ATMOSPHERIC REENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY

BUILDING 222

HISTORICAL DOCUMENTATION

Prepared for:
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

Prepared by:
Archaeological Consultants, Inc.
Sarasota, Florida

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PREFACE

In response to President George W. Bush's announcement in January 2004 that the Space Shuttle Program (SSP) would end in 2010, the National Aeronautics and Space Administration (NASA) completed a nation-wide historical survey and evaluation of NASA-owned facilities and properties (real property assets) at all its Centers and component facilities. The buildings and structures which supported the SSP were inventoried and assessed as per the criteria of eligibility for listing in the National Register of Historic Places (NRHP) in the context of this program. This study was performed in compliance with Section 110 of the National Historic Preservation Act (NHPA) of 1966 (Public Law 89-665), as amended; the National Environmental Policy Act (NEPA) of 1969 (Public Law 91-190); Executive Order (EO) 11593: Protection and Enhancement of the Cultural Environment; EO 13287: Preserve America, and other relevant legislation.

As part of this nation-wide study, in September 2006, a historical survey and evaluation of NASA-owned and managed facilities was conducted by NASA's Lyndon B. Johnson Space Center (JSC) in Houston, Texas. The results of this study are presented in a report entitled "Survey and Evaluation of NASA-owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program, Lyndon B. Johnson Space Center, Houston, Texas," which was prepared in November 2007 by NASA JSC's contractor, Archaeological Consultants, Inc. As a result of this survey, the Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF; Building 222) was determined eligible for listing in the NRHP, with concurrence by the Texas State Historic Preservation Officer (SHPO). The survey concluded that Building 222 is eligible for the NRHP under Criteria A and C in the context of the U.S. Space Shuttle Program (1969-2010). Because it has achieved significance within the past 50 years, Criteria Consideration G applies.

At the time of this documentation, Building 222 was still used to support the SSP as a research and development facility. This documentation package precedes any undertaking as defined by Section 106 of the NHPA, as amended, and implemented in 36 CFR Part 800, as NASA JSC has decided to proactively pursue efforts to mitigate the potential adverse affects of any future modifications to the facility. It includes a historical summary of the SSP; the history of JSC in relation to the SSP; a narrative of the history of Building 222 and how it supported the SSP; and a physical description of the structure. In addition, photographs documenting the construction and historical use of Building 222 in support of the SSP, as well as photographs of the facility documenting the existing conditions, special technological features, and engineering details, are included. A contact sheet printed on archival paper, and an electronic copy of the work product on CD, are also provided.

ACKNOWLEDGEMENTS

Archaeological Consultants, Inc. (ACI) of Sarasota, Florida extends their gratitude to Perri E. Fox, NASA JSC's Shuttle Transition Manager, and Sandra J. Tetley, NASA JSC's Real Property Officer and Historic Preservation Officer (HPO), for making all arrangements for access and information gathering in support of this documentation. We also thank the staff of the JSC Imagery Repository for their cooperation in providing historical photographs; and the staff of the Engineering Drawing Control Center for their cooperation in providing architectural drawings of the facility. We deeply appreciate the efforts of Tien Nguyen, Building 222 Facility Manager, for serving as ACI's point of contact at the facility and providing valuable information on its use in support of the Space Shuttle program. Finally, we would like to thank Rebecca Wright and Jennifer Ross-Nazzal of Tessada & Associates, for conducting oral histories, which greatly enhanced our discussion of the building, and passing along the additional information generously provided to them by Donald Tillian.

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ATMOSPHERIC REENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY
BUILDING 222
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

Basic Information

Location:	North of Avenue B, between Third Street and Fourth Street Johnson Space Center Houston Harris County Texas U.S.G.S. 7.5. minute League City, Texas, quadrangle, Universal Transverse Mercator coordinates: 15.298090.3272115
Date of Construction:	1965-1966
Architect/Engineer:	Dale S. Cooper & Associates, Houston; Cummins-Reed & Clements, Houston
Builder:	Baxter Construction Company, Inc., Houston
Present Owner:	National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas
Present Use:	Testing of the thermal protection system materials used on the Space Shuttle orbiter vehicle.
Significance:	The Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF) is considered eligible for listing in the National Register of Historic Places (NRHP) in the context of the U.S. Space Shuttle Program (ca. 1969-2010) under Criterion A in the area of Space Exploration and under Criterion C in the area of Engineering. Because it has achieved significance within the past 50 years, Criteria Consideration G applies. The JSC ARMSEF, in addition to the facility at Ames Research Center in California, are the only two NASA-owned arc jet facilities with the capability to test and verify the thermal performance of every type of thermal protection system (TPS) material used on the Space Shuttle. Work at the JSC arc jet facility has contributed significantly to the selection of TPS materials, improvements in TPS technology, and has provided a better understanding of the operational limits and the lifespan of thermal protection materials. Additionally, numerous damage assessment tests completed here played a key role in NASA's Return to Flight efforts in the

aftermath of the *Columbia* accident. In the area of engineering, the arc jet facility was uniquely constructed to simulate the critical environmental conditions associated with the orbiter's reentry into the Earth's atmosphere. Although the ARMSEF has undergone major refurbishment to enhance facility capabilities to support the Space Shuttle Program, these changes have been evolutionary equipment upgrades; therefore, its integrity has not been compromised.

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The U.S. Space Shuttle Program

In February 1969, President Richard Nixon established a Space Task Group (STG) to recommend a future course for the U.S. Space Program to follow the Apollo Program. The STG presented the President with three choices of long-range plans, all of which included an Earth–orbiting space station, a space shuttle, and a manned Mars expedition.[1] Although none of the original programs presented was eventually selected, the National Aeronautics and Space Administration (NASA) implemented a program, shaped by the politics and economic realities of the time, which served as a first step toward any future plans for implementing a space station.[2]

On January 5, 1972, President Nixon delivered a speech in San Clemente, California, in which he outlined the end of the Apollo Era and the future of a reusable space flight vehicle, the Space Shuttle, which would provide "routine access to space." By commencing work at this time, Nixon added, "we can have the Shuttle in manned flight by 1978, and operational a short time after that."[3] As part of the speech, President Nixon instructed NASA to proceed with the design and building of a partially reusable space shuttle consisting of a reusable orbiter, three reusable main engines, two reusable solid rocket boosters (SRBs), and one non-reusable external liquid fuel tank (ET). NASA's administrators vowed that the shuttle would fly at least fifty times a year, making space travel economical and safe.

NASA gave responsibility for developing the shuttle orbiter vehicle and overall management of the Space Shuttle Program (SSP) to the Manned Spacecraft Center (MSC, now Johnson Space Center [JSC]) in Houston, based on the Center's experience. The Marshall Space Flight Center (MSFC) in Huntsville, Alabama, was responsible for development of the Space Shuttle Main Engine (SSME), SRBs, the ET, and for all propulsion-related tasks. Engineering design support continued at MSC, MSFC and NASA's Langley Research Center (LaRC), in Virginia, and engine tests were to be performed at NASA's Mississippi National Space Technology Laboratories (later named Stennis Space Center) and at the Air Force's Rocket Propulsion Laboratory in California, which later became the Santa Susana Field Laboratory.[4] NASA selected the Kennedy Space Center (KSC) in Florida, as the primary launch and landing site for the SSP. KSC, responsible for designing the launch and recovery facilities, was to develop methods for shuttle assembly, checkout, and launch operations.[5]

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[1] NASA, History Office, NASA Headquarters, "Report of the Space Task Group, 1969."
[2] Dennis R. Jenkins. *Space Shuttle, The History of the National Space Transportation System. The First 100 Missions* (Cape Canaveral, Florida: Specialty Press, 2001), 99.
[3] Marcus Lindroos. "President Nixon's 1972 Announcement on the Space Shuttle" (NASA Office of Policy and Plans, NASA History Office, updated April 14, 2000).
[4] Jenkins, 122.
[5] Linda Neuman Ezell. *NASA Historical Databook Volume III Programs and Projects 1969-1978.* The NASA History Series, NASA SP-4012 (Washington, D.C.: NASA History Office, 1988), Table 2-57; Ray A. Williamson. "Developing the Space Shuttle." *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program, Volume IV: Accessing Space* (Edited by John M. Logsdon. Washington, D.C.: U.S. Printing Office, 1999), 172-174.

On September 17, 1976, the full-scale orbiter vehicle (OV) prototype, *Enterprise* (OV-101), was completed. Designed for test purposes only and never intended for space flight, structural assembly of this orbiter had started more than two years earlier in June 1974 at Air Force Plant (AFP) 42 in Palmdale, California. Although the *Enterprise* was an aluminum shell prototype incapable of space flight, it reflected the overall design of the orbiter. As such, it served successfully in 1977 as the test article during the Approach and Landing Tests (ALT) aimed at checking both the mating with the shuttle carrier aircraft (SCA) for ferry operations, as well as the orbiter's unpowered landing capabilities.

The first orbiter intended for space flight, *Columbia* (OV-102*)*, arrived at KSC from the shuttle assembly facility in Palmdale in March 1979. Originally scheduled to lift off in late 1979, the launch date was delayed by problems with both the SSME components, as well as the thermal protection system (TPS). *Columbia* spent 610 days in the Orbiter Processing Facility (OPF), another thirty-five days in the Vehicle Assembly Building (VAB), and 105 days on Pad 39A before finally lifting off on April 12, 1981. STS-1, the first orbital test flight and first Space Shuttle program mission, ended with a landing on April 14 at Edwards Air Force Base (AFB) in California. This launch demonstrated *Columbia's* ability to fly into orbit, conduct on-orbit operations, and return safely.[6] *Columbia* flew three additional test flights in 1981 and 1982, all with a crew of two. The Orbital Test Flight Program ended in July 1982 with 95% of its objectives completed. After the end of the fourth mission, President Ronald Reagan declared that with the next flight the Shuttle would be "fully operational."

A total of 129 Space Shuttle missions have been launched from the KSC between April 1981 and December 2009. From April 1981 until the *Challenger* accident in January 1986, between two and nine missions were flown yearly, with an average of four to five per year. The milestone year was 1985, when nine flights were successfully completed. The years between 1992 and 1997 were the most productive, with seven or eight yearly missions. Since 1995, in addition to its unique responsibility as the shuttle launch site, KSC also became the preferred landing site.

Over the past two decades, the SSP has launched a number of planetary and astronomy missions including the Hubble Space Telescope (HST), the Galileo probe to Jupiter, Magellan to Venus, and the Upper Atmospheric Research Satellite. In addition to astronomy and military satellites, a series of Spacelab research missions were flown, which carried dozens of international experiments in disciplines ranging from materials science to plant biology. Spacelab was a manned, reusable, microgravity laboratory flown into space in the rear of the Space Shuttle cargo bay. It was developed on a modular basis allowing assembly in a dozen arrangements depending on the specific mission requirements.[7] The first Spacelab mission, carried aboard *Columbia* (STS-9), began on November 28, 1983. Four Spacelab missions were flown between 1983 and 1985. Following a hiatus in the aftermath of the *Challenger* disaster, the next Spacelab mission was not launched until 1990. In total, twenty-four Space Shuttle missions carried Spacelab

[6] Jenkins, 268.
[7] NASA. *NASA Shuttle Reference Manual* (1988).

hardware before the program was decommissioned in 1998.[8] In addition to astronomical, atmospheric, microgravity, and life sciences missions, Spacelab was also used as a supply carrier to the HST and the Soviet space station *Mir*.

In 1995, a joint U.S./Russian Shuttle-*Mir* Program was initiated as a precursor to construction of the International Space Station (ISS). *Mir* had been launched in February 1986 and remained in orbit until March 2001.[9] The first approach and flyaround of *Mir* took place on February 3, 1995 (STS-63); the first *Mir* docking was in June 1995 (STS-71, *Atlantis*). During the three-year Shuttle-*Mir* Program (June 27, 1995 to June 2, 1998) the Space Shuttle docked with *Mir* nine times. All but the last two of these docking missions used the Orbiter *Atlantis*. Many of the activities carried out were similar to what would be performed on the ISS.[10]

On December 4, 1999, *Endeavour* (STS-88) launched the first component of the ISS into orbit. As noted by Williamson, this event marked, "at long last the start of the Shuttle's use for which it was primarily designed – transport to and from a permanently inhabited orbital space station."[11] STS-96 (*Discovery*), launched on May 27, 1999, marked the first mission to dock with the ISS. Since that time, most Space Shuttle missions have supported the continued assembly of the space station. As currently planned, ISS assembly missions will continue through the life of the SSP.

The SSP suffered two major setbacks with the tragic losses of *Challenger* and *Columbia* on January 28, 1986, and February 1, 2003, respectively. Following the *Challenger* accident, the SSP was suspended, and President Ronald Reagan formed a thirteen-member commission to identify the cause of the disaster. The Rogers Commission report, issued on June 6, 1986, which also included a review of the SSP, concluded "that the drive to declare the Shuttle operational had put enormous pressures on the system and stretched its resources to the limit."[12] In addition to mechanical failure, the Commission noted a number of NASA management failures that contributed to the catastrophe. As a result, among the tangible actions taken were extensive redesign of the SRBs; an upgrade of the Space Shuttle tires, brakes, and nose wheel steering mechanisms; the addition of a drag chute to help reduce speed upon landing; the addition of a crew escape system; and the requirement for astronauts to wear pressurized flight safety suits during launch and landing operations. Other changes involved reorganization and decentralization of the SSP. NASA moved the management of the program from JSC to NASA Headquarters, with the aim of preventing communication deficiencies.[13] Experienced astronauts were placed in key NASA management positions, all documented waivers to existing flight safety criteria were revoked and forbidden, and a policy of open reviews was implemented.[14] In

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[8] STS-90, which landed on May 3, 1998, was the final Spacelab mission. NASA. "Shuttle Payloads and Related Information." *KSC Factoids* Revised November 18, 2002.
[9] Tony Reichhardt (editor). *Space Shuttle, The First 20 Years* (Washington, D.C.: Smithsonian Institution, 2002), 85.
[10] Judy A. Rumerman, with Stephen J. Garber. *Chronology of Space Shuttle Flights 1981-2000*. HHR-70 (Washington, D.C.: NASA History Division, Office of Policy and Plans, October 2000), 3.
[11] Williamson, 191.
[12] Columbia Accident Investigation Board (CAIB). *Report Volume I* (August 2003), 25.
[13] CAIB, 101.
[14] Cliff Lethbridge. "History of the Space Shuttle Program" (2001), 4.

addition, NASA adopted a Space Shuttle flight schedule with a reduced average number of launches, and discontinued the long-term practice of launching commercial and military payloads.[15] The launch of *Discovery* (STS-26) from KSC Pad 39B on September 29, 1988, marked a Return to Flight after a 32-month hiatus in manned spaceflight following the *Challenger* accident.

In the aftermath of the 2003 *Columbia* accident, a seven month investigation ensued, concluding with the findings of the Columbia Accident Investigation Board (CAIB), which determined that both technical and management conditions accounted for the loss of the orbiter and crew. According to the CAIB Report, the physical cause of the accident was a breach in the TPS on the leading edge of the left wing, caused by a piece of insulating foam, which separated from the ET after launch and struck the wing.[16] NASA spent more than two years researching and implementing safety improvements for the orbiters, SRBs and ET. Following a two-year hiatus, the launch of STS-114 (*Discovery*) on July 26, 2005, marked the first Return to Flight since the loss of *Columbia*.

On January 14, 2004, President George W. Bush outlined a new space exploration initiative in a speech given at NASA Headquarters.

> *Today I announce a new plan to explore space and extend a human presence across our solar system . . . Our first goal is to complete the International Space Station by 2010 . . . The Shuttle's chief purpose over the next several years will be to help finish assembly of the International Space Station. In 2010, the Space Shuttle – after nearly 30 years of duty – will be retired from service. . . Our second goal is to develop and test a new spacecraft, the Crew Exploration Vehicle, by 2008, and to conduct the first manned mission no later than 2014. . . Our third goal is to return to the Moon by 2020, as the launching point for missions beyond ...*[17]

Following the President's speech, NASA released *The Vision for Space Exploration*, which outlined the Agency's approach to the new direction in space exploration.[18] In 2006, NASA announced the start of the Constellation Program, which included development of the Crew Exploration Vehicle (CEV), named *Orion*, and a launch vehicle to place the CEV into space. As part of this initiative, NASA decided to use the Space Shuttle to complete assembly of the ISS, after which the SSP would be retired. The Constellation Program, and its vehicles, would then take over transporting humans to the ISS, and eventually carry both crew and cargo on missions to explore the Moon, Mars, and beyond.

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[15] Lethbridge, 5.
[16] CAIB, 9.
[17] The White House. "A Renewed Spirit of Discovery – The President's Vision for Space Exploration" (January 2004).
[18] National Aeronautics and Space Administration (NASA), Headquarters. "The Vision for Space Exploration" (February 2004).

On October 11, 2010, President Barack Obama signed the *National Aeronautics and Space Administration Authorization Act of 2010*, which redefined the future direction of NASA. As part of this Act, the moon-oriented Constellation Program was cancelled in favor of a manned mission to an asteroid by 2025, followed by a manned mission to Mars in the 2030s. The CEV, however, was retained to serve as an escape capsule for the ISS and, potentially, a deep space vehicle. The plan also extended operations on the ISS to the year 2020, calling for private American companies to develop spacecraft for carrying astronauts to the station.[19]

[19] "President Obama Signs NASA Space Exploration Act Into Law." FoxNews.com, October 12, 2010; *National Aeronautics and Space Administration Authorization Act of 2010*, 111th Congress, 2d session (October 11, 2010).

Lyndon B. Johnson Space Center

The Lyndon B. Johnson Space Center (JSC) officially opened in June 1964 as the Manned Spacecraft Center (MSC). This approximately 1,620-acre facility is located about 25 miles from downtown Houston, Texas, in Harris County. Many of the buildings are specialized facilities devoted to spacecraft systems, materials research and development, and astronaut training. JSC also includes the Sonny Carter Training Facility, located roughly 4.5 miles to the northwest of the center, close to Ellington Field. Opened in 1997, this facility is situated on land acquired through a lease/purchase agreement with the McDonnell Douglas Corporation. In addition, NASA JSC owns some of the facilities at Ellington Field, which are generally where the aircraft used for astronaut training are stored and maintained.

The origins of JSC can be traced to the summer of 1958 when three executives of the National Advisory Committee for Aeronautics (NACA), Dr. Hugh L. Dryden, Dr. Robert R. Gilruth, and Dr. Abe Silverstein, began to formulate a space program.[20] Almost immediately, Gilruth began to focus on manned spaceflight, and subsequently convened a group of his associates at Langley Aeronautical Laboratory, in Hampton, Virginia. This group compiled the basics of what would become Project Mercury, the first U.S. manned space program. Eight days following the activation of NASA (October 1, 1958), with the approval of NASA's first administrator, Dr. T. Keith Glennan, the Space Task Group (STG) was created to implement this program.[21] The group was formally established on November 3, 1958, with Gilruth named as Project Manager. The initial staff of the STG came from Langley, but was soon supplemented with engineers from Lewis Research Center, in Cleveland, Ohio (now John H. Glenn Research Center), and AVRO Aircraft, Ltd. of Canada.[22]

At first, the STG's offices were located at Langley. With the May 1959 establishment of the Goddard Space Flight Center in Greenbelt, Maryland, plans were made to move the STG to Goddard, thus creating a new "space projects center," but it was later decided to leave the STG at Langley until the completion of Project Mercury.[23] However, as Project Mercury continued and NASA began to consider sending men to the Moon, it was obvious that the STG, which at that moment was essentially a project office, would need to develop into an autonomous center, and

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[20] Dryden was the Director of NACA; Gilruth was the head of the flight research section of NACA's Langley Aeronautical Laboratory in Hampton, Virginia; and Silverstein was the Director of NACA's Lewis Flight Propulsion Laboratory in Cleveland, Ohio. James M. Grimwood. *Project Mercury: A Chronology* (Washington, D.C.: NASA, Office of Scientific and Technical Information, 1963); Roger D. Launius. *NASA: A History of the U.S. Civil Space Program* (Malabar, Fla.: Krieger Publishing Company, 2001), 29.

[21] As part of NASA's establishment, NACA, was deactivated and all of its personnel and facilities were transferred to NASA. Also at this time, the names of the three NACA Laboratories were changed: Langley Aeronautical Laboratory became Langley Research Center; Lewis Flight Propulsion Laboratory became Lewis Research Center; and Ames Aeronautical Laboratory (at Moffitt Field, in California) became Ames Research Center. Loyd S. Swenson, Jr., James M. Grimwood and Charles C. Alexander. *This New Ocean: A History of Project Mercury* (Washington, D.C.: NASA, Office of Technology Utilization, 1966), 113.

[22] Grimwood; Swenson, et al., 153.

[23] Swenson, et al., 115.

on January 3, it was designated as such.[24] The May 25, 1961, announcement by President John F. Kennedy to send a man to the Moon by the end of the decade reinforced the idea that the STG needed its independence, and soon. Thus, in August 1961, John Parsons, Associate Director of the Ames Research Center (ARC), was charged with establishing a survey team to locate a site for the new center.[25]

On September 19, 1961, James Webb, NASA Administrator, announced that Houston, Texas, would be the site for NASA's new Center for Manned Spaceflight.[26] Numerous factors influenced the choice of Houston as the home of the MSC. First of all, Rice University was willing to donate 1000 acres of land for the Center. Additionally, Houston met all of the requirements set forth in the selection criteria. For example, air operations could be supported at nearby Ellington Air Force Base, and the proximity of Clear Lake and Galveston Bay facilitated barge traffic. Houston also has a year-round moderate climate, and both Rice University and the University of Houston were in close proximity to the new site.[27]

On November 1, 1961, the STG officially became the "Manned Spacecraft Center," with Gilruth as its first Director.[28] The first employees officially transferred to Houston from Langley were Ed Campagna of the Facilities Division, John Powers, from Public Affairs, and Martin Byrnes, Site Manager; their first offices were two vacant dress shops in the Gulfgate Shopping Center, which were donated by its site manager, Marvin Kaplan.[29] The trio was assigned the responsibilities of procuring temporary office space, hiring new personnel, and meeting with local organizations to help facilitate the needs of those co-workers who would soon be joining them.[30] From November 1961 until April 1962, nearly 400 additional employees were transferred from LaRC to Houston; the new Center officially became operational in Houston on March 1, 1962, when Gilruth moved the MSC's headquarters there.[31]

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[24] Swenson, et al., 251.
[25] Swenson, et al., 363-364.
[26] Glennan resigned effective January 22, 1961 when President Eisenhower left office. Webb was sworn into office on February 15, 1961. Grimwood.
[27] From a political viewpoint, Houston was located within the district of U.S. House Representative, Albert Thomas, chairman of the House Appropriations Committee, and Texas was the home state of Vice President Lyndon B. Johnson. Dr. Robert Gilruth Oral History Interview, February 27, 1987, 273-275, *The Glennan-Webb-Seamans Project*, National Air and Space Museum.
[28] "STG Renamed; Will Move." *Space News Roundup* (1, 1), November 1, 1961, 1.
[29] Martin A. Byrnes, Jr., interview by Robert Merrifield, December 12, 1967 (Houston, TX, Archives Department, Lyndon B. Johnson Space Center), 6.
[30] Temporary offices were located in buildings throughout the Houston area, including the Phil Rich Building, the Farnsworth-Chambers Building, the Lane-Wells Building, the Canada Dry Bottling Building, and a Veterans Administration Building; and at Ellington Field. "Houston Site Offices Move to Rich Building." *Space News Roundup* (1, 3), November 29, 1961, 1; "Move To Houston Area Is On Schedule." *Space News Roundup* (1, 6), January 10, 1962, 1; "Photo Captions." *Space News Roundup* (1, 18), June 27, 1962, 2.
[31] Henry C. Dethloff. *Suddenly, Tomorrow Came…A History of the Johnson Space Center* (Houston: Lyndon B. Johnson Space Center, 1993), 48.

To supplement the 1000 acres of land promised by Rice University, NASA purchased an additional 620 acres, mainly to provide highway access for the estimated 4000 employees.[32] In September 1961, the Fort Worth Division of the U.S. Army Corps of Engineers (ACOE), under District Engineer, Colonel R. Paul West, was designated as the construction agency for the new Center. Their first task was to hire an architecture/engineering (A/E) team to complete the initial design work. Twenty teams were considered for the initial contract, and after three rounds of reviews and cuts, an A/E team headed by Brown & Root, Inc., of Houston, Texas, was selected. Partnered with them were master planners Charles Luckman Associates, Los Angeles, California; and the architectural firms of Brooks & Barr, Austin, Texas; Harvin C. Moore, Houston, Texas; MacKie & Kamrath, Houston, Texas; and Wirtz, Calhoun, Tungate, & Jackson, Houston, Texas.[33] The nearly $1.5 million contract was officially awarded in December 1961, and included general site development; master planning; design of the flight project facility, the engineering evaluation laboratory and the flight operations facility; and various site utilities.[34]

Charles Luckman Associates developed the master plan of the Center, and "did an outstanding job of meeting the functional requirements that had been set forth in developing a campus-like atmosphere for the facility."[35] The central "quad" area was bounded by 2nd Street on the west, Avenue D on the south, 5th Street on the east, and Avenue C on the north. Three "lagoons" surrounded by small, man-made hills, as well as various walkways, trees, and shrubs characterized the quad area.[36] Luckman Associates also advocated the use of a modular design system for the buildings with materials that could be manufactured off-site, which aided in meeting the tight schedule for completion. Most of the buildings incorporated a poured concrete foundation, and skeletal steel walls faced with precast exposed aggregate facing (PEAF) panels. This allowed for the fabrication of the steel components while the foundation was being poured, and subsequently the manufacture of the PEAF panels while the steel skeleton was being erected.[37]

Initial construction of the Center was completed in three main phases. The contract for the first phase, preliminary site development, was awarded on March 29, 1962, to a joint venture of Morrison-Knudsen Construction Company of Boise, Idaho, and Paul Hardeman of Stanton, California; it amounted to $3,673,000. They began the work in early April; it was completed on July 18, 1963.[38] The task included "overall site grading and drainage, utility installations

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[32] "Interview with I. Edward Campagna, Assistant Chief, Technical Services Division, Maintenance and Operations." August 24, 1967, Box MERR1, Oral History Series. Johnson Space Center History Collection, University of Houston-Clear Lake; Dethloff, 48.
[33] "Photo Captions." *Space News Roundup* (1, 12), April 4, 1962, 2.
[34] "Design Work Contract Is Let For Clear Lake." *Space News Roundup* (1, 5), December 27, 1961, 8.
[35] "Interview with James L. Ballard, Jr." August 1, 1968, Box MERR1, Oral History Series. Johnson Space Center History Collection, University of Houston-Clear Lake.
[36] Campagna, August 24, 1967.
[37] Ballard, August 1, 1968; Campagna, August 24, 1967.
[38] "First Construction Contract Work Underway at Clear Lake." *Space News Roundup* (1, 13), April 18, 1962, 1; "Clear Lake Site Commitment Now Stands At $38,911,458." *Space News Roundup* (3, 4), December 11, 1963, 3.

including an electrical power system, a complete water supply and distribution system, sanitary and storm drainage systems, basic roads, security fence and street lighting."[39]

The invitations to bid for the Phase II contract of the construction, which was the first to include actual buildings, were distributed in early July 1962. At first, the task included an office building, a shop building and warehouse, a garage, a central heating and cooling plant, a fire station, and a sewage disposal plant, as well as all necessary paving and utilities for these structures.[40] By the time bids were received and opened, the statement of work had been revised to exclude the office building, the shop building, and the warehouse, all of which were replaced by the Data Processing Center (Building 12). The task had changed a second time, prior to contract award in October 1962. In the end, the ACOE signed a contract with the joint venture of W.S. Bellows Construction Corporation and Peter Kiewit & Sons Corporation, both of Houston, in the amount of $4,145,044, for the construction of Building 12, the sewage disposal plant, the central heating and cooling plant, the fire station, and a water treatment plant and associated building.[41] Of these facilities, the fire station was the first to be completed in September 1963; the central heating and cooling plant was last, finished in December 1963.[42]

Phase III of the Center's construction incorporated the largest grouping of buildings under one contract. The invitations to bid on this phase were issued on September 25, 1962, and listed ten buildings with an approximate total area of 760,000 square feet.[43] Similar to Phase II, the statement of work was revised prior to the submittal of the bids to include eleven office and lab buildings, and the temperature and humidity control machinery for the entire site. Interested firms were also asked to submit alternate proposals that incorporated additional facilities, which NASA was hoping to add to the contract if funding became available.[44] On December 3, 1962, Colonel Francis P. Koish, the new ACOE District Engineer, signed the official contract, which amounted to roughly $19 million, with the joint venture of C.H. Leavell and Company of El Paso, Texas, Morrison-Knudsen Construction Company, and Paul Hardeman. Eleven major facilities were part of this contract, including the project management building, the cafeteria, the flight operations and astronaut training facility, the crew systems laboratory, the technical services office and shop buildings, the systems evaluation laboratory, a spacecraft research lab and office building, and a data acquisition building. Funding for other facilities had become available by this time, so additional support buildings, such as the shop building and warehouse,

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[39] "Interview with Jack P. Shields." August 1, 1968, Box MERR4, Oral History Series. Johnson Space Center History Collection, University of Houston-Clear Lake; "First Construction Contract Work."
[40] "Second Major Clear Lake Building Contract Awarded." *Space News Roundup* (1, 17), June 13, 1962, 8.
[41] "Bids Open On Phase Two Of Clear Lake Work." *Space News Roundup* (1, 23), September 5, 1962, 1; "Phase II Contract Goes to Bellows, Peter Kiewet, Sons." *Space News Roundup* (1, 25), October 3, 1962, 8; Shields, August 1, 1968.
[42] "Photo Captions." *Space News Roundup* (2, 23), September 4, 1963, 3; "Central Heating and Cooling Plant Completed." *Space News Roundup* (3, 5), December 25, 1963, 8.
[43] "First Building Contract To Be Let In November." *Space News Roundup* (1, 20), July 25, 1962, 8.
[44] "Bids Open On Phase 3 Of Center Construction." *Space News Roundup* (2, 2), November 11, 1962, 1-2.

were also included. Per the contract, the buildings were to be ready for occupancy in 450 calendar days.[45]

In October 1963, the Logistics Division became the first to move into its complete facility, the Support Office (Building 419) and its shops and warehouse (Building 420). By the end of 1963, twelve additional buildings were certified as operational.[46] The major relocation to the new Center occurred between February and April 1964, and included the occupation of facilities such as the Auditorium and Public Affairs Facility (Building 1), the Flight Crew Operations Office (Building 4), the Flight Crew Operations Lab (Building 7), the Systems Evaluation Lab (Building 13), and the Spacecraft Technical Lab (Building 16). The Director's office officially moved on March 6, 1964, into what was then Building 2 (it was later designated Building 1, the Project Management Building; the original Building 1, the Auditorium and Public Affairs Facility, became Building 2 at that time). During May, the Instrument and Electronics Lab (Building 15) was occupied, followed by the Manned Spaceflight Control Center, Houston (Building 30) at the end of June, when all leases on the temporary facilities expired.[47]

Although the MSC officially moved to Houston prior to the completion of Project Mercury, Project Gemini and the Apollo Program were the first tasks to be organized and operated from the new Center.[48] The Apollo Program, initiated in 1960, was officially announced by President Kennedy on May 25, 1961. Project Gemini was officially announced in December 1961, less than two months after the STG was renamed the MSC, because NASA officials decided that an intermediate step between Project Mercury and the Apollo Program was essential, in order to develop procedures necessary for a lunar mission.[49] Gemini flew 12 missions between April 1964 and November 1966, all but the first two manned. The program met all of its goals, including the production of a two-man vessel, the first successful extravehicular activity, the first vehicle rendezvous and docking sequence, and the longest flight duration, 14 days, as of that date. Gemini IV, which flew in June 1965, was also the first mission controlled by Houston's MCC.[50] Apollo flew 11 manned and six unmanned missions between May 1964 and December 1972; all but the initial unmanned flights were controlled from Houston. Like Mercury and Gemini, it met all of its goals with the first lunar orbit (Apollo 8) and the first lunar landing (Apollo 11).

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[45] "19 Million Dollar Construction Contract Signed." *Space News Roundup* (2, 4), December 12, 1962, 1; "MSC 'Site' Three-Fourths Complete, First Move Scheduled Next Month." *Space News Roundup* (2, 24), September 18, 1963, 1; Shields, August 1, 1968.

[46] "MSC 'Site' Three-Fourths Complete;" "Major Move To Clear Lake Begins February 20." *Space News Roundup* (3, 6), January 8, 1964, 1.

[47] "Majority of MSC Personnel Relocated At New Site." *Space News Roundup* (3, 11), March 18, 1964, 2; "Final Relocation Of Center Employees Begins Today." *Space News Roundup* (3, 18), June 24, 1964, 1.

[48] For continuity, the Project Mercury offices remained at Langley, until their official closure in November 1963, when all staff was transferred to the Apollo Program. All of the missions were controlled from the Cape Canaveral Air Force Station in Florida. ACI 2007, Section 4.3.2.

[49] Dethloff, 77.

[50] Dethloff, 92; "Future Gemini Flights To Be Controlled Here." *Space News Roundup* (4, 13), April 16, 1965, 1.

Following the death of former President Lyndon B. Johnson on January 22, 1973, U.S. Senator Lloyd Bentsen of Texas, introduced a resolution to rename the MSC in Johnson' memory. President Johnson had been a firm supporter of the U.S. Space Program when he was a Senator, when he helped draft and enact the legislation that became the National Aeronautics and Space Act of 1958; as Vice President, when he served as the chairman of the National Aeronautics and Space Council and hired the first NASA Administrator; and as President.[51] The Senate passed the resolution, and President Nixon signed it on February 17, 1973, saying "Few men in our time have better understood the value of space exploration than Lyndon Johnson." The formal dedication ceremonies were held at the newly-designated Lyndon B. Johnson Space Center (JSC) on August 27, 1973.[52]

During the dedication ceremonies, the second manned mission of the Skylab Program was underway. Skylab, an application of the Apollo Program, was the largest habitable structure ever placed in space at the time, and served as an early type of space station. Skylab's prime objectives were to experiment in earth and medical sciences, as well as study astronomy, at a much lower cost. As with the Apollo lunar flights, JSC was responsible for the scientific experiments, modifications to the spacecraft, flight operations, and astronaut training.[53] The Apollo-Soyuz Test Project of 1975, was the final application of the Apollo Program, and the country's first joint international space mission. The Center played a prominent role in working group meetings to evaluate the possibility of a test flight between the Soviets and Americans, and iron out other issues once an agreement was reached. The mission produced a common docking system, allowing the two spacecraft to rendezvous in orbit.[54]

With the initiation of the SSP, JSC was again given the responsibility of the development of the spacecraft, in this case, the orbiter, as well as the integration of all shuttle systems; MSFC handled the propulsion elements, i.e., the SSMEs, the SRBs, and the ET; KSC controlled the shuttle processing, launch and landing.[55] From 1969 to 1972, while private companies under contract to NASA performed initial studies for the spacecraft's design, JSC, under the direction of Max Faget, performed their own in-house study of the vehicle design. Ultimately, JSC's "MSC-040C" design became the base for the shuttle design, which was modified as wind tunnel tests provided more data on the design.[56] With President Nixon's instruction to proceed with the design and building of a partially reusable space shuttle (see page 3), NASA issued an RFP for development of a Space Shuttle. The contract, which was awarded to the Space Division of North American Rockwell Corporation of Downey, California, was managed by JSC.

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[51] Launius, 30-32; "MSC Is Renamed 'JSC'." *Roundup* (12, 8), March 2, 1973, 1.
[52] "MSC Is Renamed 'JSC'," 1; "Capacity Crowd View Dedication Ceremonies." *Roundup* (12, 20), August 31, 1973, 1.
[53] "Skylab Mission Forges Ahead, Trouble Shooting Pays Dividends." *Roundup* (12, 15), June 8, 1973, 1 and 4.
[54] Dethloff, 219-221.
[55] T. A. Heppenheimer. *Development of the Space Shuttle, 1972-1981*. Volume Two of *History of the Space Shuttle* (Washington, D.C.: Smithsonian Institution Press, 2002), 37.
[56] Jenkins, 79, 142-149, 201.

As the Center in charge of the orbiter, it was JSC who conducted the ALT program from the MCC (see page 4), constructed numerous facilities for the continual research and testing of the vehicle's systems and any planned upgrades, and tested and developed the various materials used on the orbiter. Aside from the development and testing of the orbiter, JSC's role in the shuttle program has remained consistent with that of the previous programs. Johnson was to handle mission control and operations, astronaut selection and training, and overall engineering and systems integration.[57]

Principle Functions of JSC

Since its beginnings as the STG, JSC has had four main tasks with regard to manned spaceflight: spacecraft development; mission control; research and development; and astronaut selection and training.[58] The basic design guidelines for each space vehicle used during the Mercury, Gemini, Apollo, and Space Shuttle programs were developed by JSC engineers. JSC subsequently managed the contracts with private firms for spacecraft manufacture. It was also the responsibility of JSC engineers to develop the proper interfacing between the spacecraft and its respective launch vehicle, which was developed separately by NASA's MSFC (Mercury-Redstone, Apollo-Saturn, Shuttle SRBs, ET, and SSMEs) or the U.S. Air Force (Mercury-Atlas, Gemini-Titan).[59]

Mission control at JSC begins once the space vehicle has cleared the launch pad, and ends when the vehicle lands.[60] The key figure of mission control is the Flight Director, who makes all final decisions with regards to the proceedings. All communication between the ground and the spacecraft is coordinated through the Spacecraft Communicator. The mission control team also includes personnel who monitor all aspects of the space vehicle, such as flight dynamics, communications links, data processing, and instrumentation. Between missions, the controllers plan for the next flight, conduct various in-house training exercises, and aid with astronaut training.[61]

In conjunction with vehicle design, JSC has historically conducted related research and development, which generally falls into four categories: materials, electrical systems, life systems, and life sciences. The materials category includes development and testing of active

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[57] "Three NASA Centers to share in Space Shuttle Management Tasks." *Roundup* (10, 16), June 18 1971, 1; "Agency gets Go-ahead to Develop Shuttle." *Roundup* (11, 4), January 7, 1972, 1.

[58] "Gilruth Cites MSC Progress Despite Difficult Relocation." *Space News Roundup* (1, 19), July 11, 1962, 1.

[59] Archaeological Consultants, Inc. (ACI). *Survey and Evaluation of NASA-owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program. Lyndon B. Johnson Space Center, Houston, Texas*, November 2007, Section 4.3.1.

[60] Likewise, those who designed the launch vehicle generally handled the actual launch process. It should be noted that the Kennedy Space Center, which has conducted all launches for Apollo and Space Shuttle, grew from MSFC's Launch Operations Directorate, which controlled the initial Mercury-Redstone launches.

[61] All Mercury missions and the first four Gemini missions were controlled from the old Mercury Control Center at Cape Canaveral, Florida. The Mission Control Center at Houston took over starting with Gemini IV. ACI, Section 4.3.3.

thermal control systems as well as spacecraft structure testing. Electrical systems includes testing of the various interfaces with spacecraft hardware and software, ensuring there are no anomalies within the wiring and electronics systems, and confirming the ability of the spacecraft's communications systems to connect to relay satellites and ground stations. Life systems and life sciences are inherently connected to one another and include the astronauts' spacesuits and backpacks, as well as ensuring that their meals meet nutritional guidelines, taste good and store well.[62]

Probably the most well-known task of JSC, besides mission control, is astronaut selection and training. From the original "Mercury 7," JSC has determined the criteria for astronaut selection and handled all interviews and examinations during the selection procedure. Additionally, the Center has established all training curricula, which provide astronauts with the basic knowledge needed to fly a mission and survive in emergency circumstances, as well as more specific training for tasks associated with a particular mission. Since Project Gemini, program-specific spacecraft simulators and trainers have been located within various buildings at JSC for astronaut training.[63]

[62] ACI, Section 4.3.4.
[63] ACI, Section 4.3.2.

Atmospheric Reentry Materials and Structures Evaluation Facility (Building 222)

Construction

The Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF), which includes the 13,193 square foot main building (Building 222), the Rectifier Building (222a), the Boiler Building No. 1 (222b) and the Arc Power Supply (222aa), was originally built to support reentry environment testing for the Apollo Program.[64] The facility was designed by a combination of two Houston, Texas, architecture and engineering firms: Dale S. Cooper & Associates and Cummins-Reed & Clements. It was built by the Baxter Construction Company, Inc. of Houston, Texas, under the direction of the ACOE, at a cost of roughly $1.1 million. Construction of the facility occurred between October 1965 and November 1966; it became operational in 1967.[65] At the time of construction, the ARMSEF included a 10-megawatt (MW) arc jet, one vacuum tunnel position and two atmospheric exhaust positions. The arc heaters used were of a dual constrictor design with a Linde tube, and were provided by the Avco Corporation, who also furnished the 8' vacuum test chamber and the test article mount mechanisms.[66] Electro-mechanical console systems provided the control mechanisms for the test operations.[67]

In 1972, the ARMSEF was upgraded to support the SSP, by modifying the equipment to better simulate the conditions of low-Earth orbit.[68] One of the key changes was the removal of the original Avco arc heaters, which were replaced by 10 MW segmented constricted arc heaters manufactured by Aerotherm Corporation. Although the new heaters allowed for greater flexibility with regards to test enthalpies, ARMSEF engineers and technicians found it necessary to modify the heaters. One such adjustment was to move the oxygen feed lines so that the gas would be introduced to the arc column sooner and, therefore, heated properly.[69] Another major change to the facility was the installation of a 10'-diameter vacuum test chamber to the east of the 8' chamber. Additionally, due to the projected size of the orbiter (as compared to the Apollo spacecraft), a set of rectangular channel nozzles, which supported larger test articles, was developed in-house; the nozzles were assembled by Fluidyne Corporation.[70] Other modifications to the facility included a new boiler and interconnecting piping, and new ejector equipment.[71]

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[64] Linda Copley. "Building readied for new test demands." *Space News Roundup* (28, 49), December 15, 1989, 4.
[65] Donald J. Tillian, interview by Jennifer Ross-Nazzal, May 20, 2009, Houston, TX, Manuscript on file, Tessada & Associates, Houston, TX, 3; Dale S. Cooper & Associates and Cummins-Reed & Clements, Houston. "Building No. 222, Atmospheric Re-entry Materials and Structures Evaluation Facility," August 10, 1965. On file, JSC EDCC; D.J. Tillian. "The Evolution and History of Arc Jet Testing Thermal Testing- The NASA/Lyndon B. Johnson Space Center (1963-2006). Manuscript provided by author, November 2, 2006, JSC, Houston; ACI, Section 6.2.7.
[66] Although installed in a facility capable of producing a 10 MW heat load, the 8' vacuum test chamber was designed for a maximum heat load of only 5 MW; Jose Vera and James Milhoan, interview by Jennifer Ross-Nazzal, September 30, 2009, Houston, TX, Manuscript on file, Tessada & Associates, Houston, TX, 12.
[67] Copley; Tillian, "Evolution;" Vera and Milhoan, 11.
[68] Vera and Milhoan, 9.
[69] Vera and Milhoan, 11-12. See pages 17-20 for more information on the system's operation.
[70] Tillian, interview, 5; Vera and Milhoan, 12-13.
[71] Tillian, interview, 5; Copley.

In 1989, general contractor, Harrop Inc. of Houston, Texas, began work on a $4.9 million modernization of the ARMSEF that had originally been proposed in 1984. The most prominent physical changes to the facility included the replacement of the 8'-diameter vacuum test chamber with a new 12'-diameter vacuum test chamber to support larger test articles, and the construction of a Laser Diagnostics Room within the building's High Bay. Other modifications to the ARMSEF included a new automated control system to replace the original electro-mechanical systems; new shop buildings; and a new boiler building, as well as a new steam boiler to replace the two existing boilers.[72]

Space Shuttle Program Testing

Throughout the SSP, the ARMSEF has been used to test every type of TPS material applied to the shuttle orbiter, by simulating the environments experienced during reentry. According to Donald Tillian, an engineer involved with the facility throughout the 40-year shuttle program, the ARMSEF "has probably done in excess of over 10,000 tests."[73] These tests have fallen under various categories, the major ones being materials screening and selection; life cycle; thermal characteristics and performance; development; certification; flight anomaly resolution; and damage repair. Tests were conducted on standard sections of the orbiter, as well as special areas of the vehicle, such as leading edges, penetrations, seals, and nozzle areas.[74]

Materials screening and selection tests were some of the earliest performed at the ARMSEF. From ca. 1969 until ca. 1973, the facility, in cooperation with NASA's ARC and LaRC, screened potential thermal protection materials from various contractors. From the initial screening tests, the choices for the TPS materials to cover the large, standard sections of the orbiter were subsequently narrowed down to three contractors: GE, McDonnell Douglas, and Lockheed. Lockheed eventually received the formal contract to manufacture what became known as the Reusable Surface Insulation (RSI). Three types of RSI were initially used over the body of the orbiter: High Temperature RSI (HRSI) tiles, Low Temperature RSI (LRSI) tiles, and Flexible RSI (FRSI) blankets.[75] Only two companies, LTV of Dallas, Texas, and McDonnell Douglas, submitted materials to be evaluated for the orbiter nose and wing leading edges. From its series of tests, LTV's Reinforced Carbon-Carbon (RCC) was selected. All of the initial TPS materials were chosen by the time the contract to build the shuttle orbiter was awarded.[76]

Once the initial materials were selected, life cycle, thermal characteristics and performance, certification, and development test sequences could begin. These types of tests were conducted from roughly 1975 up to the time of this documentation package; they will continue until the end

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[72] Tillian, "Evolution;" Kelly Humphries. "Ultra Hot Upgrade gives reentry test facility new tools for evaluating lighter, more durable thermal protection." *Space News Roundup* (31, 14), April 3, 1992, 3.
[73] Tillian, interview, 32.
[74] Tillian, interview, 6-8.
[75] W.C. Rochelle, et al. "Orbiter TPS Development and Certification Testing At the NASA/JSC 10 MW Atmospheric Reentry Materials and Structures Evaluation Facility," (paper presented at the AIAA 21st Aerospace Sciences Meeting, Reno, Nevada, January 10-13, 1983), 2.
[76] Tillian, interview, 3, 5; Rochelle, et al., 11.

of the Space Shuttle Program. For the life cycle testing, engineers subjected the materials to the anticipated environmental conditions for extended lengths of time, which accumulated to roughly the same number of hours for the planned 100 missions per orbiter.[77] Thermal characteristics and performance tests evaluated the basic thermal performance of each TPS material. Included under this category were overtemperature tests, which "determined TPS temperature limits and verified one-flight survivability" of each of the materials.[78] Certification tests on each material were then conducted for the final qualification of their use on the orbiter.

Simultaneously, development tests were planned and conducted as the results from the other test sequences shed light on possible issues and potential improvements. One issue that was discovered during early tests was that heat was penetrating to the orbiter's base aluminum structure through the gaps between the HRSI and LRSI tiles. This led to various development tests to locate the best material that could be used as a "gap filler."[79] Improvements to the TPS system that have been tested throughout the Space Shuttle Program have included different densification methods for the HRSI and LRSI tile, which led to the development of Fibrous Refractory Composite Insulation (FRCI) tile that subsequently replaced most of the HRSI tiles on OV-103 and OV-104. This new tile ultimately led to the introduction of Toughened Uni-Piece Fibrous Insulation (TUFI) tiles ca. 1993. Other improvements included new coatings for the FRSI blankets, and eventually the Advanced Flexible Reusable Surface Insulation (AFRSI) blankets.[80]

Prior to the first flight of the SSP in April 1981, a few lost tile tests were performed at the ARMSEF, which "determined the survivability of Orbiter structure materials as a function of body point location, type and thickness of TPS, and type and thickness of structure."[81] Following STS-1, as well as the next three "development" flights, these tests, as well as flight anomaly resolution tests, began in earnest. Flight anomaly programs tested minor unpredicted damages to an orbiter's TPS that occurred during a mission, in an effort to prevent a recurrence of the problem. Although these types of tests were intermittently run throughout the program, they emerged as a focal point following the 2003 *Columbia* accident. The ARMSEF conducted roughly 189 individual tests categorized into four different test programs: RCC damage assessment; RCC repair; HRSI damage assessment; and HRSI repair. Specific examples include the testing of the Shuttle Tile Ablator (STA)-54 material, which could be used by the astronauts while in orbit to repair certain kinds of tile damages, as well as tests on post-flight specimens of tiles that had been "repaired" by STA-54 in orbit using the Tile Repair Ablator Dispenser.[82]

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[77] Tillian, interview, 6-8.
[78] Tillian, interview, 6; Rochelle, et al., 11.
[79] Rochelle, 11
[80] Tillian, 17-19, 34; Rochelle, et al., 2, 11; Jenkins, 395, 400-402.
[81] Tillian, 12; Rochelle, 11.
[82] Fact sheet, Tillian interview, 14 and 15.

Testing Operations

The ARMSEF is managed by the Experimental Heat Transfer Section of JSC Engineering's Structures and Mechanics Division.[83] The facility operates on a two-shift basis, currently divided among roughly twenty-two engineers and technicians. Generally, the testing process begins long before the arc heater is fired up, with a request for a specific test sequence to be conducted. Once the test is approved by the division heads, it is placed on the facility's schedule. The next step is the fabrication of the test article, or a set of test articles, the quantity of which depends on the number of requested scenarios for the particular test sequence. Each test article is a complex construction, comprised of a "complete" representation of the orbiter structure, which included the densified TPS tile/blanket, the underlying strain isolation pad, and the vehicle's aluminum structure, as well as adequate instrumentation to collect the necessary data from the outer face and inner depths of the test article.[84] In most cases, the test article is supplied by the manufacturer of the specific material being tested; however, there have also been instances where it was built in-house by ARMSEF technicians.[85]

Once the test articles have been received and the appointed time for the test sequence arrives, ARMSEF personnel begin to set up the equipment for the test. With the aid of a hydraulic system, the test article is placed within the nozzle; a laser line is used to ensure that the model is properly positioned.[86] Afterwards, a group of mechanical technicians places the required quantity of segments within the arc heater, and runs a check of all mechanical systems.[87] At the same time, a team of electrical technicians connects all of the required instrumentation devices to the test article, and ensures that all electrical and computer systems are operating properly. Additionally, a boiler operator inspects the boiler and makes all necessary preparations. When all of this work is completed, the Test Conductor oversees a test readiness review to verify all systems and test parameters.[88] The ARMSEF High Bay is then cleared, as all required personnel position themselves at their appropriate stations to begin the test.

During the actual test, the key members of the test team are positioned within the Control Room, the Data Center, and the Boiler Building. Four of these key team members are located within the Control Room, along with support personnel and, in some instances, an agent for the customer who made the initial request for testing. One key individual is the Test Director, typically a NASA employee, who makes sure the test runs within the set parameters, monitors the safety of the operations, and ensures that the customer's objectives are met. The second key player is the Test Conductor, who makes sure the facility is ready for test operations and then monitors all facility parameters, such as arc position, pressure, and temperature. The Test Conductor is

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[83] Humphries, 3. During the 1980s, at the peak of operation, there was around 27-28 people working in the facility, on a two-shift basis. Vera and Milhoan, 25.
[84] Rochelle, et al., 1; Tillian, interview, 6-8; Vera and Milhoan, 25-26.
[85] Tien Nguyen. Interview with Patricia Slovinac and Christine Newman, JSC, ARMSEF, September 17, 2009; Vera and Milhoan, 24.
[86] Nguyen; Vera and Milhoan, 7, 25-26.
[87] The length of the arc heater determines how much heat is produced. Nguyen.
[88] Tillian, interview, 10; Vera and Milhoan, 25-26.

assisted by the Quality Control Officer. The last key individual within the Control Room is the Power Operator, who controls and monitors the power systems.[89] Within the Data Center is a lead Data Monitor, who monitors all data output during the test and alerts the appropriate team member(s) of any problems that develop. Finally, the Boiler Operator, who controls and monitors the boiler, is stationed within the separate Boiler Building.[90]

When the actual test begins, four large generators to the northwest of the main building begin to generate a large supply of alternating current (AC) electricity. Four rectifiers located in the Rectifier Building transform this into 10 MW of direct current (DC) power, which provides up to 5000 volts (V) of electricity to operate one of the two arc heaters.[91] Each 10'-long arc heater has a cathode at the outer end, where the arc begins; the arc ends at the anode, which is approximately 1' from the nozzle opening.[92] Along the arc, nitrogen and oxygen (at a ratio of 77% to 23%, respectively) are introduced and mixed within the heater column.[93] These gases surround the electrical spark and are heated to roughly 10,000 degrees Fahrenheit. Various coolant lines along the heater column prevent the equipment from overheating.[94]

At the end of the heater column, the now-heated air enters a small plenum area, which provides one last place for the nitrogen and oxygen to mix prior to entering the nozzle. Once it enters the nozzle, the heated gas expands to generate a supersonic or hypersonic flow field. For the tests, one of two different nozzle styles is used. Test Position 1 (10' Chamber) is fitted with a channel nozzle that allows the air flow to run tangential to the test article. To create this spatial relationship, the test article is fitted into the nozzle so that it becomes one of the nozzle's sides. Three different-sized channel nozzles, 8"x10", 12"x12", and 24"x24", are used to run tests that mimic the effects on the orbiter's belly, top surface, and sides. Test Position 2 (12' Chamber) contains a conical nozzle, in which the test article can be placed anywhere between the 5" and 40" diameter mark. In this position, the flow directly hits the test article, which simulates the conditions experienced by the orbiter's nose and wing leading edges. All of the nozzles are lined with water-cooled copper plates, to prevent overheating.[95]

As the supersonic gas flow enters the nozzle, it engulfs the test article with pressures ranging from 20 to 300 pounds per square foot and surface temperatures from 1,200 to 3,400 degrees Fahrenheit, which replicate reentry pressures and temperatures experienced by the orbiter. It even produces the same kind of orange glow seen by shuttle astronauts on reentry, which can be seen through the test chambers' observation ports.[96] Once it passes over the test article, the heated gas enters a diffuser pipe within the large vacuum chamber. A four-stage ejector system powered by an 80,000 pound per hour boiler maintains the proper ambient pressure. Like the arc

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[89] Nguyen; Vera and Milhoan, 7.
[90] Nguyen.
[91] The facility is designed so that only one of the arc heaters/test positions can be operated at a given time.
[92] Nguyen; Vera and Milhoan, 8.
[93] By injecting the gases into the heaters, the test conductor can control the humidity of the air; Nguyen.
[94] Humphries; Nguyen.
[95] Humphries; Nguyen; Vera and Milhoan, 7-8.
[96] Humphries.

heater column and the nozzles, the test chambers and diffusers are lined with coolant pumps to prevent overheating.[97]

The data from each individual test is collected and recorded through 256 video, data, and thermocouple channels. Additionally, the collection devices take "snapshots" of the tests at various intervals. All critical real time data are displayed on monitors within the Control Room. This process is followed for each individual test within the testing sequence, as more often than not, different test models and/or parameters are used for successive runs. After the entire test sequence is completed, all of the data is collected and analyzed by the test team's engineers and technicians, who then generate a report detailing the results.[98]

[97] Humphries; Nguyen; Vera and Milhoan, 7.
[98] Vera and Milhoan, 25-26.

Physical Description

The one- and two-story ARMSEF has approximate overall dimensions of 110' in length (north-south), 104' in width (east-west), and 25' in height. The entirety sits on a reinforced concrete slab foundation and features a flat, precast concrete roof faced with rigid insulation. The facility is divisible into two sections: a one-story office area on the south connected to a two-story test area on the north.

The office area measures approximately 94' in length (east-west), 32' in width (north-south), and stands 13'-6" in height. It is constructed of plate glass window walls shaded by a 7'-deep concrete canopy. One glass swing door is located in the center of both the west and east elevations. The west door opens directly into a model shop, while the east door opens into a central hallway. On either side of the corridor are various offices and support rooms; at the west end is the model shop. Approximately three-quarters of the way down the hall is a second corridor, which extends into the northern test area.

The northern test area measures approximately 104' in length (east-west), 76' in width (north-south), and 25' in height and has walls composed of ribbed precast concrete panels. It features one pair of metal doors and one metal swing door on the east elevation; two metal swing doors on the north elevation; and two metal swing doors and one metal rolling door on the west elevation. On the south elevation, above the office area, are five one-light fixed windows. Internally, the test area is divided into a High Bay, a model shop, a storage area, a Control Room, a data center, and a mechanical room; above the Control Room and the Data Center is a conference room. As defined by the "Survey and Evaluation of NASA-owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program, Lyndon B. Johnson Space Center, Houston, Texas," the ARMSEF receives its significance from the following areas within this northern wing: the High Bay (Room No. 120), which also contains the Laser Diagnostics Room (Room No. 120A) and the Blockhouse (Room No. 1CN); the Control Room (Room No. 116); and the Data Center (Room No. 117).[99]

The High Bay measures approximately 108' in length (east-west) and 51' in width (north-south). It has two metal swing doors to the exterior on the west wall, and one metal swing door on the east wall. On the south wall, there is one pair of metal swing doors to the model shop, one metal swing door to the corridor, and one pair of metal swing doors into the Data Center. The inner wall surfaces of the High Bay are faced with wire mesh panels, and it contains a drop ceiling composed of 2'x2' acoustic tiles. Across the floor is a series of trenches used to run cabling between the arc jets and the Control Room/Data Center, and to provide the necessary utilities to the arc jet heaters. Additionally, there is a 9-ton overhead bridge crane, which rolls east-west across tracks positioned roughly 17' above the finished floor on the north and south walls. The two arc jet test chambers sit along the north wall; Test Position No. 1 near the west wall and Test Position No. 2 near the center. Between the two chambers sits the Blockhouse, and to the east of Test Position No. 2 is the Laser Diagnostics Room.

[99] ACI, Section 6.2.7.

Each of the two test positions (Test Position No. 1 [TP-1] and Test Position No. 2 [TP-2]) within the High Bay is comprised of three main elements: the arc heater, the vacuum test chamber, and the diffuser. For both, the arc heater sits to the south of its respective test chamber, and is comprised of a multi-pack dual-diameter constricted segmented arc column, which contains 200 individual segments in removable modular packs of twenty.[100] Along the length of the arc column are dozens of plastic tubes in two different sizes. The smaller tubes are nitrogen and oxygen feed lines, which supply the air for the test. Each of these gases is carried to the arc heater by a metal pipe, to which the plastic tubes are attached. For ease of reference and use, they are color coded so that the nitrogen lines are blue and the oxygen lines are green. The larger tubes are coolant lines for water, which is brought into the High Bay through six large, flexible hoses (black in color; three per side). These black hoses are attached to the lower branch of a U-shaped rigid metal pipe; the plastic tubes are connected to the top branch. Additionally, on the east side of each arc heater are two electrical connectors, each with three red power cables and two neutral black cables.

To the north of each arc heater is its respective air nozzle and vacuum test chamber. Here is where the only physical differences between the two test positions are located. The first difference is in the shape of the air nozzle; TP-1 has a channel (rectangular) nozzle, while TP-2 has a conical nozzle. The nozzle for TP-1 is non-adjustable, and grows from a 2”x2” throat at the south end to a 18” high by 2” wide rectangle at the vacuum test chamber wall, where it continues into the chamber while extending to a height of more than 24” and keeping the 2” width. The conical nozzle of TP-2 grows from a 2.5” diameter throat at the south end to a 40” diameter at the vacuum test chamber wall. Within the nozzle are two arms, which allow the test article to be placed at the proper distance from the throat.[101] The other major difference between the two test positions is the size of the vacuum test chamber. The TP-1 test chamber has approximate dimensions of 10’ in diameter and 13’-6” in length; TP-2 is roughly 12’ in diameter and about 14’ in length. The vacuum chambers are constructed of steel and have a door on both the east and west sides for test article placement; each door can be fitted with a viewing port. Viewing ports can also be placed in the top surface of the chamber, which is accessed via a metal platform.

The last major element of each test position is the water-cooled diffuser, used to maintain a vacuum within the test chamber. In both chambers, the diffuser is a metal pipe, approximately 5’ in diameter. The diffuser opening sits roughly 1’ to the north of the side doors; the pipe extends through the back wall of the chamber, then through the north exterior wall of the High Bay where it continues to the ejector system, which sits roughly 40’ to the north of the ARMSEF building. Across the length of the diffuser are various cooling panels and coolant pipes.

The Blockhouse (Room No. 1CN) has approximate overall dimensions of 22’ in length (north-south), 5’ in width (east-west), and 9’ in height. The walls are composed of reinforced concrete

[100] Rochelle, et al., 4.
[101] The TP-2 nozzle diameter is adjustable, allowing variables, such as temperature and pressure, to be changed.

block, and the ceiling is formed from prestressed, hollow-core concrete slabs. The east and west walls each feature a 2'x4' viewing window, which lines up with the viewing portals of the test chambers. A metal swing door on the south wall provides access to the Blockhouse from the High Bay; there is also a door on the north wall, which leads to the exterior of the building. Internally, the Blockhouse is comprised of a single room lit by surface-mounted fluorescent lights.

The Laser Diagnostics Room (Room 120A) has rough overall dimensions of 24' in length (north-south), 18' in width (east-west), and 10' in height. Like the Blockhouse, the walls are composed of reinforced concrete block, and the ceiling is made of prestressed, hollow-core concrete slabs. There is a pair of metal swing doors on the south wall that provide access to the lab from the High Bay. Additionally, there is a small niche with a metal swing door on the north side, which leads to the exterior of the building. The interior of the lab contains one open space, with surface-mounted fluorescent lights. The laser diagnostics equipment sits roughly in the center of the room.

The Control Room (Room No. 116) sits directly to the south of the High Bay. This room measures approximately 28' in length and 18' in width, and has a ceiling height of 9'-6". The control room features a painted concrete north wall, gypsum board east, west and south walls, a raised tile floor, and an acoustical tile ceiling. The east wall contains one metal swing door; the west wall has one single metal swing door and one pair of metal swing doors. A 2'-6" x 8'-8" window on the north wall provides visual access to the High Bay; a ribbon of three windows on the south wall looks into the Data Center. The Control Room contains two rows of computer consoles, the first of which extends along the north wall. At the left sits the Power Operator, who still uses the original power systems console. In the center is the Test Conductor; at the right is the Quality Control station. The second row of consoles sits near the south wall and contains two stations; one for the Test Director (left) and one for the Customer (right). Suspended from the ceiling along the north wall are two video screens, one of which shows a filtered image of the test in progress, the other an unfiltered image. Below them, on a ledge just above the High Bay window, are seven additional screens that provide visuals to other components of the arc jet facility.

The Data Center (Room No. 117) is an "L"-shaped room situated to the south and east of the Control Room. The portion of the room to the east of the Control Room has approximate dimensions of 18' in length and 9' in width, and serves as a corridor from the High Bay to the Data Center. Its north wall is composed of concrete block; the other walls are gypsum board. The floor is poured concrete, while the ceiling is composed of acoustical tile. The southern portion of the Data Center measures roughly 21' in length and 18' in width, and contains all of the room's equipment. The entirety has walls of gypsum board, a raised tile floor, and an acoustical tile ceiling fitted with recessed fluorescent lights. Within this area, there are computer consoles on the west and south walls; a row of data collecting equipment sits near the east wall.

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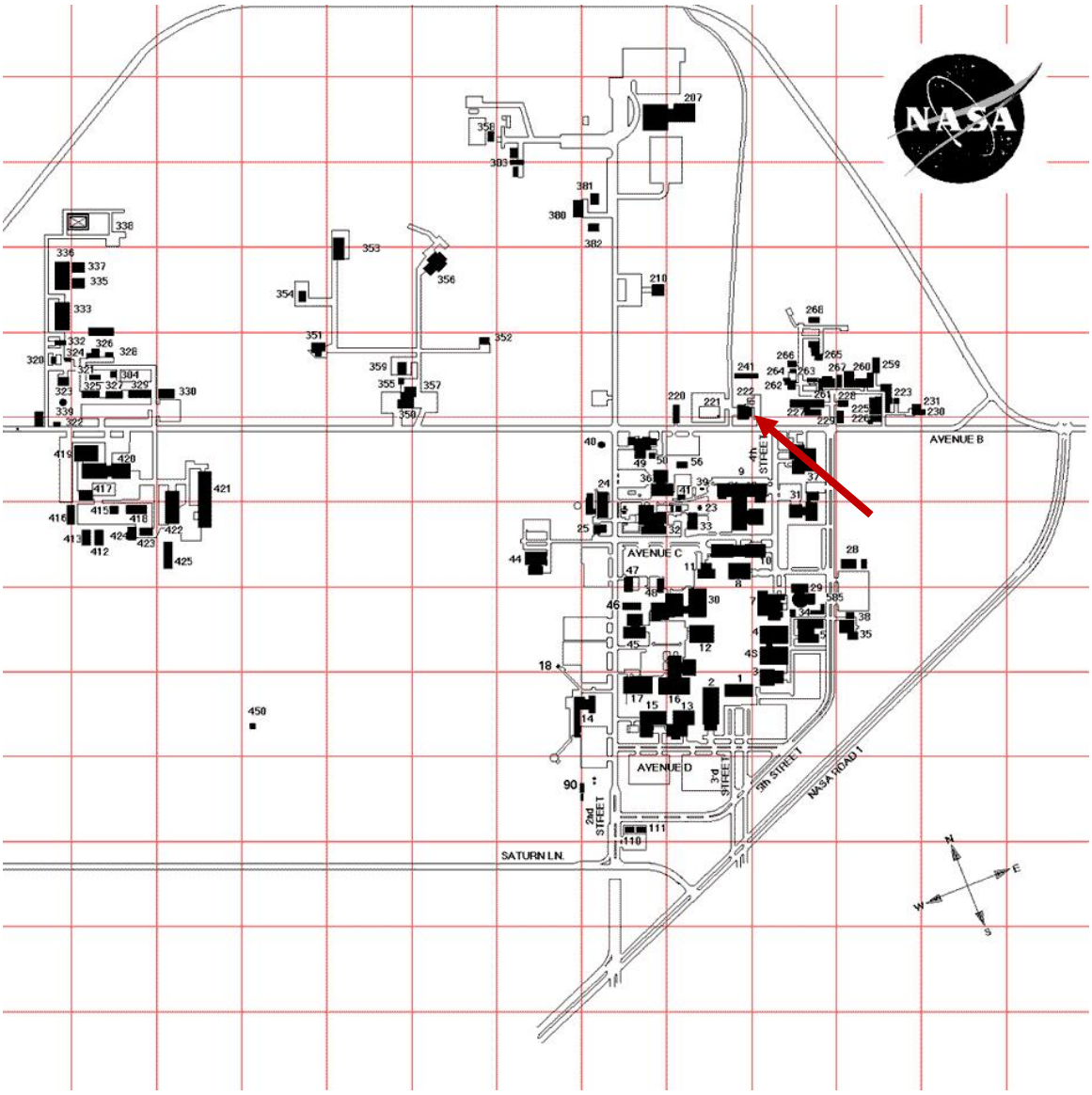

Figure 1. Location of Atmospheric Reentry Materials and Structures Evaluation Facility.
Source: JSC, 2006.

Figure 2. Layout of the Atmospheric Reentry Materials and Structures Evaluation Facility, red denotes significant areas.

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NASA, Manned Spacecraft Center, Texas
Drawing A-222-2, Dale S. Cooper & Associates, 1965
FLOOR PLANS
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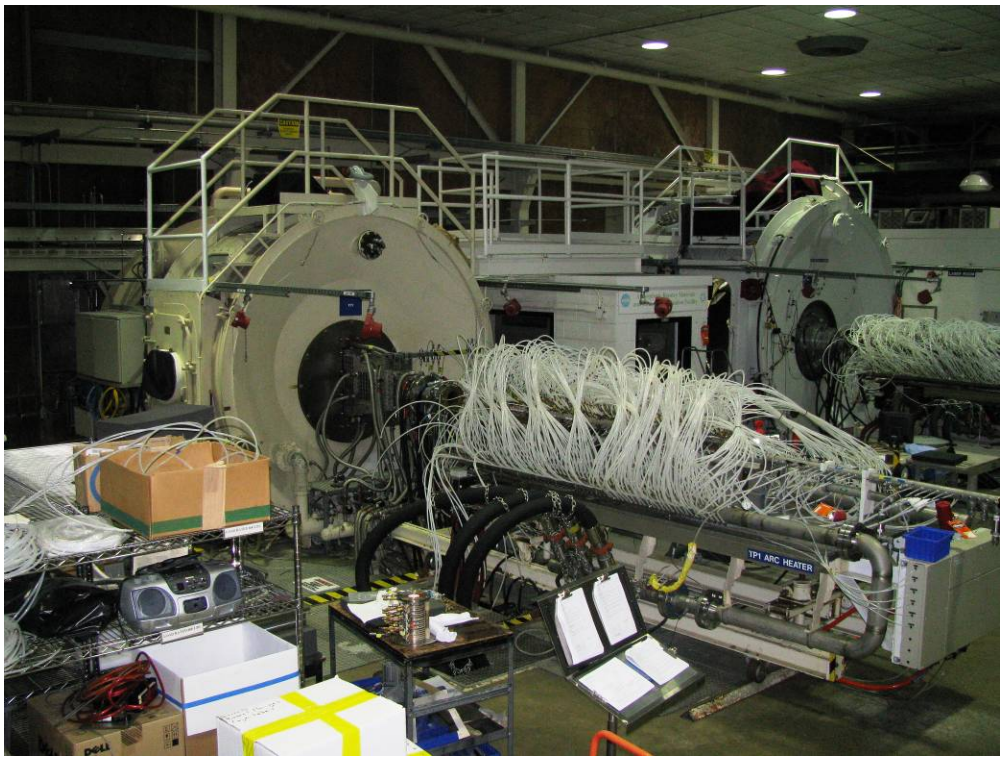

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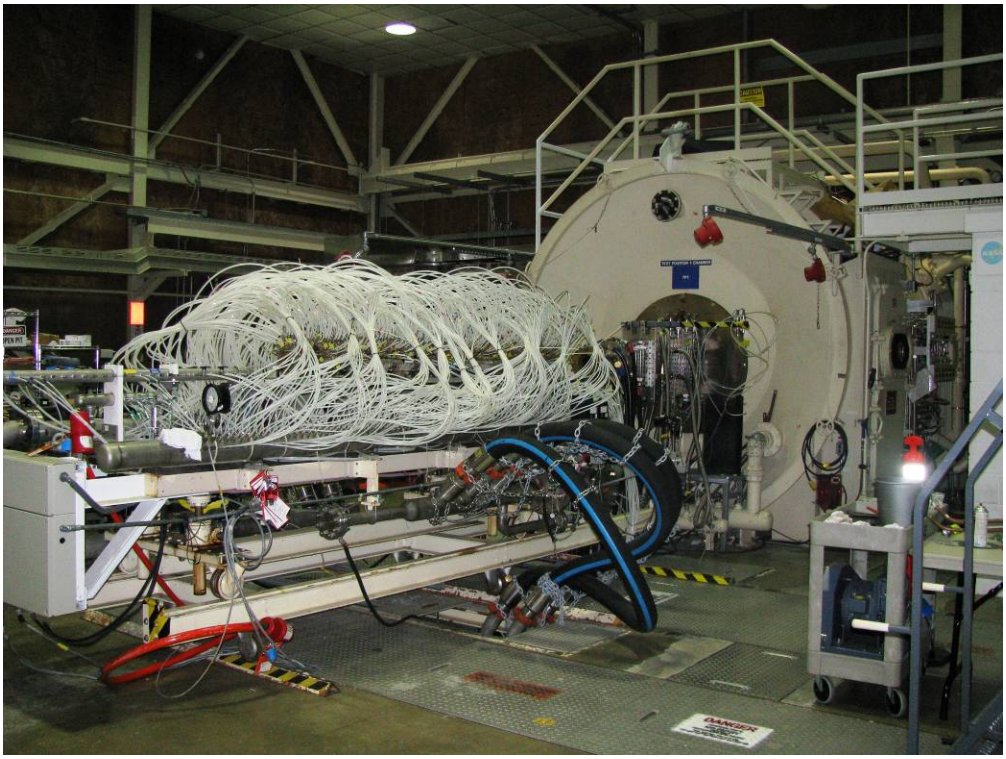

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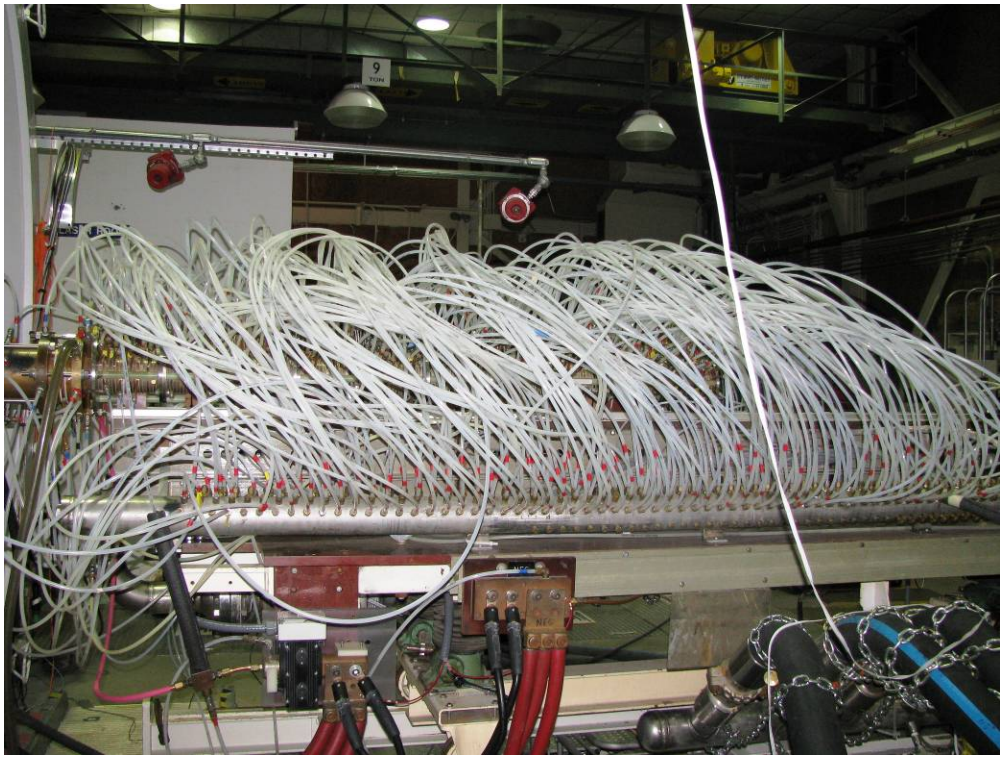

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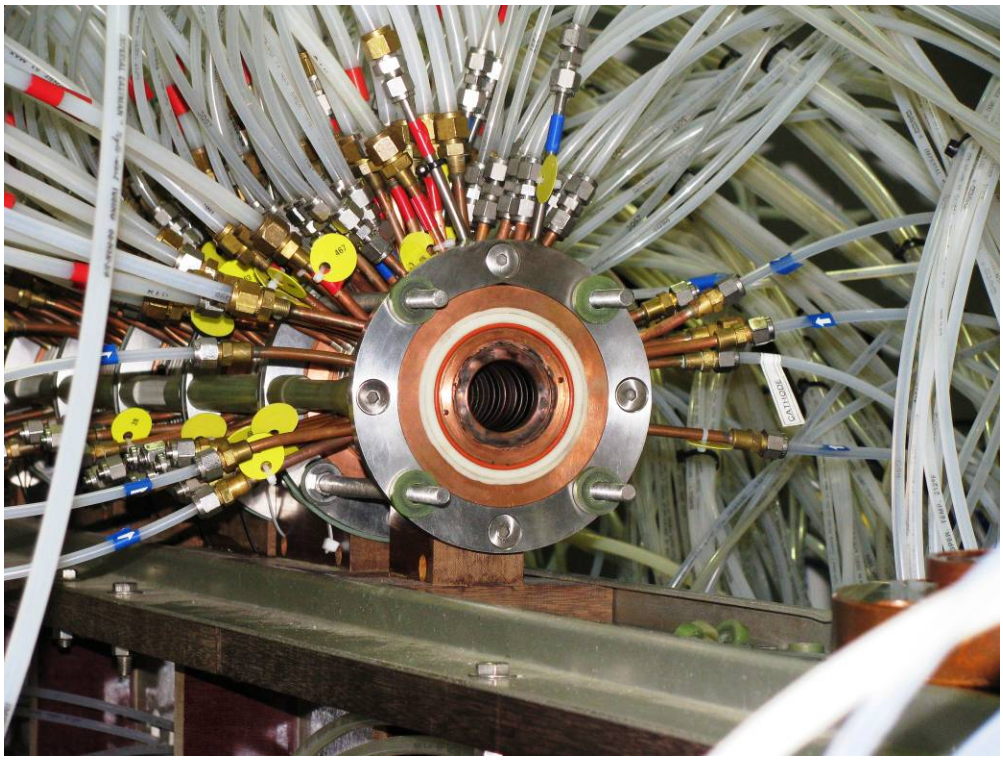

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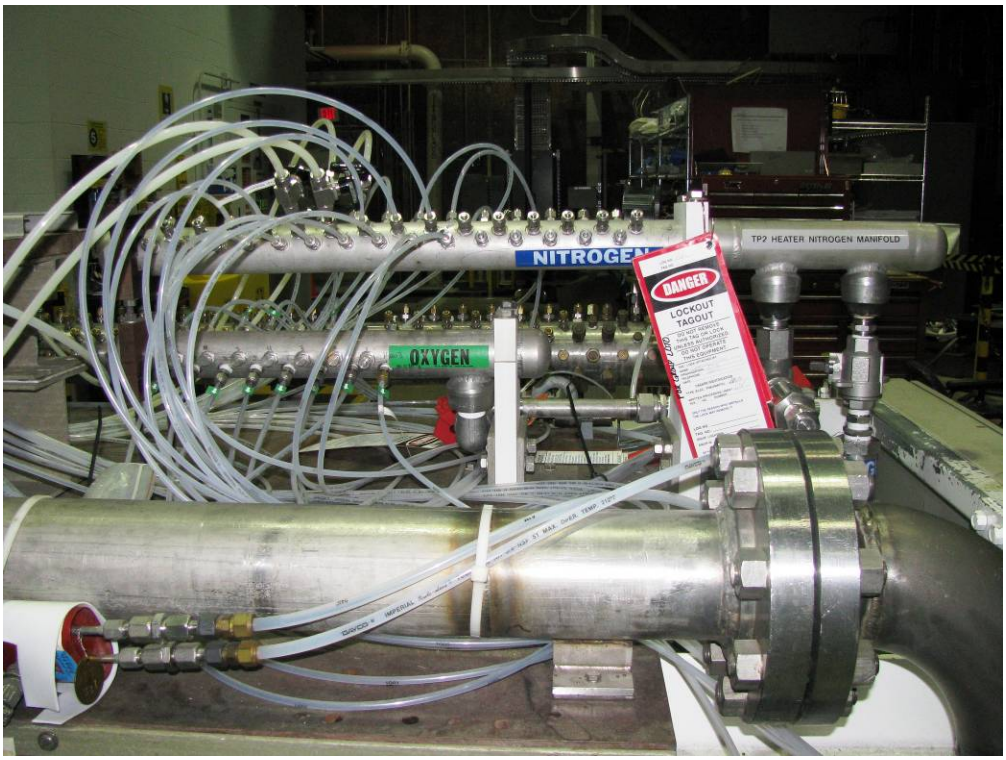

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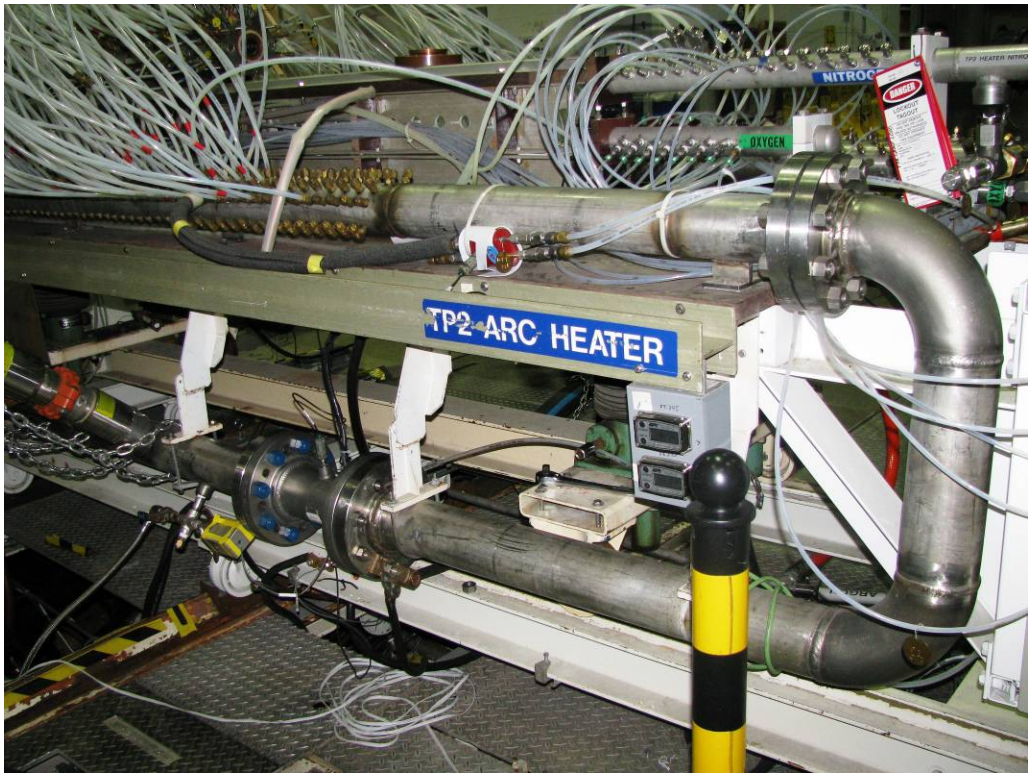

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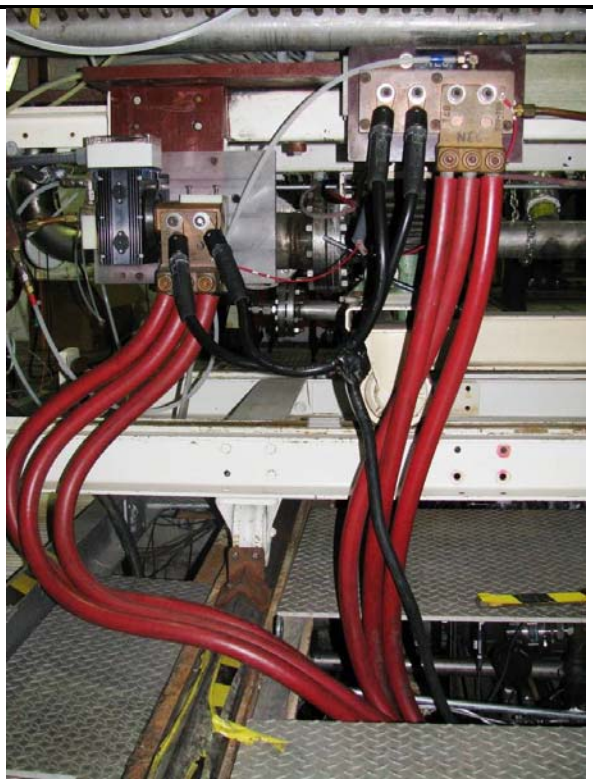

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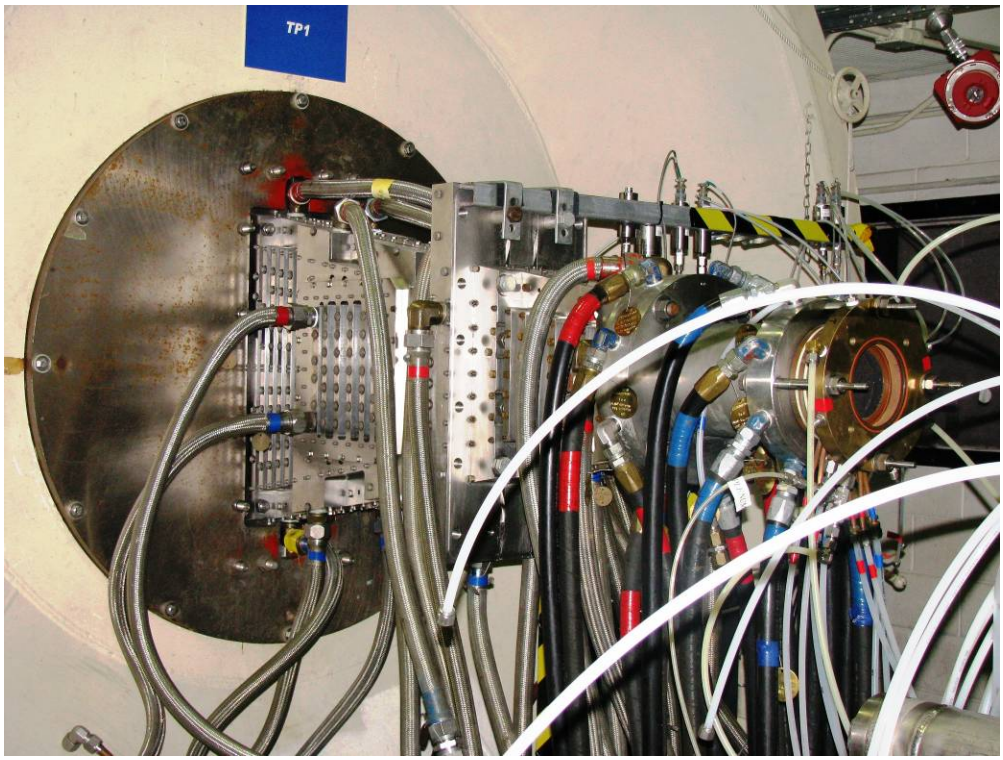

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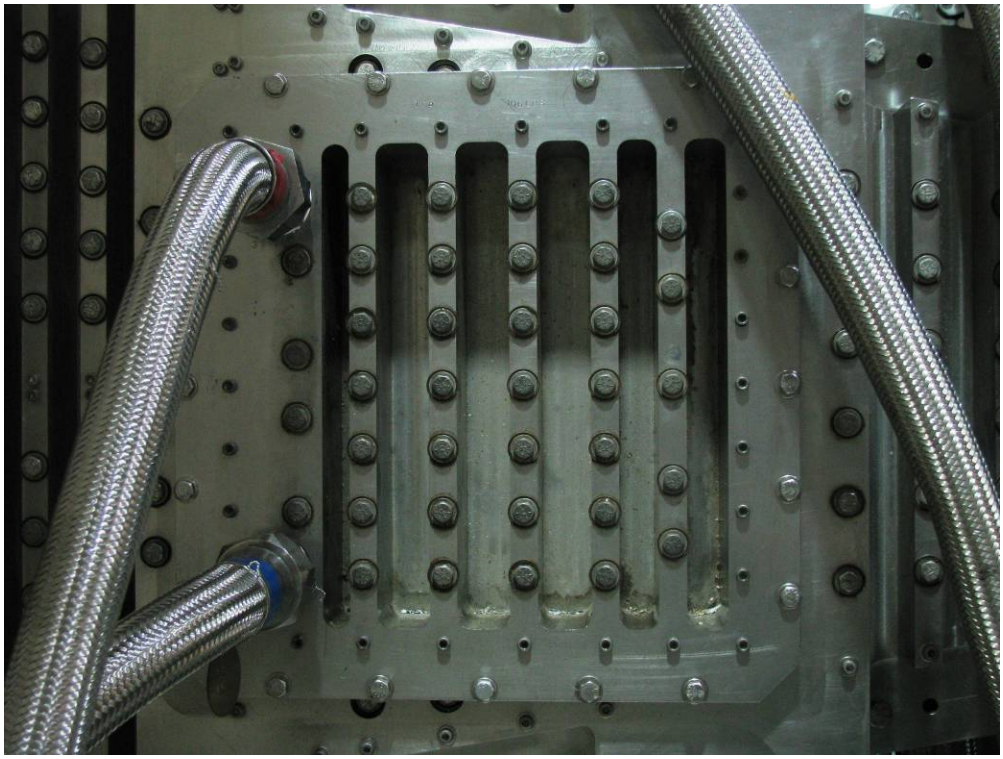

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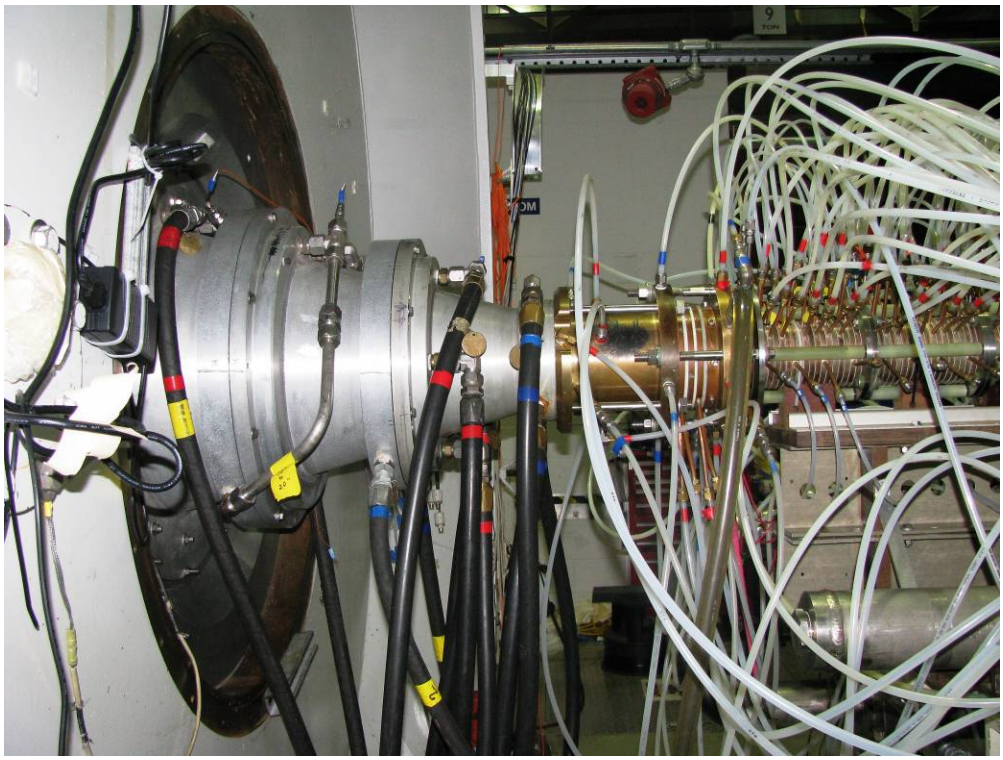

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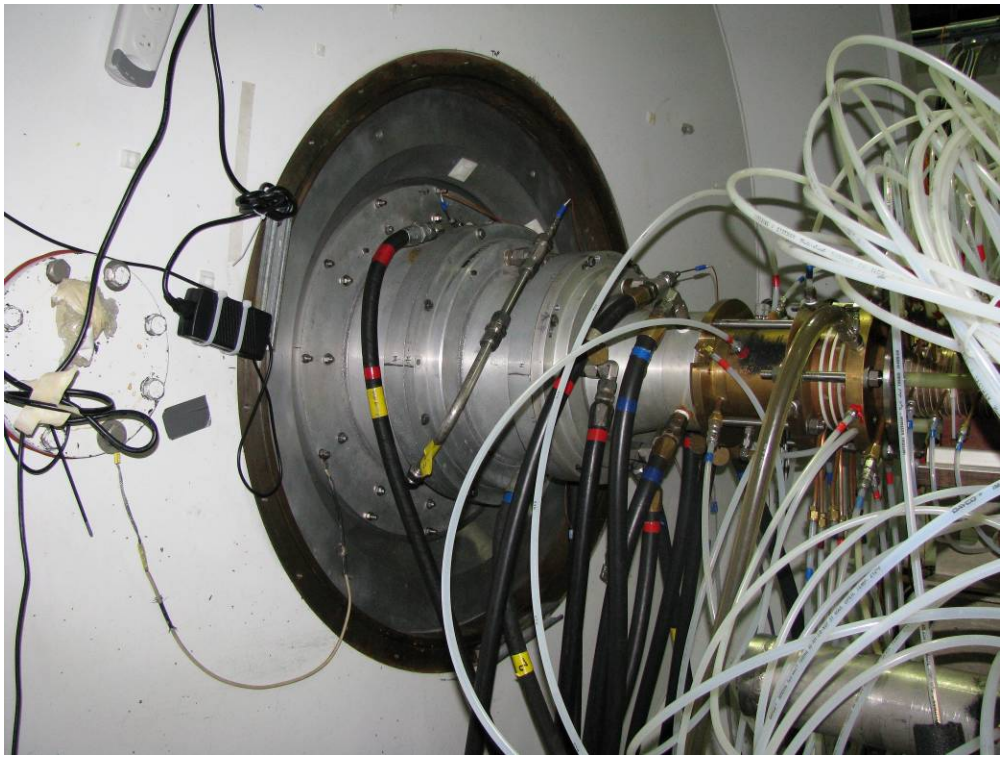

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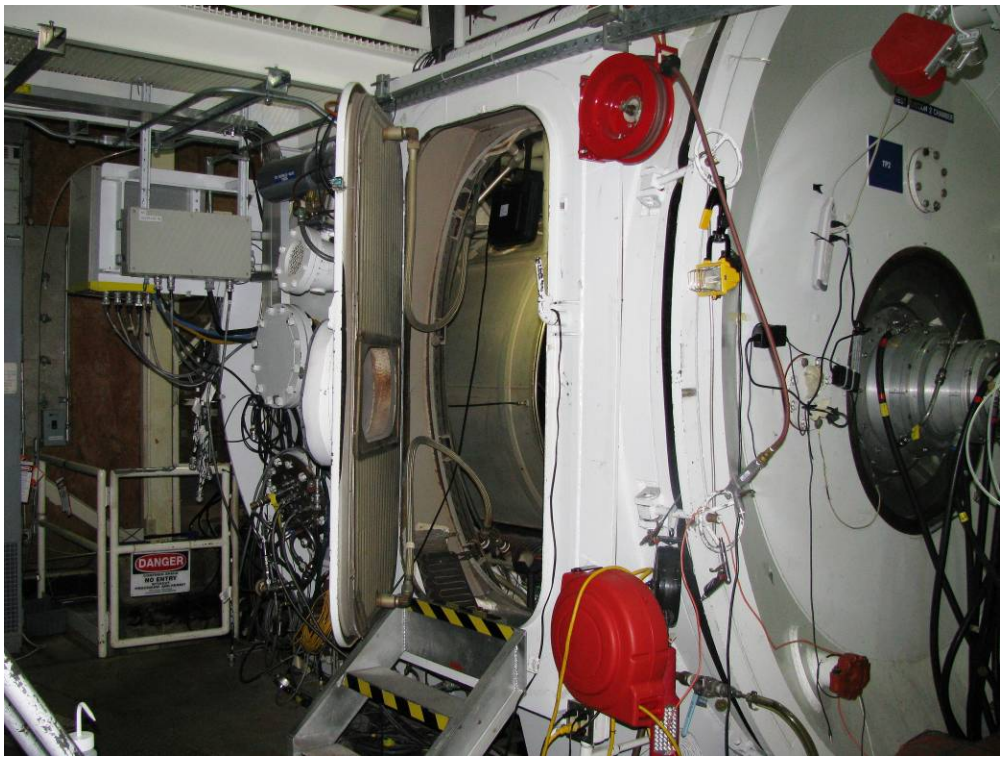
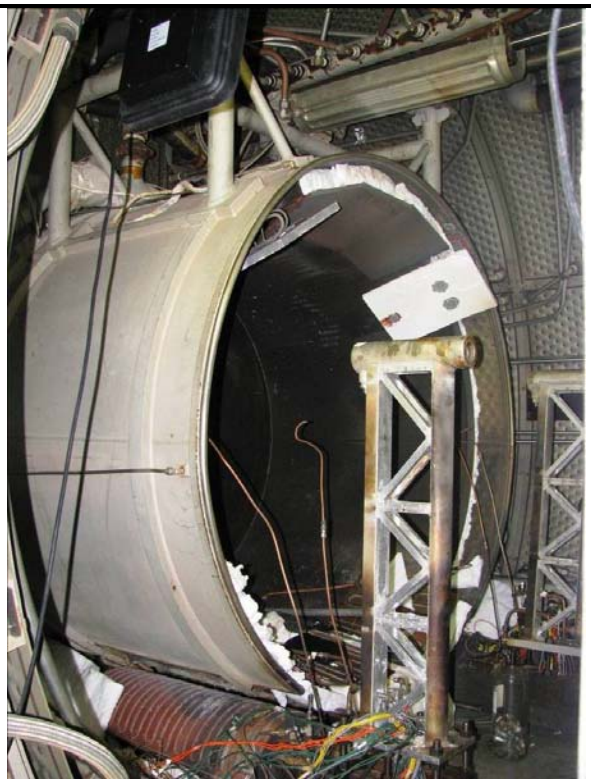


ARMSEF-34

ARMSEF-35

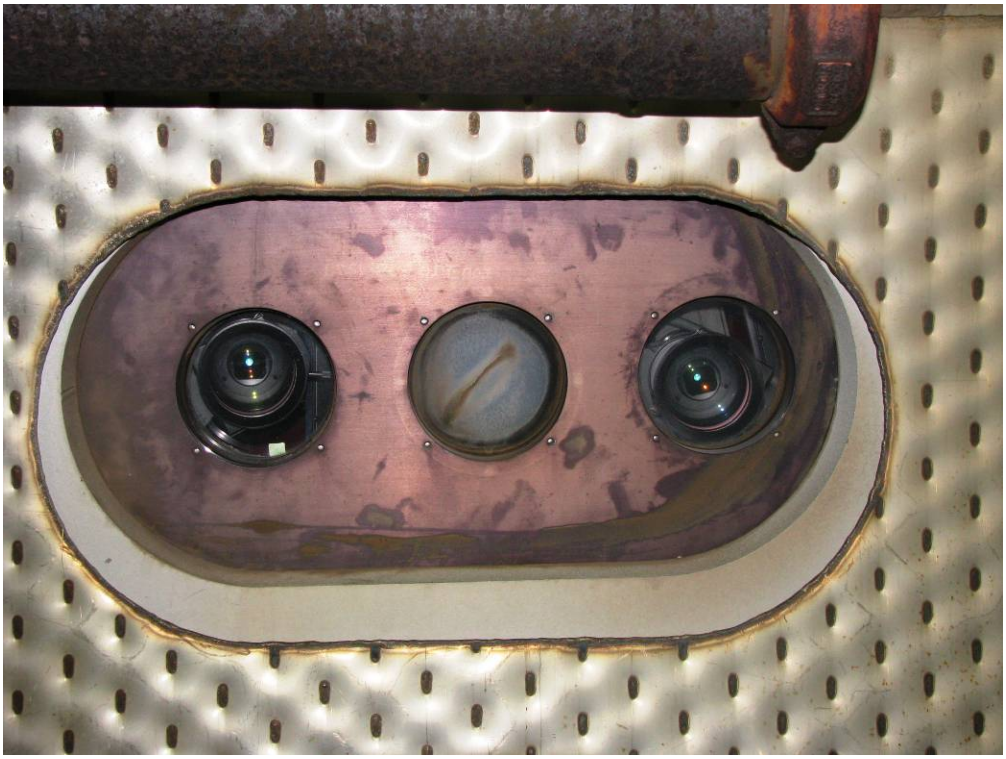
ARMSEF-36

ARMSEF-37



ARMSEF-38

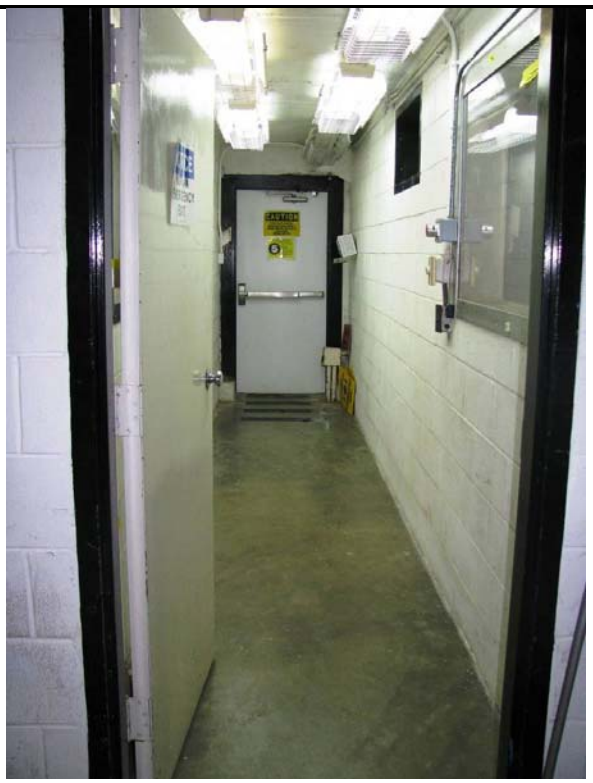
ARMSEF-39



ARMSEF-40

ARMSEF-41

ARMSEF-42



ARMSEF-43

ARMSEF-44

ARMSEF-45

ARMSEF-46

ARMSEF-47

ARMSEF-48

ARMSEF-49

ARMSEF-50

ARMSEF-51

ARMSEF-52

ARMSEF-53

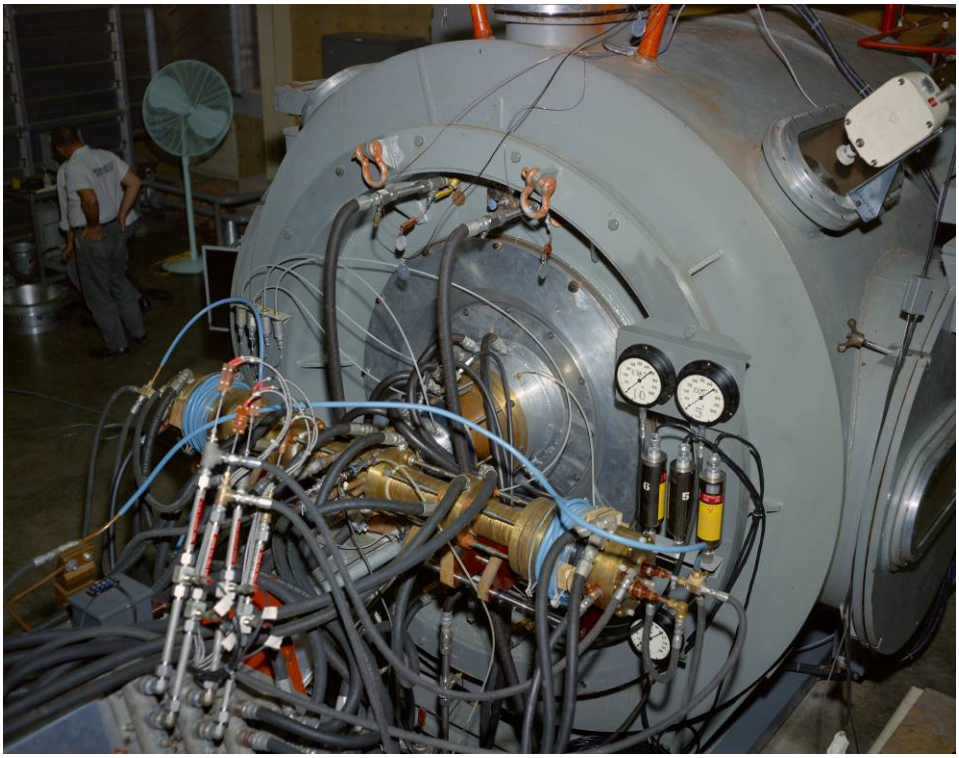
ARMSEF-54

ARMSEF-55

ARMSEF-56

ARMSEF-57

ARMSEF-58



ARMSEF-59

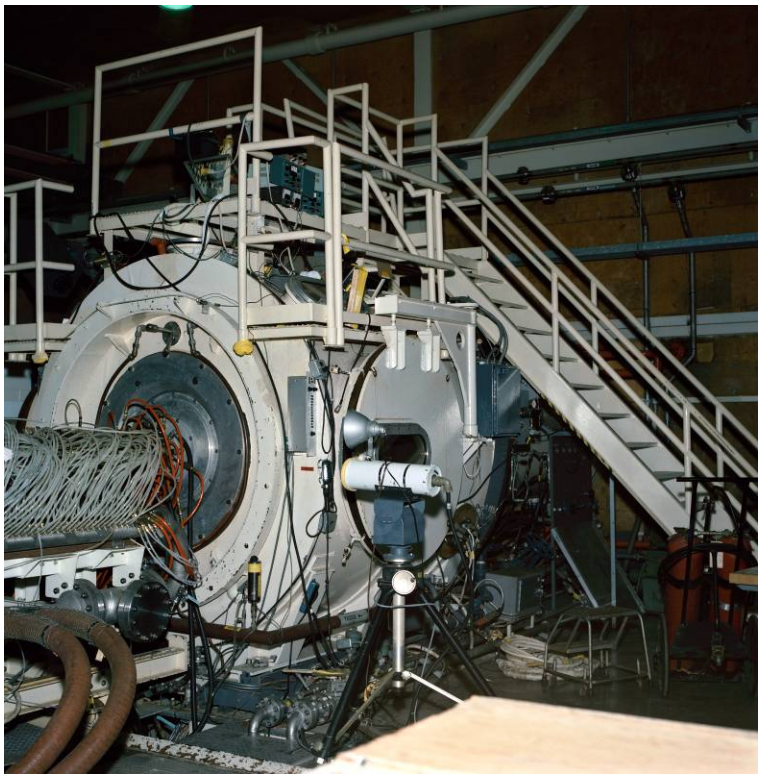
ARMSEF-60

ARMSEF-61

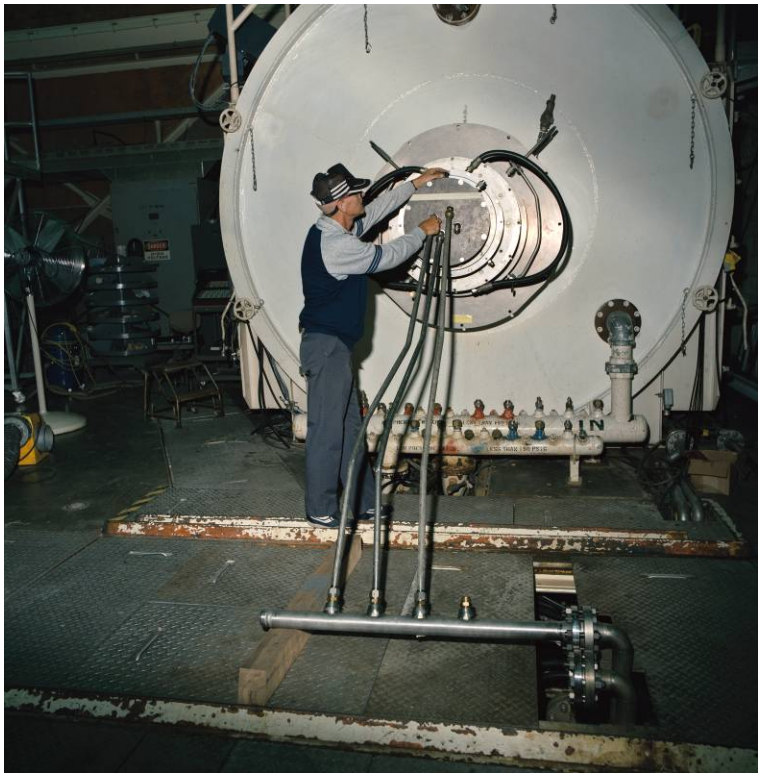
ARMSEF-62

ARMSEF-63

ARMSEF-64



ARMSEF-65



ARMSEF-66

ARMSEF-67

ARMSEF-68

ARMSEF-69

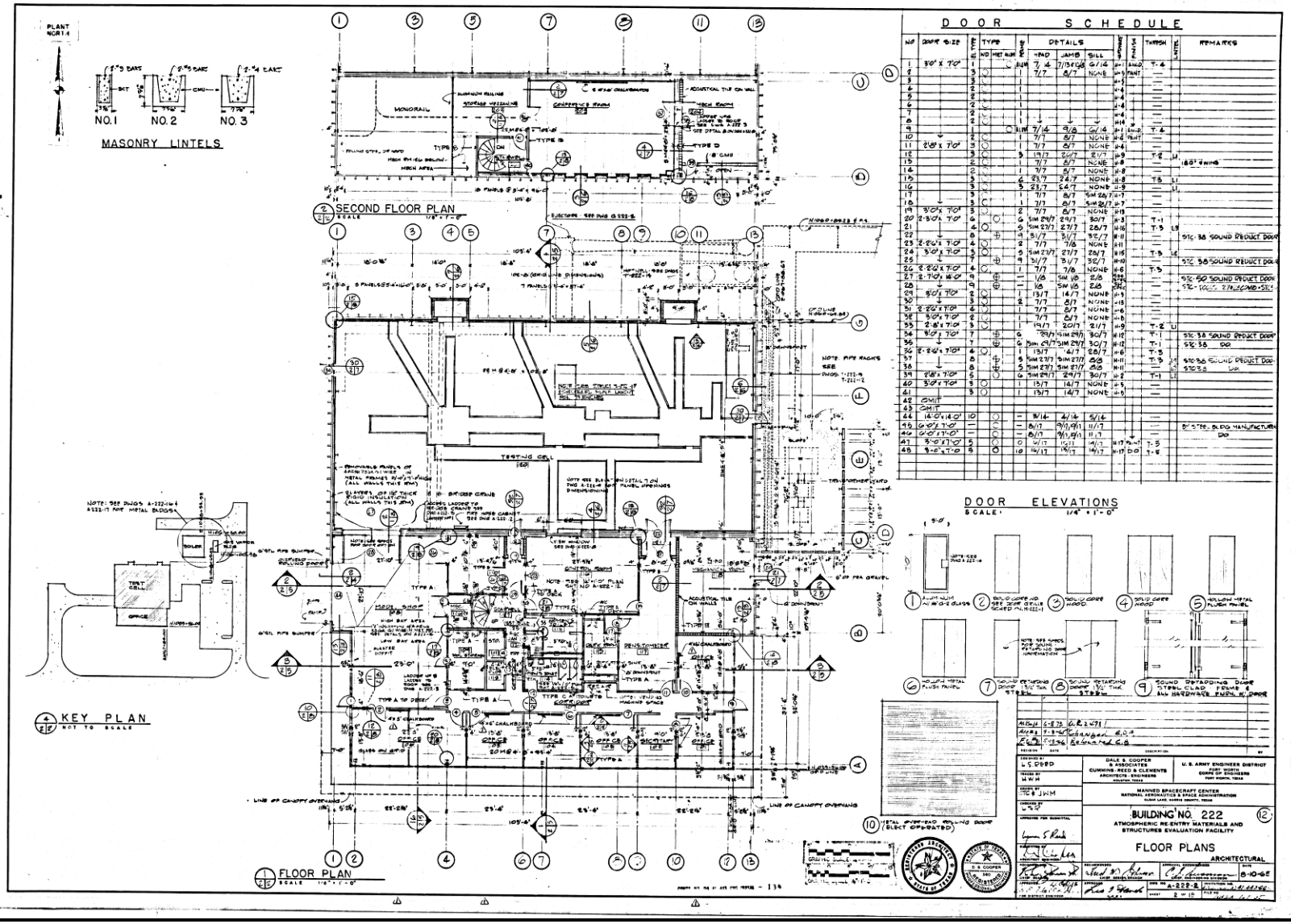
ARMSEF-70

ARMSEF-71

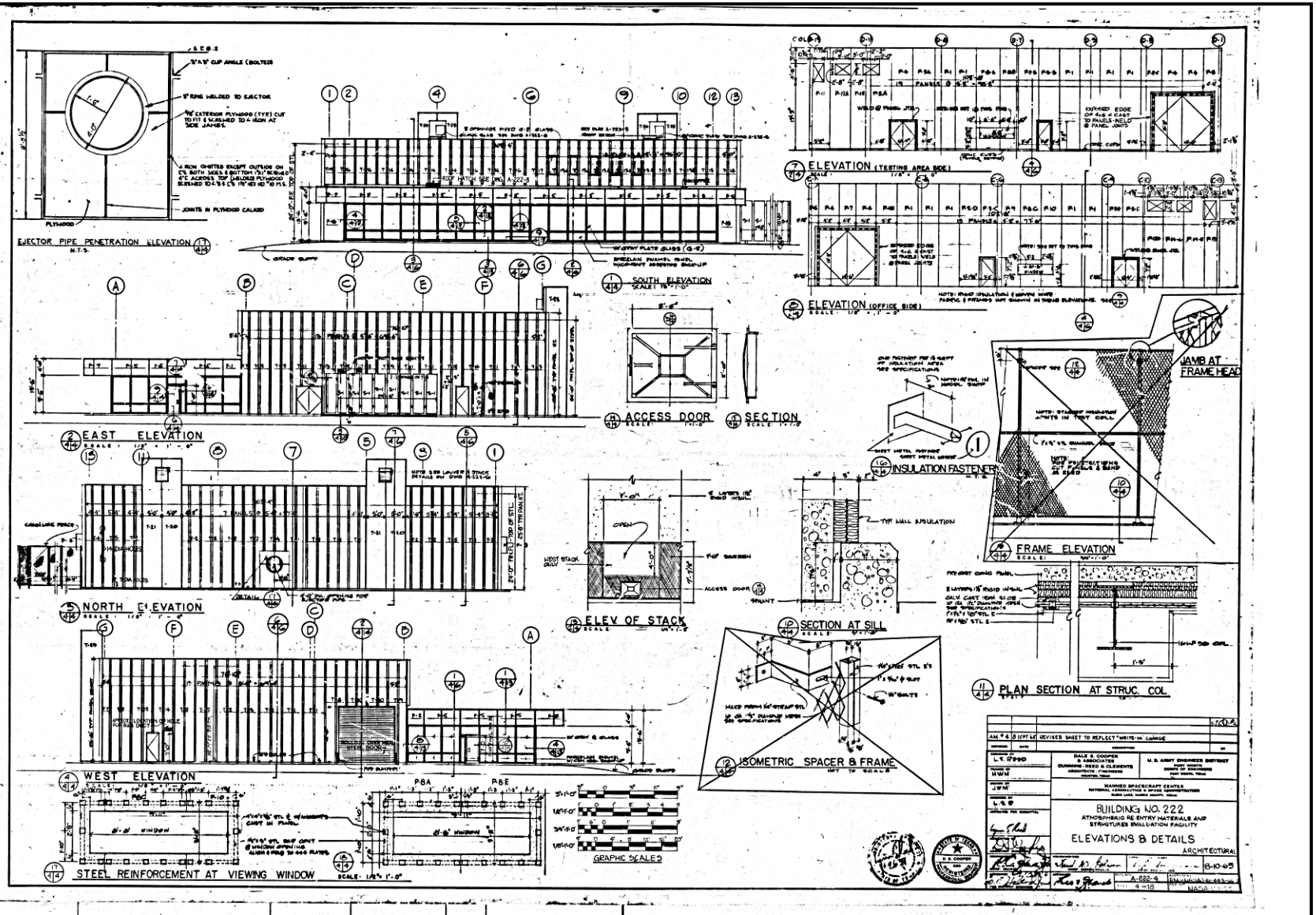
ARMSEF-72

ARMSEF-73

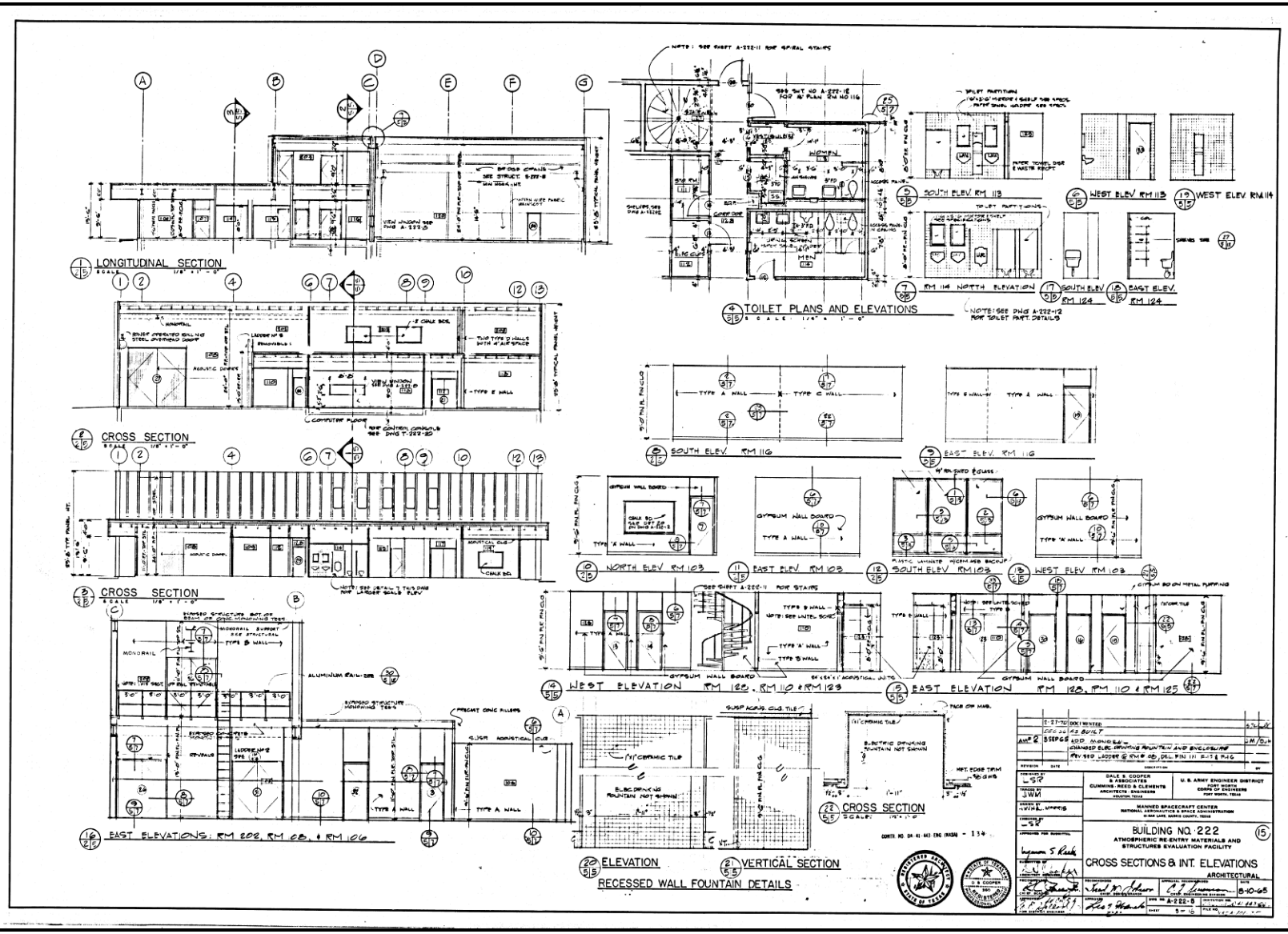
ARMSEF-74


MASONRY LINTELS
NO.1
NO.2
NO.3
SECOND FLOOR PLAN
FLOOR PLAN
KEY PLAN
DOOR SCHEDULE
DOOR ELEVATIONS
BUILDING NO. 222
ATMOSPHERIC RE-ENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY
FLOOR PLANS
ARCHITECTURAL
U. S. ARMY ENGINEER DISTRICT
FORT WORTH
CORPS OF ENGINEERS
MANNED SPACECRAFT CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
DALE S. COOPER & ASSOCIATES
CUMMINS-REED & CLEMENTS
ARCHITECTS-ENGINEERS

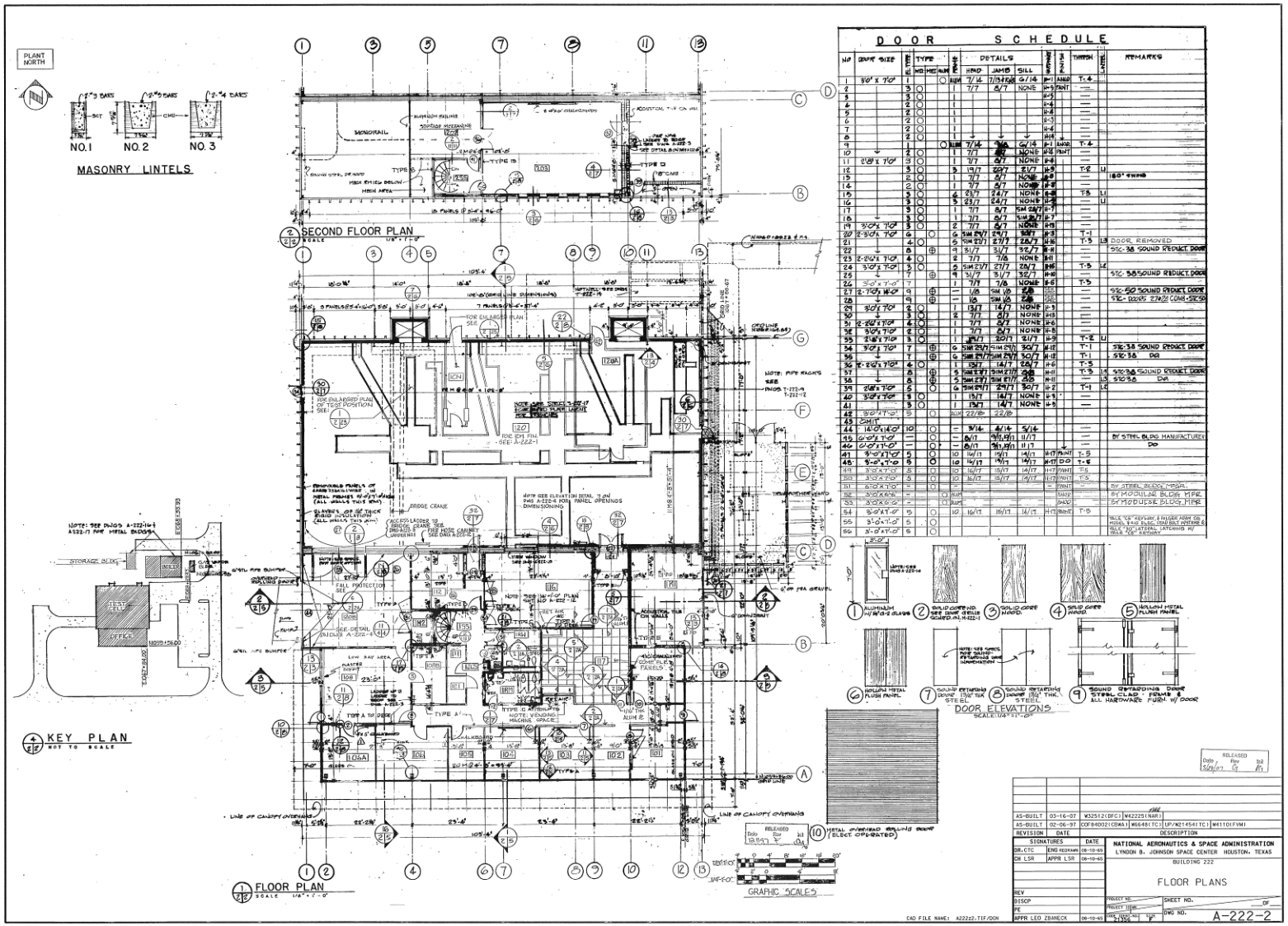
ARMSEF-75

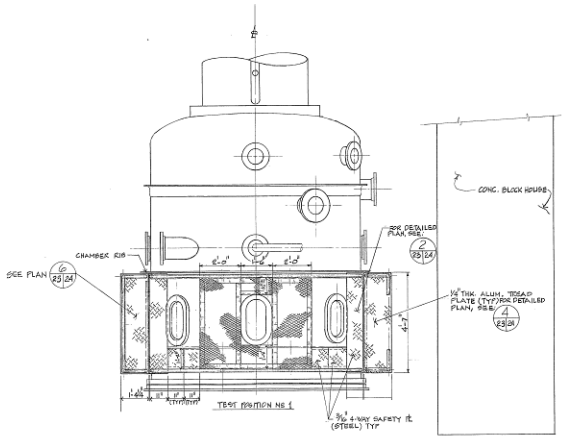

EJECTOR PIPE PENETRATION ELEVATION
SOUTH ELEVATION
ELEVATION (TESTING AREA SIDE)
ELEVATION (OFFICE SIDE)
EAST ELEVATION
ACCESS DOOR
SECTION
INSULATION FASTENER
JAMB AT FRAME HEAD
FRAME ELEVATION
NORTH ELEVATION
ELEV OF STACK
SECTION AT SILL
PLAN SECTION AT STRUC. COL
WEST ELEVATION
ISOMETRIC SPACER & FRAME
STEEL REINFORCEMENT AT VIEWING WINDOW
GRAPHIC SCALES
BUILDING NO. 222
ATMOSPHERIC RE ENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY
ELEVATIONS & DETAILS
ARCHITECTURAL
MANNED SPACECRAFT CENTER
U. S. ARMY ENGINEER DISTRICT
DALE B. COOPER & ASSOCIATES
A-222-4

ARMSEF-76

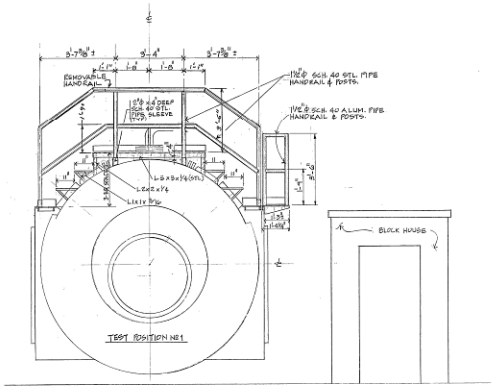

LONGITUDINAL SECTION
CROSS SECTION
CROSS SECTION
TOILET PLANS AND ELEVATIONS
SOUTH ELEV. RM 113
WEST ELEV RM 113
WEST ELEV RM 114
RM 114 NORTH ELEVATION
SOUTH ELEV RM 124
EAST ELEV. RM 124
SOUTH ELEV. RM 116
EAST ELEV. RM 116
NORTH ELEV RM 103
EAST ELEV RM 103
SOUTH ELEV RM 103
WEST ELEV RM 103
WEST ELEVATION RM 120, RM 110 & RM 123
EAST ELEVATION RM 120, RM 110 & RM 125
EAST ELEVATIONS: RM 202, RM 68, & RM 106
ELEVATION
VERTICAL SECTION
RECESSED WALL FOUNTAIN DETAILS
CROSS SECTION
BUILDING NO. 222
ATMOSPHERIC RE-ENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY
CROSS SECTIONS & INT. ELEVATIONS
ARCHITECTURAL
MANNED SPACECRAFT CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
DALE S. COOPER & ASSOCIATES
CUMMINS-REED & CLEMENTS
U. S. ARMY ENGINEER DISTRICT
FORT WORTH
CONSULTING ENGINEERS
FORT WORTH, TEXAS
8-10-65

ARMSEF-77


PLANT NORTH
MASONRY LINTELS
NO.1
NO.2
NO.3
SECOND FLOOR PLAN
FLOOR PLAN
KEY PLAN
NOT TO SCALE
DOOR ELEVATIONS
GRAPHIC SCALES
DOOR SCHEDULE
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER HOUSTON, TEXAS
BUILDING 222
FLOOR PLANS
A-222-2



1/23/25 TEST POSITION PLAN
SCALE: 1/8"=1'-0"



2/23/25 ELEVATION
SCALE: 1/8"=1'-0"

1/8"=1'-0"
GRAPHIC SCALE

REVISION	DATE	DESCRIPTION		
AS-BUILT	11-22-96	W6648(TC)-1/8		

RELEASED Date Rev. Int 3.10.97 MC

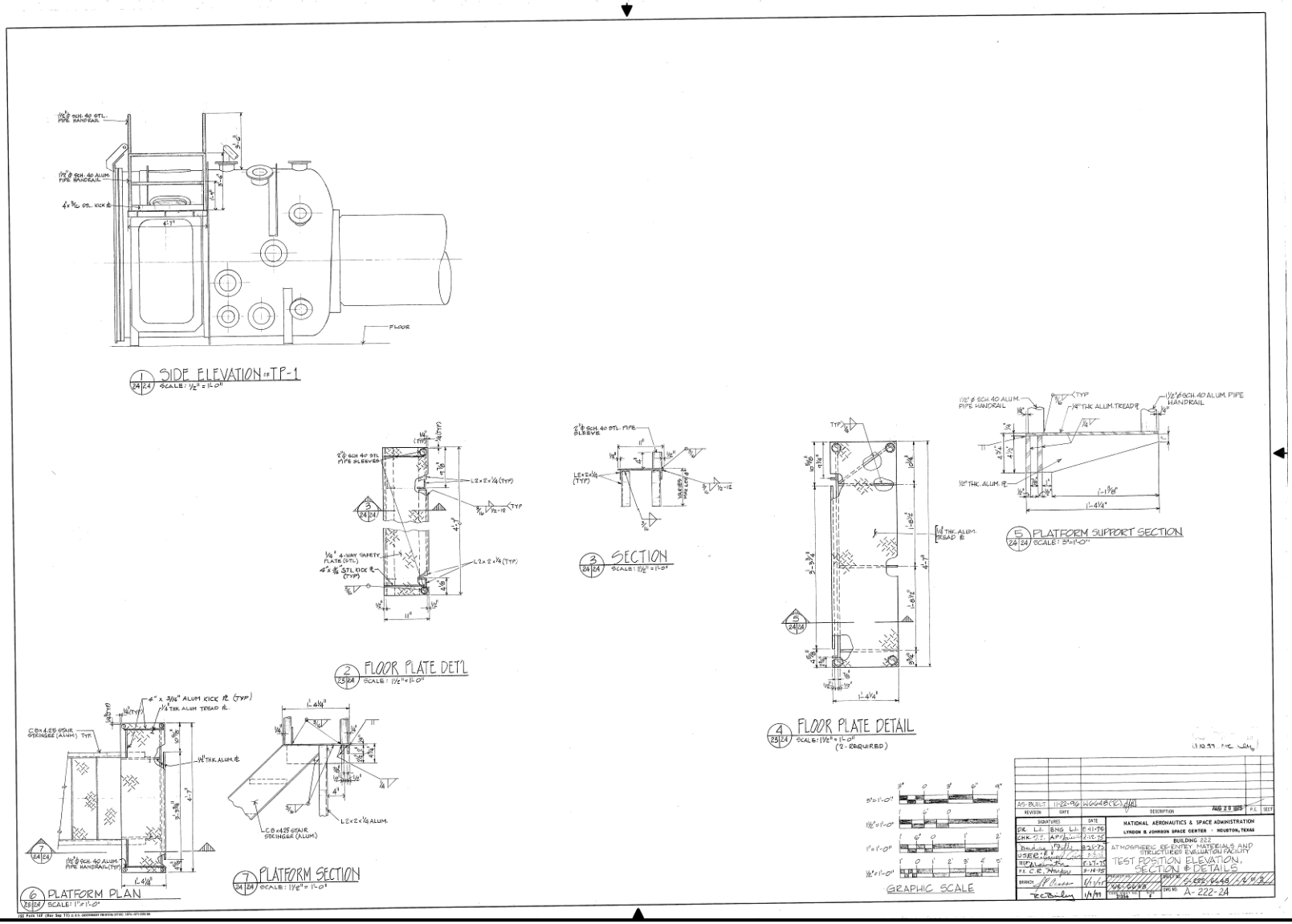
SIGNATURES		DATE
DR. L.J.	ENG. L.J.	8-11-75
SAE C.C.	APPROVED	7-12-75
SAFETY		8-6-75
USER		
REP.		8-27-75
P.I. C.R.		9-19-75
BRNCH		
		1/14/97

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER · HOUSTON, TEXAS

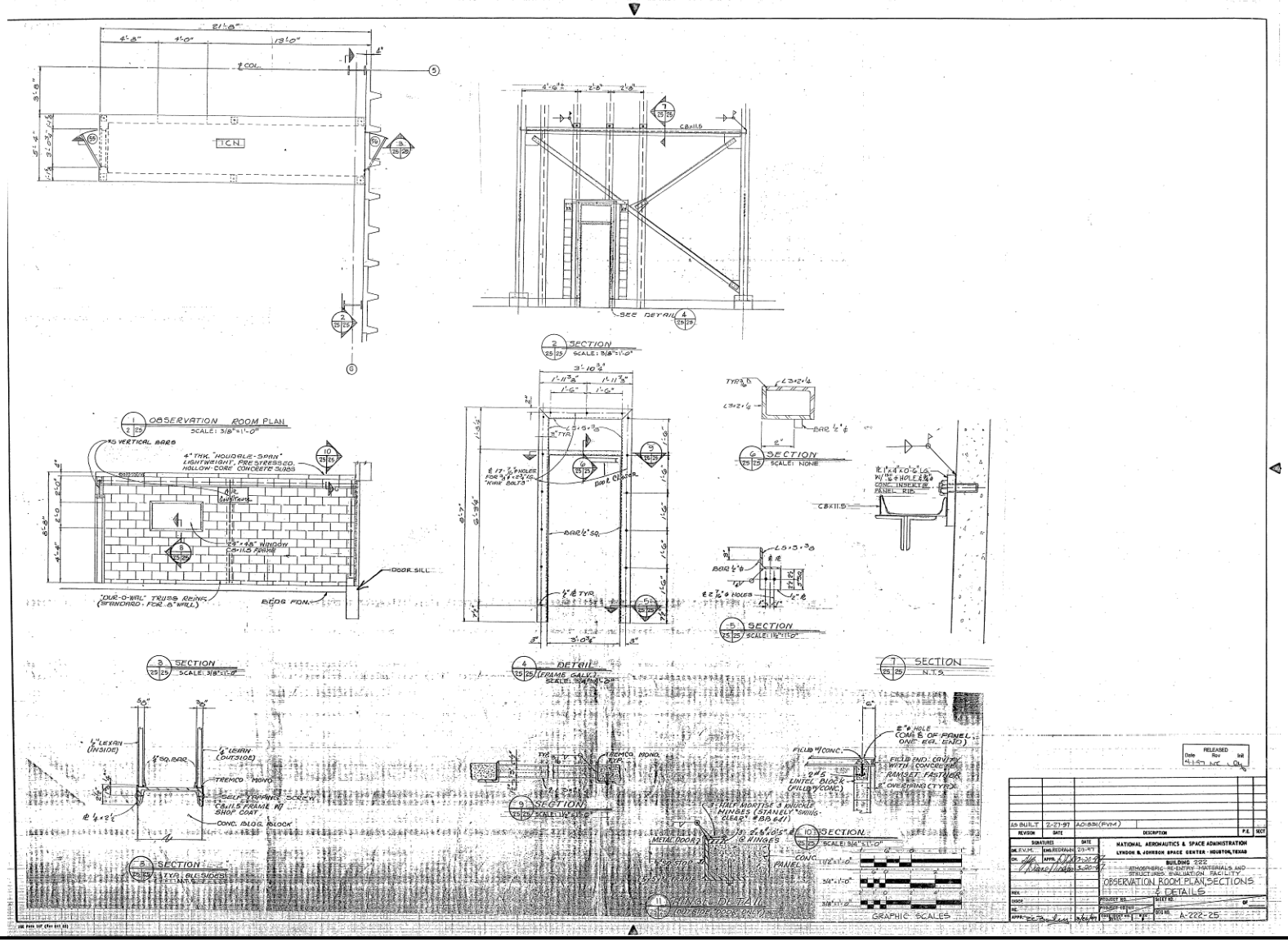
BUILDING 222
ATMOSPHERIC RE-ENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY
TEST POSITION
PLAN & ELEVATION

SIZE D | CODE IDENT NO. 81205 | DRG NO. A-222-23

ARMSEF-79


1 SIDE ELEVATION OF TP-1
SCALE: 1/2" = 1'-0"
2 FLOOR PLATE DET'L
SCALE: 1 1/2" = 1'-0"
3 SECTION
SCALE: 1 1/2" = 1'-0"
4 FLOOR PLATE DETAIL
SCALE: 1 1/2" = 1'-0"
(2-REQUIRED)
5 PLATFORM SUPPORT SECTION
SCALE: 3"=1'-0"
6 PLATFORM PLAN
SCALE: 1"=1'-0"
7 PLATFORM SECTION
SCALE: 1 1/2" = 1'-0"
GRAPHIC SCALE
AS-BUILT
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER · HOUSTON, TEXAS
BUILDING 222
ATMOSPHERIC RE-ENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY
TEST POSITION ELEVATION, SECTION & DETAILS
A-222-2A

ARMSEF-80


OBSERVATION ROOM PLAN
SCALE: 3/8"=1'-0"
SECTION
SCALE: 3/8"=1'-0"
SECTION
SCALE: NONE
SECTION
SCALE: 1/2"=1'-0"
DETAIL
(FRAME GALV.)
SECTION
N.T.S.
SECTION
SECTION
SECTION
HINGE DETAIL
(OUTSIDE DOOR ONLY)
GRAPHIC SCALES
AS BUILT 2-27-97
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER - HOUSTON, TEXAS
BUILDING 222
ATMOSPHERIC RE-ENTRY MATERIALS AND STRUCTURES EVALUATION FACILITY
OBSERVATION ROOM PLAN, SECTIONS & DETAILS
A-222-25

ARMSEF-81