These sheets measured 5/16" thick and were lightly fastened to the framework. If an explosion occurred during a test, the sudden increase in pressure inside the test cell blew these sheets free of the frame and relieved the internal pressure. The sheathing was then easily replaced. In later years, lightweight, translucent fiberglass/resin sheets replaced the cement asbestos panels. These provide the same benefits as the asbestos cement, but they also allowed more light into the test cell.

The west facade of the test cell had a double sliding door that, when opened, exposed approximately one-third of the cell's width to the outside. A window centered over the sliding door measured 7' high and 16'-6" wide, and consisted of thirty-five lights, which were arranged in seven horizontal and five vertical rows. When opened, a double sliding door on the north side of the test cell exposed about one-half of the cell interior to the outside. The fuel and oxidant pits partly conceal the lower east facade of the test cell. A window extended across the

[9] The descriptive material on the test cell and its operation was obtained during a videotaped tour of the facility led by George Repas, who was employed as a hardware design engineer at the Rocket Engine Test Facility during most of the years that the facility was in operation.

facade above the roofline of the fuel and oxidant pits. This window was a steel-frame industrial type unit that measured 4' 6" high and 27' wide. This window had forty-two lights, mounted three high and fourteen wide. An additional louvered vent with a windscreen was placed at the peak of the shed roof and covered the full width of the test cell. This louvered vent was approximately 3' high. The roof slanted upwards to the east to allow loose hydrogen gas to escape.

Two gas unit heaters maintained a comfortable working temperature inside the test cell during set-up operations.[10] Pipes supplied with nozzles were positioned along the inner perimeter of the test cell near the roofline, and could spray water into the cell to suppress fire. Additional pipes and nozzles could flood the test cell with carbon dioxide to control fires.

A centrally located opening led from the test cell into the scrubber/silencer below. This oversized circular opening was covered by as many as twelve wedge-shaped steel plates that could be adjusted to change the diameter of the opening to accommodate various engine support systems. The transitional passage into the scrubber/silencer was a conical piece approximately 6'-9" high. The top of the cone was a heavy steel flange with a circular opening that measured 4' in diameter. At the bottom of the cone, where the piece joined the horizontal tank, the aperture measured 12' in diameter.[11] Several burners near the rocket exhaust ignited any hydrogen or other fuel that had not burned inside the engine. These burners prevented unburned fuel from building to explosive levels inside the scrubber. The test stand or rig that supported the engine was mounted over the flange at the top of the cone so that engine exhaust vented directly into the scrubber/silencer.

The Scrubber/Silencer:

The remaining section of the base of the building's L-shaped plan contained the scrubber/silencer that treated exhaust by directing the hot gas through a heavy spray of water. The water for scrubbing exhaust was supplied by a tank on the hillside at an elevation of 760' above sea level, approximately 50' above the inlet to the scrubber/silencer.[12] This tank had a capacity of 500,000 gallons.

The scrubber/silencer consisted of several sections. The test engine was supported on a thrust stand over the inlet end. This conical section was attached to a horizontal tank that measured 25' in diameter and approximately 60' long. The conical section was equipped with four water spray nozzles for cooling. A concave end cap closed the end of the tank closest to the thrust stand, and a manifold fitted with spray nozzles was mounted on this end cap. Additional manifolds with spray nozzles cooled and protected three sides of the "firing duct" immediately

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[10] Drawing F-101580 – Plot Plan Equipment Location.

[11] Drawing CD-101266 – Exhaust Duct – Inlet Cone and Details.

[12] *Ibid*.

below the inlet cone. While the spray from these nozzles somewhat cooled the exhaust, their chief function was to protect the scrubber/silencer components nearest the rocket exhaust from thermal damage.[13] The distal end of the tank section housed five pipe manifolds that supported additional water spray nozzles for thermal diffusion.[14] The silencer/scrubber configuration then narrowed through a 7'-long transitional cone to a diameter of 20'. The exhaust path then entered a ninety-degree elbow before passing through the vertical stack, which measured 20' in diameter and rose to 35' 9" above the test cell floor.[15] Two spray manifolds with nozzles were located inside the stack just above the elbow and provided additional cooling and cleaning. Once the exhaust passed through this transition to the scrubber/silencer's vertical stack, the stream had cooled and was clear of most water-soluble compounds. Near the top of the stack, several de-mister units removed small water droplets from the exhaust stream.[16]

During a test run, the reservoir supplied water under gravity flow to the nozzles at a rate as high as 50,000 gallons per minute. This water flow was controlled by a bank of valves mounted on the south side of the scrubber/silencer's horizontal portion. Exhaust gases exited the rocket engines at velocities of 9,000 to 12,000' per second and at temperatures of 6,000°F. The water spray dissolved soluble matter, captured solids, and cooled exhaust gases. The passage of the exhaust stream from a rocket nozzle no larger than a few square inches to a horizontal scrubber/silencer tank with a cross section of more than 490 square feet slowed the exhaust to a velocity of approximately 25' per second. By the time the exhaust stream emerged from the stack at about 20' per second, the temperature had decreased to less than 160°F.

Additional equipment for water treatment was located north of the scrubber/silencer. Water, condensed steam, and combustion by-products trapped by the scrubber drained into a 20,000-gallon detention tank. This tank was located at the lowest point in the complex, adjacent to a fork of Abram Creek. This tank held wastewater until the completion of the daily test program, when the water was pumped to a neutralizing tank. The neutralizing tank consisted of an oil separation chamber and a sand filter. Chemical technicians analyzed the wastewater and determined the quantity and type of additive needed to neutralize acidity or alkalinity and establish a pH value[17] that met municipal wastewater standards. Technicians added chemicals to the neutralizing tank through a "lime pump house," and the additives reacted with the combustion by-products in the wastewater. Some fuel/oxidizer combinations produced highly corrosive acid by-products, and the use of fluorine created hydrofluoric acid as a by-product.

[13] Drawing CD-101276 – Exhaust Duct Wash Down Spray System.

[14] Drawing CD-101263 – Exhaust Duct Elevations and Sections.

[15] *Ibid*.

[16] Drawing CD-101261 – Demister Support Details.

[17] The pH is a measure of acidity or alkalinity. Values below 7.0 indicate increasing acidity while values between 7.0 and 14.0 indicate increasing alkalinity.

Reaction of water containing hydrofluoric acid with a calcium compound in the neutralizing tank produced a stable, solid precipitate of calcium fluoride. After treatment, technicians then retested the water before pumping it into a holding tank known as the "collector basin," or "swimming pool," as it was commonly called. This treated water was then pumped to a municipal wastewater treatment plant, and the solid wastes were sent to a stable landfill.

The 500,000-gallon reservoir also supplied water to cool the rocket engine nozzle during active testing. This cooling water was pumped using a 650- or a 1,450-gallon-per-minute pump. In addition, the reservoir supplied the line of fire suppression spray nozzles positioned around three sides of the test cell approximately 24' above the floor. The west side of the cell was not equipped with nozzles.

Operations:

Standard operating procedures were followed when preparing an engine test. JP-4 was pumped from a mobile tanker-trailer into cylindrical tanks in the fuel pit. These tanks were mounted in a suspension framework equipped with load cells that measured the weight of both empty and full tanks. The load cells could determine the weight of the tank while fuel was being drawn, and by comparing the weight of a full tank with the tank's weight after completing a test, test engineers could accurately calculate the weight of fuel burned during the procedure. Rocket Engine Test Facility personnel could determine the rate of fuel use by plotting tank weight against run time. Variable position hydraulic valves controlled the pressure of inert helium gas flowing into the fuel tanks. This gas pressure forced fuel from the tanks and into the rocket engine under test.

Liquid oxygen was transferred from a mobile tanker-trailer, also known as a mobile liquid Dewar, into a double-walled, vacuum-insulated tank, or stationary Dewar. The stationary Dewar was located on the hillside west of Building 202. Oxygen flowed through a pipe that was jacketed in a liquid nitrogen bath, and ran to the tanks in the oxidizer pit. The tanks in the oxidizer pit were encased in outer tanks that also contained a liquid nitrogen bath. These liquid nitrogen baths maintained the oxygen in a liquid state. The liquid oxygen was then forced from the tanks and into the test engine by displacement from helium gas under pressure. The system of using gas pressure to move reactants to the engine eliminated the need for expensive turbo pumps. The rocket engine under test was then cooled by water supplied from the reservoir and pumped using a 650- or a 1,450-gallon-per-minute pump.

Working pressure ratings for the primary liquid hydrogen, liquid oxygen, cooling water, and hydrocarbon propellant systems was 5,000 pounds per square inch (psi). Storage pressures were 4,000 psi for gaseous hydrogen, 6,000 psi for gaseous helium, and 3,000 psi for gaseous nitrogen. The site provided bulk storage for 28,000 gallons of liquid nitrogen, 2,000 gallons of liquid oxygen, and 18,000 gallons of liquid hydrogen. Gas pumping equipment could provide hydrogen at 4,000 psi, helium at 6,000 psi, and nitrogen at 3,000 psi to the gas bottle farms.

History:

While exotic propellants offered higher specific impulse, from a practical standpoint, researchers could develop many solutions to rocket engineering design problems by using common fuels. Technicians and engineers gained valuable experience and knowledge by testing and operating prototype rocket engines, regardless of which reactants were used. Consequently, the first experimental engines tested at the Rocket Engine Test Facility were gasoline-fueled and tested on a vertical test stand at the center of the test cell. This stand was capable of supporting engines that exerted up to 20,000 pounds of thrust. Liquid oxygen was used as the oxidant. Building 202 was originally designed to handle these volatile reactants.

The Rocket Engine Test Facility was planned and constructed as a rocket engine research facility. As part of its mission as a nationwide laboratory focused on aircraft engines, Lewis Flight Propulsion Laboratory had begun rocket propulsion research as early as 1944. There was strong interest in rocketry for U.S. military applications during the early Cold War years due to the success of the German V-2 rocket during World War II. Rocket propulsion research completed at Lewis Laboratory in the late 1940s was circulated to the Navy Bureau of Aeronautics, Air Materiel Command, and other U.S. military organizations.[18] When the initial request for construction of the Rocket Engine Test Facility was made in 1952, much of the rocket research at Lewis Laboratory was related to military applications. This was still true in 1955, when construction began on the Rocket Engine Test Facility.[19] It was only after the successful launch of Sputnik by the Soviet Union in 1957 that the potential of the Rocket Engine Test Facility research for space travel was more strongly emphasized.[20]

Building 202 was constructed from 1955-57 as part of the original Rocket Engine Test Facility construction phase. Construction drawings of the buildings date from 1955-56. The original building consisted of a test cell, shop area, the observation room, oxygen and fuel pits, a scrubber/silencer, and associated pump and wastewater handling facilities. By the late 1950s, research engineers and scientists working at the Lewis Research Center were persuaded that hydrogen was the optimum fuel for upper-stage rockets, although whether liquid oxygen or fluorine was the ideal oxidizer was still being debated. However, many practical solutions for engineering problems had to be resolved before the theoretical advantages of hydrogen/oxygen propulsion could be achieved. Hydrogen is a powerful fuel that must be handled carefully to minimize the danger of an explosion. In addition, large quantities of hydrogen were not available during the early years of the rocket research program.

The Rocket Engine Test Facility was originally designed to handle engines using liquid oxygen (LOX) and rocket propellant (RP), which was a refined grade of kerosene. NASA researchers tested early experimental engines on the facility's vertical test stand (Stand A), which could

[18] Virginia P. Dawson, "History of the Rocket Engine Test Facility at NASA-Glenn Research Center" (draft). On file at Hardlines Design Company, Columbus, Ohio, (February 19, 2003), 4-10.

[19] *Ibid*., 12, 25.

[20] *Ibid*., 30-32.

support engines that exerted 20,000 pounds of thrust. Liquid oxygen was used as the oxidant. However, records indicate that engines using a hydrogen-fluorine combination were tested at the Rocket Engine Test Facility from 1957-59, including a 1959 test of a regeneratively-cooled hydrogen-fluorine engine with a 480-pound thrust, the highest thrust attained by any chemical rocket engine up to that time.[21]

By the 1960s, reactants such as nitrogen tetroxide, un-symmetrical dimethyl hydrazine, and fluorine were increasingly used in tests at the Rocket Engine Test Facility, although all fluorine testing ended by 1966 because it was considered impractical as an oxidizer.[22] Use of these chemicals at the Rocket Engine Test Facility resulted in the extension of the scrubber exhaust stack to guarantee thorough removal of toxic exhaust products. A transitional cone was mounted on top of the stack, thereby reducing the opening to 6' in diameter and extending the stack to a total height of 118'. At the top of the scrubber stack a flare ring ignited any residual hydrogen. In its original form and as modified, the scrubber/silencer was a well-engineered solution to a waste treatment problem. The scrubber system was instrumental to the maintenance of high environmental quality in the vicinity of the Rocket Engine Test Facility.

When the Rocket Engine Test Facility closed in 1995, there were nine propellant systems consisting of Dewars and tanks with working pressures of 1,500 to 6,000 psi connected to the test stands with stainless steel, vacuum, or liquid-nitrogen-jacketed pipelines. The use of gas pressure to force the reactants from the tanks and into the test engines eliminated the need for high-pressure rocket turbo machinery and pumps. Hydraulic variable position valves controlled both the pressurized gas flows to the run tanks and the reactant gas flows to the rocket engine. The system was flexible and allowed multiple configurations that could support any particular test program.

In 1984 Building 202 was modified to add capabilities for evaluating rocket nozzles with ratios of up to 1,000:1 on small, low-thrust engines. The new test stand, called Test Stand B, simulated the vacuum of space through a large vacuum tank that housed the engine during active testing. Engines were mounted horizontally in this test stand, while the engine exhaust was directed through a water-cooled diffuser and inter-cooler, and into the existing scrubber/silencer. Two gas ejectors powered by the facility's nitrogen supplies created the vacuum.[23] Normally this type of ejector was steam-powered, but the availability of an existing on-site high-pressure nitrogen supply made the use of this gas cost-effective.

[21] *Ibid.*, 30-31.

[22] According to George Repas; cited in NASA-Glenn Research Center, "Comments on Rocket Engine Test Facility Historic American Engineering Record Documentation" (January 24, 2003), 5.

[23] Ejectors use the venturi effect to create a vacuum. An ejector is a simple form of vacuum pump having no moving parts. It consists of a gas nozzle that discharges a high-velocity jet of nitrogen across a suction chamber connected to the vacuum chamber. The gas to be evacuated is entrained by the nitrogen and carried into a venturi-shaped diffuser that converts the velocity energy of the nitrogen into pressure energy.

In 1991 Test Stand C was added to Building 202. This stand was used for testing seal materials and designs for liquid oxygen pumps and other components. The initial test program tested seals on a turbo pump rig. Some of the controls for Stand C were located in a rack on the southeast side of the control room. There was also a complete gauge board inside the test cell.[24]

The last tests at the Rocket Engine Test Facility occurred in 1995. Since that time, Building 202 has been vacant. Building 202, along with the entire Rocket Engine Test Facility at the Abram Creek site, is scheduled for demolition to make way for expansion of Cleveland Hopkins International Airport.

Conclusion:

The Rocket Engine Test Facility contributed to NASA's Apollo Program by extensive testing of liquid hydrogen/liquid oxygen propellants. These propellants were used in the upper stages of the giant Saturn rocket, the rocket propulsion system responsible for transporting human beings to the moon. NASA personnel conducted research using the test stands in Building 202 that was critical to the development of liquid hydrogen as a reliable and safe rocket fuel. The design of the Rocket Engine Test Facility was a successful, functional layout for this research facility, and NASA scientists achieved major progress in the isolation and resolution of engine design problems. The staff at the Rocket Engine Test Facility was largely responsible for creating an efficient and cost-effective methodology for rocket engine testing.

[24] Drawing CE-183172 – Gaseous Nitrogen System – Turbo Machinery Test Facility.

Sources of Information/Bibliography

A. Engineering Drawings:

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory – Cleveland, Ohio
Rocket Engine Research Facility – Exhaust Duct and Detention Tank – Demister Support Details
General Plan and Miscellaneous Details
Drawing No. CE-101261 – 7/18/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory – Cleveland, Ohio
Rocket Engine Research Facility – Exhaust Duct and Detention Tank
Exhaust Duct Elevations and Sections
Drawing No. CE-101263 – 7/18/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory – Cleveland, Ohio
Rocket Engine Research Facility – Exhaust Duct and Detention Tank
Exhaust Duct Wash Down Spray System
Drawing No. CE-101276 – 7/18/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory – Cleveland, Ohio
Rocket Engine Research Facility – Test Cell Building
Foundation Plan
Drawing No. CE-101310 – 6/29/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory – Cleveland, Ohio
Rocket Engine Research Facility – Fuel Tank General Assembly
Drawing No. CE-101634 – 9/27/55

National Aeronautics and Space Administration – Lewis Research Center – Cleveland, Ohio
Gaseous Nitrogen System – Turbo Machinery Test Facility Building 202
3000 PSIG Gaseous Nitrogen Supply Test Stand C
Drawing CE-183172 – 9/03/92

B. Interviews:

Repas, George, Hardware Design Engineer
Interview by the author, 28 May 2002
Cleveland, Video recording. Hardlines Design Company, Columbus, Ohio

C. Secondary Sources:

Butowsky, Harry. "Rocket Engine Test Facility, National Register of Historic Places Nomination." Washington, D.C.: United States Department of the Interior, National Park Service, 1984.

Dawson, Virginia P. *Engines and Innovation*. Washington, D.C.: National Aeronautics and Space Administration, Scientific and Technical Information Division, 1991.

____________. "History of the Rocket Engine Test Facility at NASA-Glenn Research Center." (draft). On file at Hardlines Design Company, Columbus, Ohio. February 19, 2003.

____________. "Rocket Propulsion Research at Lewis Research Center," 28th Joint Propulsion Conference AIAA/SAE/ASME/ASEE, July 6-8, 1992, AIAA-92-31230. NASA Contractor Report 189187.

Harris, Cyril M. *Dictionary of Architecture and Construction*. New York: McGraw-Hill Book Company, 1993.

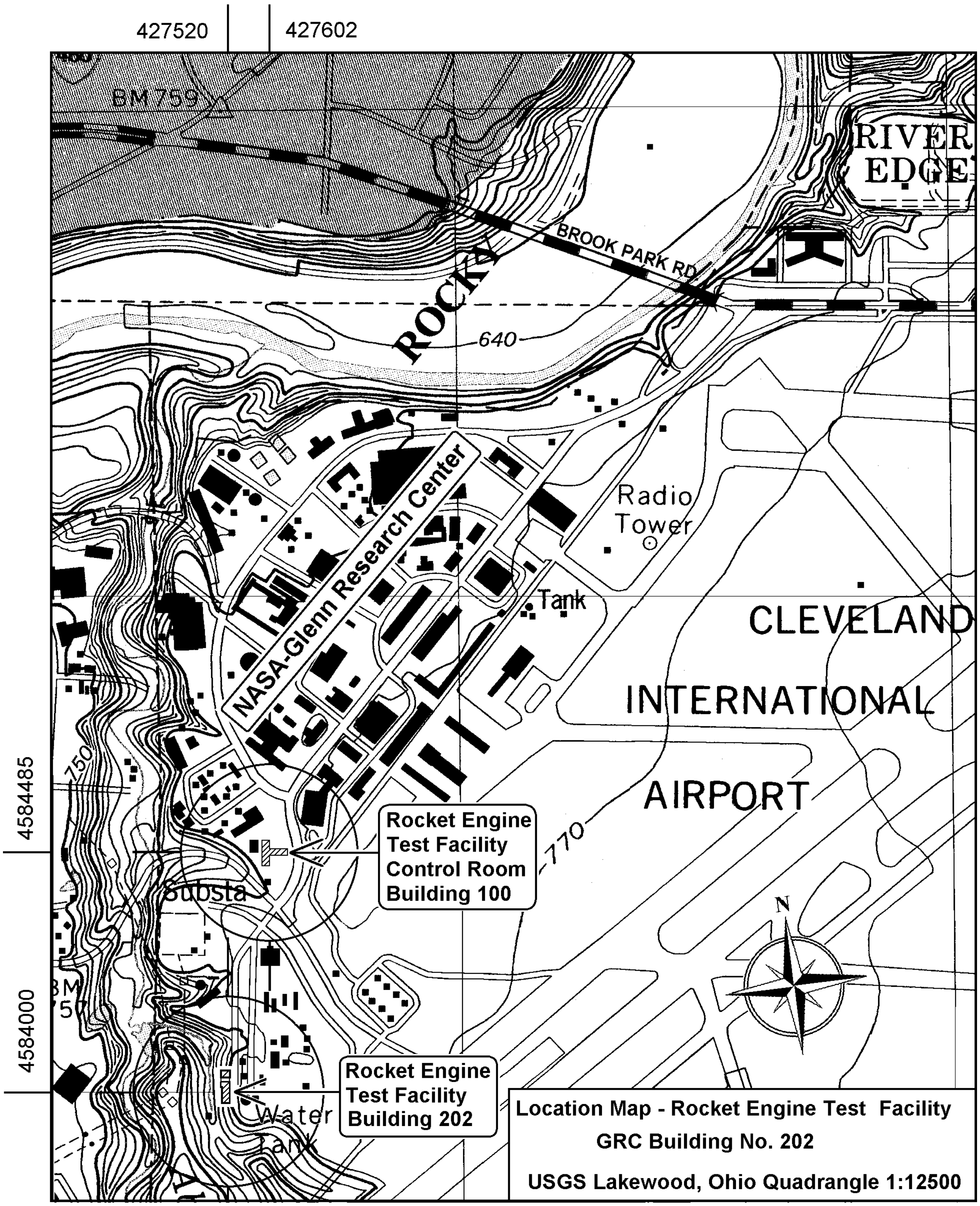
Mulready, Dick. *Advanced Engine Development at Pratt and Whitney*. Warrendale, Pennsylvania: Society of Automotive Engineers, Inc., 2001.

National Aeronautics and Space Administration. *Lands of the Lewis Research Center*. Cleveland: National Aeronautics and Space Administration, 1978.

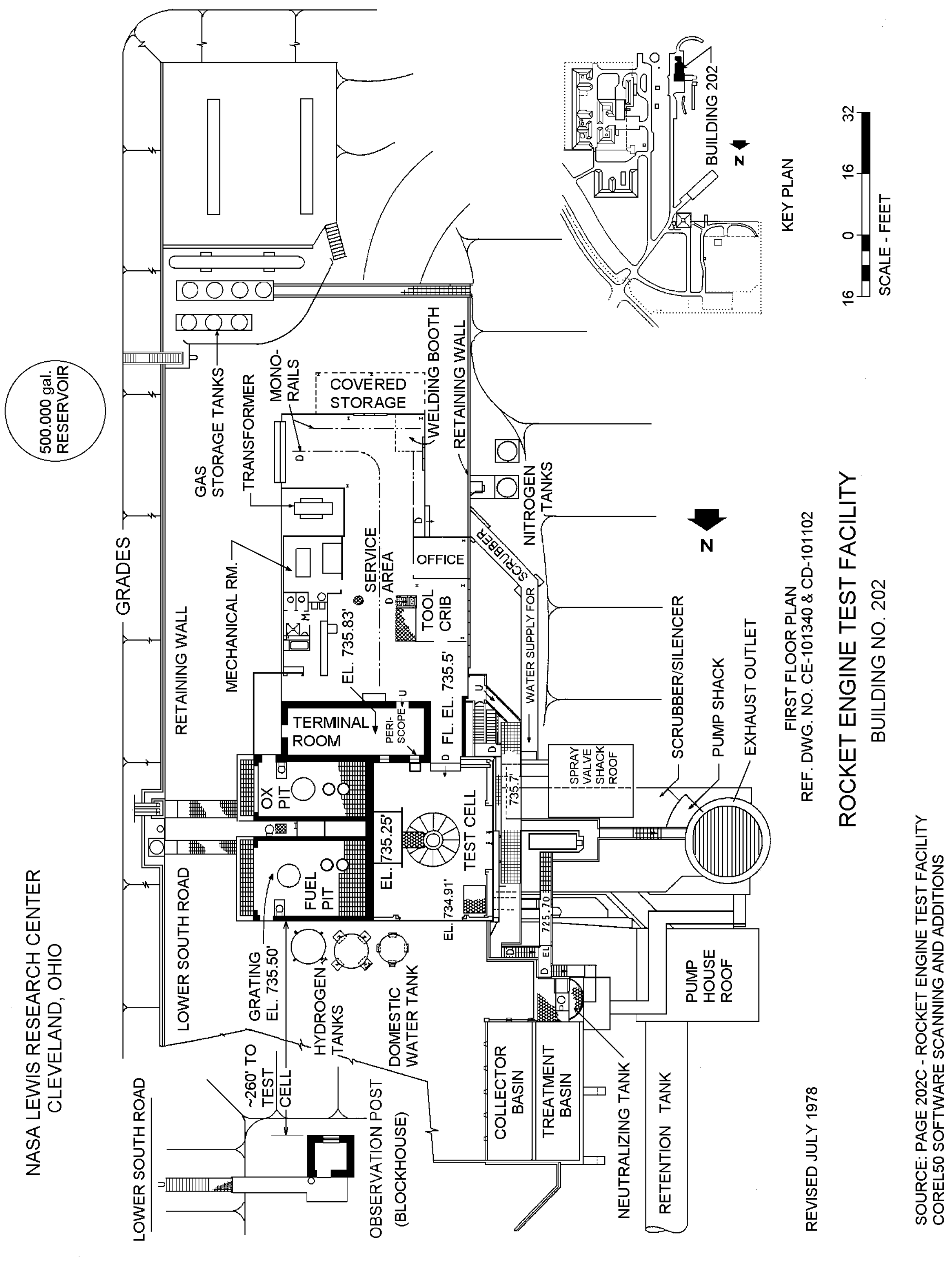
Perry, John H., Ph.D., ed. *Chemical Engineers' Handbook*. New York: McGraw-Hill Book Company, 1950.

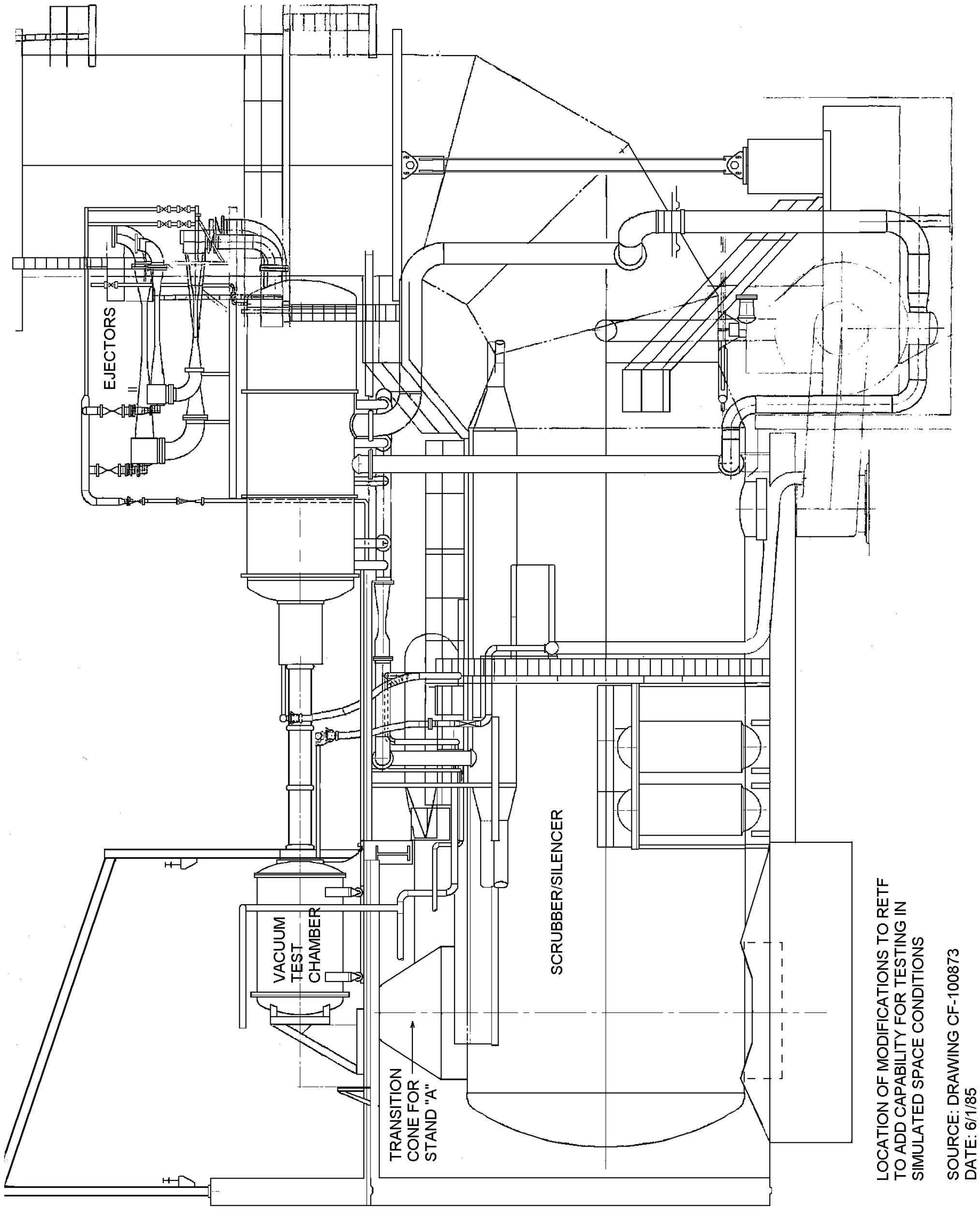
Sloop, John. *Liquid Hydrogen as a Propulsion Fuel.* Washington, D.C.: NASA Special Publication No. 4404, 1978.

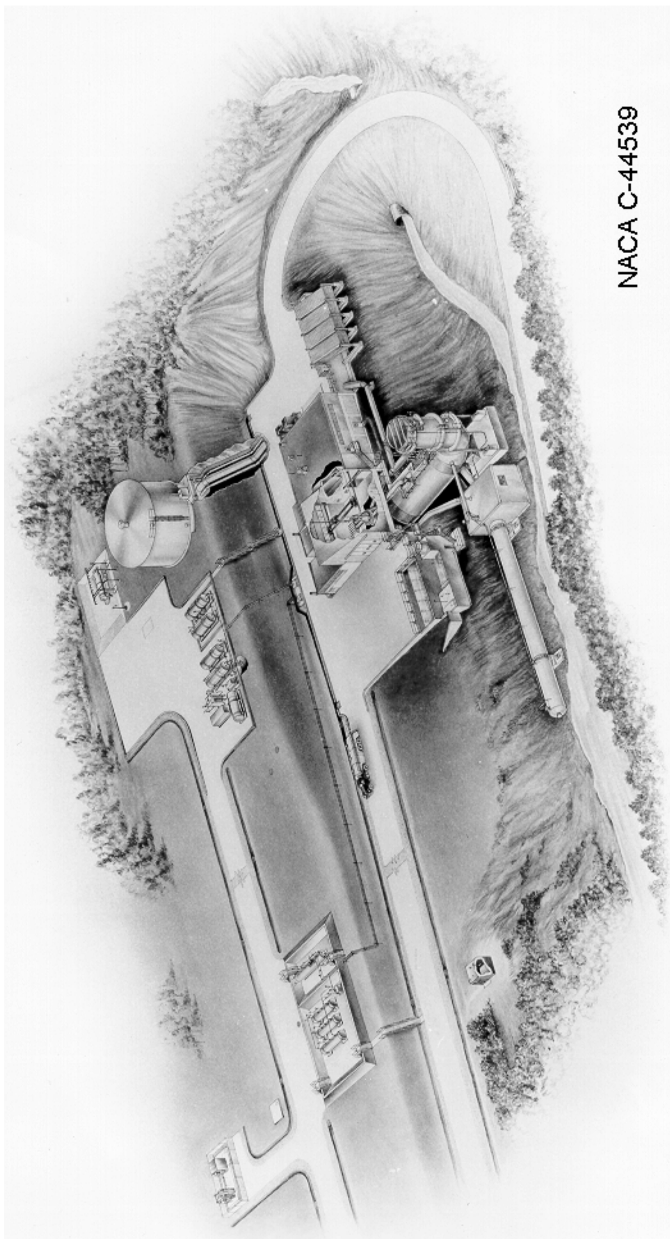
Thomas, Wayne. "Description of the Rocket Engine Test Facility." Cleveland: Lewis Research Center, 1984.



Location Map - Rocket Engine Test Facility
GRC Building No. 202
USGS Lakewood, Ohio Quadrangle 1:12500


ROCKET ENGINE TEST FACILITY
BUILDING NO. 202
FIRST FLOOR PLAN
REF. DWG. NO. CE-101340 & CD-101102
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO
REVISED JULY 1978
SOURCE: PAGE 202C - ROCKET ENGINE TEST FACILITY
COREL50 SOFTWARE SCANNING AND ADDITIONS
BY R.C. STEWART - NOVEMBER 2002
KEY PLAN
BUILDING 202
N
SCALE - FEET
16
0
16
32
500,000 gal. RESERVOIR
GRADES
RETAINING WALL
LOWER SOUTH ROAD
GAS STORAGE TANKS
TRANSFORMER
MONO-RAILS
COVERED STORAGE
WELDING BOOTH
RETAINING WALL
MECHANICAL RM.
SERVICE AREA
OFFICE
TOOL CRIB
EL. 735.83'
FL. EL. 735.5'
TERMINAL ROOM
PERI-SCOPE
OX PIT
FUEL PIT
EL. 735.25'
TEST CELL
EL. 734.91'
735.7'
NITROGEN TANKS
SCRUBBER
WATER SUPPLY FOR
SPRAY VALVE SHACK ROOF
SCRUBBER/SILENCER
PUMP SHACK
EXHAUST OUTLET
GRATING EL. 735.50'
HYDROGEN TANKS
DOMESTIC WATER TANK
~260' TO TEST CELL
OBSERVATION POST (BLOCKHOUSE)
COLLECTOR BASIN
TREATMENT BASIN
NEUTRALIZING TANK
RETENTION TANK
PUMP HOUSE ROOF


EJECTORS
VACUUM TEST CHAMBER
TRANSITION CONE FOR STAND "A"
SCRUBBER/SILENCER
LOCATION OF MODIFICATIONS TO RETF TO ADD CAPABILITY FOR TESTING IN SIMULATED SPACE CONDITIONS
SOURCE: DRAWING CF-100873
DATE: 6/1/85



Artist's Conception of the Rocket Engine Test Facility - 1957 -1959

HISTORIC AMERICAN ENGINEERING RECORD

INDEX TO PHOTOGRAPHS

ROCKET ENGINE TEST FACILITY (RETF) BUILDING 202 HAER No. OH-124-A
NASA Glenn Research Center
Cleveland
Cuyahoga County
Ohio

Jeff Bates, Hardlines Design Company, Field Photographer, May 2002
NASA Information Technology Center (ITC), Copywork Photographer, November 2002

OH-124-A-1 CONTEXT VIEW OF BUILDING 202, LOOKING SOUTH FROM ACCESS ROAD.

OH-124-A-2 CONTEXT VIEW OF SOUTHWEST CORNER OF BUILDING 202, LOOKING NORTHEAST.

OH-124-A-3 SOUTHEAST CORNER OF BUILDING 202, LOOKING NORTHWEST FROM STEPS ON HILLSIDE NEAR WATER TANK

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OH-124-A-24	HISTORIC VIEW OF BUILDING 202 SCRUBBER STACK, AUGUST 1957. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-45734.
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OH-124-A-26	HISTORIC VIEW OF BUILDING 202, MAY 22, 1957. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-45652.
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OH-124-A-29	HISTORIC VIEW OF 20,000-POUND ROCKET TEST STAND WITH ENGINE INSTALLATION IN TEST CELL OF BUILDING 202, SEPTEMBER 1957. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-45870.
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OH-124-A-32 HISTORIC VIEW OF BUILDING 202 TEST STAND A WITH ROCKET ENGINE, CLOSE-UP DETAIL OF ENGINE, NOVEMBER 19, 1957. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-46492.

OH-124-A-33 HISTORIC PHOTO OF SECTION DIAGRAM OF BUILDING 202, APRIL 30, 1958. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-47807.

OH-124-A-34 HISTORIC PHOTO OF BUILDING 202 TEST CELL WITH DAMAGE FROM FIRE OR EXPLOSION DURING ROCKET ENGINE TESTING, MAY 17, 1958. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-47965.

OH-124-A-35 HISTORIC PHOTO OF BUILDING 202 TEST STAND WITH DAMAGE TO 20,000-POUND-THRUST ROCKET ENGINE RELATED TO FAILURE DURING TESTING, SEPTEMBER 16, 1958. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-48704.

OH-124-A-36 HISTORIC PHOTO OF BUILDING 202 INTERIOR, SHOWS SHOP AREA WITH ENGINEERS ASSEMBLING 20,000-POUND-THRUST ROCKET ENGINE, DECEMBER 15, 1958. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-49343.

OH-124-A-37 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, WITH DAMAGE RELATED TO HYDROGEN FIRE DURING ROCKET ENGINE TESTING, APRIL 25, 1959. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-50473.

OH-124-A-38 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, SHOWING DAMAGE TO TEST STAND A AND ROCKET ENGINE AFTER FAILURE AND EXPLOSION OF ENGINE, DECEMBER 12, 1958. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-49376.

OH-124-A-39 HISTORIC PHOTO OF BUILDING 202 TEST CELL EXTERIOR, SHOWING FIBERGLASS CLADDING BLOWN OUT BY HYDROGEN FIRE DURING ROCKET ENGINE TESTING, APRIL 27, 1959. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-50472

OH-124-A-40 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, WITH ENGINEERS WORKING ON ROCKET ENGINE MOUNTED ON TEST STAND A, JUNE 26, 1959. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-51026.

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OH-124-A-42 HISTORIC PHOTO OF EXTERIOR OF BUILDING 202 TEST CELL, JANUARY 26, 1960. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-52534.

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OH-124-A-44 HISTORIC PHOTO OF INTERIOR OF BUILDING 202 TEST CELL, SHOWING ROCKET ENGINE ON TEST STAND AND CAMERA SET UP FOR FILMING TESTS, SEPTEMBER 1960. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-54464.

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OH-124-A-46 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, DETAIL OF TEST STAND A WITH ENGINE SEVERELY DAMAGED DURING TESTING, SEPTEMBER 7, 1961. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-57837.

OH-124-A-47 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, TEST STAND A WITH TECHNICIAN WORKING ON ZONE INJECTOR ENGINE, JUNE 3, 1966. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-66-2396.

OH-124-A-48 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, TEST STAND A WITH ZONE INJECTOR ENGINE; TECHNICIAN IS WORKING ON EQUIPMENT PANEL IN FOREGROUND, JUNE 3, 1966. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-66-2397.

OH-124-A-49 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, TEST STAND A WITH ENGINEER EXAMINING DAMAGE TO TEST ENGINE, OCTOBER 21, 1966. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-66-4064.

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OH-124-A-51 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, WITH LONGABLATIVE ROCKET ENGINE MOUNTED ON TEST STAND A, MAY 18, 1967. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-66-4084.

OH-124-A-52 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, WITH ENGINE MOUNTED ON TEST STAND A, MAY 18, 1967 ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-67-1740.

OH-124-A-53 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, WITH ENGINE MOUNTED ON TEST STAND A, SHOWING SURROUNDING FUEL AND OXIDANT DELIVERY SYSTEMS AND INSTRUMENTS, MAY 18, 1967. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-67-1739.

OH-124-A-54 HISTORIC PHOTO OF BUILDING 202 TEST CELL INTERIOR, WITH ENGINE MOUNTED ON TEST STAND A, SEPTEMBER 13, 1967. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-67-3274.

OH-124-A-55 HISTORIC PHOTO OF EXCAVATION WORK AT BUILDING 202, SHOWS FACILITY WITH DETENTION TANK IN FOREGROUND, FEBRUARY 24, 1969. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-69-711.

OH-124-A-56 HISTORIC PHOTO OF EXCAVATION WORK AT BUILDING 202, SHOWS FACILITY WITH EXHAUST SCRUBBER IN FOREGROUND, FEBRUARY 24, 1969. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-69-712.

OH-124-A-57 HISTORIC PHOTO OF INTERIOR OF TEST CELL AT BUILDING 202, SHOWING TEST STAND A WITH ENGINE AND D.T. SUPPORT RING, FEBRUARY 24, 1969. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA PHOTO NUMBER C-69-3187.

OH-124-A-58 HISTORIC PLAN, SECTION, AND DETAIL DRAWING OF BUILDING 202 TEST CELL, JUNE 29, 1955. NASA GRC DRAWING NO. CE-101340 (ON FILE AT NASA GLENN RESEARCH CENTER).

OH-124-A-59 HISTORIC ELEVATION AND DETAIL DRAWING OF BUILDING 202 TEST CELL, JUNE 29, 1955. NASA GRC DRAWING NO. CE-101341 (ON FILE AT NASA GLENN RESEARCH CENTER).

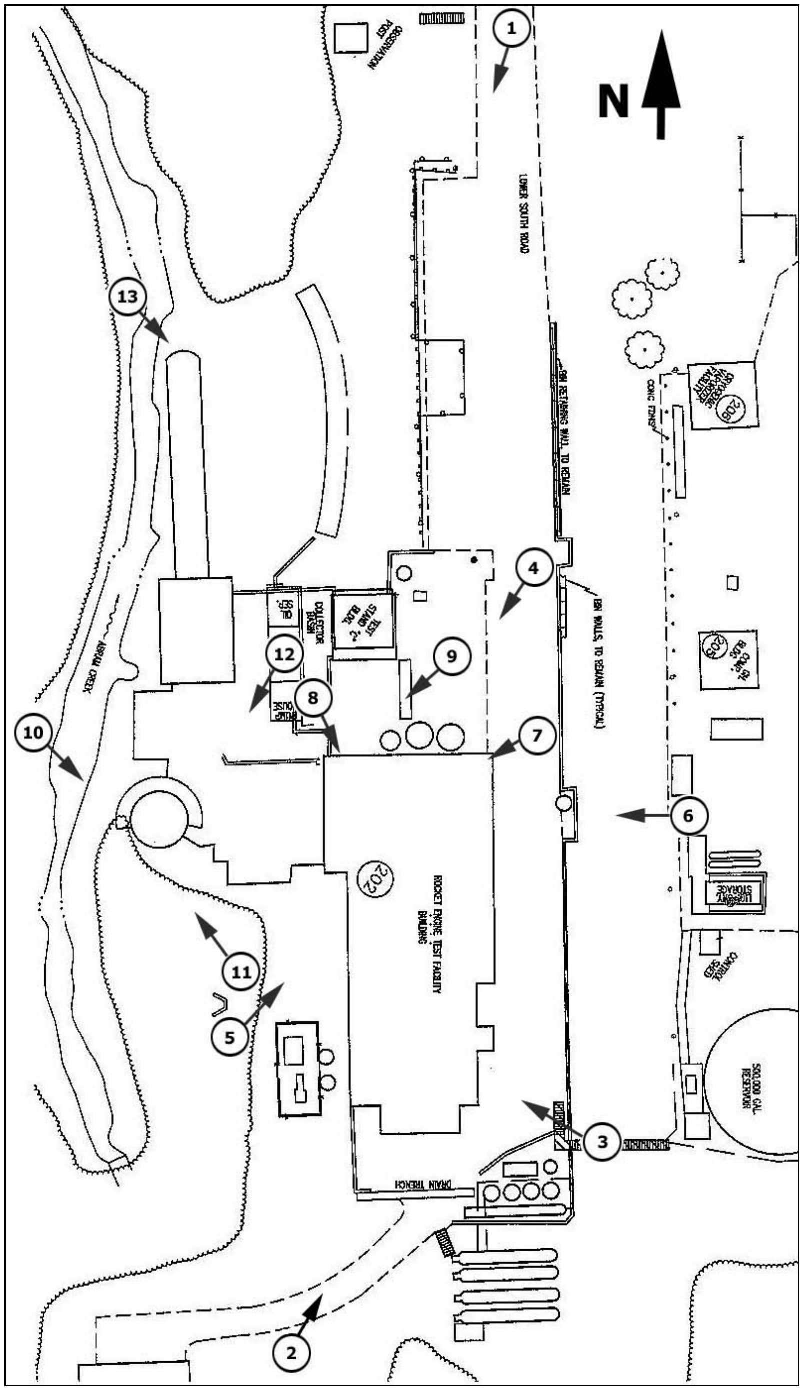
OH-124-A-60 HISTORIC PLAN OF BUILDING 202 EXHAUST SCRUBBER, JUNE 18, 1955. NASA GRC DRAWING NO. CD-101261. (ON FILE AT NASA GLENN RESEARCH CENTER).

OH-124-A-61 HISTORIC ELEVATION AND SECTION DRAWING OF BUILDING 202 EXHAUST SCRUBBER, JULY 18, 1955. NASA GRC DRAWING NO. CD-101263. (ON FILE AT NASA GLENN RESEARCH CENTER).

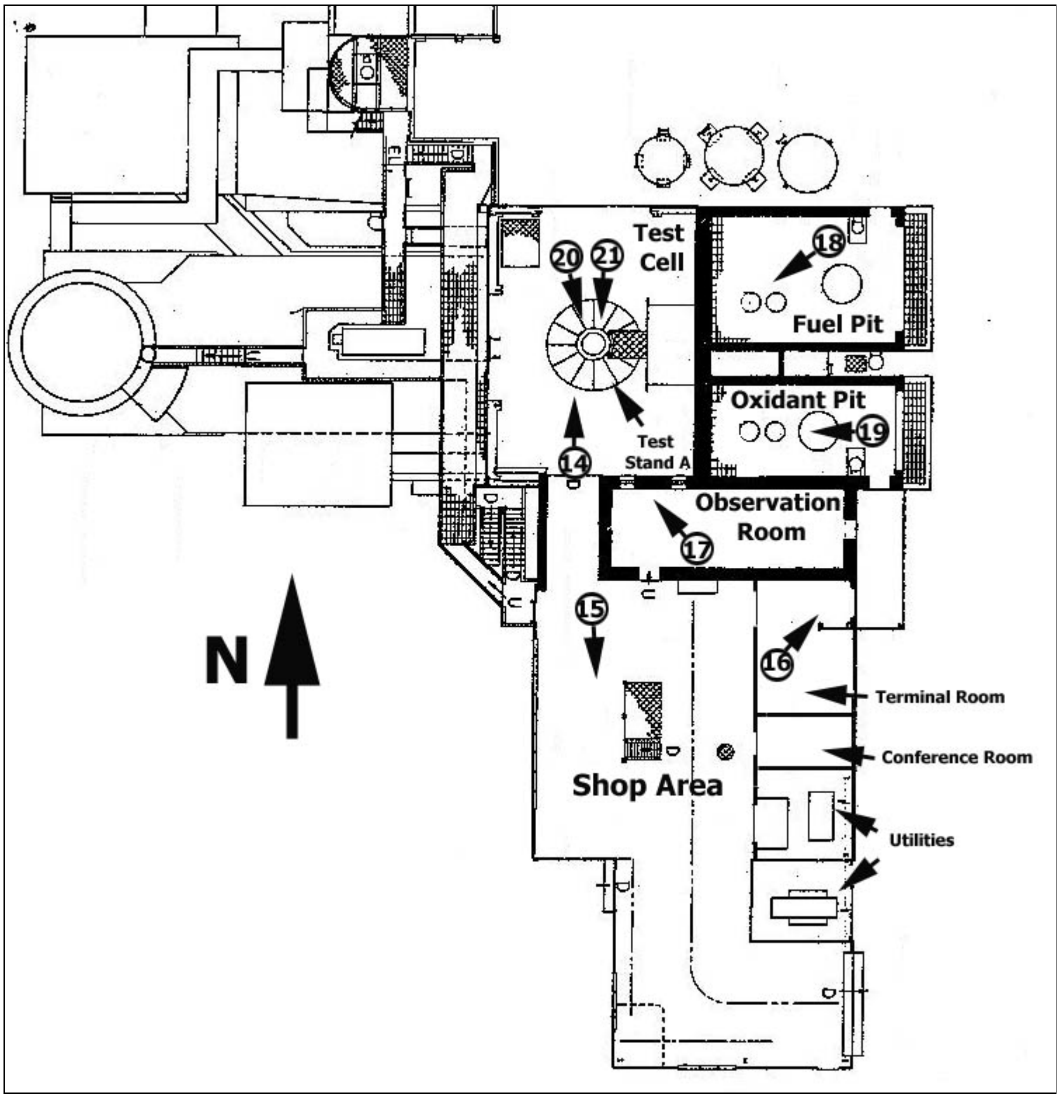
OH-124-A-62 HISTORIC PROPELLANT PIPING DIAGRAM OF OXIDANT PIT AT BUILDING 202, JANUARY 6, 1956. NASA GRC DRAWING NO. CF-101644. (ON FILE AT NASA GLENN RESEARCH CENTER).

OH-124-A-63 HISTORIC DETAIL DRAWING OF INLET DUCT CONE ON EXHAUST SCRUBBER AT BUILDING 202, JUNE 18, 1955. NASA GRC DRAWING NO. CD-101266. (ON FILE AT NASA GLENN RESEARCH CENTER).

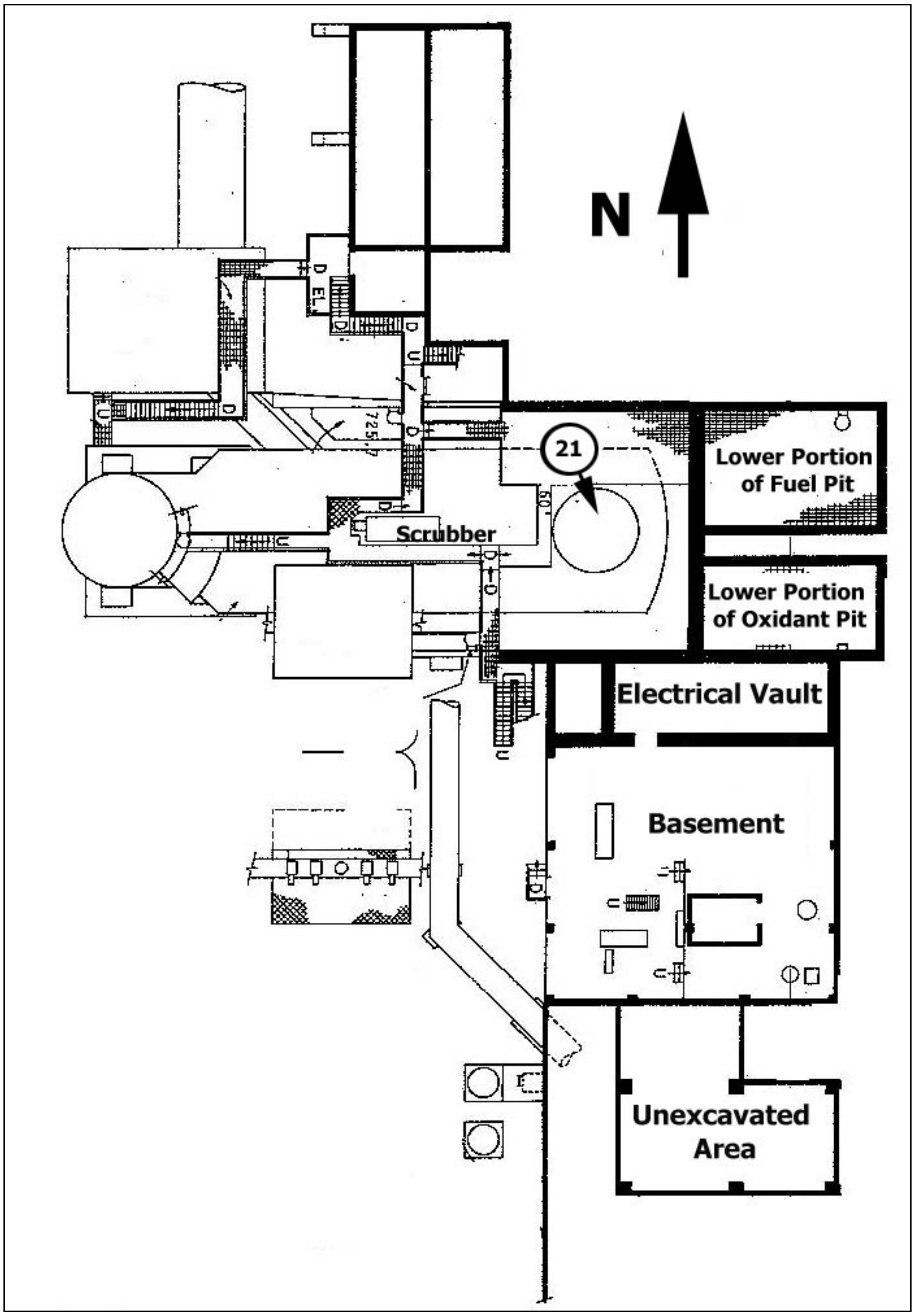
OH-124-A-64 HISTORIC PROPELLANT TANK DETAIL DRAWING FOR BUILDING 202, JUNE 6, 1958. NASA GRC DRAWING NO. CE-120322. (ON FILE AT NASA GLENN RESEARCH CENTER).



Key to Exterior Photos



Key to Interior Photos on Main Level of Building 202



Key to Interior Photo on Basement Level of Building 202

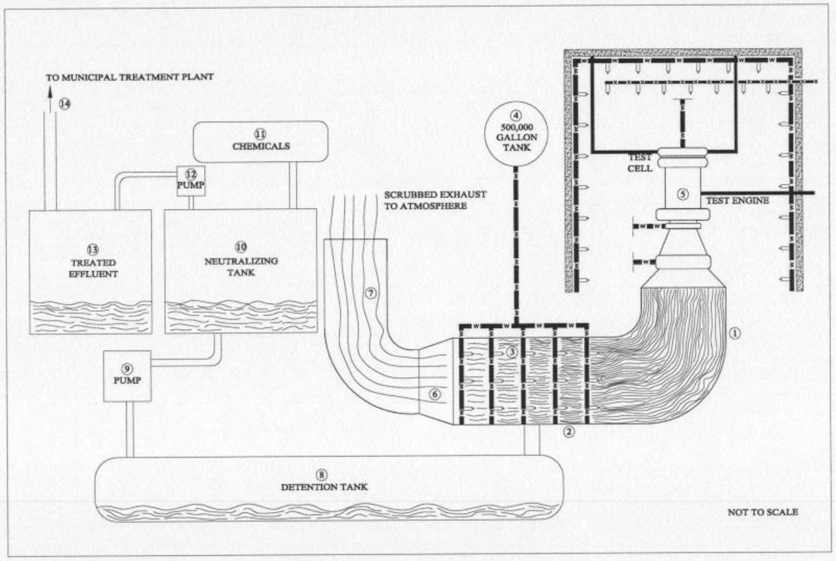
ROCKET EXHAUST FLOW CHART

The Rocket Engine Test Facility (RETF) is located near the Cleveland Municipal Airport, a number of metropolitan parks, and a series of residential neighborhoods. Because of this urban setting, it was essential to control the exhaust emissions and loud noises generated during rocket engine tests. NASA addressed these problems by including mufflers and silencers in the original design. In addition, both the original high-thrust vertical test stand and the low-thrust horizontal stand added in 1984 discharged exhaust into a scrubber/ silencer. This device removed combustion by-products from the rocket engine exhaust and decreased noise levels.

Scrubbers ① are devices that use a liquid to remove gases and dispersed particles from an exhaust stream. At the RETF, the scrubber condensed the hot exhaust produced by rocket engine tests. As the exhaust cooled and reached its dew point, the condensed exhaust was trapped in water and sprayed into the scrubber's chamber. The water was then collected for treatment and disposal.

The RETF scrubber was mounted on concrete foundations designed to support engines capable of producing up to 100,000 lbs. of thrust. However, the collective weight of mounts, plumbing controls, and instrumentation limited the facility's capability to testing engines that exerted less than 20,000 lbs. of thrust.

The main component of the scrubber system was a horizontal tank ② measuring 100' long by 25' in diameter. The tank contained five water spray bars ③ fitted with nozzles that produced a heavy aerosol spray. During test runs, water from a nearby reservoir ④ flowed through the aerosol nozzles at a rate of 50,000 gallons per minute. Rocket engines ⑤ mounted on the original test stand vertically exhausted hot gases into one end of the tank. The engines discharged this exhaust at velocities ranging from 9,000 to 12,000 feet per second (fps), and at temperatures of approximately 6,000°F. This exhaust was trapped in the water spray coming from the nozzles. Inside the tank, the exhaust stream velocity slowed to 25 fps, and much of the exhaust was converted to steam.



Additional water sprays condensed the steam. The other end of the tank ended in a transition elbow ⑥ that led to a vertical stack ⑦. This stack measured 20' in diameter and rose to 79'7" in height. Any remaining water vapor and non-condensable exhaust gas exited the vertical stack at a temperature of 160°F and a velocity of 20 fps. Several burners near the rocket exhaust source ignited any hydrogen or other fuel not consumed by the engine. These burners prevented unburned fuel from building to explosive levels inside the scrubber.

Water, condensed steam, and combustion by-products trapped by the scrubber drained into a 20,000 - gallon detention tank ⑦ located adjacent to Abram Creek, at the lowest point in the RETF complex.

Wastewater was retained in this tank until the day's test program was completed, when the wastewater was pumped ⑨ to a neutralizing tank ⑩. Chemical technicians analyzed the wastewater and determined the quantity and type of additive needed to neutralize acidity or alkalinity, so that the pH value would meet municipal wastewater standards.

Chemicals ⑪ added to the neutralizing tank reacted with combustion by-products in the wastewater. Some fuel/ oxidizer combinations produced highly corrosive acidic by-products. The use of fluorine created hydrofluoric acid by-products, and mixing a calcium compound with the hydrofluoric acid/ water mixture in the neutralizing tank produced a stable, solid precipitate of calcium fluoride. The wastewater was then re-tested and pumped ⑫ into a holding tank ⑬. The treated water was finally pumped into the municipal wastewater treatment system ⑭.

Engineers monitored the scrubber/ silencer system from the control room in Building 100. Pilot lamps on a control board panel represented the scrubber layout and enabled technicians and engineers to observe the system's operating status. From 1957-1959, RETF testing was restricted to engines using rocket propellant (RP), a refined grade of kerosene, and liquid oxygen as the reactant. In the 1960s, RETF researchers used reactants such as nitrogen tetroxide, unsymmetrical dimethyl hydrazine, and fluorine. Use of these chemicals required an extension of the scrubber's exhaust stack to guarantee thorough exhaust treatment. A transition cone was mounted on top of the original 1957 exhaust stack, which reduced the diameter of the stack opening to 6' and extended the height to 118' above grade. A flare stack at the top of the scrubber stack was installed to burn residual hydrogen.

The RETF scrubber/ silencer was an engineering solution to a significant waste treatment problem. This system was crucial to maintaining a clean, low-noise environment near the RETF.

DELINEATED BY: Hardlines Design Company, 2003

NASA ROCKET ENGINE TEST FACILITY RECORDING PROJECT

ROCKET ENGINE TEST FACILITY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, LEWIS RESEARCH CENTER

CLEVELAND | CUYAHOGA COUNTY | OHIO

SHEET 5 of 12

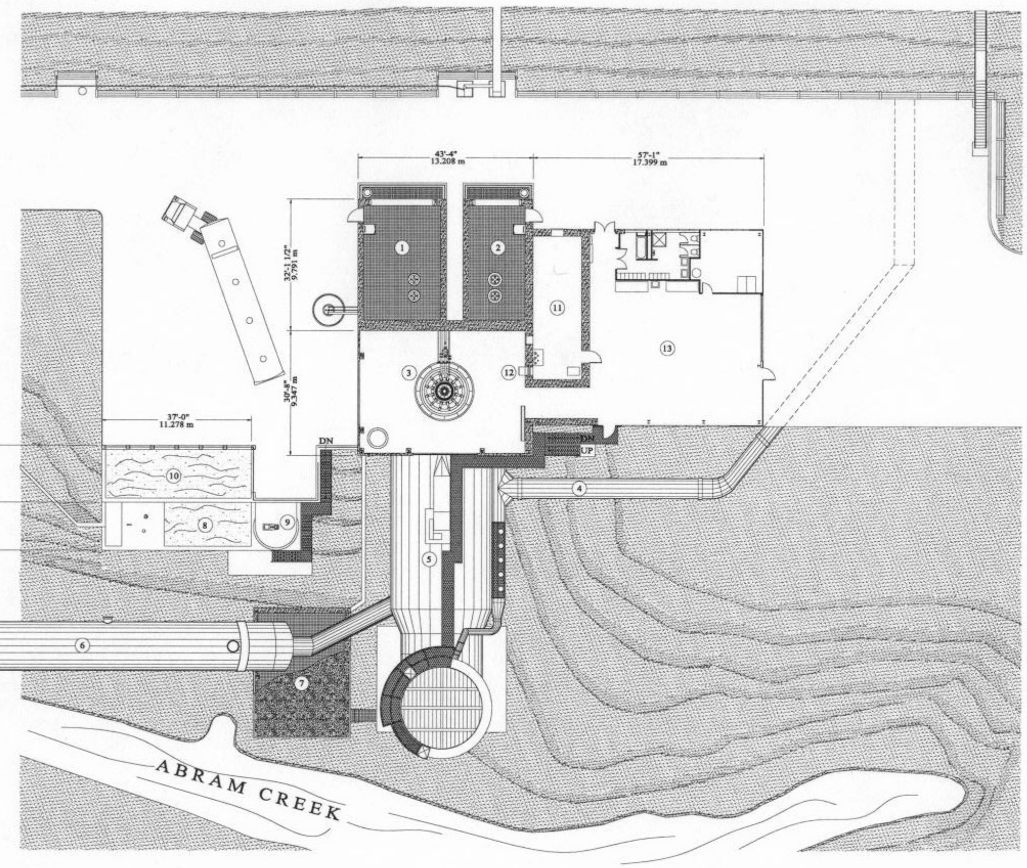
HISTORIC AMERICAN ENGINEERING RECORD OH-124-D

As originally designed and built from 1955 to 1957, the Rocket Engine Test Facility (RETF) could test engines using petroleum fuels and liquid propellants with liquid oxygen as the oxidizer. Early fuel research was completed using gasoline brought to the site in a tanker trailer. There were two main components to the facility: a fuel pit (1), which was a structure that housed cylindrical tanks for fuels, and an ox (oxidizer) pit with the double-walled tanks for storing liquid oxygen (2). The liquid oxygen tanks were jacketed in an outer tank that contained liquid nitrogen. The stand for supporting rocket engines during tests was located inside the test cell (3).

A significant feature of the RETF was the ability to remove contaminants from the rocket exhaust stream by trapping chemical pollutants in water sprays inside the scrubber. A pipe (4) supplied water to the scrubber (5) from a 500,000 - gallon reservoir. A detention tank (6) collected and held water drained from the scrubber. A pump (7) then transferred the water to a treatment basin tank (8). Chemicals were added at the mixer (9), and the treated water was finally pumped to a collector basin tank (10) before discharge to a municipal wastewater treatment facility.

The terminal room (11) housed amplifiers, thermocouple junctions, and equipment for transmitting test data to the control room in Building 100. The terminal room also provided a safe area for personnel to observe testing through a periscope built into the wall (12) between the terminal room and test cell. A small machine shop and office area (13) provided a space for technicians to assemble rigs and rocket engines for testing.

Notes: Plan depicts building as configured ca. 1955.



BUILDING 202 FLOOR PLAN

3/32"=1'-0" 0 5 10 20 FT
1:128 0 1 2 3 4 5 6M
NORTH

DELINEATED BY: Hardlines Design Company, 2003

NASA ROCKET ENGINE TEST FACILITY RECORDING PROJECT

ROCKET ENGINE TEST FACILITY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, LEWIS RESEARCH CENTER
CUYAHOGA COUNTY
CLEVELAND OHIO

SHEET 6 = 12

HISTORIC AMERICAN ENGINEERING RECORD
OH-124-D

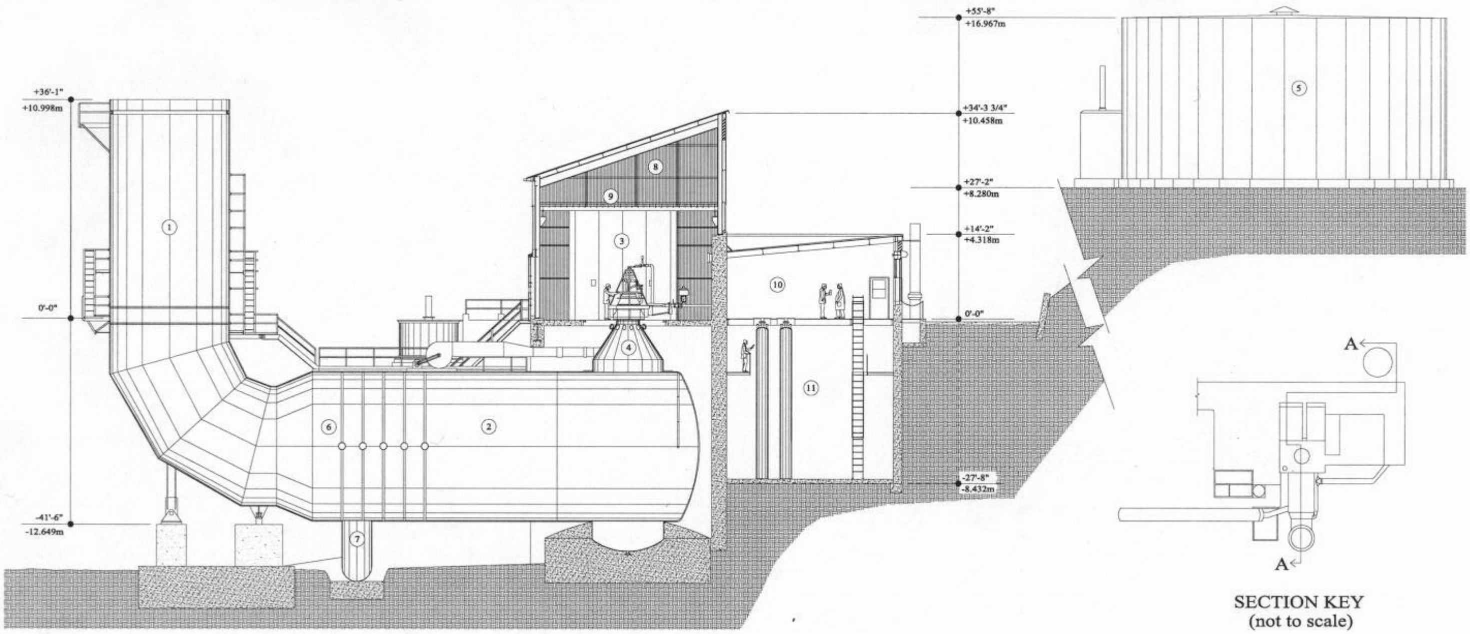
This delineation is a section view of Rocket Engine Test Facility (RETF) Building 202. The viewer is looking north along an imaginary axis through the center of the building's scrubber/silencer (1). This view shows the construction of the horizontal, transitional, and vertical sections of the scrubber. The horizontal section (2) was a cylinder measuring 100' long and 25' in diameter. During testing, researchers positioned the rocket engine on Stand A inside the test cell (3) using variously sized mounts. The exhaust was directed downward into the scrubber. Stand A was instrumented with load cells that sent engine thrust data to the observation room terminals and on to the control room in Building 100. Sensors also measured temperature and pressures at critical points on the engine.

Rocket engines mounted on Stand A discharged exhaust at velocities of up to 12,000 feet per second (fps) and at temperatures of 6,000°F. A counter-flowing water spray (4) inside the scrubber intercepted the engine exhaust. To feed this spray, water flowed from a 500,000-gallon reservoir (5) located on a hill approximately 100' east of Building 202. RETF personnel have not confirmed that the water was gravity-fed, but there are no pumps in that part of the system, and a gravity-fed system would not have been vulnerable to power interruptions. This water circulated into a manifold, and then to the nozzles mounted on a series of pipes inside the scrubber (6). The nozzles produced a heavy mist or aerosol of water that cooled the exhaust and removed soluble gases from the gas stream. The water also purged cumbustion particles, approximately 10 to 10,000 angstroms in size, which were dispersed in the exhaust stream. The condensation of water vapor during combustion also reduced the velocity of the exhaust stream. Rapid condensation and the large diameter of the scrubber tank in comparison to that of the rocket nozzle further decreased the exhaust velocity to 25 fps. Additional water sprays condensed steam, and the combined flow of condensed steam and water from the spray drained (7) into a detention tank. Non-condensable gas emerged from the exhaust stack at temperatures below 160°F and at velocities of 20 fps or less.

The stand inside the test cell (3) secured and supported the rocket engine during testing. The test cell could be closed and heated to provide a dry, sheltered area that protected the engine, associated sensors, and other instruments. Before firing the engine, engineers opened the cell's blast doors and shutters, effectively providing open-air conditions for the test. Explosions frequently resulted from the testing of experimental engines and fuels. To minimize the destructive effects of these explosions, Building 202 was sheated in panels of "Transite," (8) a mixture of asbestos and cement. Translucent fiberglass panels later replaced the original transite. In the event of an explosion, the panels blew away and quickly relieved pressure. The panels were easily replaced afterwards to re-sheath and enclose the test cell. The portion of the test cell's inner perimeter near the roofline contained a fire suppression system (9). In case of fire, some of this piping and the associated nozzles sprayed water from the 500,000 - gallon reservoir into the test cell, while others flooded the cell with carbon dioxide.

A section through the fuel pit is delineated at (10). The fuel pit housed two tanks (11) that contained petroleum-based fuels, chiefly gasoline, from 1957 to 1959. These tanks were equipped with load cells that gathered data on the weight of the tanks. By analyzing this data, engineers could monitor fuel consumption rates and determine the quantity of fuel left in the tanks.

To cool the rocket nozzles after testing, the 500,000 - gallon water tank (5) east of Building 202 fed pumps that had a capacity of either 650 or 1,400 gallons per minute. Water from this reservoir also cooled a rocket altitude simulation system added to the RETF in 1984.



SECTION KEY
(not to scale)

1/8"=1'-0" 0 5 10 20 FT
1 : 96 0 1 2 3 4 5 6M

BUILDING 202 TRANSVERSE SECTION A-A

ROCKET ENGINE TEST FACILITY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, LEWIS RESEARCH CENTER
CUYAHOGA COUNTY
CLEVELAND | OHIO

SHEET 7 - 12

HISTORIC AMERICAN ENGINEERING RECORD
OH-124-D

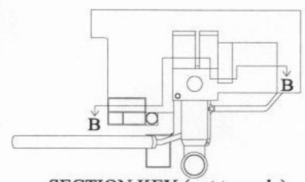
DELINEATED BY: Hardlines Design Company, 2003

NASA ROCKET ENGINE TEST FACILITY RECORDING PROJECT

This delineation shows a section through the Rocket Engine Test Facility (RETF) looking west. The functional layout of the RETF facilitated rocket engine testing and the efficient management of reactants, waste products, and other materials. In the service area ①, operators assembled the engines and attached sensors, thermocouples, and other instrumentation. Personnel also used the equipment in the small machine shop to modify components and to make special hardware that met specific requirements. Technicians and engineers also had offices in this area.

The observation room ② housed connections, amplifiers, and data transmission equipment. Raw data transmitted from instruments attached to the test engines went to terminal boards and connectors in this area. The terminal boards then transmitted the test data to the monitoring and recording equipment in the Building 100 control room. The observation room also provided a safe location from which observers could monitor tests. A glass window and periscope on the wall adjacent to the test cell ③ provided an indirect view of the test stand and engine. In addition, the observation window was mounted at a lower elevation than the rocket engine, so that the window was not directly in line with the exploding engine during catastrophic test failures.

The oxidant pit, also known as the "ox pit" ④, housed tanks for liquid oxygen ⑤ and other oxidants. These tanks were double-walled. The inner tank contained the oxidant, while the outer tank was filled with liquid nitrogen. Liquid notrogen boils at -195.8°C, and liquid oxygen boils at -183°C, so the liquid nitrogen maintained the oxygen in a liquid state and prevented significant oxygen loss. This system also facilitated the accurate measure of actual oxidant usage. The tanks were mounted on a suspension system with load cells, which transmitted data on the weight of the tanks to the control room.



SECTION KEY (not to scale)

1/8"=1'-0" 0 5 10 20 FT

1 : 96 0 1 2 3 4 5 6M

The view in this delineation shows the northeastern wall of the test cell ⑥. Shutters ⑦ at the top of the cell housing could be opened to vent the cell during engine tests. The exterior panels of the cell were made of "Transite," a combination of asbestos and cement. Translucent fiberglass panels later replaced the original Transite. In the event of an explosion, these panels blew away to relieve blast pressure. The panels were then easily replaced.

The fuel pit area is shown at ⑧. From 1957 to 1959, the fuel tank ⑨ contained gasoline or other petroleum fuels. Weight and rate of fuel use from the tank could be determined from load cells incorporated into the tank's support system.

The treatment basin tank ⑩ retained water from the scrubber detention tank. Technicians tested water in the treatment basin tank to determine the quantity of chemicals needed to neutralize the wastewater. The mixing chamber shown at ⑪ was used to apply these neutralizing chemicals to the scrubber wastewater. A vertical shaft propeller mixer assured that the neutralizing chemicals were evenly dispersed throughout the wastewater.

The collector tank ⑫ retained treated water pumped from the neutralizing tank. Technicians tested the water in this tank to confirm that treatment had been adequate. Once the water met treatment standards, it was pumped to a municipal waste treatment plant.

BUILDING 202 LONGITUDINAL SECTION B-B

DELINEATED BY: Hardlines Design Company, 2003

NASA ROCKET ENGINE TEST FACILITY RECORDING PROJECT

ROCKET ENGINE TEST FACILITY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, LEWIS RESEARCH CENTER
CUYAHOGA COUNTY
CLEVELAND | OHIO

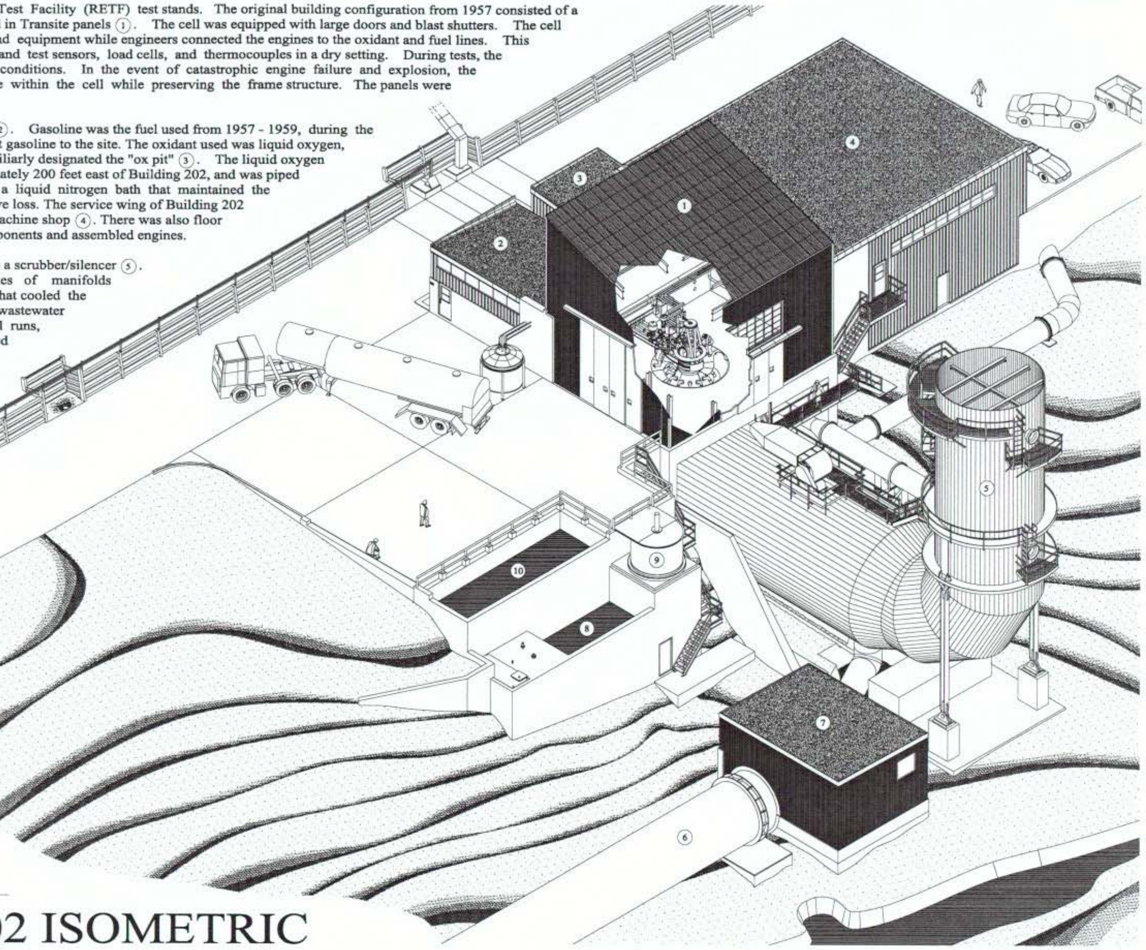
SHEET 8 of 12

HISTORIC AMERICAN ENGINEERING RECORD
OH-124-D

Building 202 was the site of the Rocket Engine Test Facility (RETF) test stands. The original building configuration from 1957 consisted of a single test stand inside a steel-frame cell sheathed in Transite panels (1). The cell was equipped with large doors and blast shutters. The cell could be enclosed to protect personnel, tools, and equipment while engineers connected the engines to the oxidant and fuel lines. This enclosed cell also allowed personnel to connect and test sensors, load cells, and thermocouples in a dry setting. During tests, the doors were opened to simulate ambient weather conditions. In the event of catastrophic engine failure and explosion, the sheathing panels blew away, relieving pressure within the cell while preserving the frame structure. The panels were then easily replaced.

Fuel was stored in tanks mounted in the fuel pit (2). Gasoline was the fuel used from 1957 - 1959, during the early years of the RETF. A tractor-trailer brought gasoline to the site. The oxidant used was liquid oxygen, which was fed from a tank in the oxidant pit, familiarly designated the "ox pit" (3). The liquid oxygen was stored in a bottle farm on a hillside approximately 200 feet east of Building 202, and was piped down to the test cell. This pipe was jacketed with a liquid nitrogen bath that maintained the oxygen in a liquid state and minimized evaporative loss. The service wing of Building 202 contained a terminal room, offices, and a small machine shop (4). There was also floor space in this wing where engineers gathered components and assembled engines.

During tests, the engine exhaust was directed into a scrubber/silencer (5). Inside the cylindrical scrubber/silencer, a series of manifolds equipped with nozzles produced sprays of water that cooled the exhaust and trapped soluble waste. The resulting wastewater drained to a detention tank (6). After several runs, pumps located in the pump house (7) transported the wastewater to a treatment basin (8). Technicians added neutralizing chemicals in a mixing chamber (9). The wastewater was then transferred to an effluent storage tank (10) before going to a municipal sewage treatment facility.



SCALE 3/32" = 1'-0"
METERS 1:128

FEET | METERS: 0, 5, 10, 15 FEET; 4 METERS; 30°

BUILDING 202 ISOMETRIC

DELINEATED BY: Hardlines Design Company, 2003

NASA ROCKET ENGINE TEST FACILITY
RECORDING PROJECT

ROCKET ENGINE TEST FACILITY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, LEWIS RESEARCH CENTER
CUYAHOGA COUNTY

CLEVELAND | OHIO

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HISTORIC AMERICAN ENGINEERING RECORD
OH-124-D

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HAER No. OH-124-A-1

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HAER No. OH-124-A-2

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HAER No. OH-124-A-3

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HAER No. OH-124-A-4

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HAER No. OH-124-A-5

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HAER No. OH-124-A-6

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HAER No. OH-124-A-7

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HAER No. OH-124-A-9

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HAER No. OH-124-A-11

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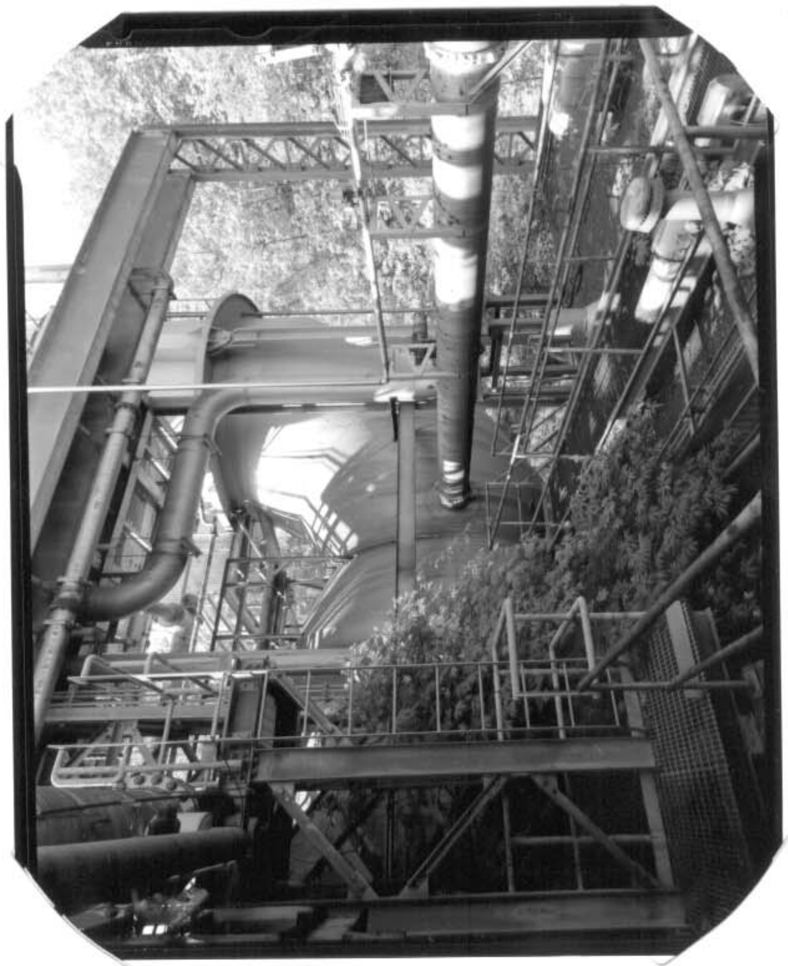
HAER No. OH-124-A-12



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HAER No. OH-124-A-13

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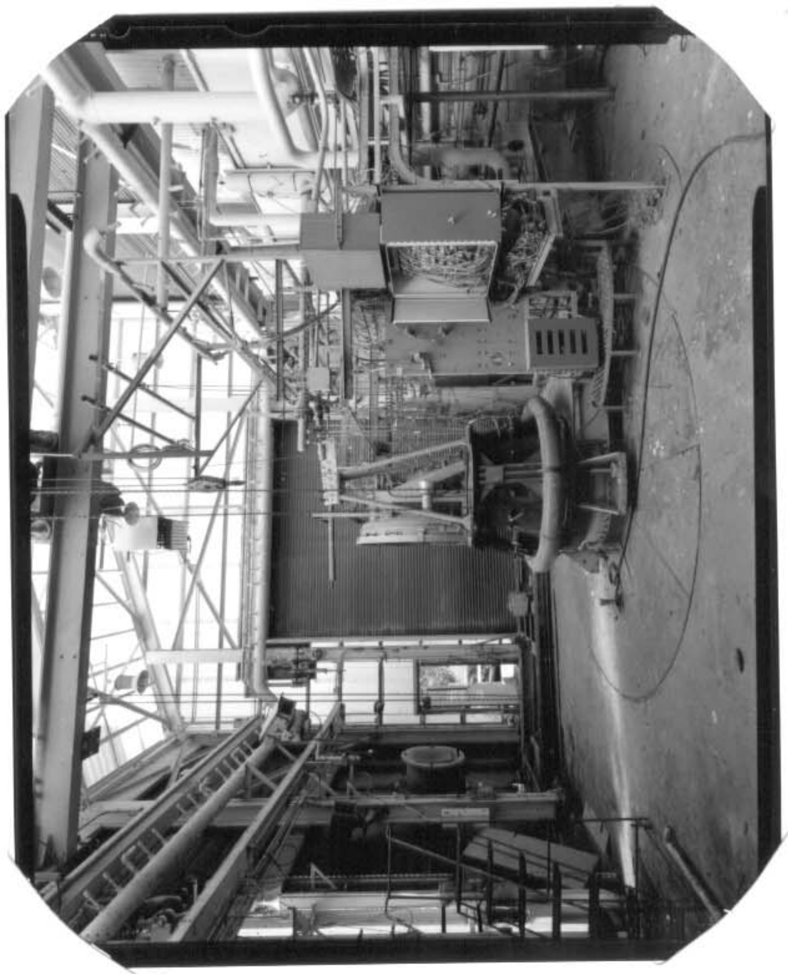
HAER No. OH-124-A-14



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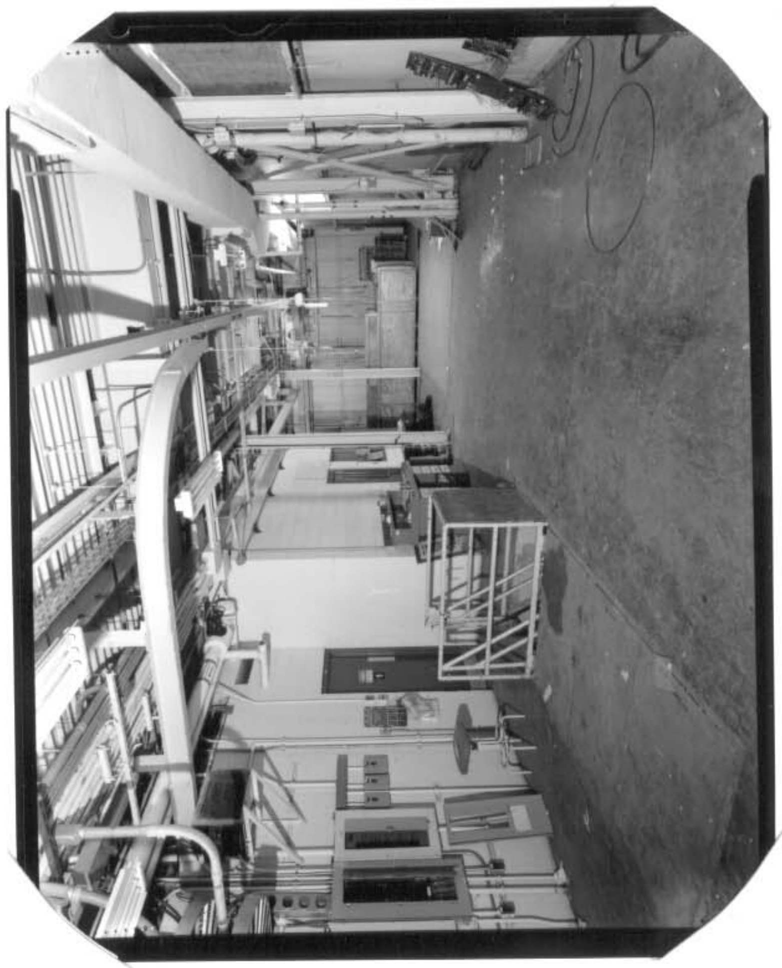

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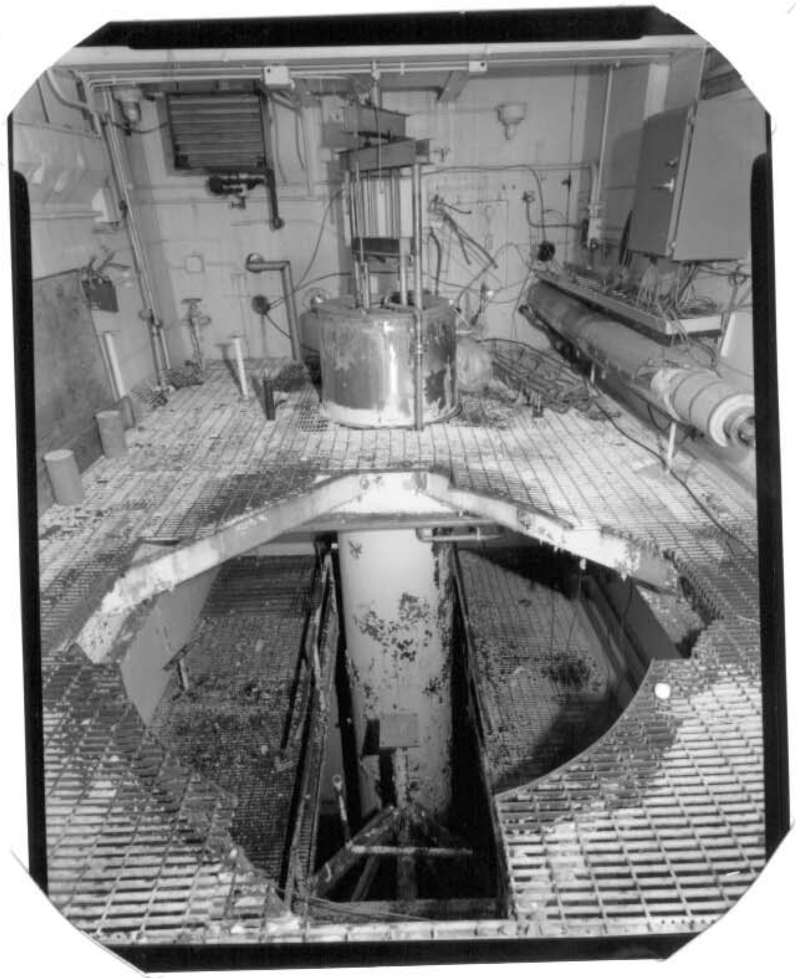

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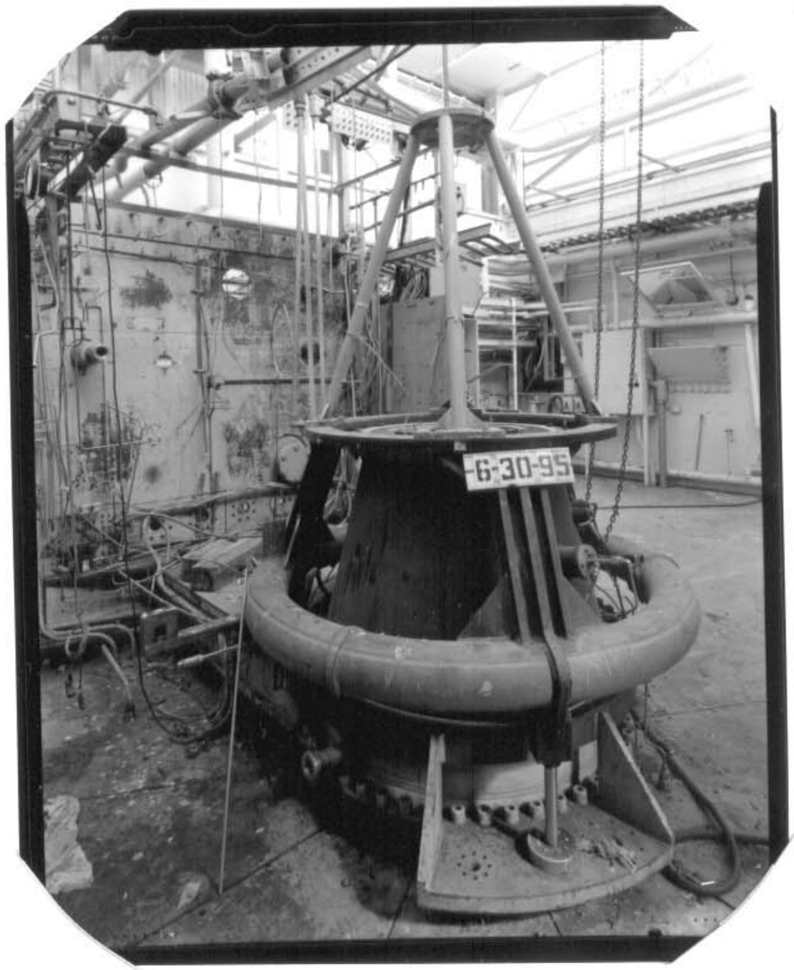

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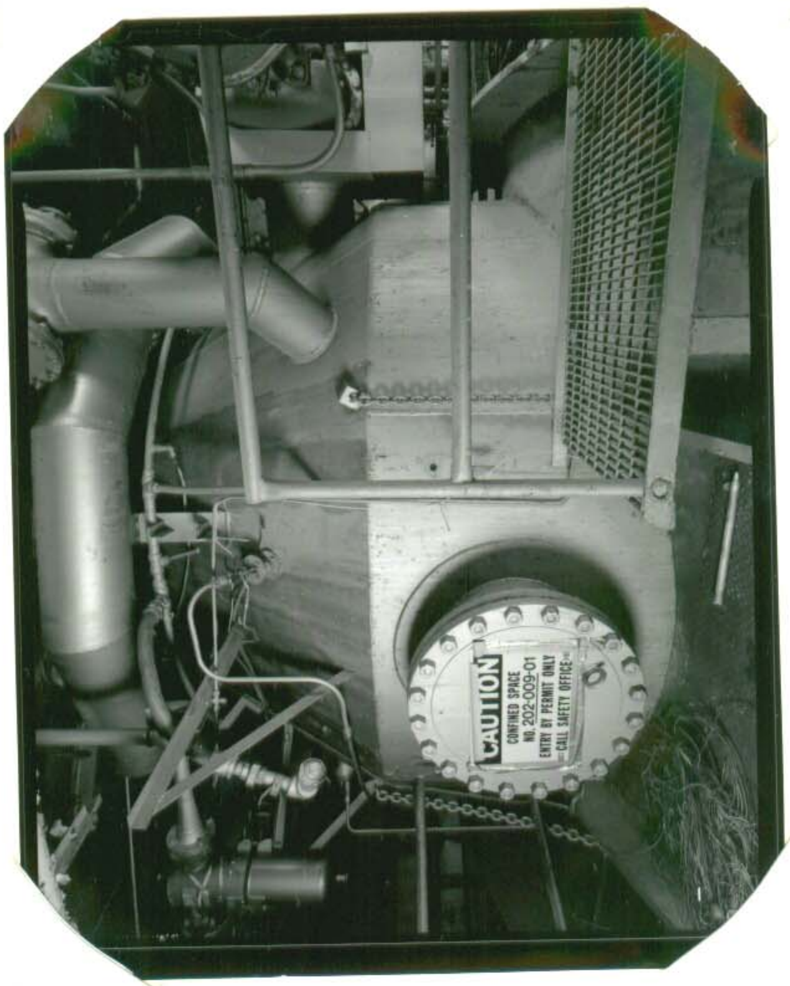

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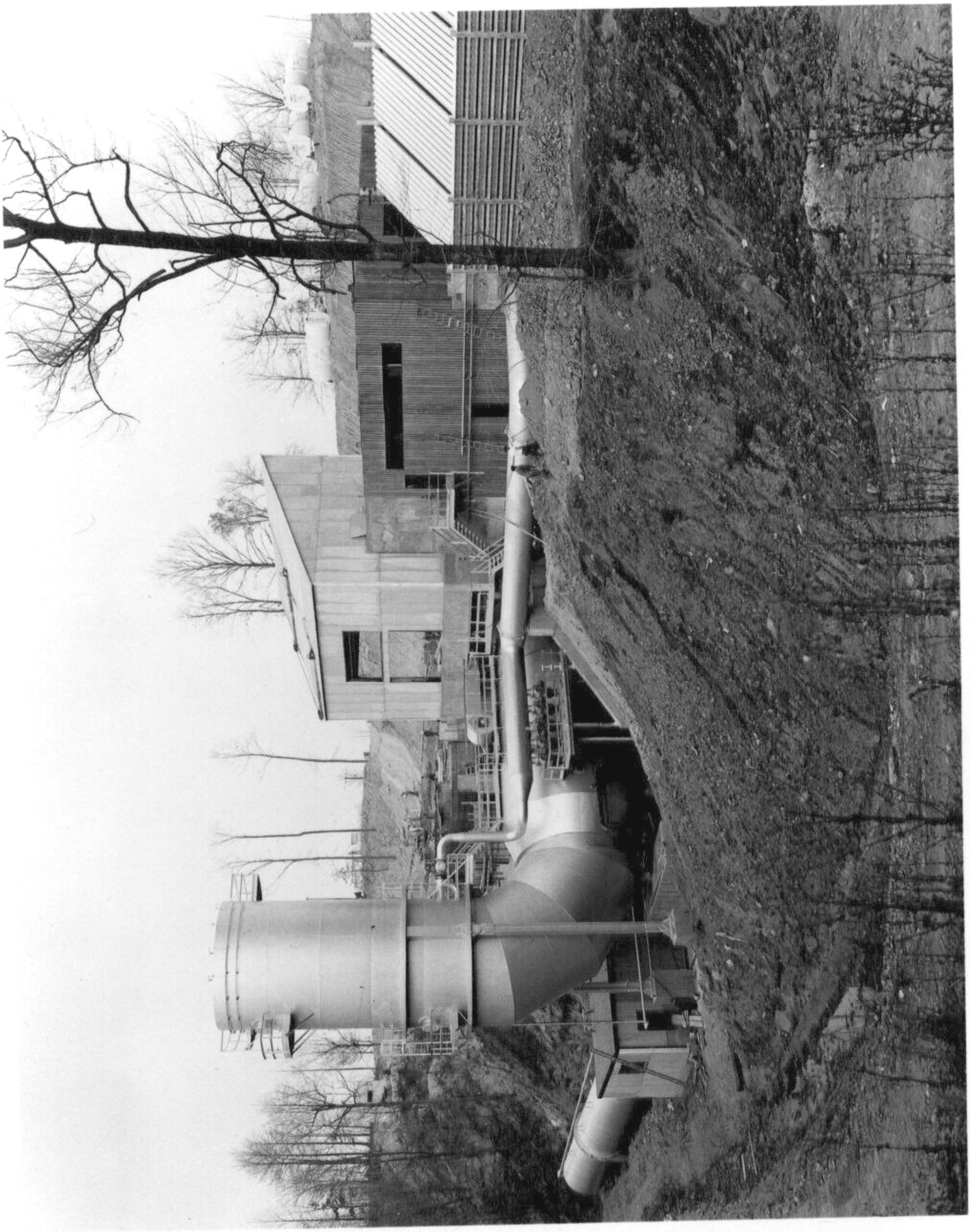

C 1710-1956

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C-4520-1956

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NACA
C-45734

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National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory

C-1957-44838

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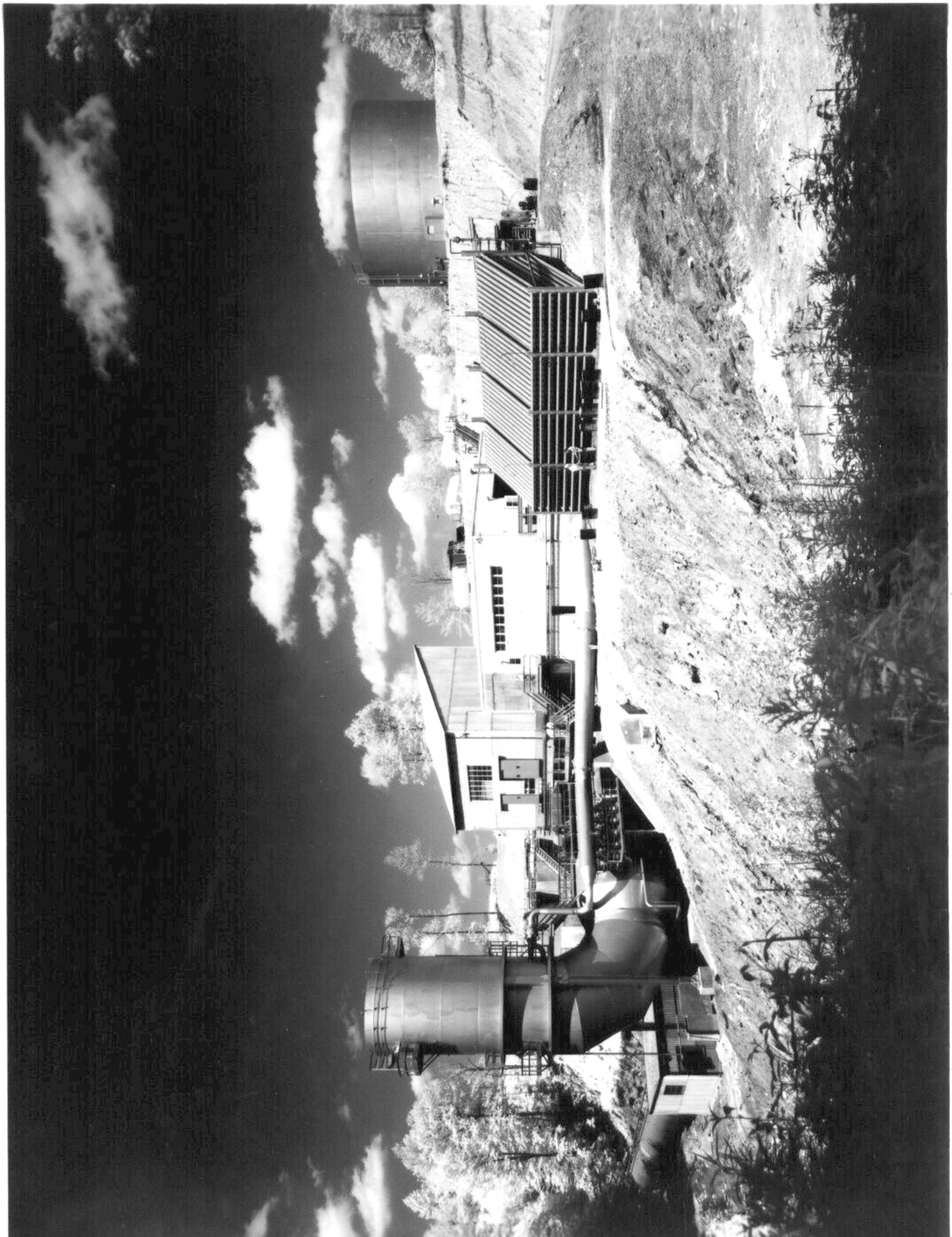
HAER No. OH-124-A-26



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HAER No. OH-124-A-27

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National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory

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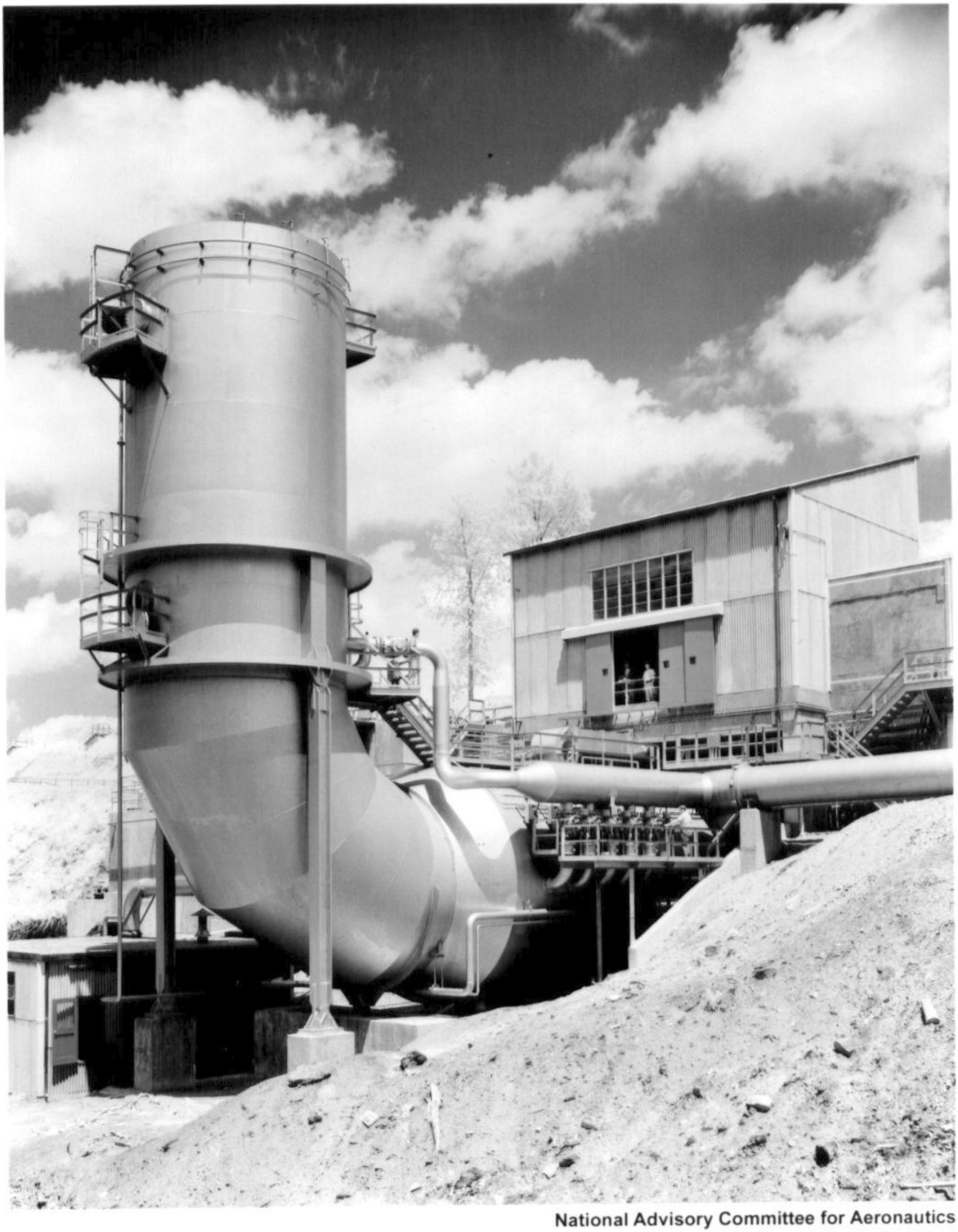
HAER No. OH-124-A-28

C-1958-45648



National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory

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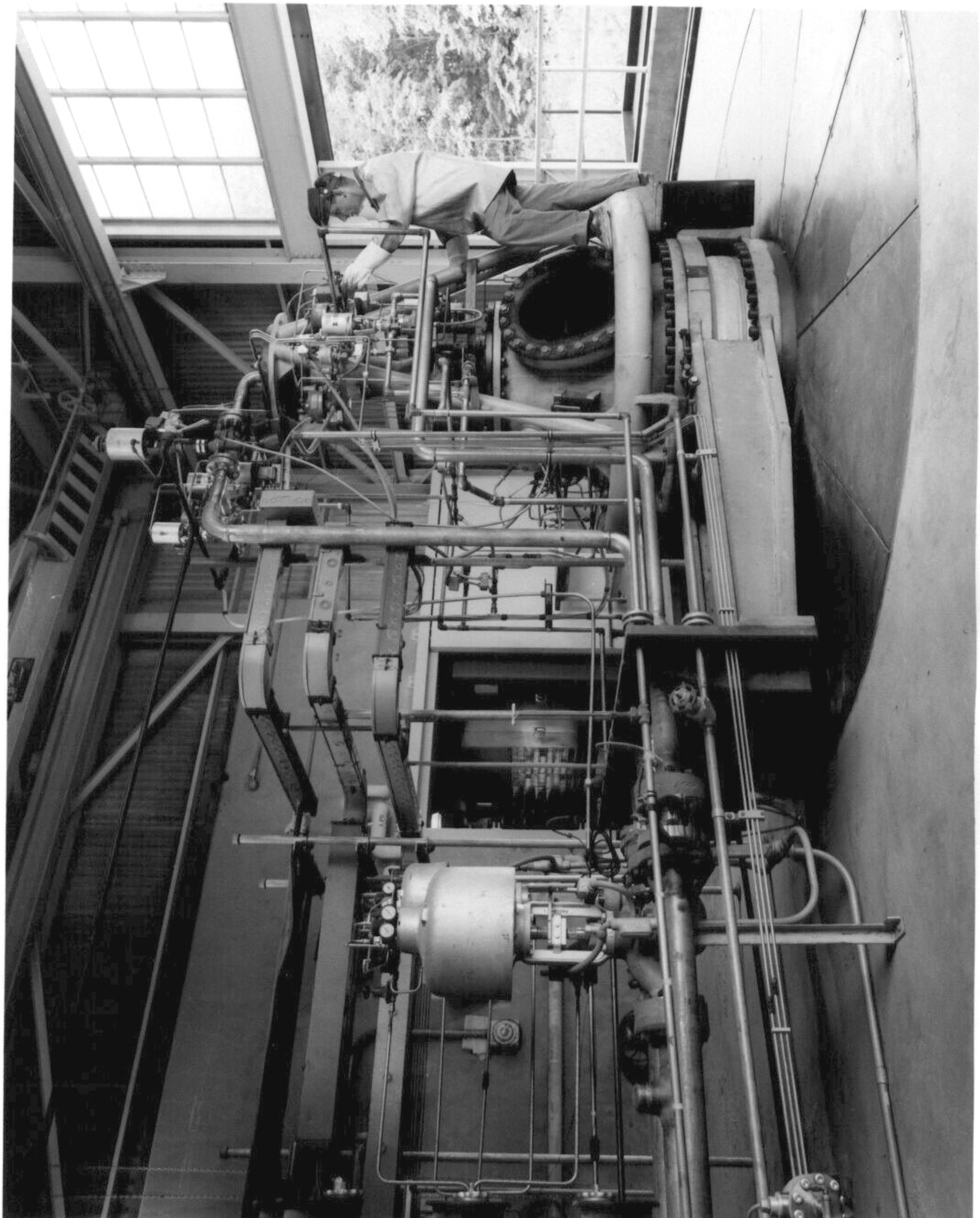

NASA

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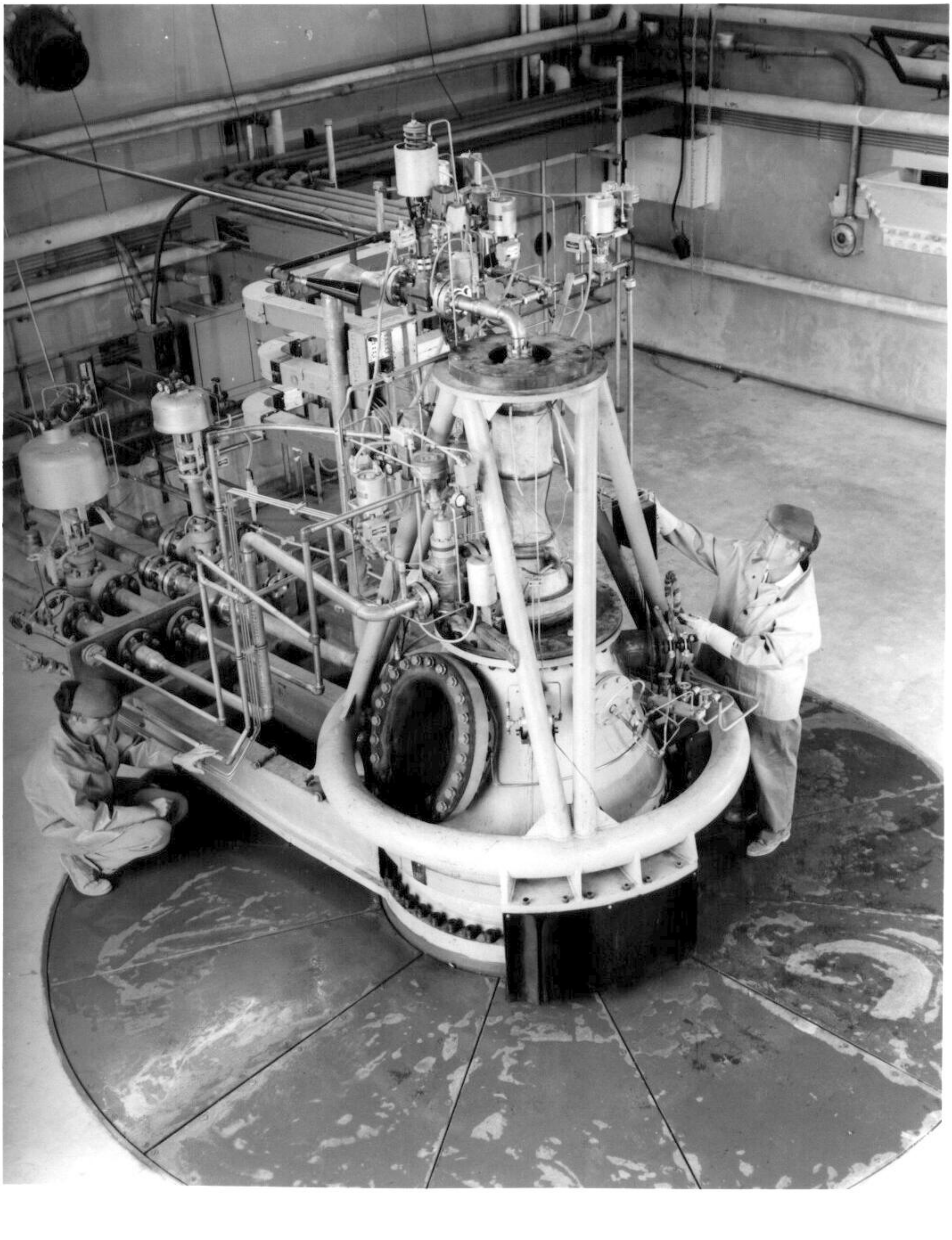
NASA
C-45872



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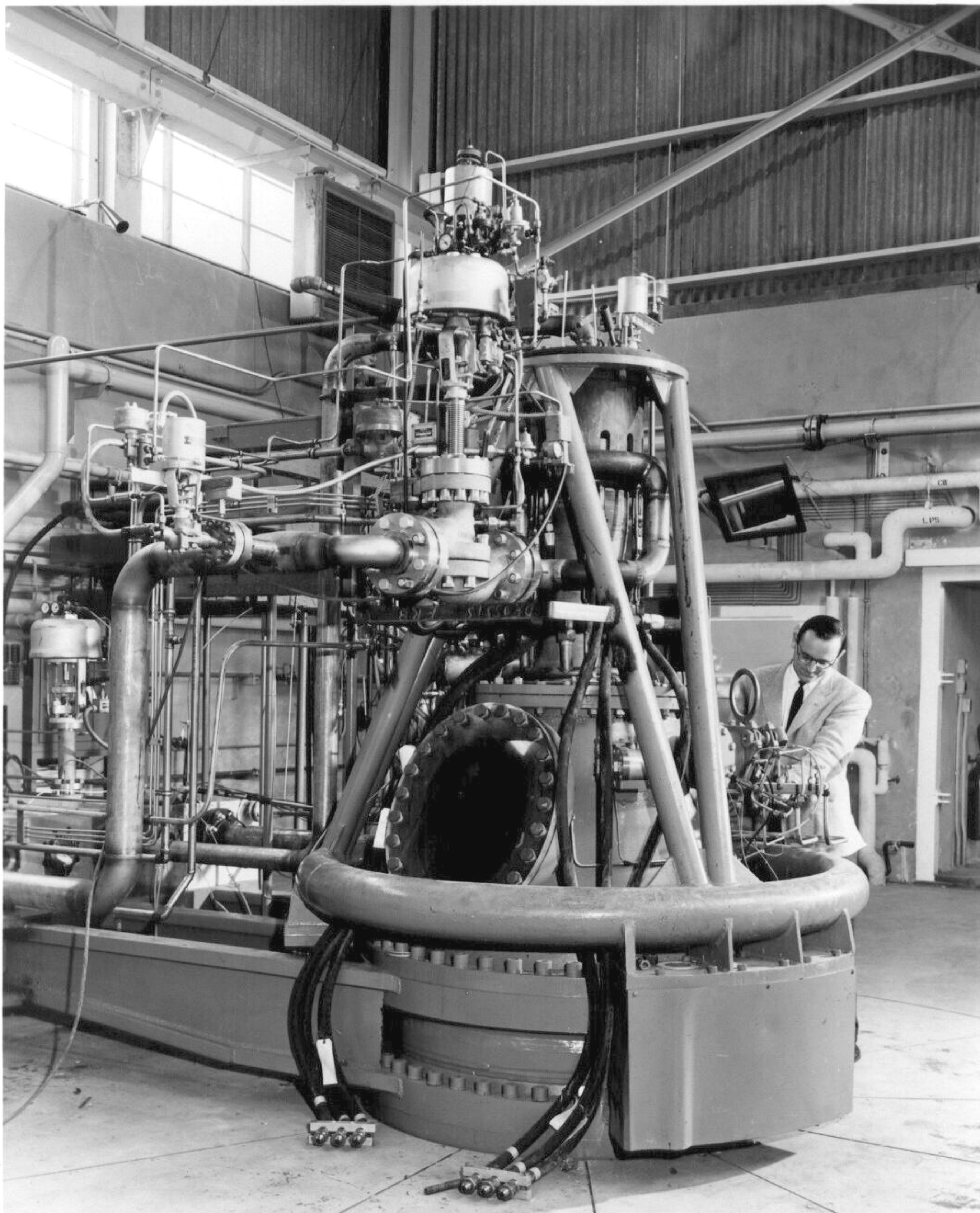

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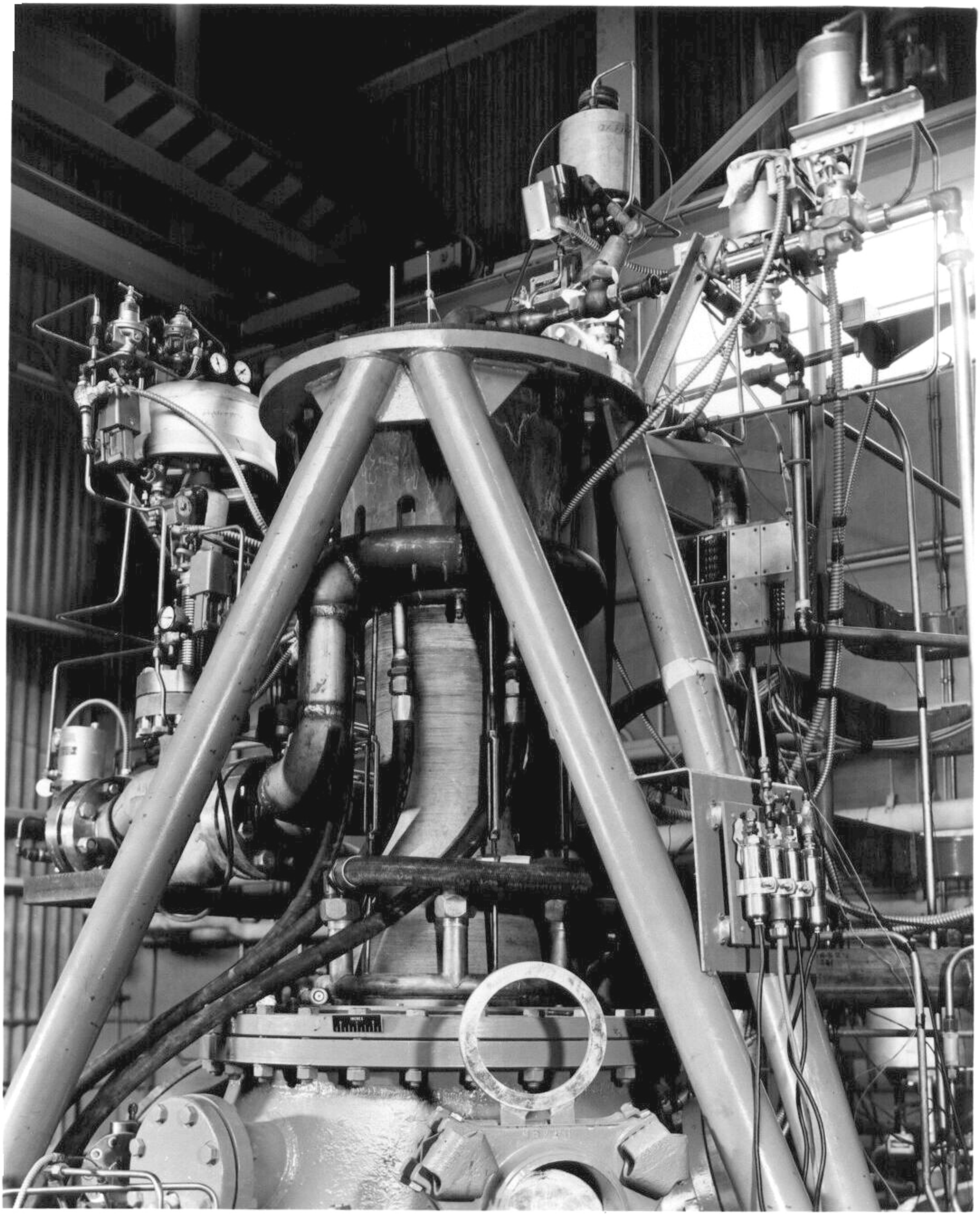

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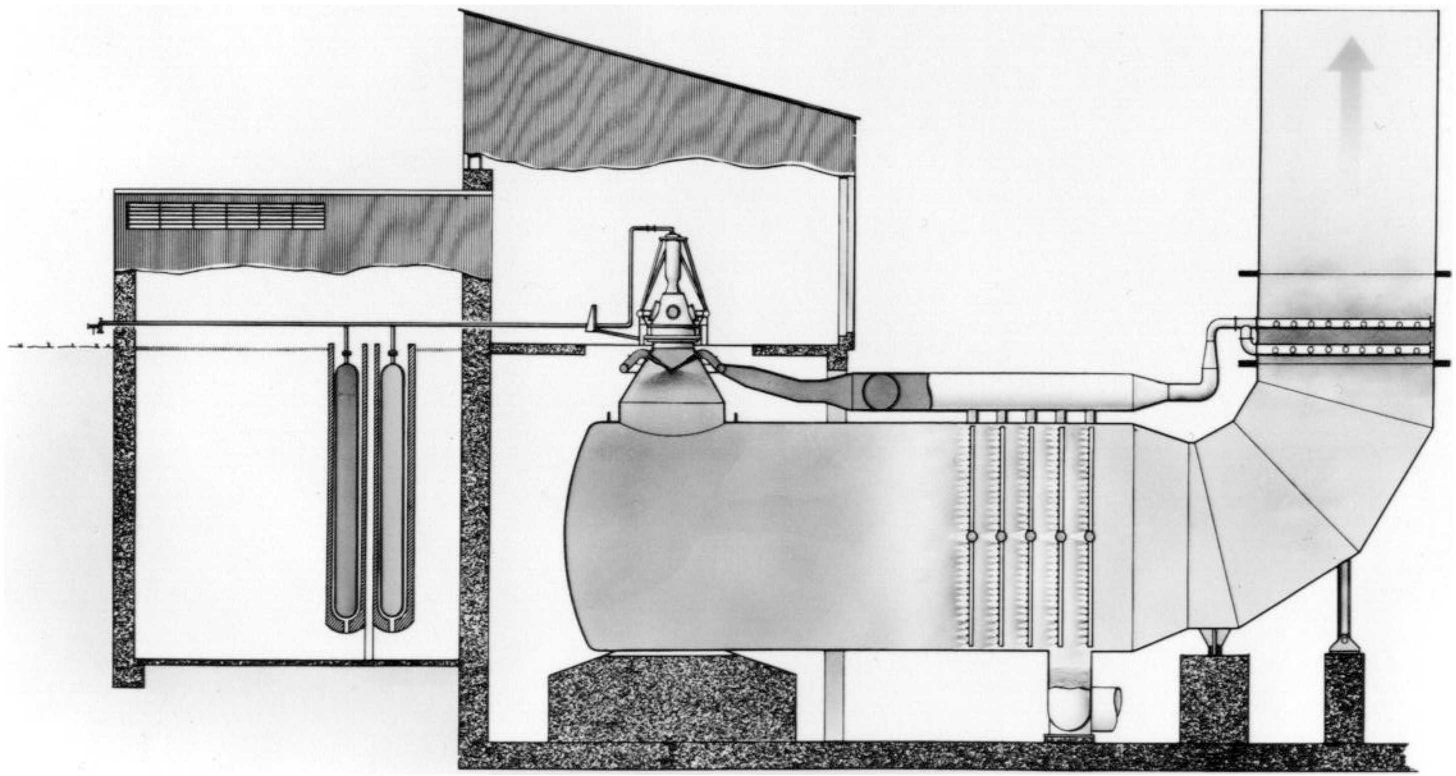
C-1958-47807

SECTIONAL VIEW OF HIGH-ENERGY
ROCKET TEST FACILITY



National Advisory Committee for Aeronautics
Lewis Flight Propulsion Laboratory

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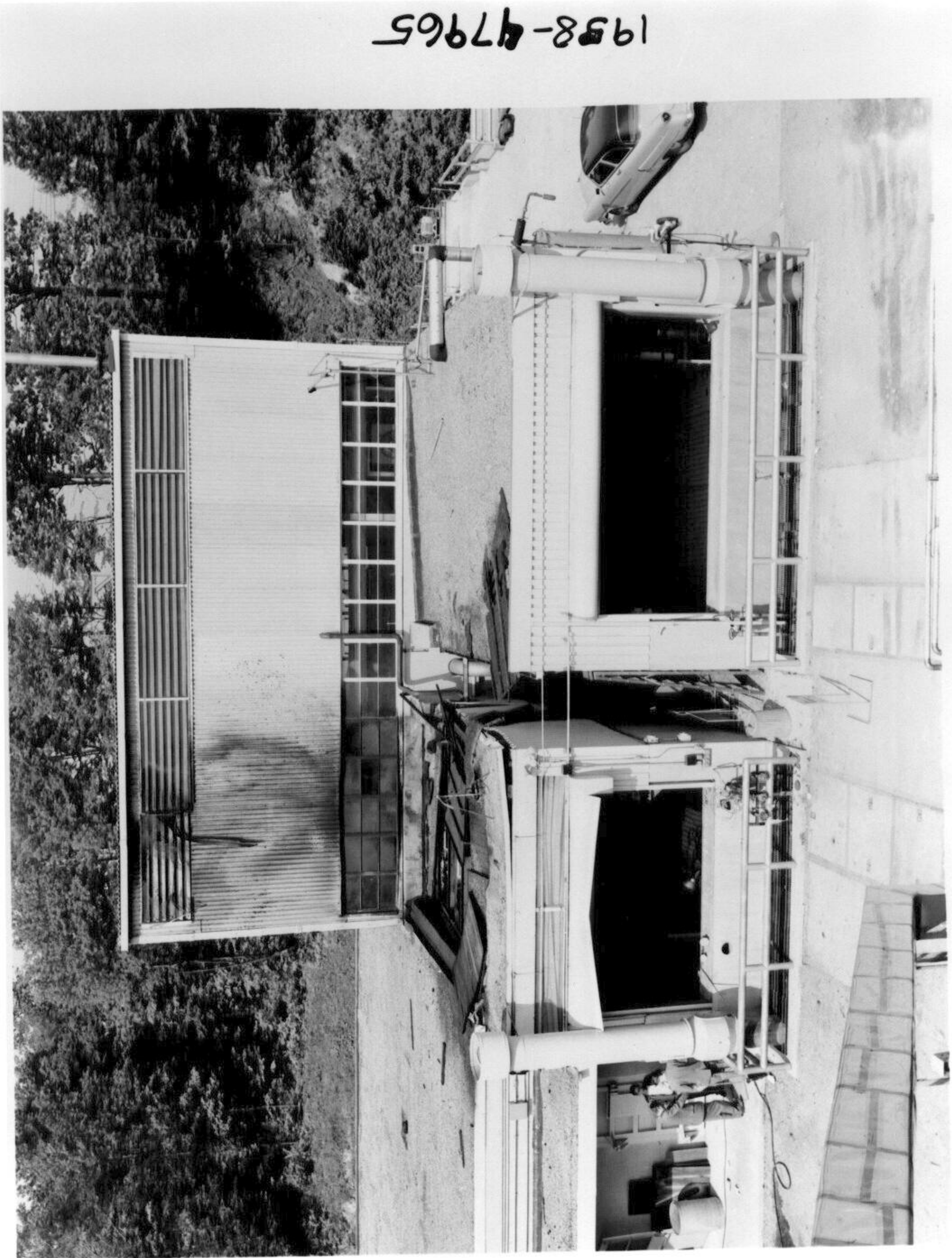

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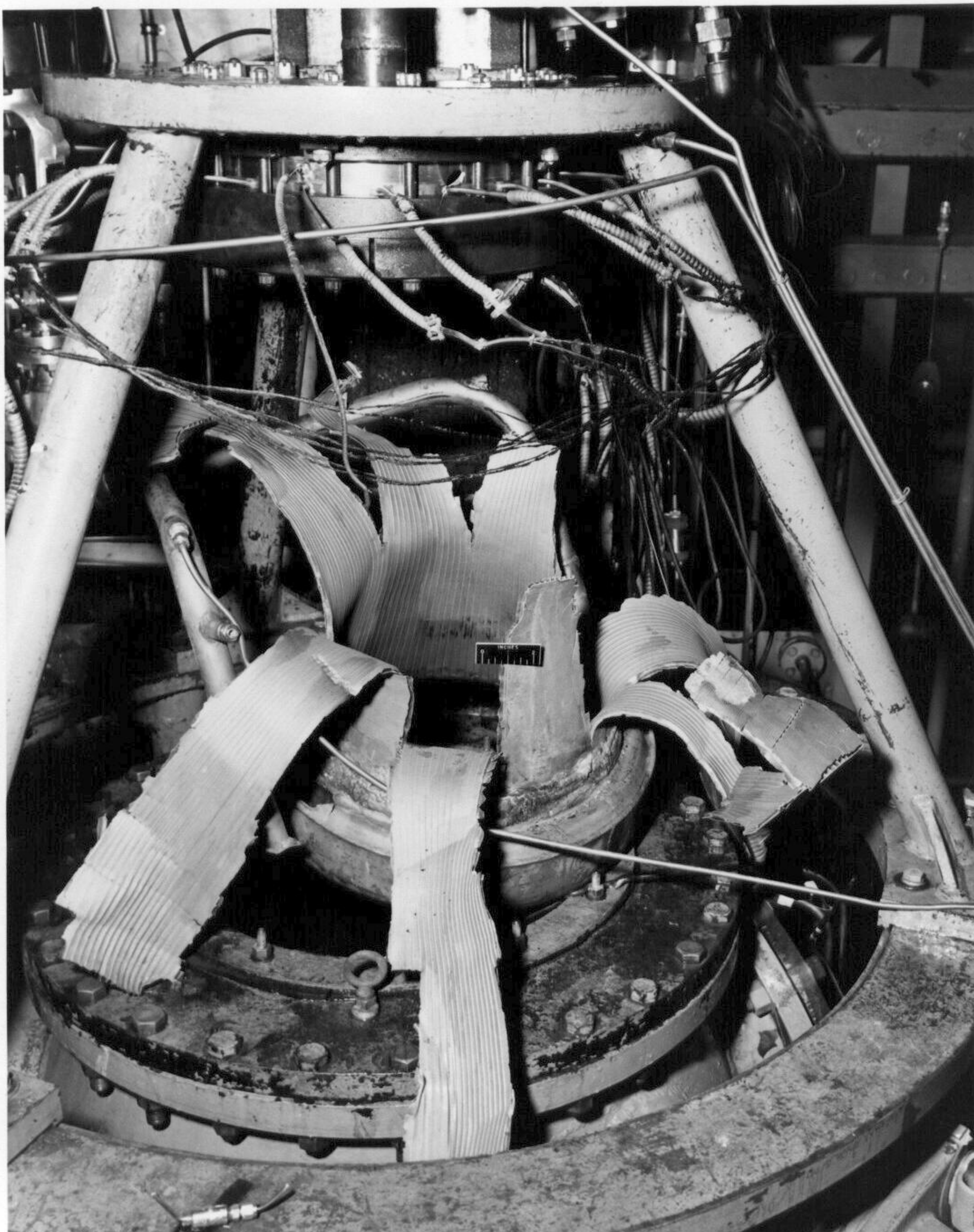
NACA
C-48704



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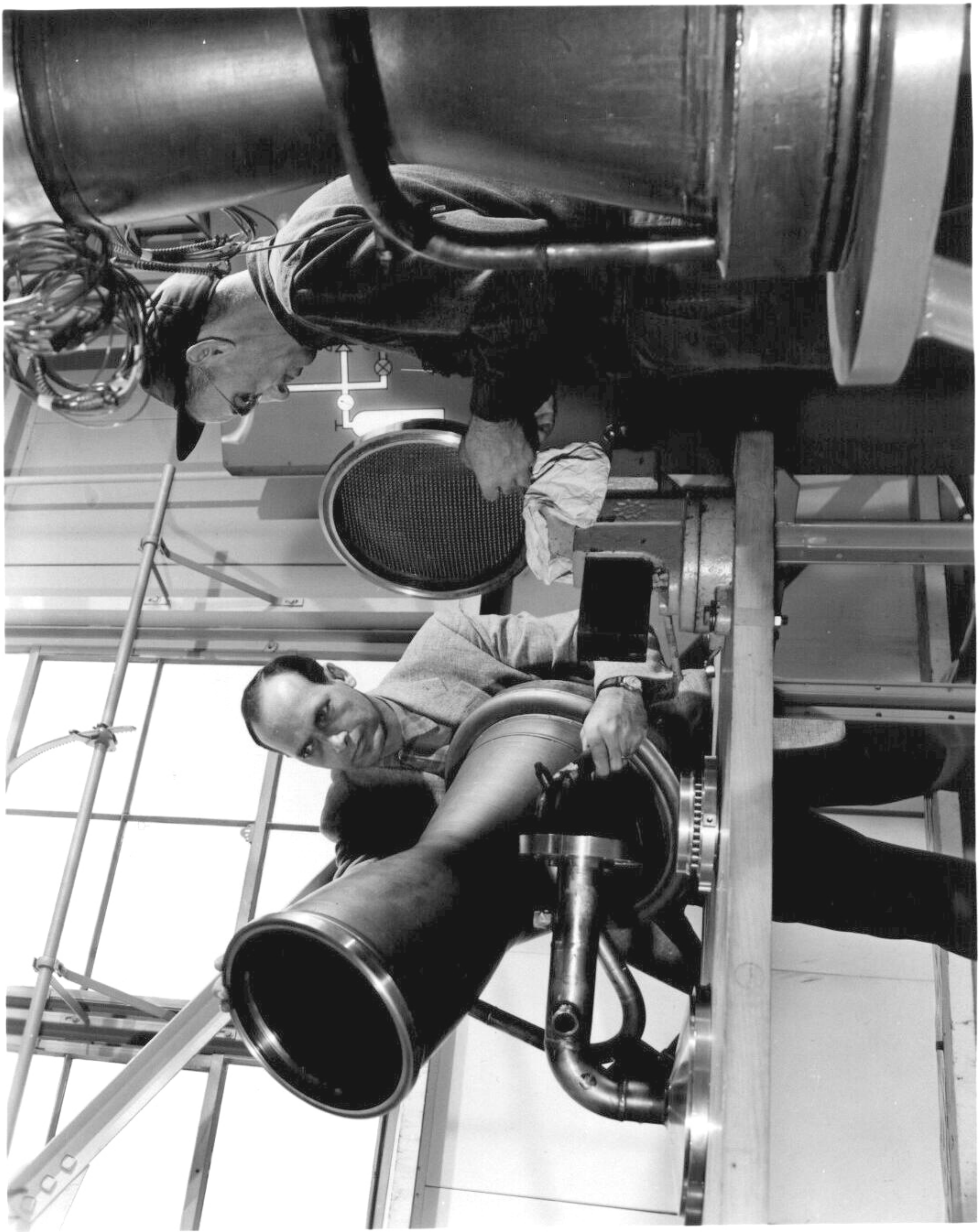

NASA
C-49343

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1959-50493

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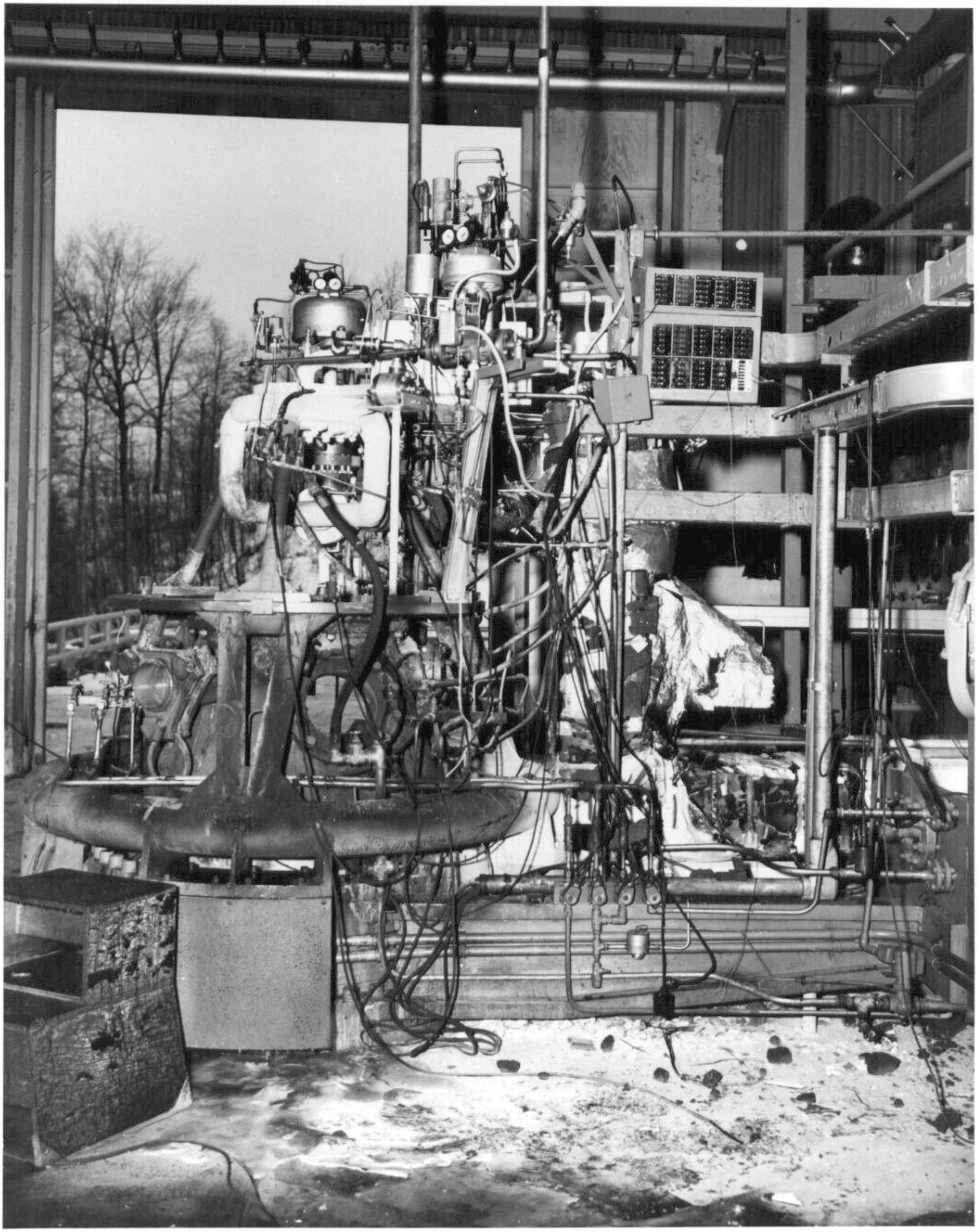
NASA
C-49376



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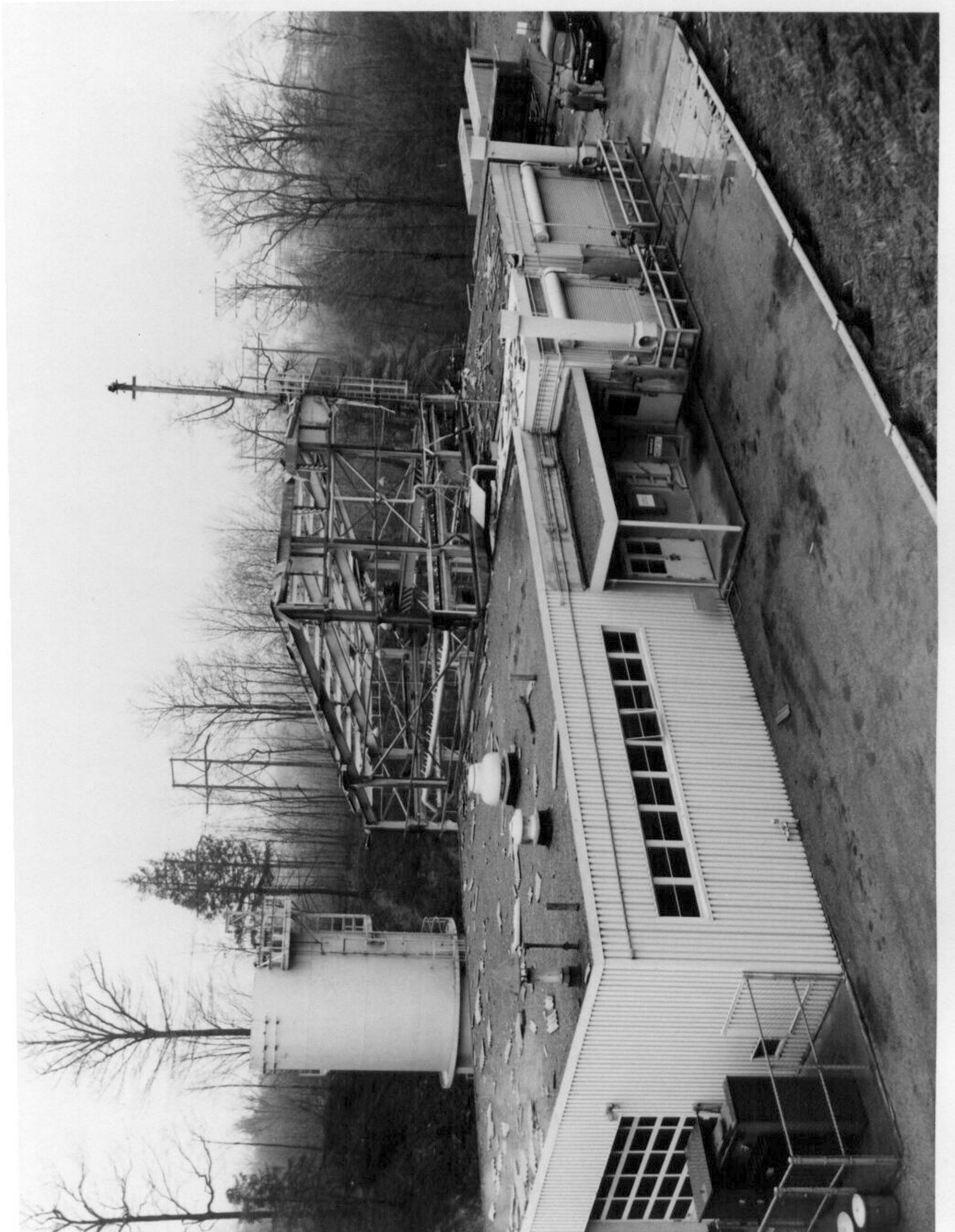

NASA
C-50472

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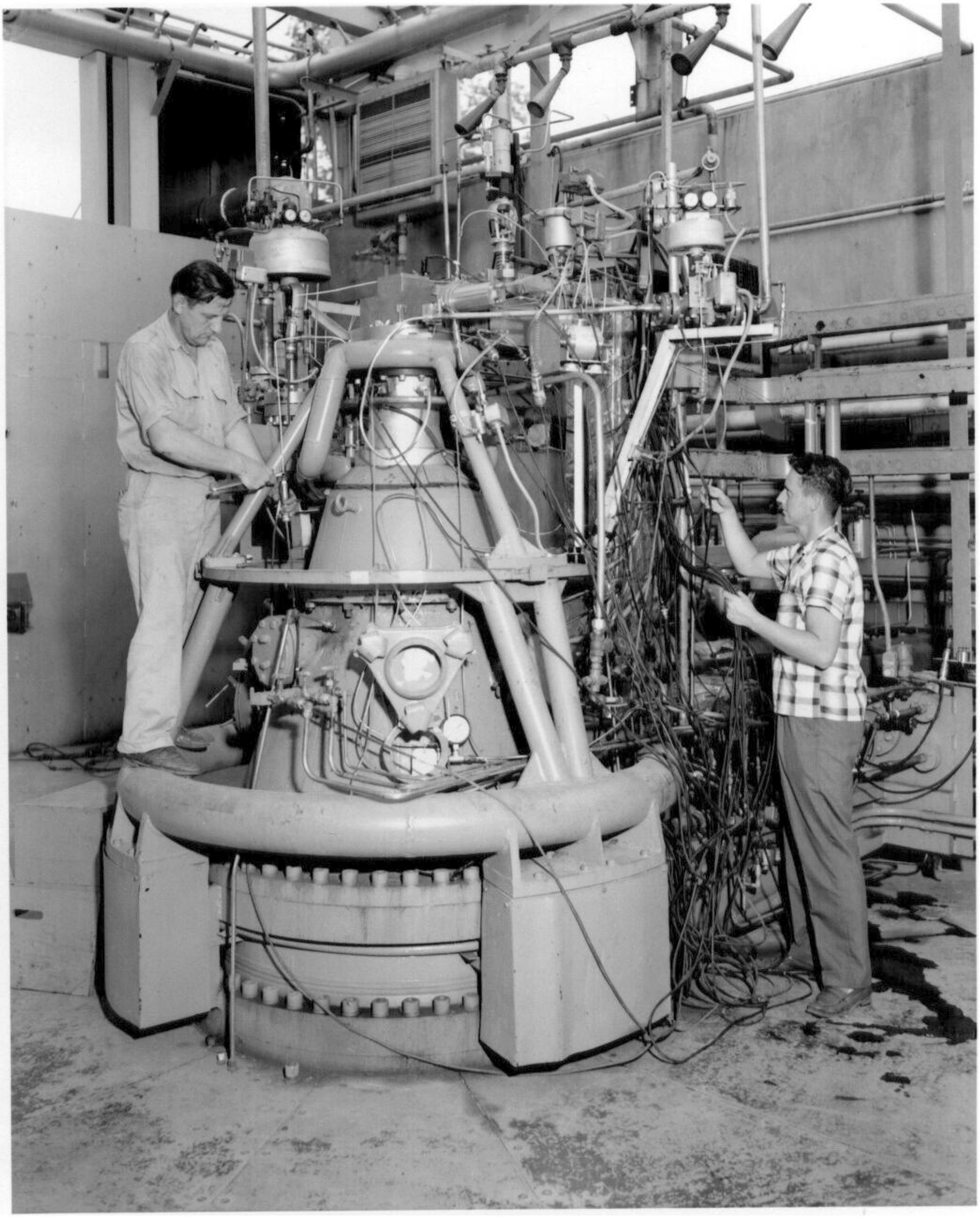

1959-51026

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NASA

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HAER No. OH-124-A-42

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C-52534

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NASA
C-53170

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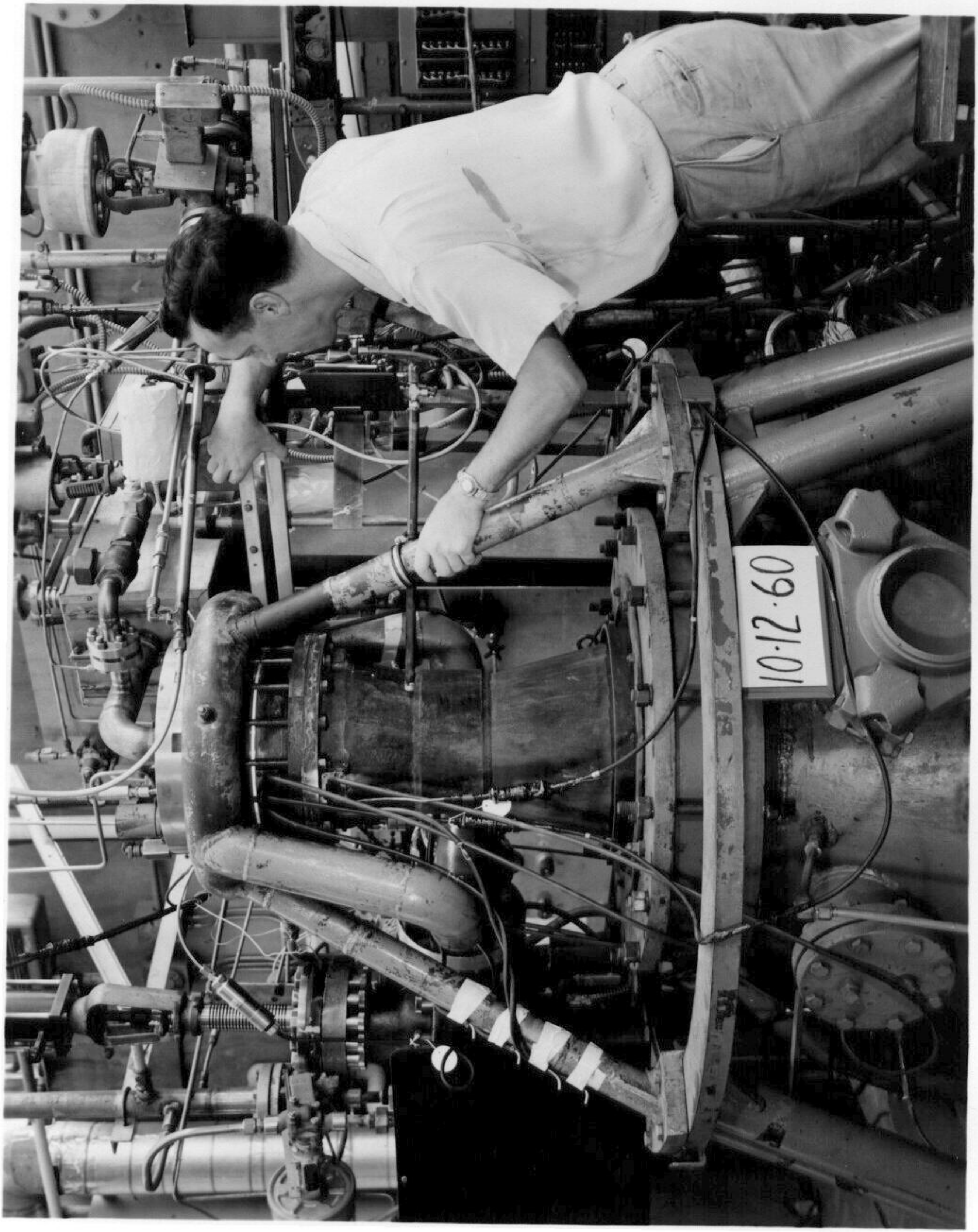

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C-54595

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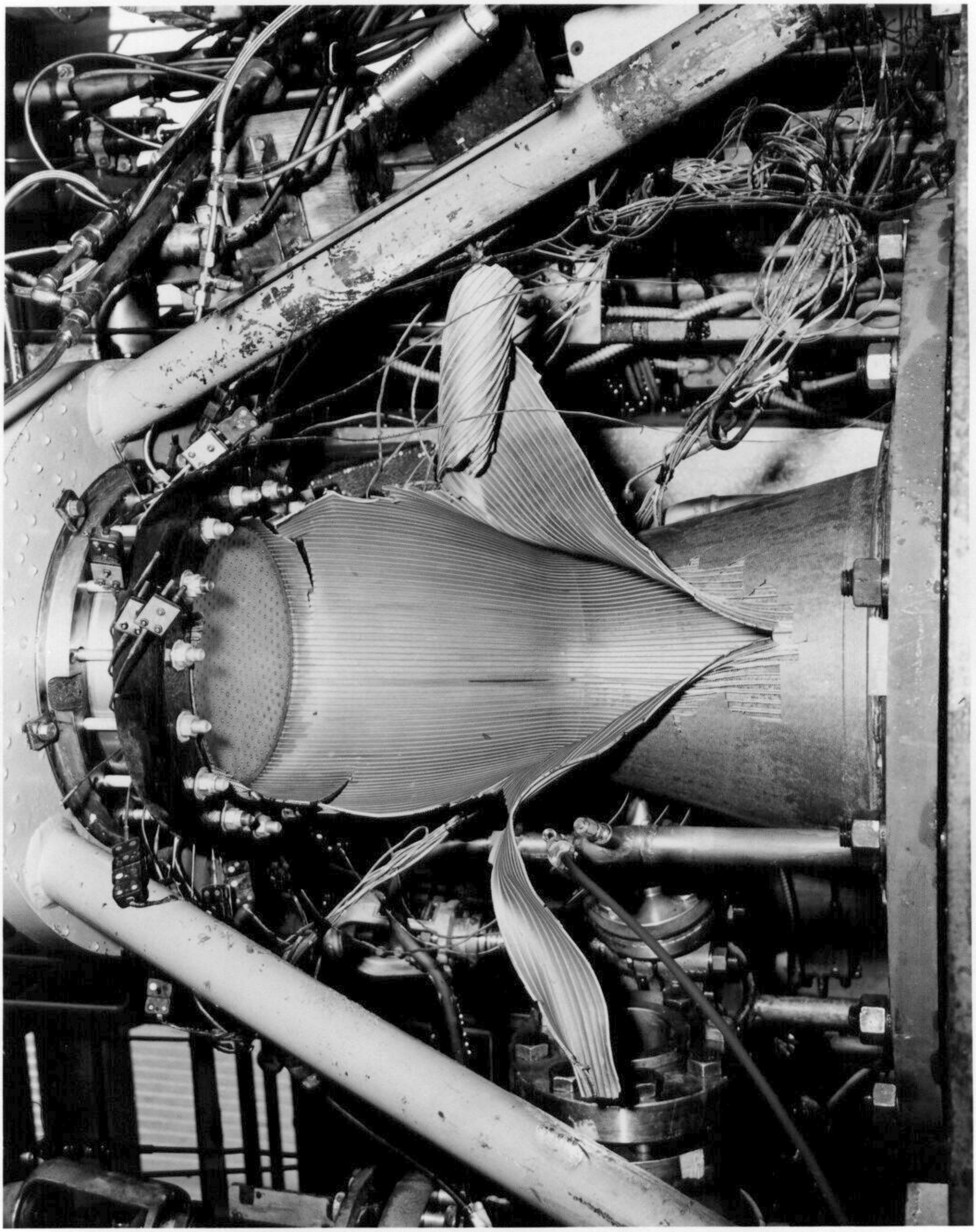

NASA
C-57837

NASA
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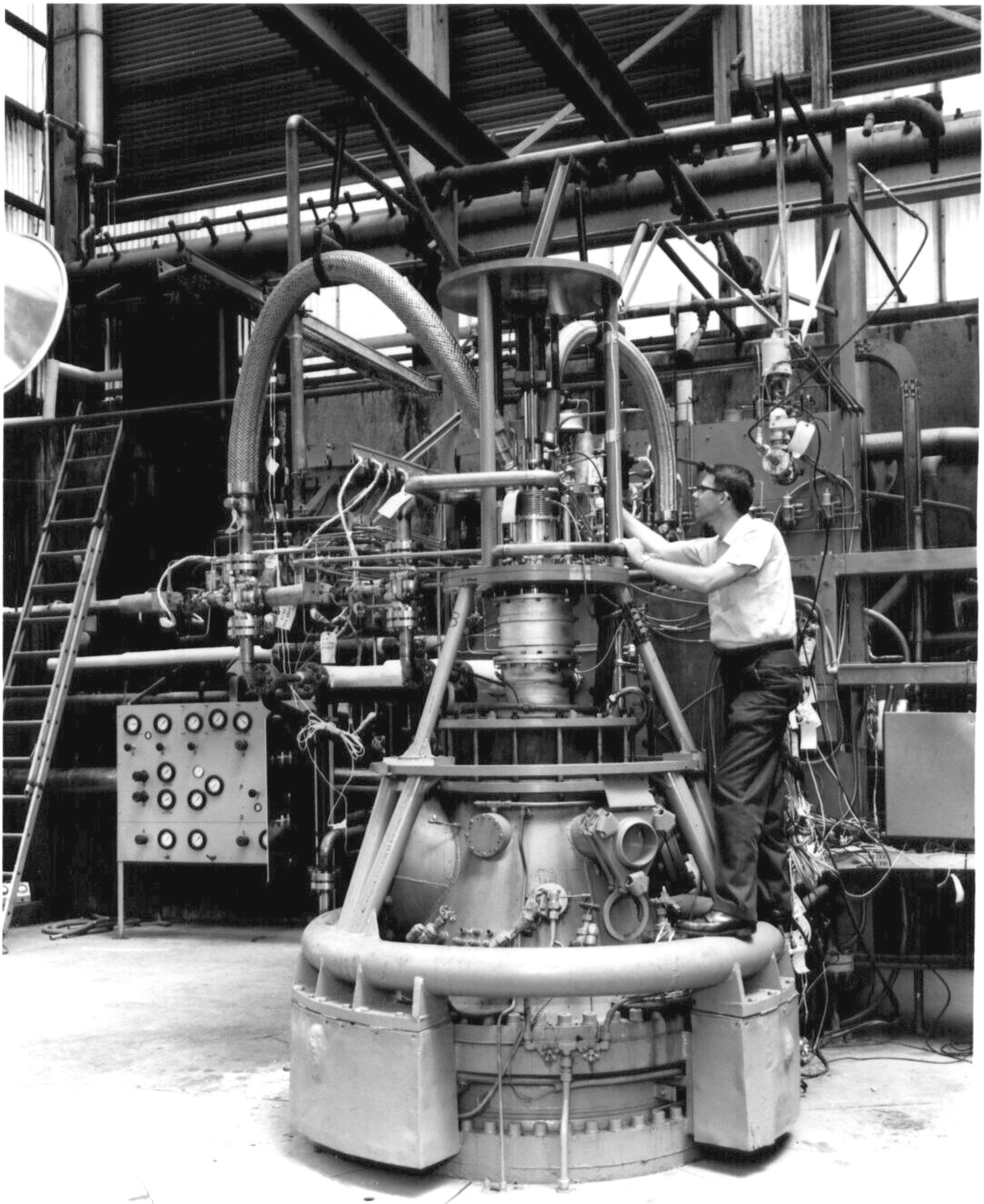

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HAER No. OH-124-A-48

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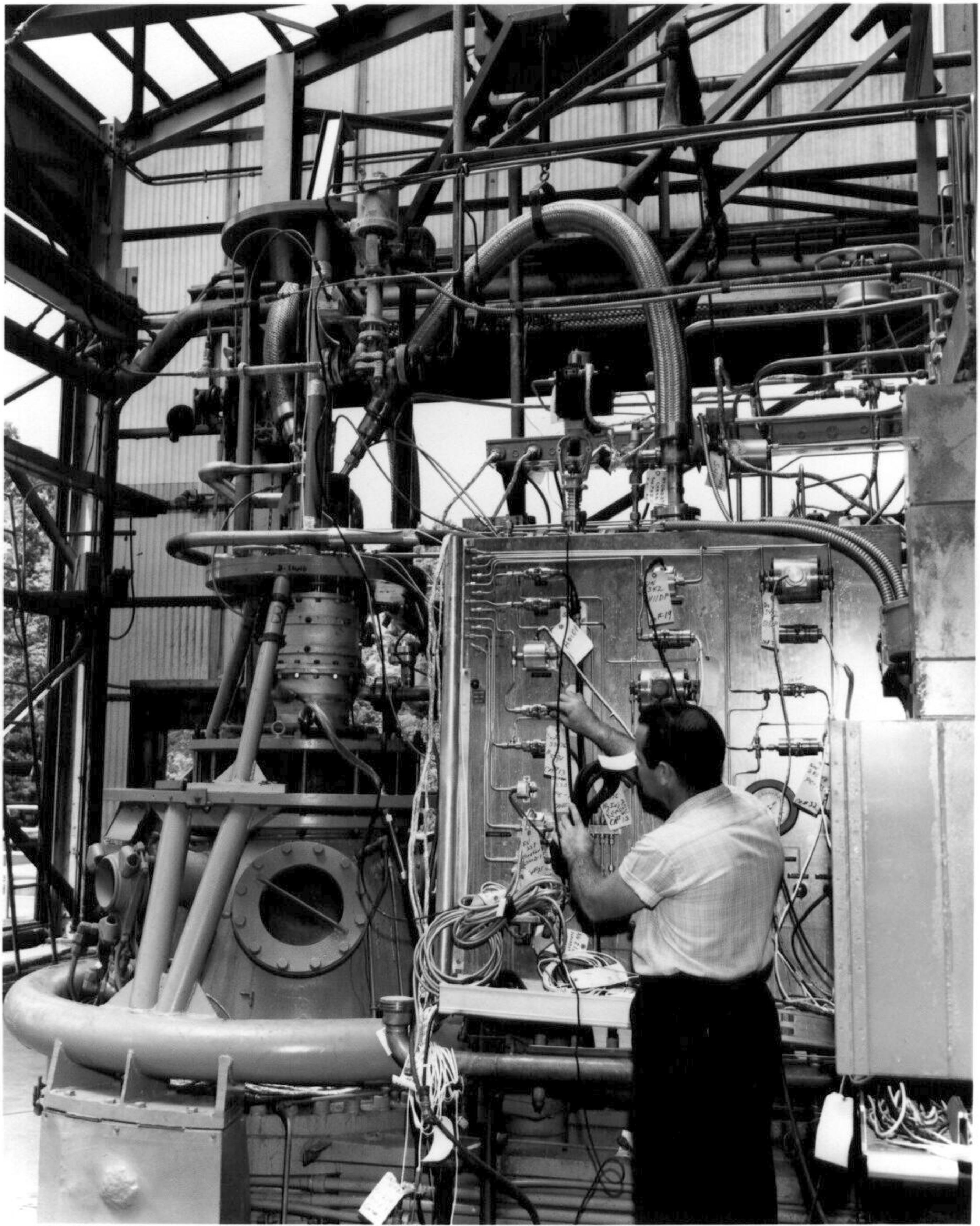
C-66-2397



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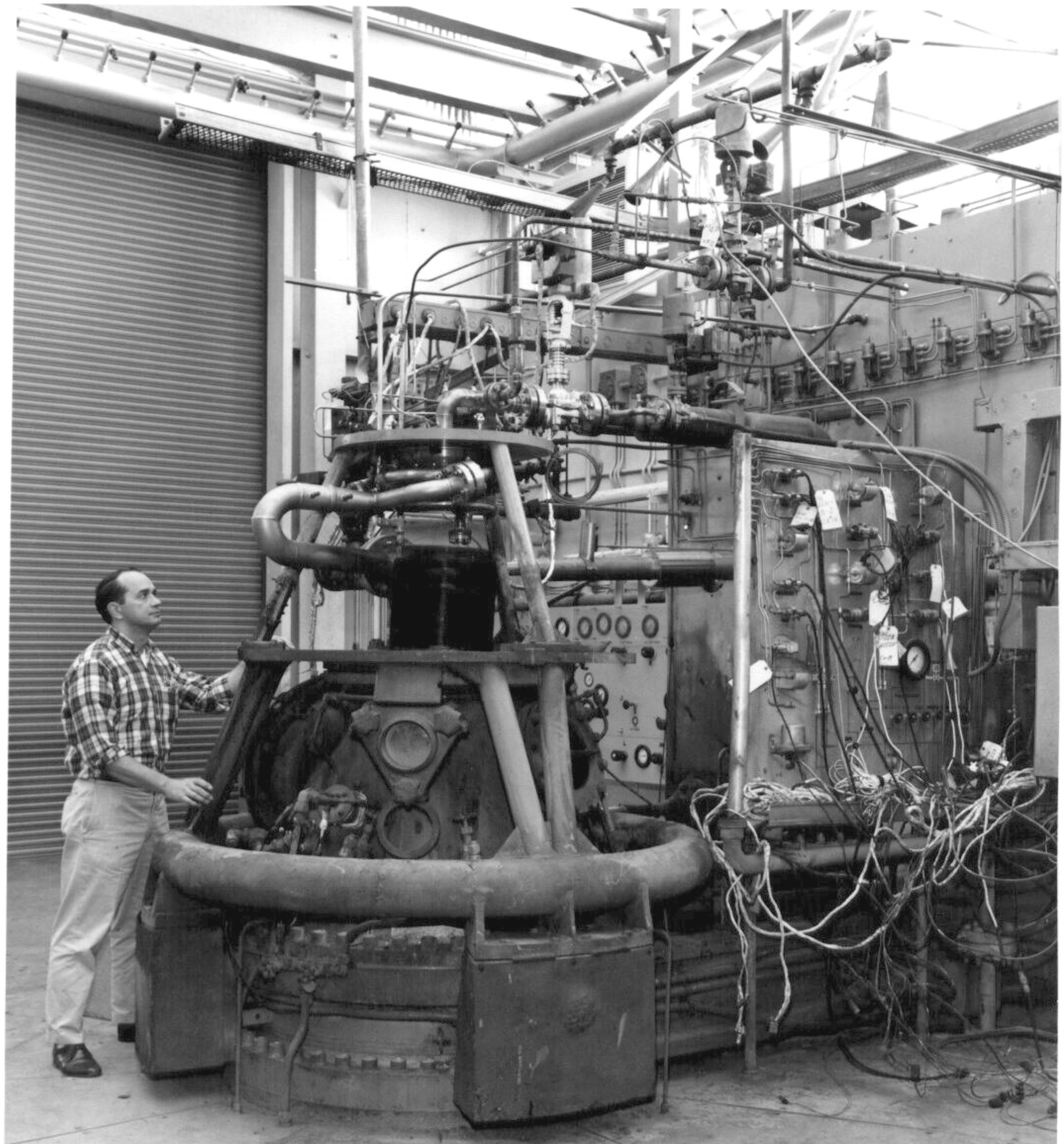
C-66-4064



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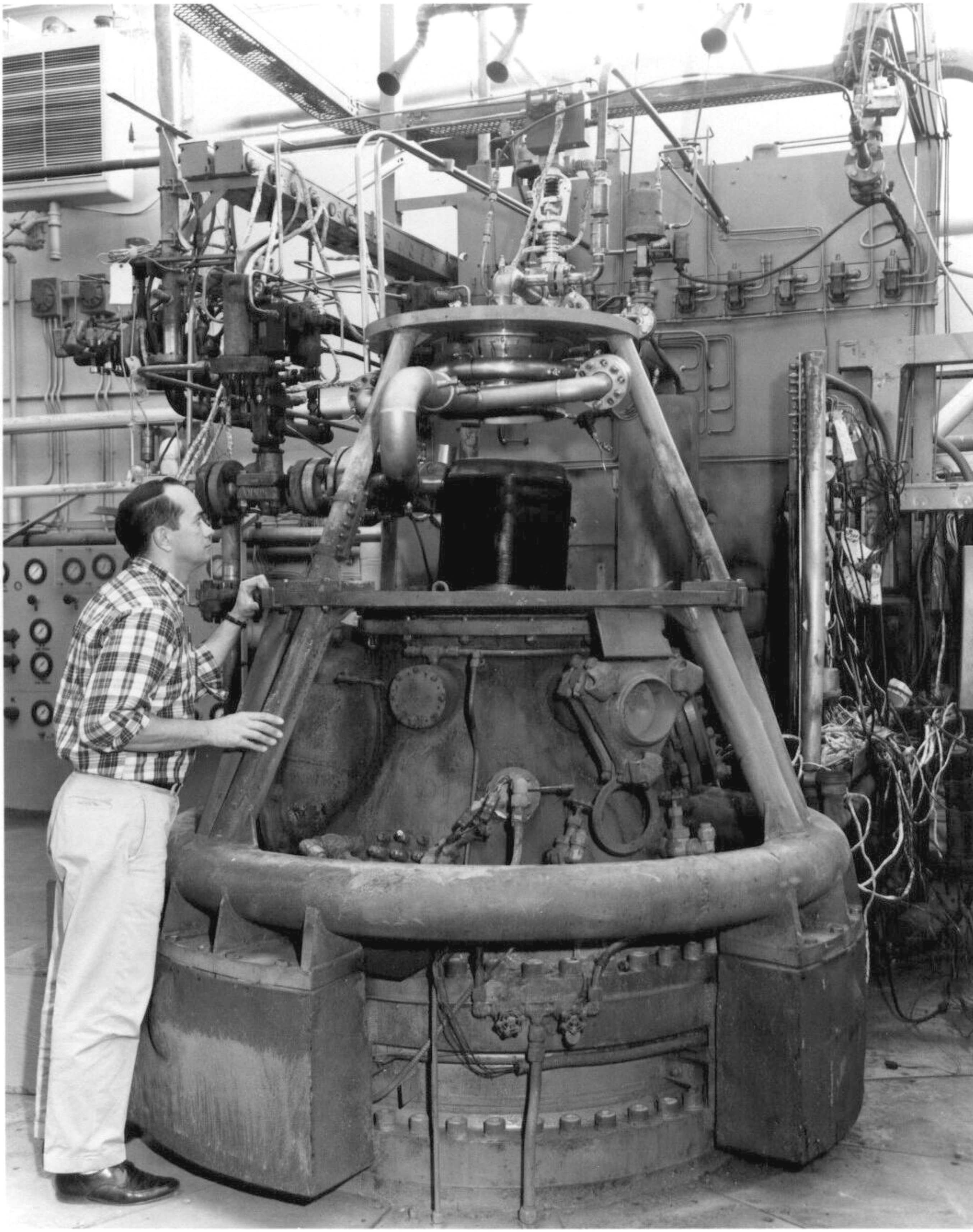

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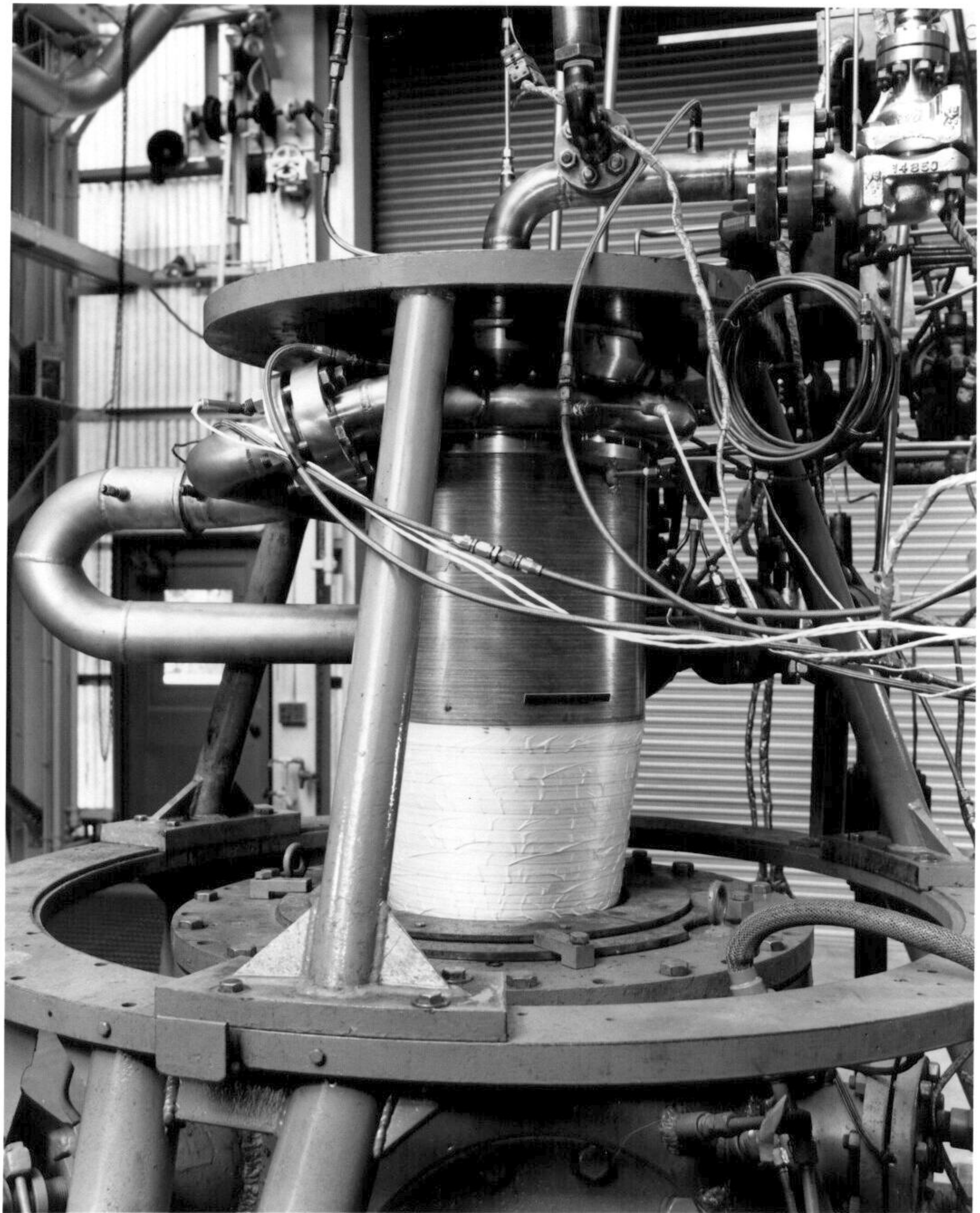

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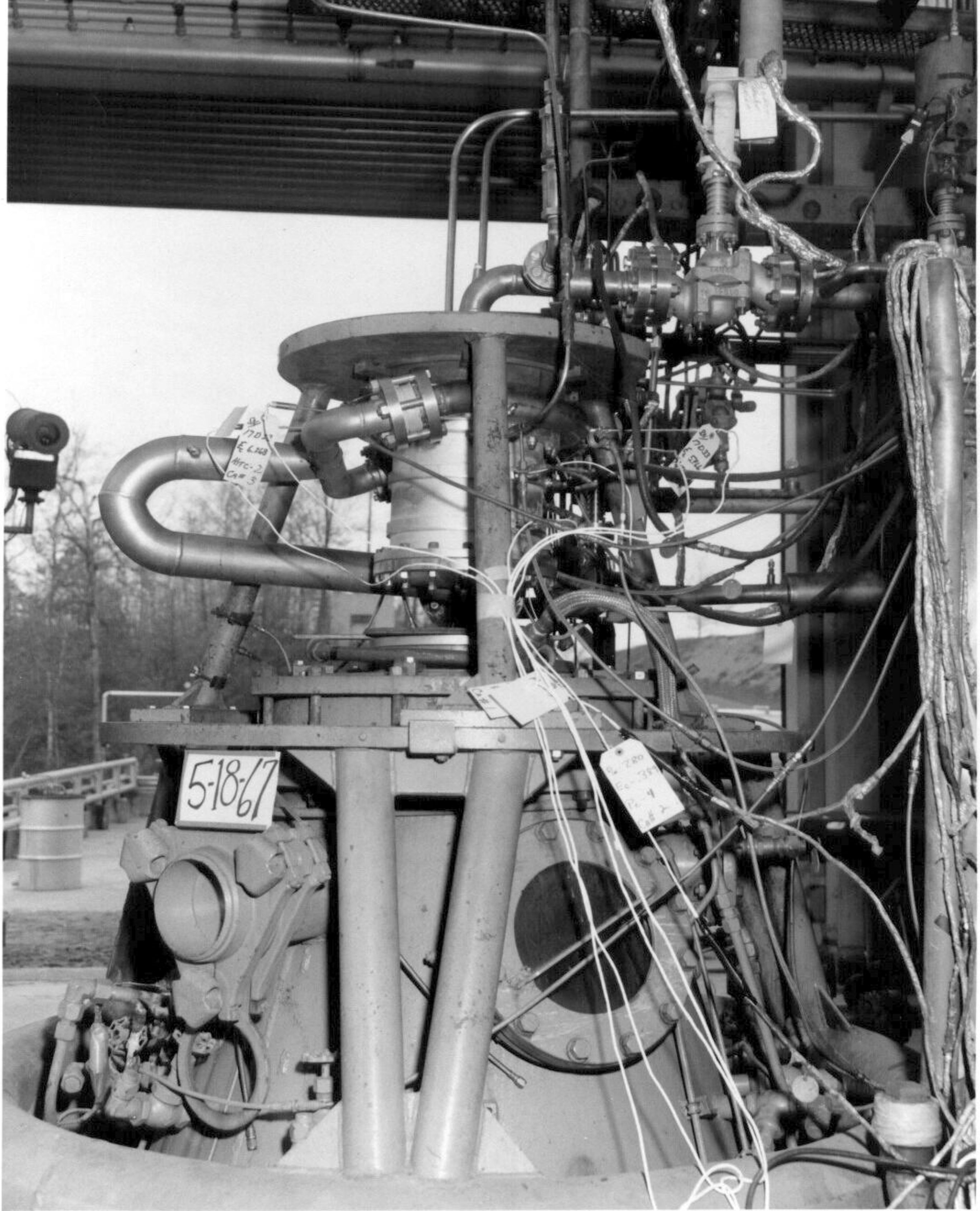

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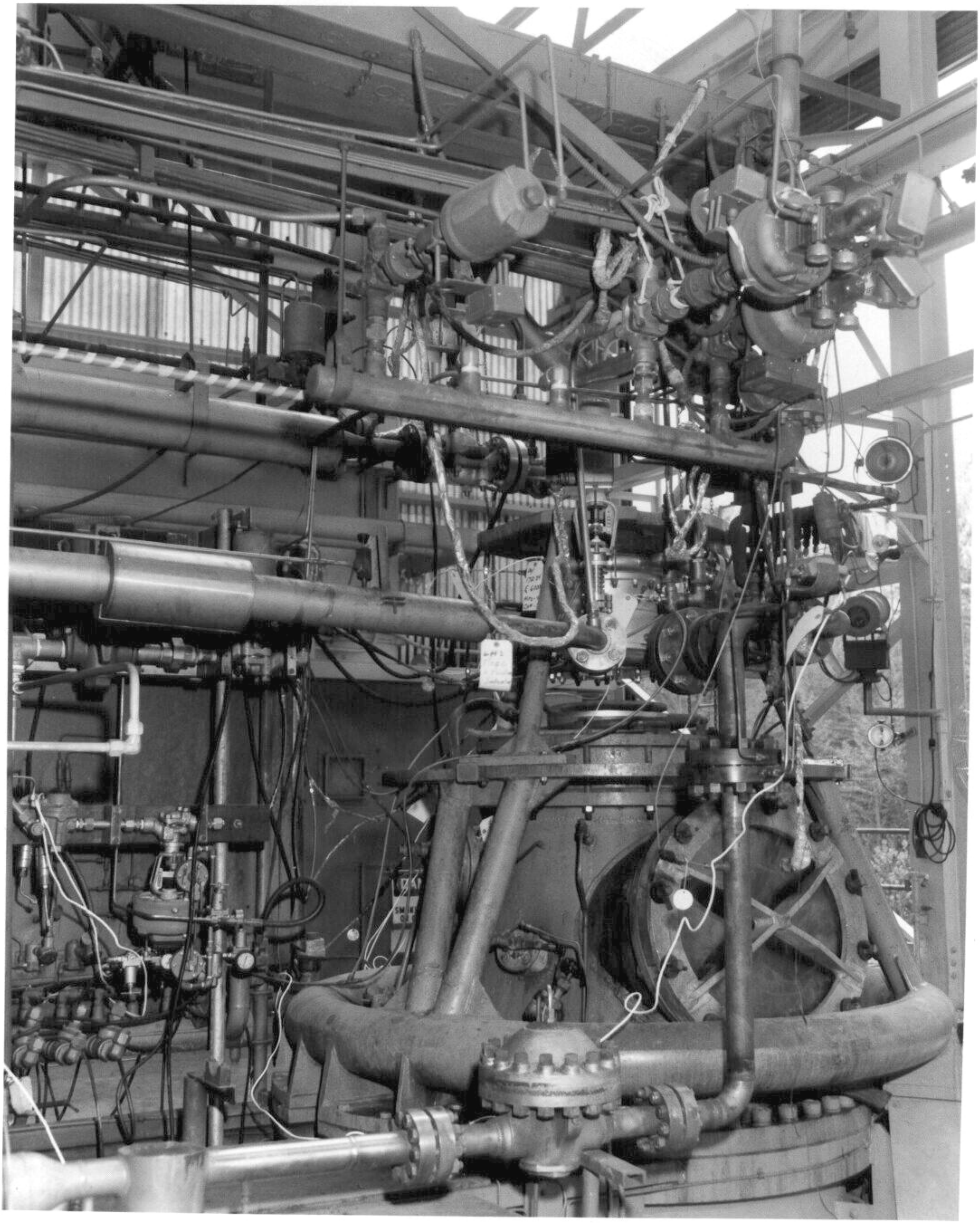

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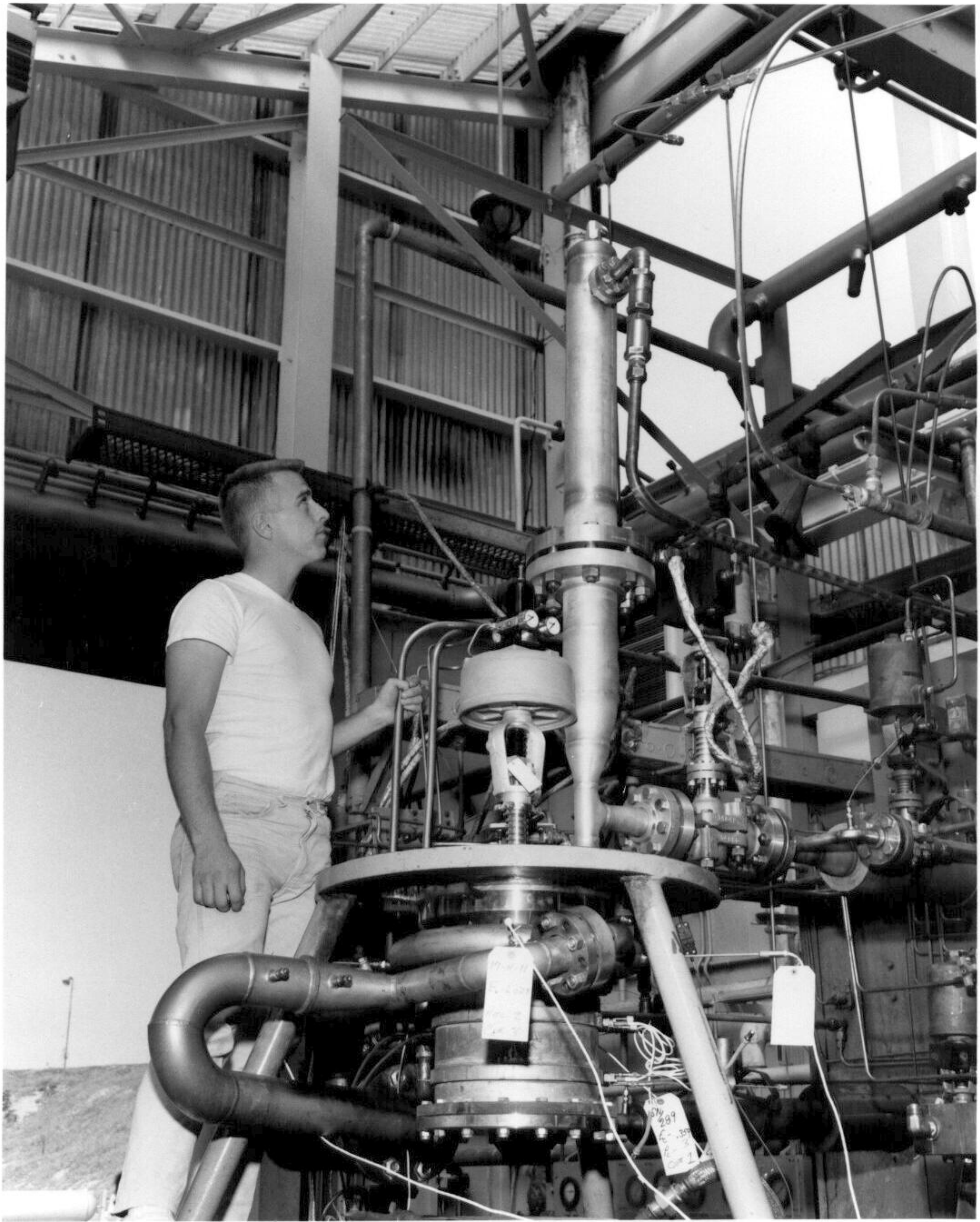

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NASA
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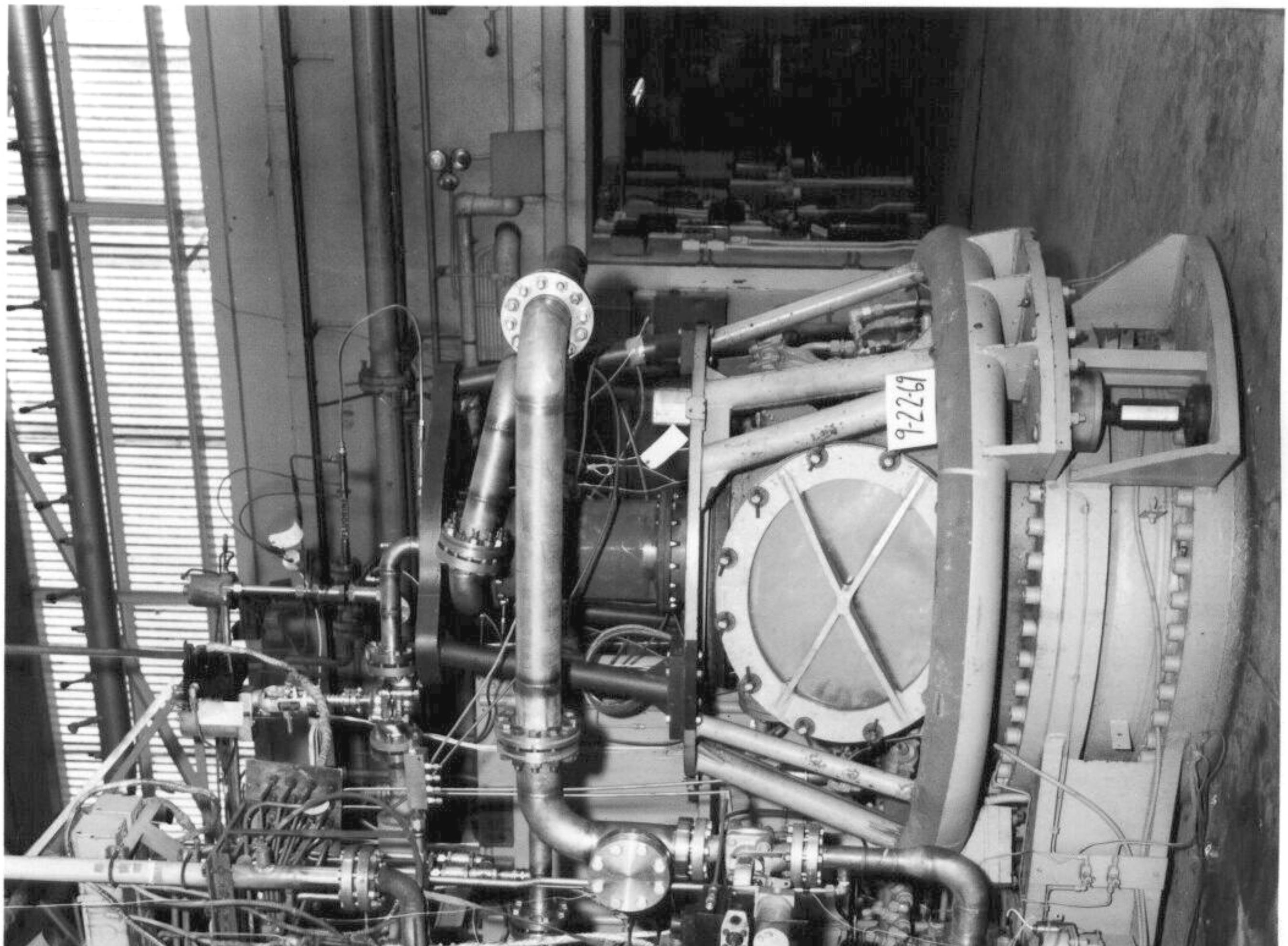

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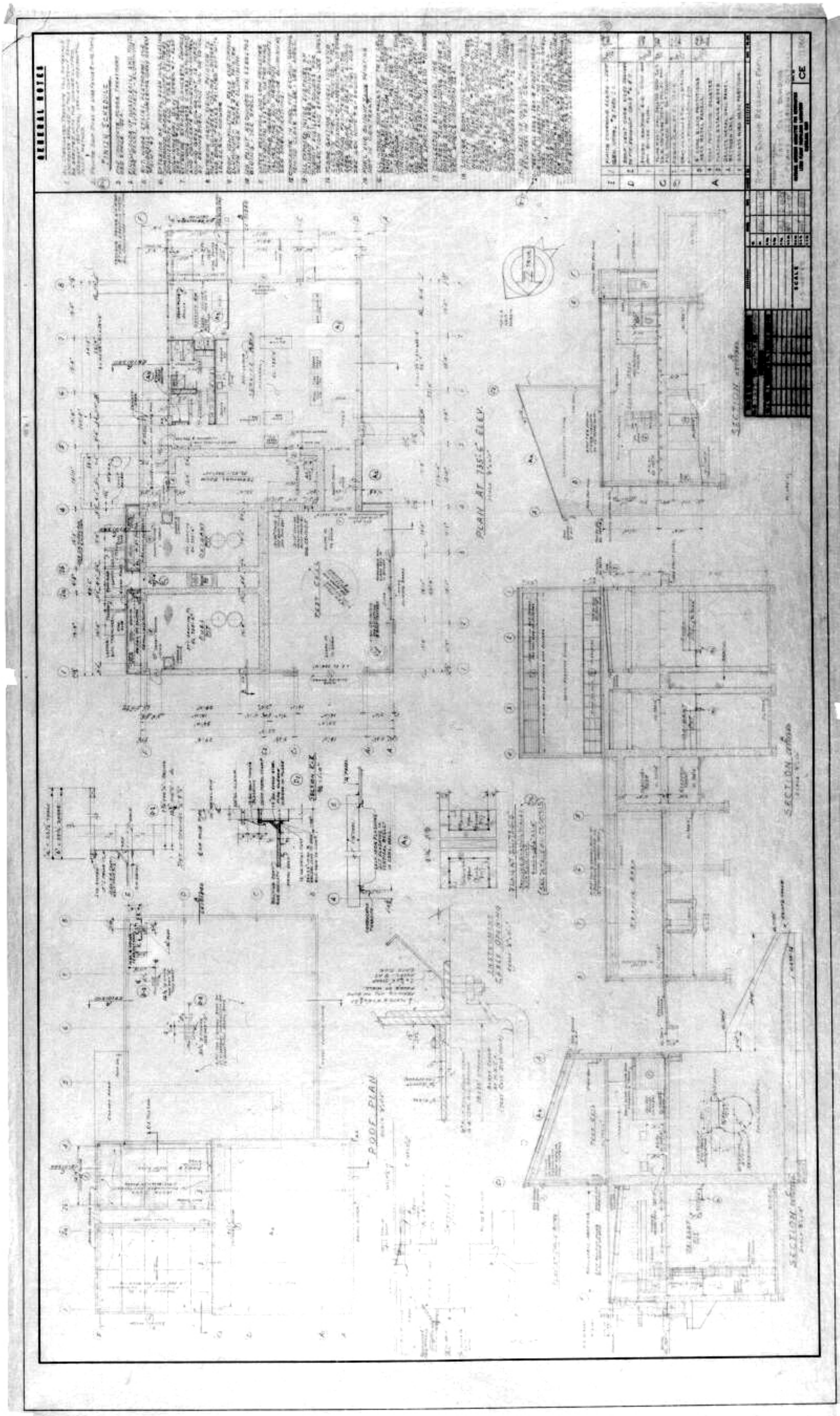

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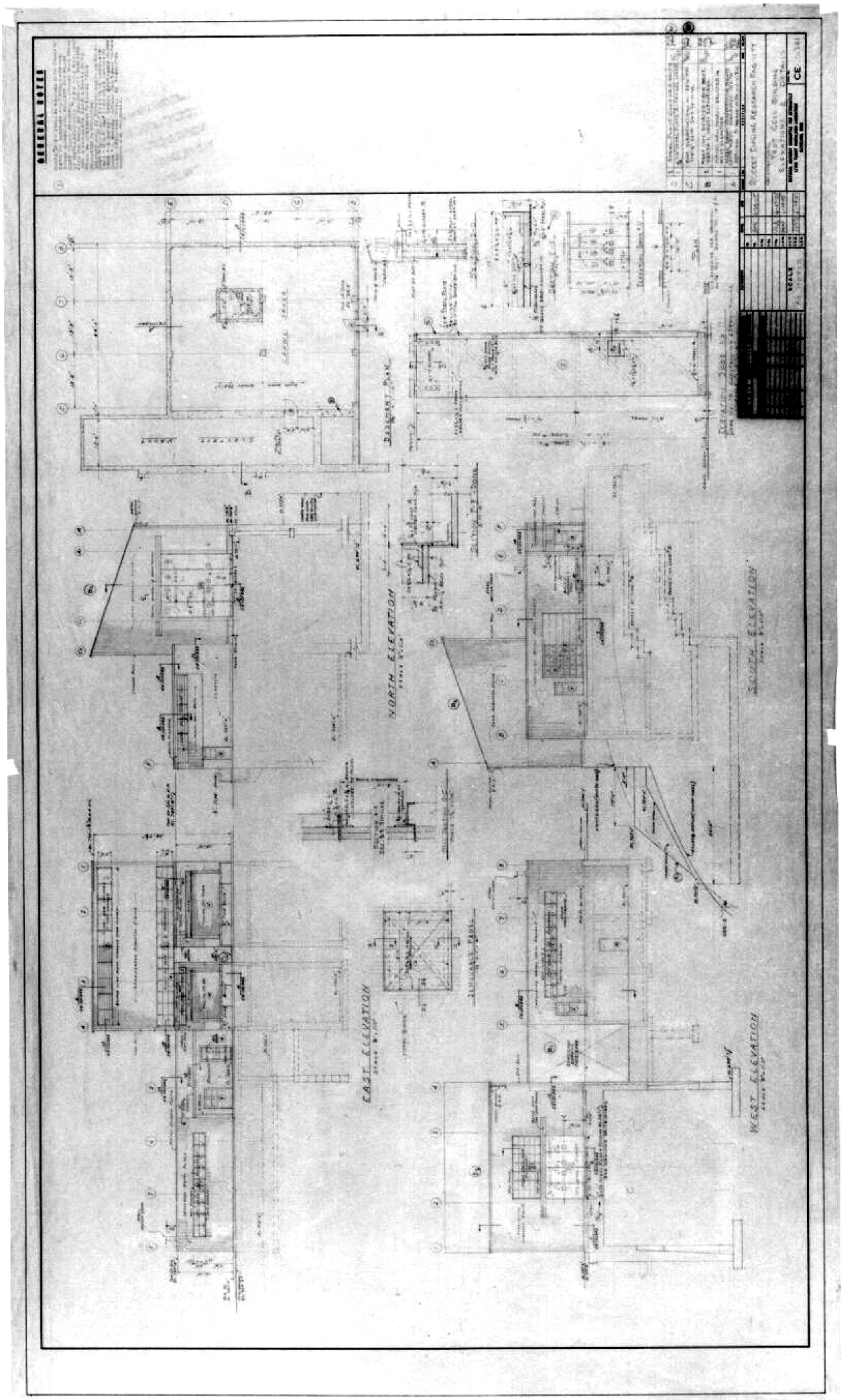

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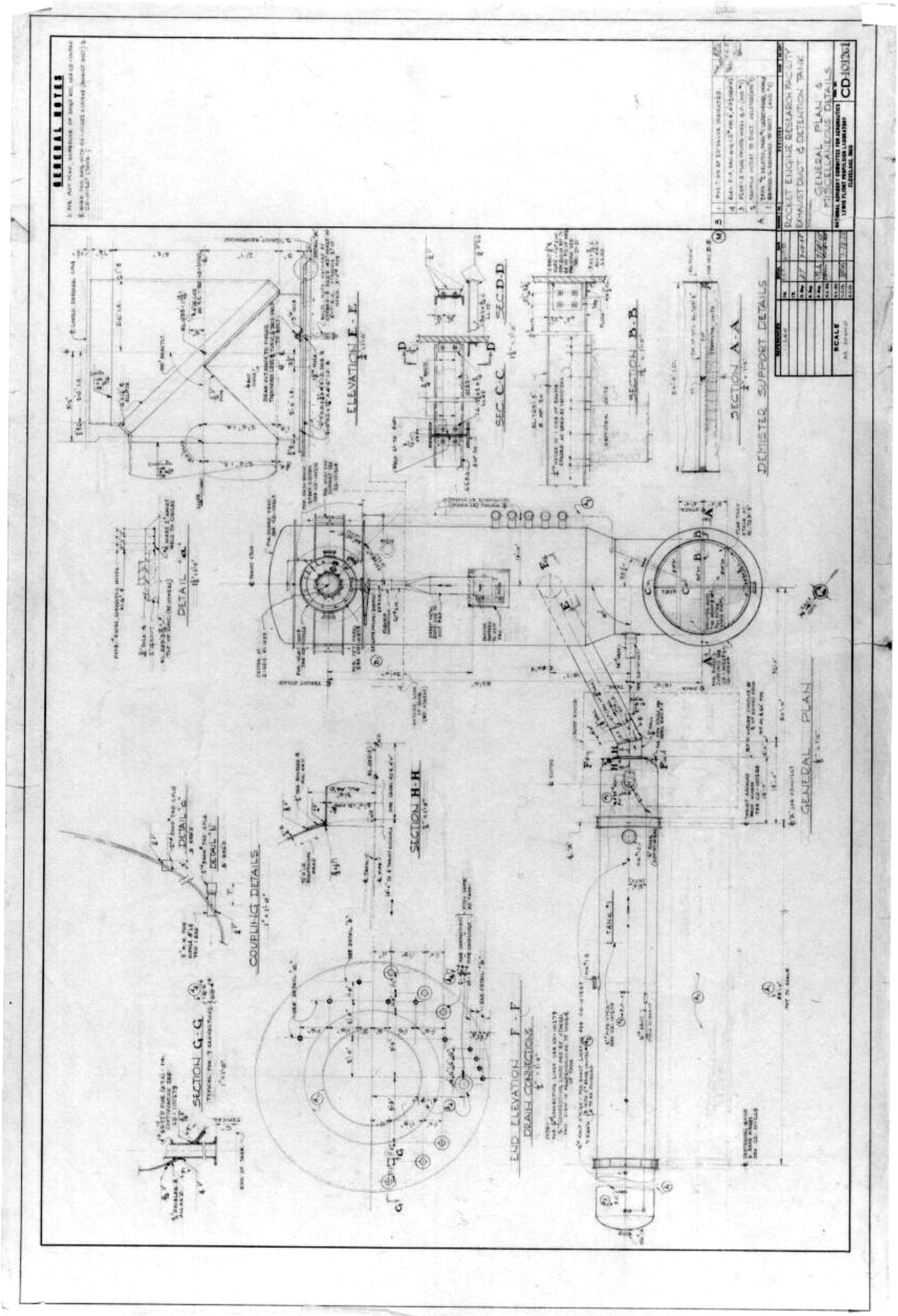

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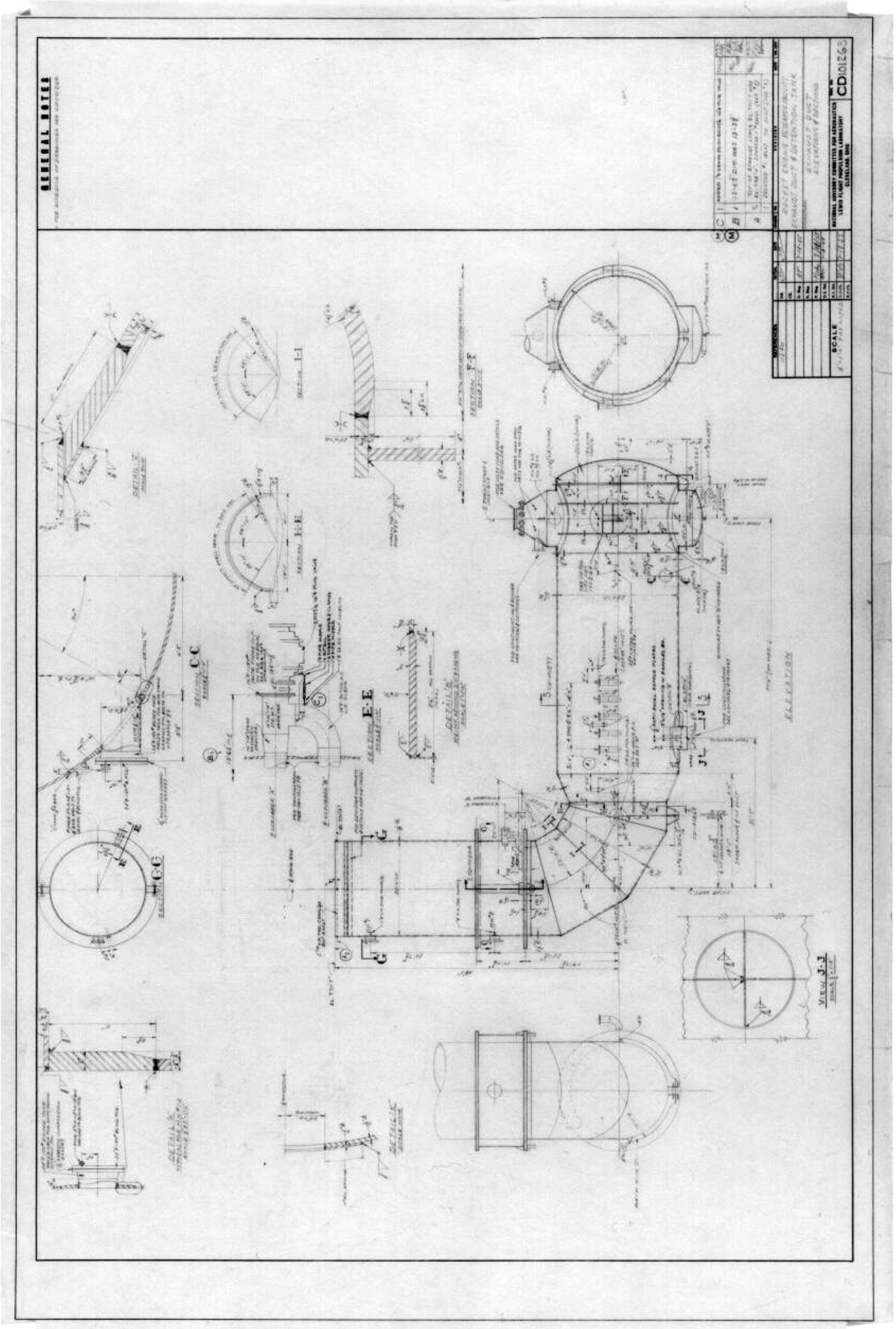

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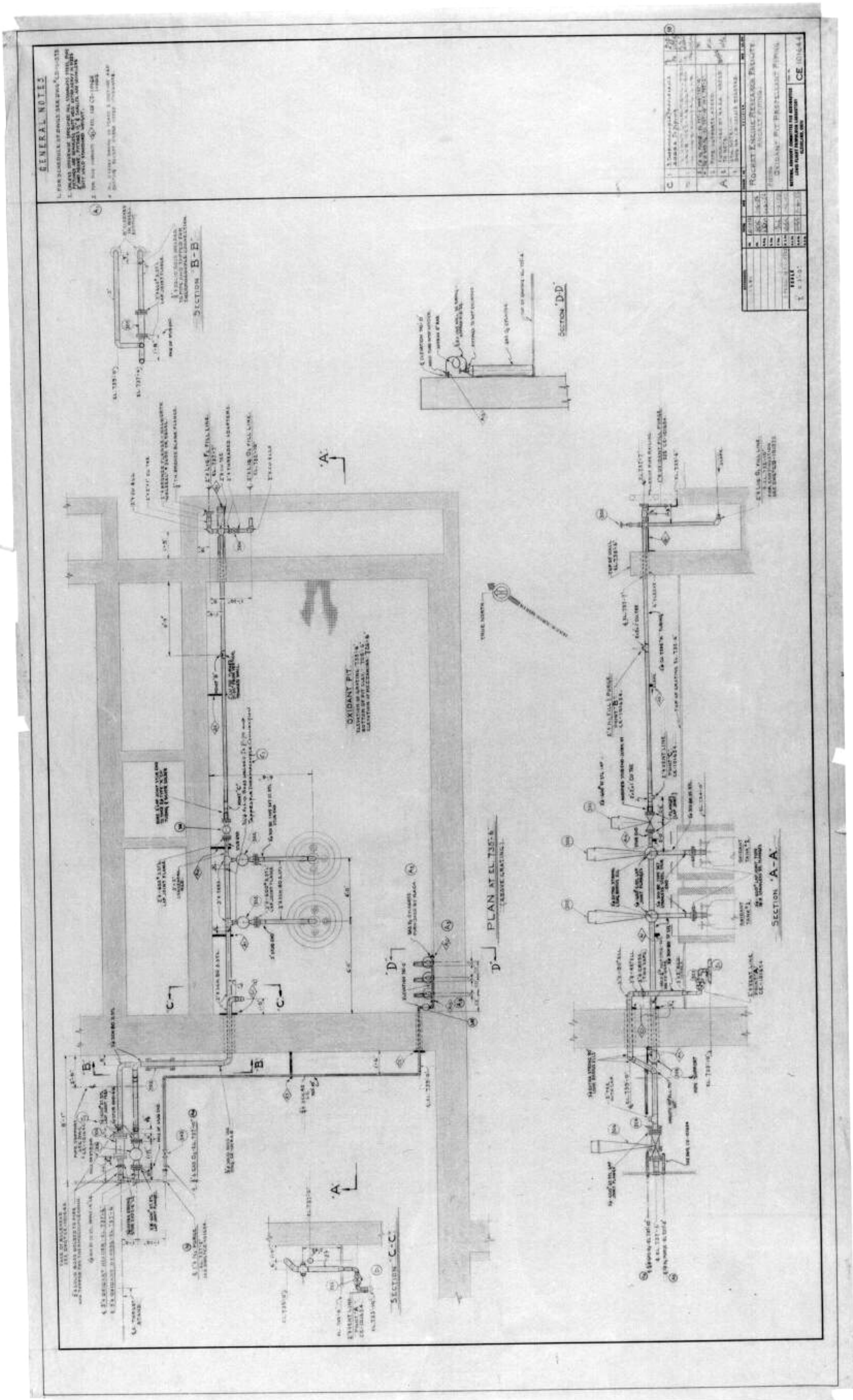

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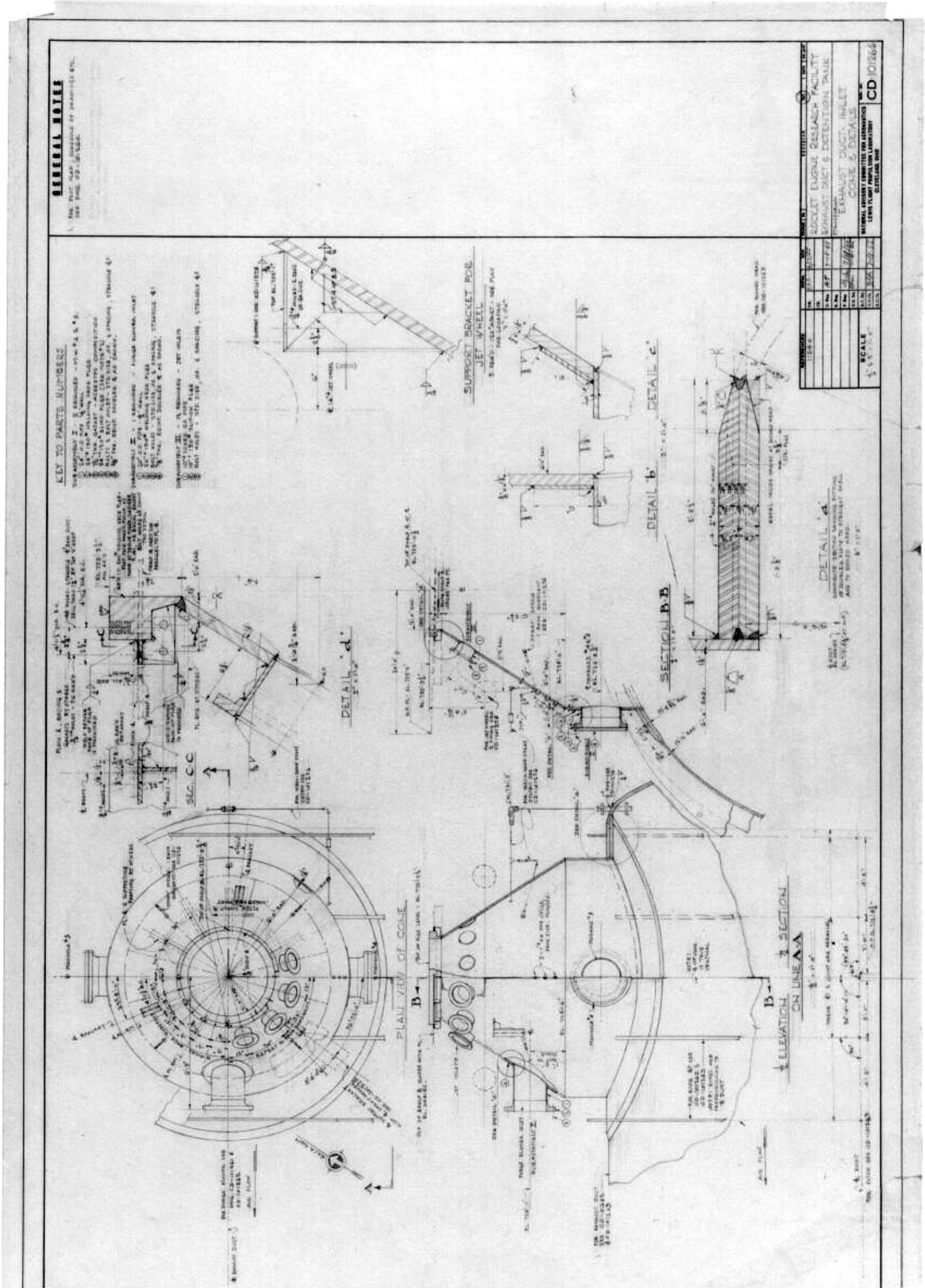

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