PACIFIC FURNACE
6633 Canoga Avenue
Canoga Park
Los Angeles County
California

HAER CA-2280
*HAER CA-2280*

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF MEASURED DRAWINGS

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240-0001

**HISTORIC AMERICAN ENGINEERING RECORD**
**PACIFIC FURNACE**

(Pratt & Whitney Rocketdyne) (Rocketdyne Propulsion & Power) (GenCorp Inc.)

HAER No. CA-2280

Location: ROCKETDYNE, INC. DIVISION OF GENCORP INC.
6633 Canoga Avenue
Canoga Park
Los Angeles County
California 91303

UTM Coordinates: Pacific Brazing Furnace, UTM: 11 S 352624.91 E 3784343.75 N
(Center of furnace building)
Quadrangle: NE/4 Calabasas 15' Scale 1:24,000

Date of Construction: 1964-1965

Engineers: Pacific Scientific Company

Original Cost $473,000 in 1966

Present Owner: United Technologies, Inc. - Pratt & Whitney Rocketdyne Division

Present Use: Limited use for brazing rocket engine components.

Significance: The Pacific Brazing Furnace is located at the south end of the Rocketdyne facility in Canoga Park, California. This facility played a key role in the development of the technology for using hydrogen as a rocket fuel. The Rocketdyne engineers and skilled workers was also responsible for extraordinary work in developing lightweight, regeneratively cooled, hydrogen-fueled rocket engines. The design of rocket nozzles used on the space shuttle main engines (SSME) required development of brazing technology that bonded tubes carrying liquid hydrogen coolant to a casing that formed the rocket nozzle. The successful development of the SSME rocket could be largely credited to the work carried out here. research personnel at this facility built or developed much of the equipment, technology, and methodology for constructing rocket engine nozzles using ingenious solutions to resolve design and operational problems.

Project Information: This documentation was initiated on May 9, 2011 in accordance with a Memorandum of Agreement among the National Aeronautics and Space Administration (NASA), The California State Historic Preservation Officer, and the Advisory Council on Historic Preservation. To mitigate the closure and possible removal of this historic facility the National Park Service stipulated that the Rocketdyne Pacific Brazing Furnace be documented to Level I standards of the Historic American Engineering Record (HAER). This project was initiated to fulfill that requirement.

Historian: Robert C. Stewart - Historical Technologies June 2013

## PART 1. HISTORICAL INFORMATION

### Physical History

Under cooperative agreements with the National Aeronautics and Space Administration-Marshall Space Flight Center (NASA-MSFC) and the National Park Service (NPS) Heritage Documentation Programs (HDP), the Historic American Engineering Record (HAER) is producing large-format photographs, measured and interpretive drawings and written historical and descriptive data on a historically significant site in the research, development and production of liquid-propelled rocket engines for NASA's manned spaceflight programs. These included the Saturn F1 engines and the Space Shuttle Main Engines (see **Figure 1** for Location Map).

### Historical Context

North American Aviation (NAA) founded Rocketdyne after WWII. Early work included analysis of the German V-2 weapon to adapt its engine to US measurements and construction practice. Rocketdyne used design concepts based on the V-2 engine to build a larger engine for the Navaho missile program. The SM-64 Navaho was a supersonic intercontinental cruise missile project built by North American Aviation. The program ran from 1946 to 1958 when it was cancelled in favor of newer designs for intercontinental ballistic missiles. The missile is named after the Navaho Nation and is in keeping with North American Aviation's policy of naming projects with code names starting with the letters "NA" (Gibson 1996:2).

The Navaho program, while it was valuable in developing many of the manufacturing techniques used in later engines, was cancelled on July 13, 1957 and superseded as the Redstone missile program achieved success. However, Rocketdyne's Navaho engine, designated the A-5 or NAA75-110, was more reliable than the Redstone engine so it was integrated into the design of the Redstone. When the Redstone went from development to production, Rocketdyne became a division of North American Aviation. In 1967 North American Aviation merged with the Rockwell Corporation to form North American Rockwell. It later became a division of Rockwell International.

During the 1960s and 1970s Rocketdyne developed several major engines. The S-3D was used on the Jupiter missile and on the long range Thor missile. The Thor did not see much military use but several versions were utilized as satellite launchers during the 1950s and 1960s. A review of Rocketdyne's research and development history shows a progression to ever larger, more powerful designs. The LR89/LR105, was used on the Atlas missile and as a satellite launcher through the 1950s and 1960s. The Atlas also had a short military career as a deterrent weapon, but later versions were used as orbital launchers for the manned spacecraft in Project Mercury and in the Atlas-Agena and Atlas-Centaur.

Rocketdyne also supplied all of the engines for NASA's Saturn rocket deigns. By 1965, the company had built the vast majority of US rocket engines, and it had 65,000 employees. Although Rocketdyne won the contract for the Space Shuttle Main Engine (SSME), there was a reduction in other military and civilian work. This led to decrease in the company's size. Several divisions of Rockwell International, including North American Aviation and Rocketdyne were sold to Boeing in 1996. Boeing agreed to sell what was by then known as Rocketdyne Propulsion & Power to Pratt & Whitney in February 2005. The sale was completed on August 2, 2005.

Pratt & Whitney sold its Rocketdyne Division to the Sacramento based aerospace firm GenCorp Inc. for $550 million. This merger of two major rocket manufacturing firms marked the end of competition between the companies. GenCorp also owns Aerojet General, a pioneering aerospace company founded in 1942. This event was recorded in the Los Angeles Times dated 24 July 2012. The sale of Rocketdyne to GenCorp marked the combination of two iconic California rocket companies — and longtime competitors.

**Methodology**

The approach to recordation of the Pacific Furnace included site visits and reviewing textbook sources on brazing. Archival records and drawings located at Rocketdyne are included in the study. Additionally, several technicians and engineers who worked on the furnace and its retort were interviewed. These "oral histories" were digitally recorded. Additional efforts were focused on reviewing patents, by and large assigned to Rocketdyne, Boeing and Pratt & Whitney, that are associated with brazing of rocket nozzles.

The development and use of the Pacific Scientific Furnace, brazing technology and equipment to produce the nozzle of the Space Shuttle Main Engine (SSME) is the primary focus of this recordation. Most of the information on the furnace and its operation was obtained from retired and current employees who worked on the furnace. Additional interviews illuminated how experimental procedures evolved into standard operating procedures for assembling and brazing the SSME nozzle. Rocketdyne personnel recalled the company's research and development efforts in developing pioneering manufacturing techniques to build the SSME. HAER technicians concentrated on using a laser scanner to perform 3D object scanning of the Pacific Furnace for conversion into drawings meeting HAER specifications.

Rocket nozzles perform a critical function in operation of a rocket engine. They accelerate and expand the gases produced by combustion of fuel and oxidizer. Gases exhaust through the stainless steel nozzle at hypersonic velocities and provide the thrust to propel the rocket. Temperatures of gas exiting through the nozzle are close to $6000^0$ F. This is well above the melting point of stainless steel, which is typically around $2700^0$ F. The standard, welded steel, double walled combustion chamber was not capable of operation with the higher thrust engine designs (Halcheck and Bampton 2000, 38). **Figure 2,** U.S. Patent 3,182,448, in the graphics section of this report is a patent drawing of the older type of double walled construction. To prevent catastrophic melt-down, the tubular wall concept was developed and used in American designed engines. By lining the inside surface of the rocket nozzle shell with type 718 stainless steel tubes that conducted, in the case of the SSME, liquid hydrogen, a stronger, lighter construction resulted. The tubes were attached to the shell using brazing technology. The design provided significantly more efficient heat transfer than the former double walled design. The heat flow through the resulting chamber wall is very high; 1-20 $MW/m^2$ is not uncommon. <u>Regenerative</u> cooling is the technical designation for this type of construction.

The concept of regenerative cooling was first developed by Siemens in 1857. An article by Konstantin Tsiolkovsky in 1903 alluded to the concept of regenerative cooling. In 1923 Robert Goddard built the first regeneratively cooled engine but abandoned the design because of its complexity (Goddard 1948: 14-15). The Italian researcher, Gaetano Arturo Crocco, built a regeneratively cooled engine in 1930. The first Soviet engine to be regeneratively cooled was Fridrikh Tsander's OR-2, tested in March 1933. The scientist Kaus Riedel tested the first German engine of this type in March of 1933. Walter Thiel designed the German V-2 engine, the most powerful of its time at 25 tons (245 kN) of thrust. It was regeneratively cooled by fuel lines coiled around the outside of the combustion chamber. The V-2 was cooled by burning diluted alcohol at low chamber pressures to prevent melting the engine. The same design was used in the American Redstone engine (Wikipedia 2011: Regenerative Cooling).

In 1945 Aleksei Mihailovich Isaev designed the Soviet U-1250. Its combustion chamber was lined by a thin copper sheet backed by a corrugated steel wall. Heat was effectively absorbed by fuel flowing through the corrugations. This design allowed higher chamber pressures, and it has been used in all Russian engines since. Modern American engines line the combustion chamber with brazed copper or nickel alloy tubes. This is type 718 alloy in the case of the SSME. The concept used in American designs is credited to Edward A. Neu who developed it at Reaction Motors Inc. in 1947. US Patent 2,686,430, granted to R.J. Andrus on August 17, 1954, specifically refers to a "Regeneratively Cooled Liquid Fuel Rocket Motor". It embodies the principles of regenerative cooling but bears little resemblance to the engines developed by Rocketdyne.

For this HAER project, the furnace, its controls, blowers, gas piping, ignition method, burn-off jets, retort, cooling methods and the mechanical support system (jigs) for the SSME nozzle being brazed were studied, drawn and documented. To understand the significance of what the engineers, technicians and scientists accomplished with the Pacific Furnace, its recordation includes a brief history of brazing and its evolution as a refined and reliable technique for fabricating rocket nozzles.

At Rocketdyne, the regeneratively cooled engine designs are credited to Al Brown and Douglas Bradley (Somerville 2011). In the SSME design the inner wall of the nozzle shell is lined with tubes which carry liquid hydrogen from the fuel tanks to the combustion chamber. As the liquid hydrogen is pumped through the tubes it cools the nozzle. This is a efficient way of rejecting heat of the burning fuel and containing pressure, which exceed 6000$^{o}$ F and 6000 psi respectively. While the interior temperature of the nozzle is around 6000$^{o}$ F the temperature on its exterior surface is around 700$^{o}$ F (Long 2011). The fabrication of the nozzle required intensive development of advanced brazing technology to fuse these tubes to the outer supporting shell.

## The Pacific Scientific Furnace

The facility was built in 1964-1965. The Pacific Furnace was so named as it was designed, built and installed by the Pacific Scientific Company in 1964-1965.[1] The original cost was $473,000.

[1] (Drawing 1964-No. E1437-E-44) shows some of the design features of the furnace and could be considered to be a first step in construction. It is dated 6-14-64.

The furnace is housed in a simple industrial-style building which originally provided utilities and security for another similar furnace. These were known as F1 and F2. As demand for brazed components diminished in the mid 1980s, the F1 furnace was removed.

The space that enclosed F1 and F2 furnaces is 119'-9" long by 61'-5" wide. The building is an industrial-style facility framed with "I" or "H" beams and sheathed in corrugated steel panels. There is a pit 10' wide and 24' long that housed components of furnace No. 1. The pit is 10' from the east wall and 14'-6" from the south wall.  All additional information in this report refers primarily to furnace F2  (see **Figure 3** for floor plan)..

While Rocketdyne scientists, designers and engineers experimented and developed brazing as a technique for fabricating the SSME and other rocket nozzles, a heat treatment furnace capable of handling large components also had to be designed and constructed.  The project was subcontracted to the Pacific Scientific Company.

The natural gas-fired Pacific Furnace and its retort had the design flexibility, temperature control and capacity to braze the SSME nozzle and other components. During heat treatment the nozzle was enclosed in a retort for atmospheric control. In terms of brazing technology a retort is a stainless steel vessel in which atmosphere can be controlled. The retort, contained within the Pacific Furnace, allowed technicians to blanket the nozzle with argon and hydrogen. The use of inert or reducing gas prevented surface oxides from forming on components and interfering with braze wetting, flow and fusion.

The Pacific Scientific Furnace is probably the largest furnace heated by natural gas in the world that is capable of maintaining a hydrogen or inert gas atmosphere within its retort. The furnace has two major components. Visual observation shows an outer, insulated tank-like shell which supports burners, ducts, flues, ancillary motors and actuators. The furnace shell is a clamshell design, that is, it has two half-tank shaped sections mounted on a split base. Each half of the base moves on  eight flanged wheels which ride on two rails (see **Figure 4**).. The two halves of the furnace are drawn apart or pushed together to gain access to the interior. Power for this movement is provided by two gearmotors that power drive wheels located near the corners of the frame halves that support the "clamshell" halves of the furnace. The two halves are locked together by electro-pneumatic mechanisms on the mating edges of the furnace halves.

The interior of the furnace was originally lined with firebrick. This was replaced by an insulating blanket of a silica-based fiber shown on construction drawings under its commercial name of Fiberfrax ©. The fiber blanket offers better insulation and lighter weight than did the firebrick.

Overall dimensions of the furnace shell are a height from floor level to the top of the exhaust stack of 26'-4". The outer diameter of the furnace when closed is 20'-6 ½ ". Within the insulation the clear diameter of the chamber is 18'-11". The interior clear height of the chamber is 24'-3". The frames supporting the furnace ride on rails that are 23'-6" apart (see **Figures 4 and 5**).

Originally, the controls for the furnace were housed in a pit under the furnace while monitoring and recording equipment were on the floor adjacent to the furnace. The operators in the pit communicated with the operators on the floor via radio. This was not an efficient use of operator resources in addition to possible personnel hazards from leaking argon, natural gas or high noise levels in the pit. There were gas monitors in the pit and alarms to warn personal to evacuate in case of danger. As a safety and efficiency practice, most of the controls and monitoring equipment were consolidated in an enclosed control room on the furnace floor adjacent to the furnace ca. 1995.

**Brazing**

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- Simple means of achieving extensive joint area or joint length
- Joint temperature capability approaching that of base metal
- Excellent stress distribution and heat transfer
- Ability to preserve protective metal coating or cladding
- Ability to join cast metals to wrought metals
- Ability to join nonmetals to metals
- Ability to join widely different metal thicknesses
- Ability to join dissimilar metals
- Ability to join porous metal components
- Ability to fabricate large assemblies in stress-free conditions
- Ability to preserve special metallurgical characteristics of metals
- Ability to join fiber and dispersion strengthened composites
- Capability for precision production tolerance
- Reproducibility and reliable quality control techniques may be used
- Economical fabrication of complex and multi-component assemblies

Table 1 - Advantages of Brazing (Schwartz 1995, 4)

Brazing is a method of permanently joining metals and other materials. Historically, the technique goes back to ancient times. Jewelry made by Phoenician artisans used brazing techniques to assemble complex pieces. It differs from welding because it is carried out below the melting points of the materials to be joined. It is differentiated from soldering by the temperatures used. Soldering uses alloys that generally melt well below the melting points of the materials being joined. If processing temperatures are above 450$^{o}$ C the procedure is considered to be brazing (Schwartz 1995, 1). Brazing is especially useful in forming strong bonds between metals. It is also useful in joining metals to ceramics. The process can fuse component joints that are inaccessible, joints between thick and thin materials and between wrought and cast alloys. Generally the thickness range of metals that can be brazed varies from 0.01 mm to 150 mm. Other characteristics of brazing are listed above in Table 1.

While brazing offered a well developed technique to create this bond, fusing 1080 tubes to a nozzle shell as large and complex as the SSME's presented significant challenges. The cross-section of the tubes varies from top to bottom according to their location along the nozzle shell. The tubes must curve to match the shape of the shell. At the throat the tubes are swaged to a tapered, "hourglass", shape. At the base the tube shape is hexagonal, and with one flat surface joined to the shell. This design permits the same number of tubes at the narrow throat as there are at the base. The specification on the tubes requires that they can withstand 600psi. However, before a nozzle is released to the customer the tubes are subjected to 8000 psi hydrostatic testing and checked for leaks.

Other problems included the design of fixtures to hold components in place during construction and firing. Sheets of braze alloy were applied to the inner surface of the nozzle. The side of tube contacting the braze sheets were stripped of the nickel plating that coated the other sides of the tubes. Then the tubes were placed in position on the braze alloy (**Figure 6**). Workers used a "tube spreader" to force 1080 tubes into the throat area of the nozzle. "You could be playing 1080 pick-up if you weren’t very careful with the last few tubes" (Knobloch 2011). At this point in the process a flexible bellows had been attached to the nozzle exit side. The nozzle was placed in a support jig with the throat in the down position. The bellows, attached to counterweights, allowed the nozzle to expand during the first braze cycle. Additional jigs were used to hold the tubes in place during brazing. The principal method of holding the tubes against the shell involved the use of a cone shaped plenum inserted into a type 718 stainless "vacuum bag" which pressed against the tubes during heat treatment. The bag was made of metal that was 0.010-0.015" thick. A sprayed coating of zirconium oxide between the bag and the tubes prevented braze alloy from bonding to the bag. Counterweights attached to a temporary bellows allowed the nozzle to expand during heating. (see Figures 7 and 8).

After heat treatment, the nozzle would be inspected for gross defects. Cooling to about 600$^{o}$ F occurred within the furnace. At that point the furnace would be opened and the cooling continued using blowers to speed up the process **(see Figure 10 ).**

A second firing was then set up with the nozzle in upright position. The second firing was conducted at a lower temperature than the first. At this point the composition of the braze alloy had been chemically modified by interactions between the parent metals and components of the alloy. Firing at a lower temperature insured that tubes already bonded to the shell did not break free while unbrazed areas could be bonded by alloy flowing opposite to the original "throat down" set up.

**Retort Brazing:**

The key to successful brazing of tubing to the nozzle shell is contained in the process of heat treatment in a reducing (Hydrogen in this case) atmosphere. A retort is a tank which contains an assembled nozzle and jigs to hold components in place during fusion of its parts. **Figure 7** shows the general configuration of the furnace, retort and piping schematic. The retort is essentially a stainless steel vessel capable of retaining pressures of 1 ½ " to 3" of water during the braze cycle. Since 28" of water (one atmosphere) is 1 psi, this is a very low pressure; however it is sufficient to prevent collapse of the retort at brazing temperatures. The braze is somewhat volatile and the pressure minimizes loss of components.

When the nozzle components are assembled and placed in the retort jigs and supports, the retort is welded shut at the junction of its base flange and hearth plate. The retort, its nozzle, jigs and supporting hardware is then placed within the opened furnace "clamshells" and the halves of the furnace are closed. The furnace provides closely controlled temperatures around the retort while the retort is purged with an inert gas, Argon, in the beginning of the cycle. Above 760 $^{o}$C (1400$^{o}$ F ) the Argon is purged with a Hydrogen atmosphere which scavenges any oxides that may have formed on the surfaces to be joined. Metallurgical bonding can then proceed. The hydrogen reacts with surface oxides to form water which is monitored by checking the dew point of reactant hydrogen (**see Figure 8**).

A simple brazed joint will have strength equal to or greater than the parent materials. Brazing generally produces a fillet (shape of the junction where the parent materials actually join) that is suited to resist metal fatigue. During the brazing cycle the base materials do not melt. Rather, the joint temperature becomes hot enough to melt the braze alloy which fills the joint between base materials and forms a metallurgical bond with the materials being joined. During brazing, wetting and flow of liquid braze alloy on the surface of a solid is critical to formation of a strong joint. Wetting of the nozzle tubing and the shell material is essential to produce a strong bond in this SSME component. Surface cleanliness and preparation are essential to produce a quality brazed joint. In addition, the space between parts to be joined by brazing is critical. The molten braze alloy is drawn between the parts by capillary action. If the space or gap is too large the braze alloy will not flow enough to fill the gap. If this space is too small the braze will not penetrate between the parts. Flow and wetting are affected by the interactions between solids, vapors and liquids which occur at interfaces and within the parent metals. The properties of the resulting joint are determined by these interactions (Schwartz 1995, 3).

Critical to the development of an acceptable brazing cycle for the SSME nozzle was the suitability of a specific braze alloy for the base or parent metal. At least fifty-three braze formulations were developed by Rocketdyne (Knobloch 2011). Several compositions were used containing up to 65% gold plus Nickel, Copper and Manganese. The alloy was manufactured to Rocketdyne specifications by Wesgo, a division of Morgan Technical Ceramics. Rocketdyne received most of the braze in sheet form. The preferred alloy was designed to flow "sluggishly" (Somerville 2011). While the actual composition of the alloys used are considered proprietary, a similar Wesgo commercial formulation, Palnicoram© 25, liquefied (liquidus) at 1052$^{o}$ C (1936 $^{o}$ F) and solidified (solidus) at 1017$^{o}$ C (1863 $^{o}$F). Other parameters that were developed for brazing the SSME were temperature and time in the furnace, that is, the rate at which furnace temperature was raised or cooled. The brazing cycle took 12 hours to reach braze temperature and 18 hours to cool down. A flow of 3000 cubic feet of Argon or Hydrogen flowed through the retort during the cycle. Excess Hydrogen was burned off in a "recombiners" or burn stacks. A series of Chromel/Alumel thermocouples monitored temperatures throughout the retort and furnace. Chromel/Alumel thermocouples are typically used at a maximum temperature of 2100$^{o}$ F (1198$^{o}$ C) (Somerville 2011)..

Each nozzle was heat treated at least twice but if defects were found, additional firings not totaling more than six could occur. The first firing was done with the throat of the nozzle in the down position while the second was done with the nozzle up (**see Figure 9**). If testing revealed un-brazed areas or leaks, a paste form of the braze would be applied to the defective area and the nozzle re-fired (Knobloch 2011).

After the second firing the nozzle was inspected and tested. Areas that needed additional braze were repaired using powdered braze in a vehicle that would burn off without residue. The nozzle would then be fired again. **Figure 10** shows the nozzle ready to be removed from the furnace.

**Conclusion:**

From the 1920s until recently aircraft design and production was a major contributor to the economy of Southern California. The entire aerospace program required engineering and manufacturing solutions to a host of problems. While scientists and engineers all over the world made contributions to aerospace industries, fortuitously, the area surrounding Los Angeles, California housed aircraft factories, universities, workers and the infrastructure that could support innovative development of equipment for the exploration of space.

The Pacific Furnace and development of the SSME is a singular expression of these factors that enabled the space shuttle vehicle to successfully perform its mission. While the concept of regenerative cooling evolved in the 19th century, construction of the SSME nozzle required the contributions of design engineers and particularly workers who were masters of the skills needed for building an object as large as the SSME nozzle.

The Pacific Furnace Project encompassed the documentation of complex manufacturing tools, jigs and fixtures that had a major role in developing the technique for fabricating the SSME nozzle. Fusing 1080 tubes, of changing cross section, to the internal surface of the rocket nozzle shell, required engineering expertise as well as a major contribution of shop-floor knowledge. The practical execution of the SSME nozzle design and its heat treatment was a technological triumph.

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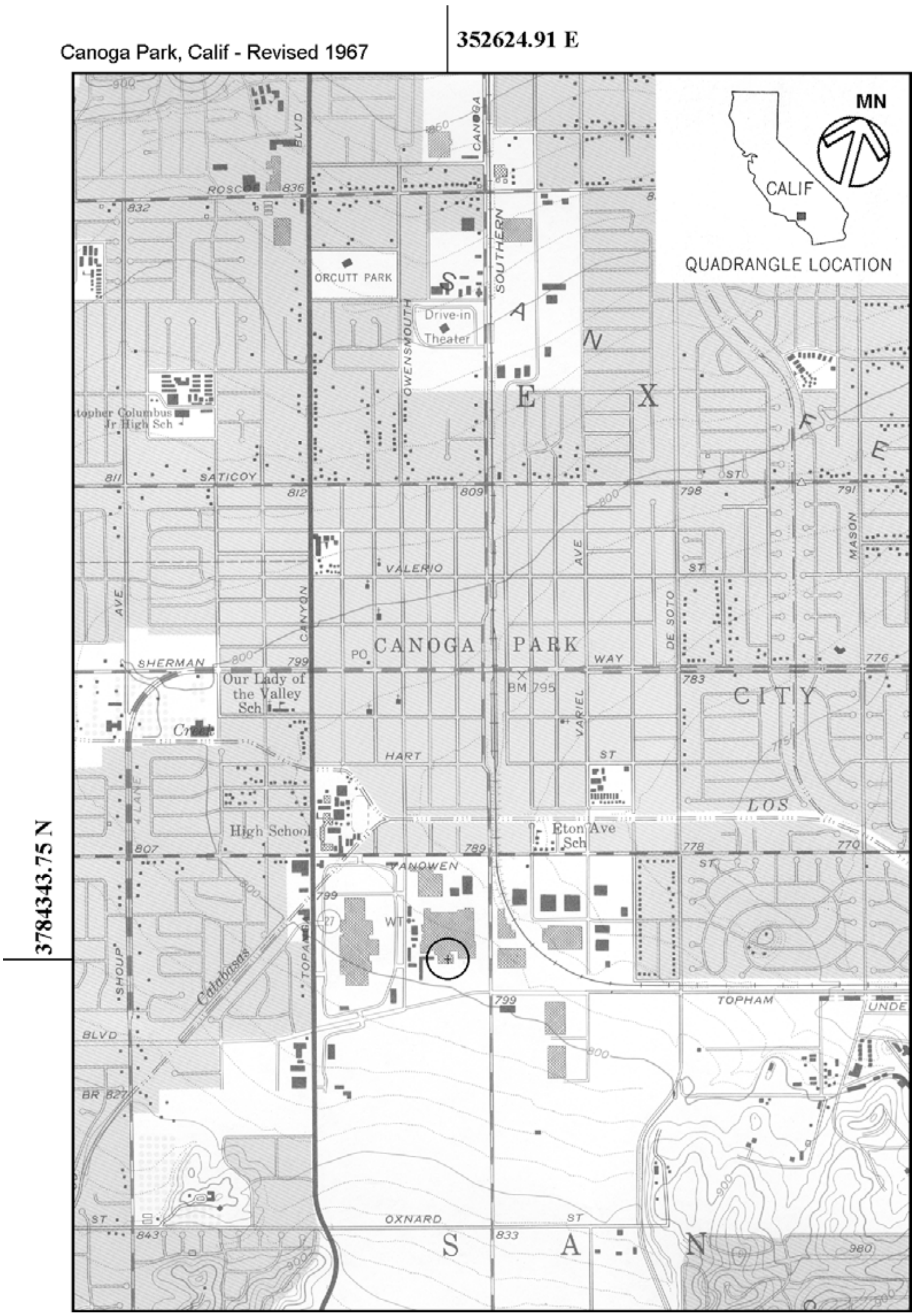


Figure 1 – Location Map

**May 11, 1965** **G. B. RABE** **3,182,448**

ROCKET MOTOR CONSTRUCTION

Filed June 22, 1960 2 Sheets-Sheet 2

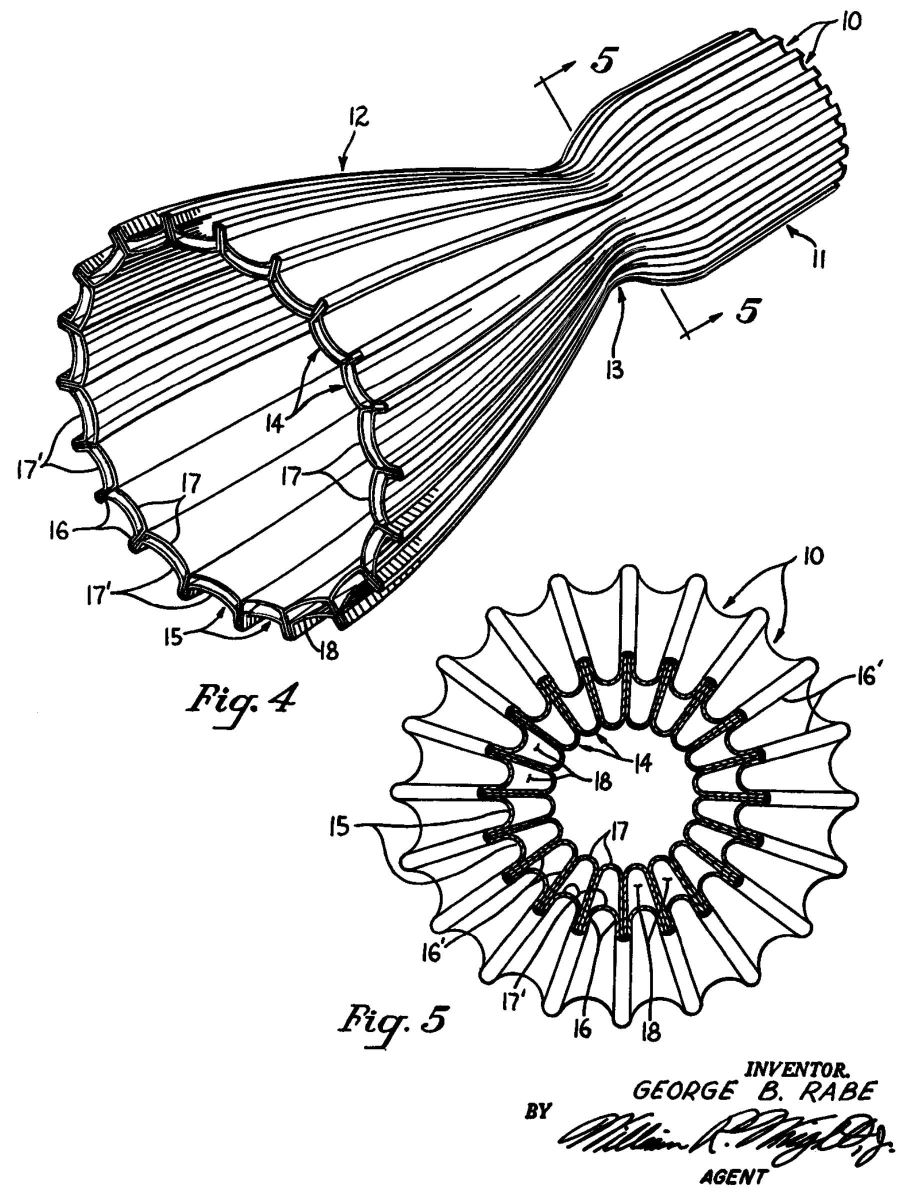


Figure 2 - Example of double walled construction on a rocket nozzle.

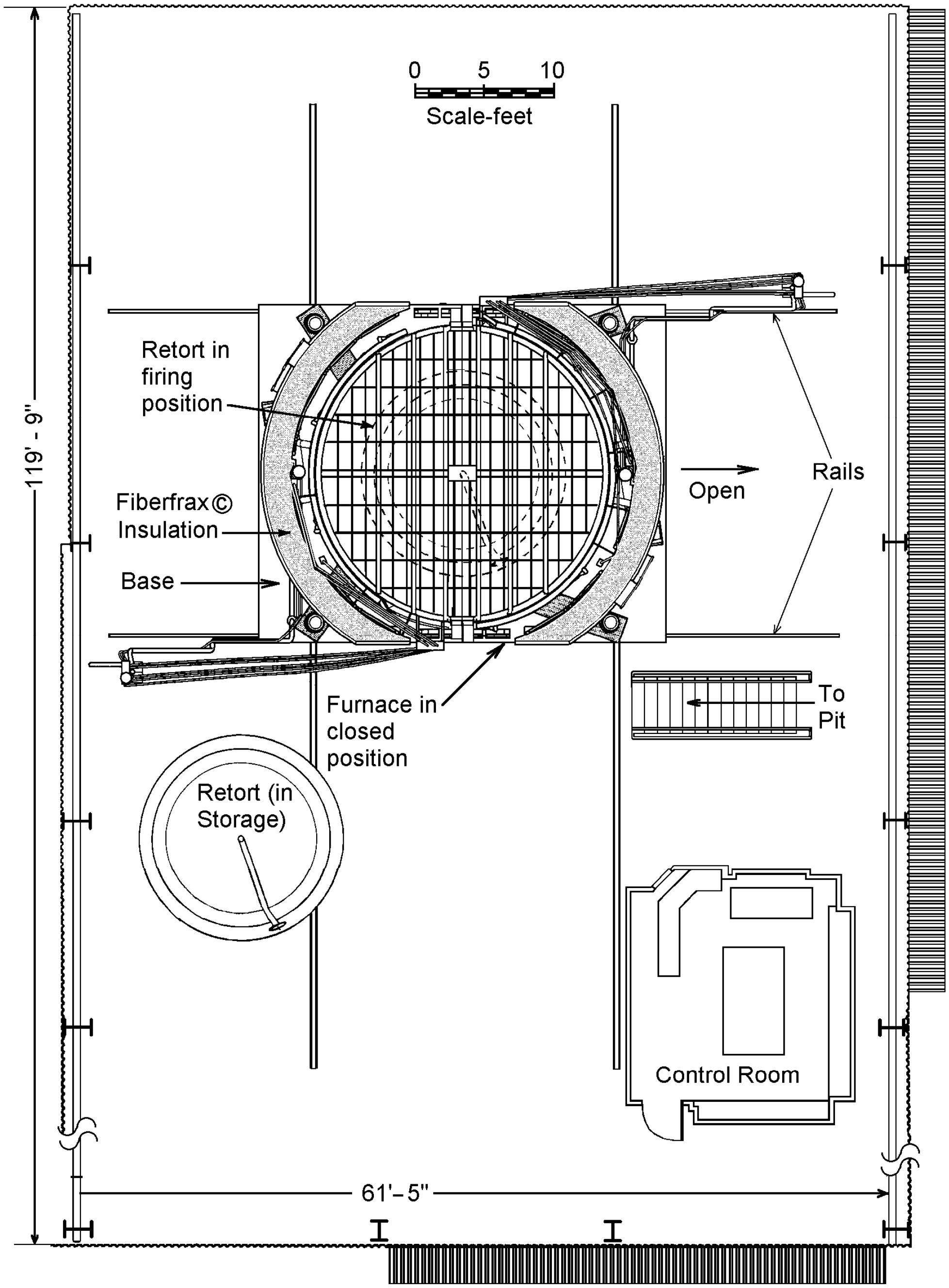


Figure 3 - Floor Plan of Pacific Furnace Facility

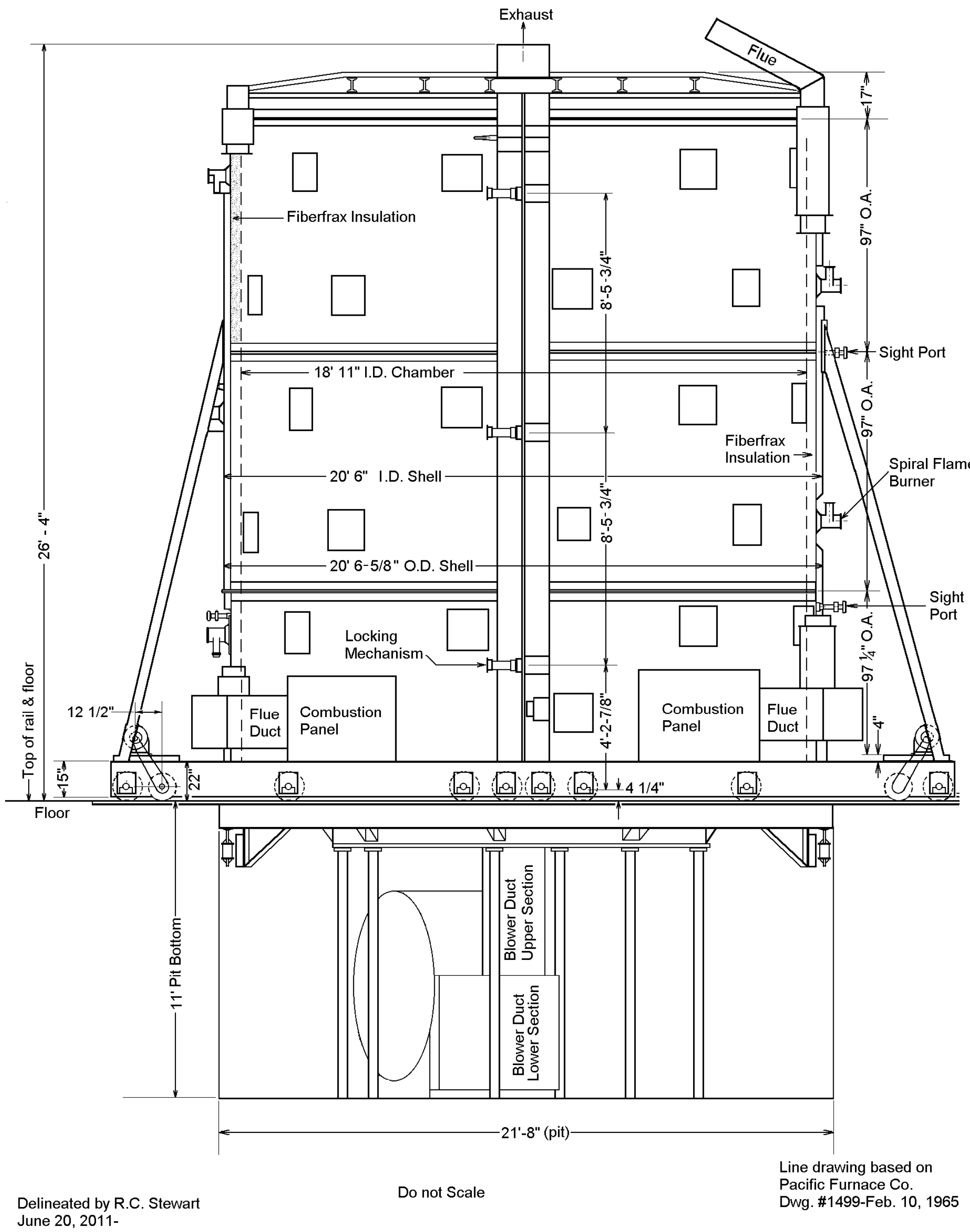


Figure 4 - Elevation sketch of Pacific Furnace

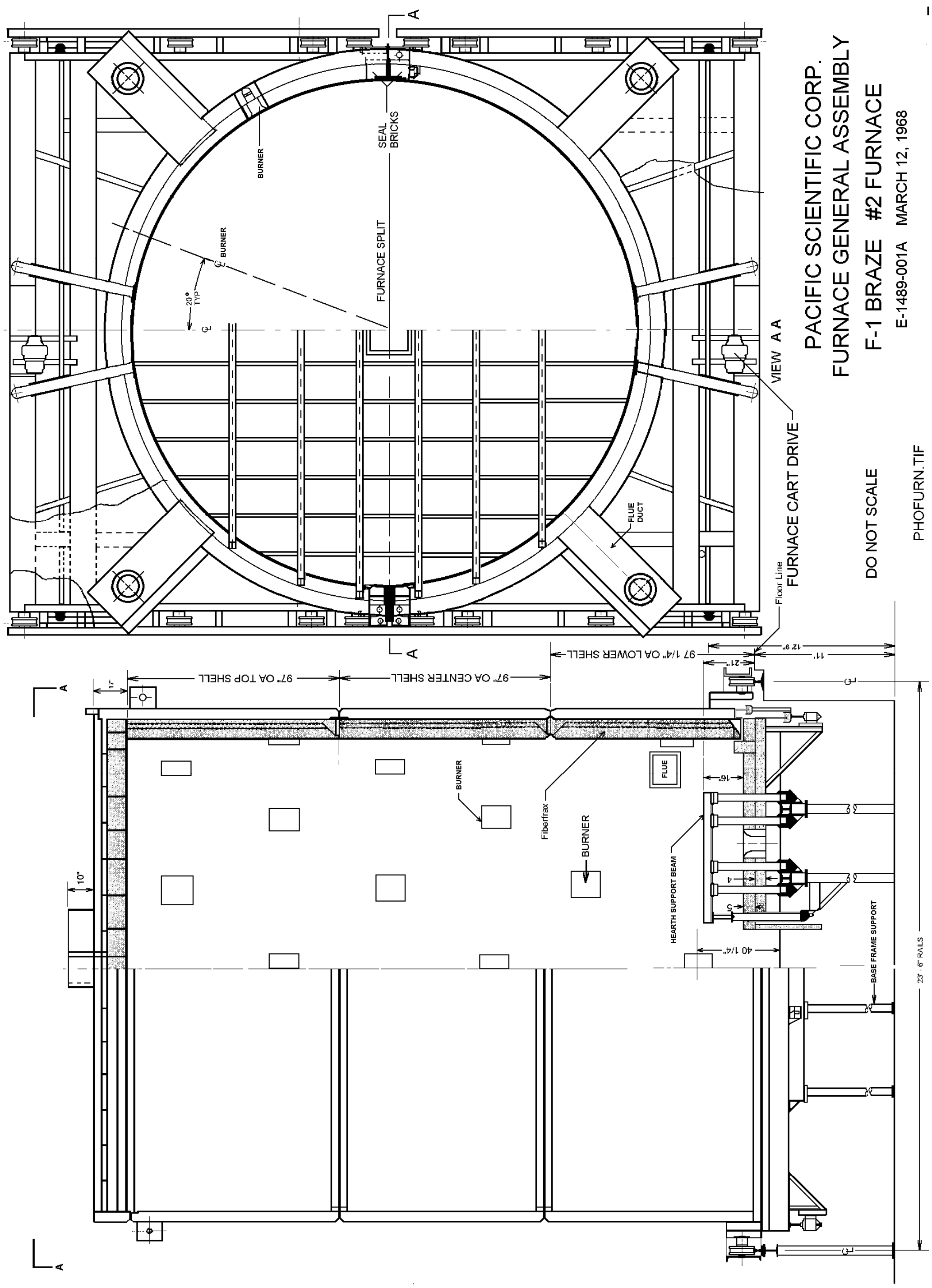


Figure 5 - Roof and Elevation of the Pacific Furnace

Figure 6 - Interior view of nozzle with tubes in place.

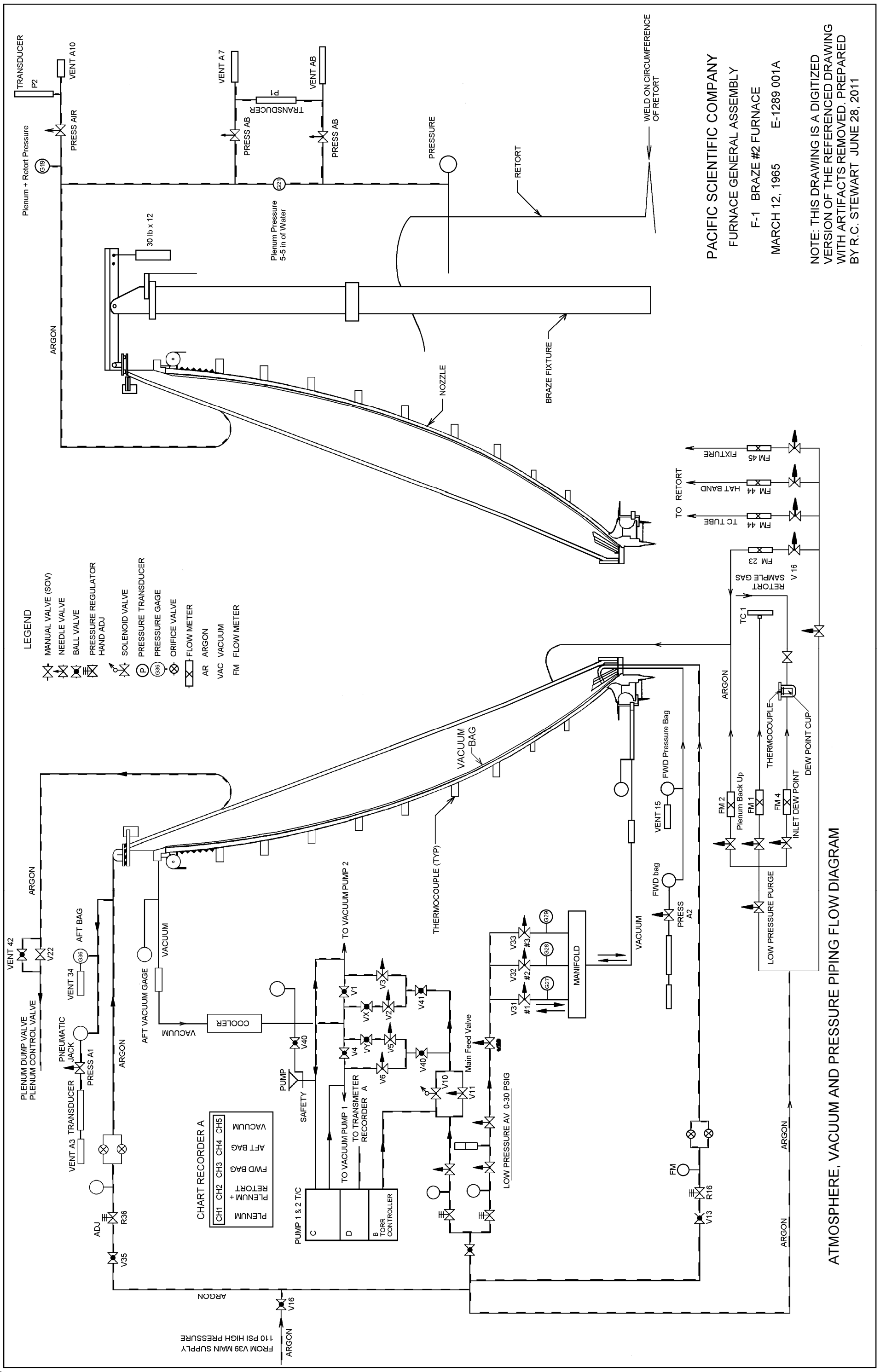


Figure 7- Retort set-up and schematic piping for the SSME

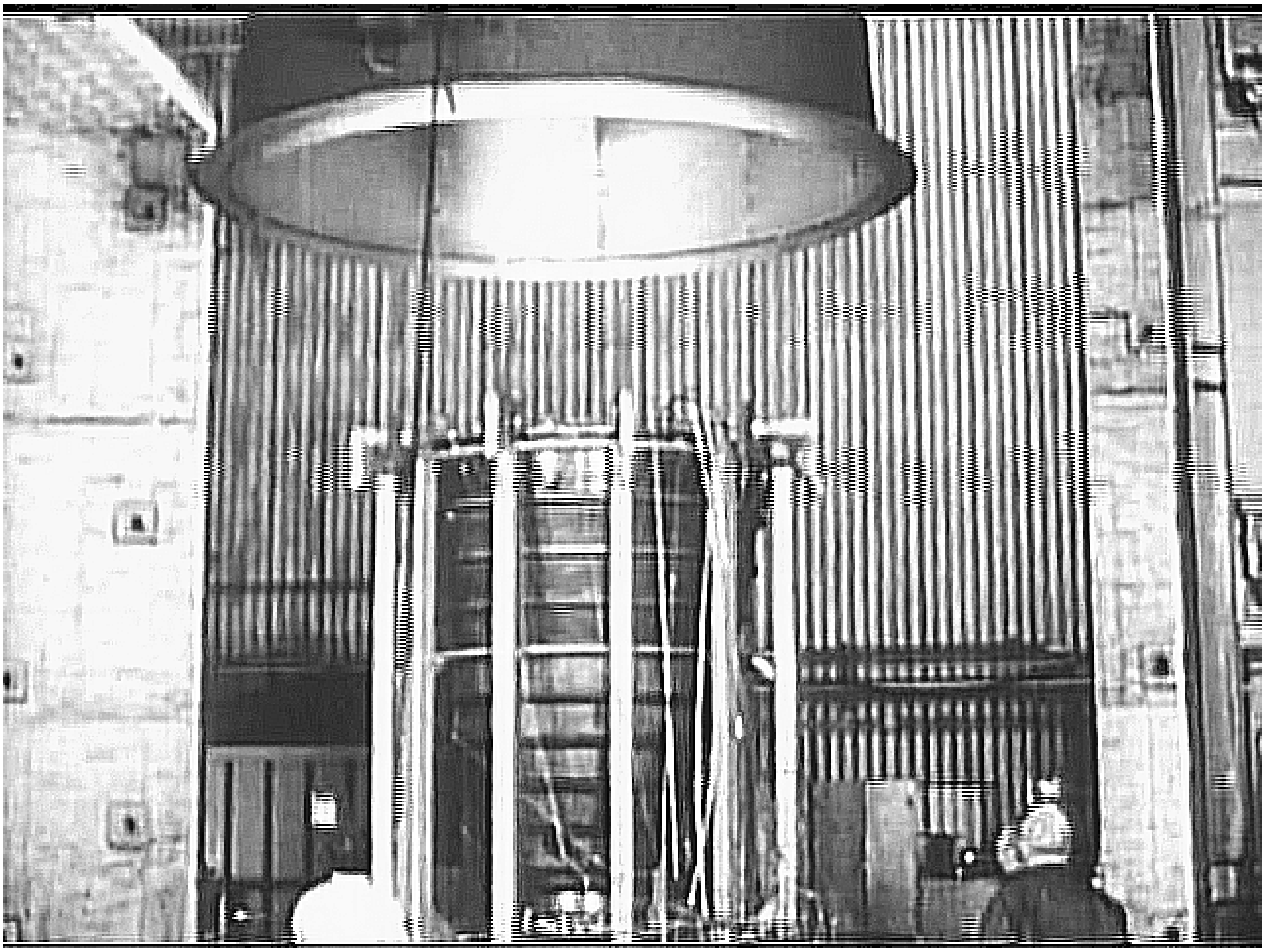

Figure 8 - Nozzle in position for first firing-note "bellows" fixed to nozzle and uprights which support pulleys and 12 - 30 lb. counterweights space evenly around the nozzle.

Figure 9 - Nozzle ready for second firing. Retort being lowered into position.

Figure 10 - Nozzle after second firing.